FOR THE INCREASE AND DIFFUSION OF KNOWLEDGE AMONG MEN

PER ORBEM

SMITHSONIAN INSTITUTION WASHINGTON 1846

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

1933

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LETTER OF TRANSMITTAL

SMITHSONIAN INSTITUTION,
Washington, July 1, 1934.

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 ended June 30, 1933. I have the honor to be,

Very respectfully, your obedient servant,

C. G. ABBOT, *Secretary.*

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2. Report of the executive committee of the Board of Regents, exhibting the financial affairs of the Institution, including a statement of the Smithsonian fund, and receipts and expenditures for the year ending June 30, 1933.

3. Proceedings of the Board of Regents for the fiscal year ending June 30, 1933.

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 1933.

THE SMITHSONIAN INSTITUTION

June 30, 1933

Presiding officer ex officio.—FRANKLIN D. ROOSEVELT, President of the United States.

Chancellor.—CHARLES EVANS HUGHES, Chief Justice of the United States.

Members of the Institution:

FRANKLIN D. ROOSEVELT, President of the United States.
JOHN N. GARNER, Vice President of the United States.
CHARLES EVANS HUGHES, Chief Justice of the United States.
CORDELL HULL, Secretary of State.
WILLIAM H. WOODIN, Secretary of the Treasury.
GEORGE H. DERN, Secretary of War.
HOMER S. CUMMINGS, Attorney General.
JAMES A. FARLEY, Postmaster General.
CLAUDE A. SWANSON, Secretary of the Navy.
HAROLD L. ICKES, Secretary of the Interior.
HENRY A. WALLACE, Secretary of Agriculture.
DANIEL C. ROPER, Secretary of Commerce.
FRANCES PERKINS, Secretary of Labor.

Regents of the Institution:

CHARLES EVANS HUGHES, Chief Justice of the United States, Chancellor.
JOHN N. GARNER, Vice President of the United States.
JOSEPH T. ROBINSON, Member of the Senate.
M. M. LOGAN, Member of the Senate.
DAVID A. REED, Member of the Senate.
T. ALAN GOLDSBOROUGH, Member of the House of Representatives.
EDWARD H. CRUMP, Member of the House of Representatives.
CHARLES L. GIFFORD, Member of the House of Representatives.
IRWIN B. LAUGHLIN, citizen of Pennsylvania.
FREDERIC A. DELANO, citizen of Washington, D.C.
JOHN C. MERRIAM, citizen of Washington, D.C.
R. WALTON MOORE, citizen of Virginia.
ROBERT W. BINGHAM, citizen of Kentucky.
AUGUSTUS P. LORING, citizen of Massachusetts.

Executive committee.—FREDERIC A. DELANO, JOHN C. MERRIAM, R. WALTON MOORE.

Secretary.—CHARLES G. ABBOT.

Assistant Secretary.—ALEXANDER WETMORE.

Chief clerk and administrative assistant to the Secretary.—HARRY W. DORSEY.

Treasurer and disbursing agent.—NICHOLAS W. DORSEY.

Editor.—WEBSTER P. TRUE.

Librarian.—WILLIAM L. CORBIN.

Personnel officer.—HELEN A. OLMSTED.

Property clerk.—JAMES H. HILL.

UNITED STATES NATIONAL MUSEUM

Keeper ex officio.—CHARLES G. ABBOT.
Assistant Secretary (in charge).—ALEXANDER WETMORE.
Associate Director.—JOHN E. GRAF.

SCIENTIFIC STAFF

DEPARTMENT OF ANTHROPOLOGY:

Walter Hough, head curator; W. H. Egberts, chief preparator.

Division of Ethnology: Walter Hough, curator; H. W. Krieger, curator; H. B. Collins, Jr., assistant curator; Arthur P. Rice, collaborator.

Section of Musical Instruments: Hugo Worch, custodian.

Section of Ceramics: Samuel W. Woodhouse, collaborator.

Division of Archeology: Neil M. Judd, curator; F. M. Setzler, assistant curator; R. G. Paine, aide; J. Townsend Russell, honorary assistant curator of Old World archeology.

Division of Physical Anthropology: Aleš Hrdlička, curator; Thomas D. Stewart, assistant curator.

Collaborator in anthropology: George Grant MacCurdy; D. I. Bushnell, Jr.

Associate in historic archeology: Cyrus Adler.

DEPARTMENT OF BIOLOGY:

Leonhard Stejneger, head curator; W. L. Brown, chief taxidermist.

Division of Mammals: Gerrit S. Miller, Jr., curator; Remington Kellogg, assistant curator; A. J. Poole, scientific aide; A. Brazier Howell, collaborator.

Division of Birds: Herbert Friedmann, curator; J. H. Riley, associate curator; Alexander Wetmore, custodian of alcoholic and skeleton collections; Edward J. Brown, collaborator; Casey A. Wood, collaborator; Arthur C. Bent, collaborator.

Division of Reptiles and Batrachians: Leonhard Stejneger, curator; Doris M. Cochran, assistant curator.

Division of Fishes: George S. Myers, assistant curator; E. D. Reid, aide.

Division of Insects: L. O. Howard, honorary curator; J. M. Aldrich, asso ciate curator; William Schaus, honorary assistant curator; B. Preston Clark, collaborator.

Section of Hymenoptera: S. A. Rohwer, custodian; W. M. Mann, assistant custodian; Robert A. Cushman, assistant custodian.

Section of Myriapoda: O. F. Cook, custodian.

Section of Diptera: J. M. Aldrich, in charge; Charles T. Greene, assistant custodian.

Section of Coleoptera: L. L. Buchanan, specialist for Casey collection.

Section of Lepidoptera: J. T. Barnes, collaborator.

Section of Orthoptera: A. N. Caudell, custodian.

Section of Hemiptera: W. L. McAtee, acting custodian.

Section of Forest Tree Beetles: A. D. Hopkins, custodian.

Division of Marine Invertebrates: Waldo L. Schmitt, curator; C. R. Shoemaker, assistant curator; James O. Maloney, aide; Mrs. Harriet Richardson Searle, collaborator; Max M. Ellis, collaborator; William H. Longley, collaborator; Maynard M. Metcalf, collaborator; Joseph A. Cushman, collaborator in foraminifera; Charles Branch Wilson, collaborator in Copepoda.

Division of Mollusks: Paul Bartsch, curator; William B. Marshall, assistant curator; Harald A. Rehder, aide; Mary Breen, collaborator.

Section of Helminthological Collections: Maurice C. Hall, custodian.

Department of Biology—Continued.

Division of Echinoderms: Austin H. Clark, curator.

Division of Plants (National Herbarium): Frederick V. Coville, honorary curator; W. R. Maxon, associate curator; Ellsworth P. Killip, associate curator; Emery C. Leonard, assistant curator; Conrad V. Morton, aide; Egbert H. Walker, aide; John A. Stevenson, custodian of C. G. Lloyd mycological collection.

Section of Grasses: Albert S. Hitchcock, custodian.

Section of Cryptogamic Collections: O. F. Cook, assistant curator.

Section of Higher Algae: W. T. Swingle, custodian.

Section of Lower Fungi: D. G. Fairchild, custodian.

Section of Diatoms: Albert Mann, custodian.

Associates in Zoology: C. Hart Merriam, W. L. Abbott, Mary J. Rathbun, C. W. Stiles, Edward W. Nelson.

Associate Curator in Zoology: Hugh M. Smith.

Associate in Marine Sediments: T. Wayland Vaughan.

Collaborator in Zoology: Robert Sterling Clark.

Collaborators in Biology: A. K. Fisher, David C. Graham.

Department of Geology:

R. S. Bassler, head curator.

Division of Physical and Chemical Geology (systematic and applied): W. F. Foshag, curator; Edward P. Henderson, assistant curator.

Division of Mineralogy and Petrology: W. F. Foshag, curator; Frank L. Hess, custodian of rare metals and rare earths.

Division of Stratigraphic Paleontology: Charles E. Resser, curator; Gustav A. Cooper, assistant curator; Jessie G. Beach, aide; Margaret W. Moodey, aide for Springer collection.

Section of Invertebrate Paleontology: T. W. Stanton, custodian of Mesozoic collection; Paul Bartsch, curator of Cenozoic collection.

Section of Paleobotany: David White, associate curator.

Division of Vertebrate Paleontology: Charles W. Gilmore, curator; Charles L. Gazin, assistant curator; Norman H. Boss, chief preparator.

Associate in Mineralogy: W. T. Schaller.

Associates in Paleontology: E. O. Ulrich, August F. Foerste.

Associate in Petrology: Whitman Cross.

Department of Arts and Industries:

Carl W. Mitman, head curator.

Division of Engineering: Frank A. Taylor, curator.

Section of Mechanical Technology: Frank A. Taylor, in charge; Fred C. Reed, scientific aide.

Section of Aeronautics: Paul E. Garber, assistant curator.

Section of Mineral Technology: Carl W. Mitman, in charge; Chester G. Gilbert, honorary curator.

Division of Textiles: Frederick L. Lewton, curator; Mrs. E. W. Rosson, aide.

Section of Wood Technology: William N. Watkins, assistant curator.

Section of Organic Chemistry: Aida M. Doyle, aide.

Division of Medicine: Charles Whitebread, assistant curator.

Division of Graphic Arts: R. P. Tolman, curator.

Section of Photography: A. J. Olmsted, assistant curator.

Loeb Collection of Chemical Types: Aida M. Doyle, in charge.

Division of History: T. T. Belote, curator; Charles Carey, assistant curator; Mrs. C. L. Manning, philatelist.

ADMINISTRATIVE STAFF

Chief of correspondence and documents.—H. S. Bryant.
Assistant chief of correspondence and documents.—L. E. Commerford.
Superintendent of buildings and labor.—J. S. Goldsmith.
Assistant superintendent of buildings and labor.—R. H. Trembly.
Editor.—Paul H. Oehser.
Engineer.—C. R. Denmark.
Disbursing agent.—N. W. Dorsey.
Photographer.—A. J. Olmsted.
Property clerk.—W. A. Knowles.
Assistant librarian.—Leila G. Forbes.

NATIONAL GALLERY OF ART

Acting director.—Ruel P. Tolman.

FREER GALLERY OF ART

Curator.—John Ellerton Lodge.
Associate curator.—Carl Whiting Bishop.
Assistant curator.—Grace Dunham Guest.
Associate.—Katharine Nash Rhoades.
Assistant.—Archibald G. Wenley.
Superintendent.—John Bundy.

BUREAU OF AMERICAN ETHNOLOGY

Chief.—Matthew W. Stirling.
Ethnologists.—John P. Harrington, John N. B. Hewitt, Truman Michelson, John R. Swanton, William D. Strong.
Archeologist.—Frank H. H. Roberts, Jr.
Associate Anthropologist.—Winslow M. Walker.
Editor.—Stanley Searles.
Librarian.—Ella Leary.
Illustrator.—Edwin G. Cassedy.

INTERNATIONAL EXCHANGES

Secretary (in charge).—Charles G. Abbot.
Chief clerk.—Coates W. Shoemaker.

NATIONAL ZOOLOGICAL PARK

Director.—William M. Mann.
Assistant director.—Ernest P. Walker.

ASTROPHYSICAL OBSERVATORY

Director.—Charles G. Abbot.
Assistant director.—Loyal B. Aldrich.
Research assistant.—Frederick E. Fowle, Jr.
Associate research assistant.—William H. Hoover.

DIVISION OF RADIATION AND ORGANISMS

Director.—Charles G. Abbot.
Assistant director.—Earl S. Johnston.
Research and consulting physicist—Frederick S. Brackett.
Associate research assistant.—Edward D. McAlister.
Assistant in radiation research—Leland B. Clark.
Research associate.—Florence E. Meier.

REGIONAL BUREAU FOR THE UNITED STATES, INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE

Assistant in charge.—Leonard C. Gunnell.

REPORT OF THE SECRETARY OF THE SMITHSONIAN INSTITUTION

C. G. ABBOT

FOR THE YEAR ENDING JUNE 30, 1933

To the Board of Regents of the Smithsonian Institution.

GENTLEMEN: I have the honor to submit herewith my report showing the activities and condition of the Smithsonian Institution and the Government bureaus under its administrative charge during the fiscal year ended June 30, 1933. In part 1 the first 11 pages contain a summary account of the affairs of the Institution, and appendixes 1 to 10 give more detailed reports of the operations of the National Gallery of Art, the Freer Gallery of Art, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, the Astrophysical Observatory, the Division of Radiation and Organisms, the United States Regional Bureau of the International Catalogue of Scientific Literature, the Smithsonian Library, and of the publications issued under the direction of the Institution; part 2 contains the report of the United States National Museum, hitherto a separate document. On page 188 is the financial report of the executive committee of the Board of Regents, hitherto a separate document.

PART 1. REPORT ON THE SMITHSONIAN INSTITUTION AND ALL THE BUREAUS UNDER ITS DIRECTION EXCEPT THE NATIONAL MUSEUM

SUMMARY OF THE YEAR'S ACTIVITIES

Outstanding events.—Mr. Eldridge R. Johnson placed his yacht and a considerable sum of money at the disposal of the Institution for the first of a series of scientific cruises in the interests of oceanography. The first cruise, covering the Puerto Rican deep, returned in March 1933, with highly gratifying results, which will later be described in Smithsonian publications. The Gellatly collection of art objects, valued at $4,000,000, given to the Institution by John Gellatly, was safely transferred from New York to Washington and is now on public exhibition in the National Gallery of Art. Through the generous aid of Mr. John A. Roebling, a new astrophysical observing station is being equipped on Mount St. Katherine, Sinai Peninsula. Among the year's publications were several of special interest from the plant researches of the Division of Radiation and Organisms, and the first of the new series, Oriental Studies, issued by the Freer Gallery of Art, entitled "The Story of Kālaka", by W. Norman Brown.

National Museum.—Available appropriations for the past year totaled $701,456, or $133,634 less than for the previous year. Additions to the collections numbered 348,012 specimens. Important anthropological material came from Philippine and South American Indian tribes and from village sites in Alaska, Texas, Virginia, and Puerto Rico. Noteworthy biological material received consisted of mammals from Siam, Java, and British Columbia; birds from Alaska, Siam, and the southwestern United States; reptiles and amphibians from the Tennessee and Cumberland Rivers and from Puerto Rico and French Indo China; fishes, mollusks, and marine invertebrates collected on the Johnson-Smithsonian and Hancock expeditions; the Owen collection of Lepidoptera (about 40,000 specimens); and 3,600 plants from the historic Mutis Herbarium. In geology many valuable examples of minerals, gems, ores, and meteorites were received, and representative lots of fossil plants and animals, including the most perfect bird skeleton yet collected from the Oligocene of North America. The industrial collections were augmented by many generous gifts from commercial firms and individuals, and many objects of historic interest were received. The number of visitors for the year totaled 1,427,358.

National Gallery of Art.—Dr. William H. Holmes, director of the Gallery since its creation as a separate unit of the Institution in 1920, was retired on June 30, 1932, and his death occurred on April 20, 1933. During the year the Gallery has been under the direction of Ruel P. Tolman, acting director. Early in the year, a large part of the Gallery was occupied by exhibits of the National Society of Mural Painters, the National Sculpture Society, and the alumni of the American Academy in Rome, in connection with the George Washington Bicentennial celebration. An exhibition of paintings of Gaucho life in Argentina, by Señor Don Cesareo Bernaldo de Quiros, was held from January 13 to March 13, 1933. The Gellatly collection was transferred from New York and installed in the Gallery, a special opening view being held on June 22, 1933. A number of art works were accessioned by the Institution subject to transfer to the Gallery if approved by the National Gallery of Art Commission.

Freer Gallery of Art.—Additions to the collection include a Chinese bronze vessel from the Chou dynasty; Chinese pottery, porcelain, and jades; Japanese, Persian, and Arabic illuminated manuscripts; and Japanese, Persian, and Arabic paintings. Curatorial work has been devoted to the critical study of Armenian, Chinese, and Japanese texts associated with acquisitions, and to the translation of Arabic and Persian manuscript texts. Visitors totaled 120,732. The gallery issued "The Story of Kālaka", by W. Norman Brown, the first volume in its series of Oriental Studies. In spite of disturbed conditions in China, the field staff of the Gallery conducted archeological explorations throughout a large part of Shansi Province.

Bureau of American Ethnology.—The Bureau continued its studies of the American Indians, the members of its staff being occupied both in field work and in preparing for publication the results of their investigations. Attention was given particularly to the ethnology of the southeastern Indians, the Cheyenne and Arapaho of the West, the Foxes of Iowa, the Indians of southern California, and the Iroquois of New York State and Canada, and to archeological investigations in Arizona, in Nebraska, and in the mound area of the Mississippi Valley. In the study of Indian music many songs were recorded among the tribes in the Gulf States.

International exchanges.—The number of packages handled during the year, in the official exchange with other countries of parliamentary and departmental documents and scientific and literary publications, was 720,209, with a total weight of 634,707 pounds.

National Zoological Park.—A total of 1,330 animals were added during the year, and 1,136 were removed through various causes, bringing the collection on June 30, 1933, to 2,496 animals. The attendance was 2,463,350, including classes from 628 different schools in various parts of the country. Although no new construction of buildings was undertaken, a number of needed improvements were completed, including the laying of a larger water main from the Connecticut Avenue main, providing a more adequate supply of water to the west side of the park and greater fire protection.

Astrophysical Observatory.—Progress was made on the dependence of terrestrial temperature departures on the variation of the sun; studies were begun on the dependence of terrestrial temperature departures on the ozone content of the atmosphere; and solar-radiation observations were continued at Table Mountain, Calif., and Montezuma, Chile. Financed by Mr. John A. Roebling, a new observing station is being equipped on Mount St. Katherine, near Mount Sinai in Egypt, under the charge of Harlan H. Zodtner, assisted by Frederick A. Greeley. A new radiation-measuring instrument, called the kampometer, has been devised by Dr. Abbot and used with success in preliminary measurements of the extreme infrared solar spectrum.

Division of Radiation and Organisms.—In March 1933 the Secretary undertook the general charge of the division, succeeding the former director, Dr. F. S. Brackett, who continued with the division on a part-time basis as consulting physicist. Dr. E. S. Johnston was

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appointed assistant director. During the year the following lines of study have been pursued by the scientific staff of the division: The growth of wheat under measured concentrations of water vapor and carbonic acid with fixed temperature and illuminated by measured quantities of light from helium discharge tubes; the improvement in methods of producing substantially monochromatic light of any desired wave length for use in plant growth experiments; the propagation of unicellular algae under 12 different varieties of light; the growth of wheat under outdoor conditions with different concentrations of carbon dioxide; and investigations with the quartz and the rock salt spectrographs of the absorption energy spectra of organic substances including the extreme infrared spectrum.

International Catalogue of Scientific Literature.—The work of the United States Bureau in recording current scientific literature of this country was continued, so that the necessary data may be available for indexing when it is found possible to resume publication of the catalogue. Efforts to refinance the organization were unsuccessful, and as Congress failed to provide funds for the continuation of the United States Bureau, work was suspended at the close of the fiscal year. It is hoped, however, that the enterprise may eventually be resumed, as there is nothing to take its place in providing not only an index, but also a condensed digest, of the world's scientific literature.

THE ESTABLISHMENT

The Smithsonian Institution was created by act of Congress in 1846, according to the terms of the will of James Smithson, of England, who in 1826 bequeathed his property to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men." In receiving the property and accepting the trust, Congress determined that the Federal Government was without authority to administer the trust directly and, therefore, constituted an "establishment" whose statutory members are "the President, the Vice President, the Chief Justice, and the heads of the executive departments."

THE BOARD OF REGENTS

The affairs of the Institution are administered by a Board of Regents whose membership consists of "the Vice President, the Chief Justice, 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 them of the same State." One of the regents is elected chancellor of the board. In the past the selection has fallen upon the Vice President or the Chief Justice, and a suitable person is chosen by the regents as Secretary of the Institution, who is also secretary of the Board of Regents, and the executive officer directly in charge of the Institution's activities.

A number of changes in the personnel of the Board occurred during the year. The Hon. John N. Garner, as Vice President, became on March 4, 1933, a regent of the Institution ex officio. On May 31, 1933, Senator M. M. Logan, of Kentucky, was appointed a regent to succeed Senator Reed Smoot, whose term as a Senator expired March 3, 1933, and on May 31, 1933, also, Senator David A. Reed, of Pennsylvania, was appointed a regent to succeed Senator Claude A. Swanson, of Virginia, on the latter's resignation from the Senate. On March 27, 1933, the Speaker appointed Representative Charles L. Gifford, of Massachusetts, a regent to succeed Representative Albert Johnson, of Washington.

The roll of regents at the close of the year was as follows: Charles Evans Hughes, Chief Justice of the United States, Chancellor; John N. Garner, Vice President of the United States; members from the Senate—Joseph T. Robinson, M. M. Logan, David A. Reed; members from the House of Representatives—T. Alan Goldsborough, Edward H. Crump, Charles L. Gifford; citizen members—Irwin B. Laughlin, Pennsylvania; Frederic A. Delano, Washington, D.C.; John C. Merriam, Washington, D.C.; R. Walton Moore, Virginia; Robert W. Bingham, Kentucky; Augustus P. Loring, Massachusetts.

Proceedings.—Only one meeting of the Board was held during the year—the annual meeting on December 8, 1932. The regents present were Chief Justice Charles Evans Hughes, Chancellor, Senator Joseph T. Robinson, Senator Claude A. Swanson, Representative T. Alan Goldsborough, Representative Edward H. Crump, Mr. Frederic A. Delano, Dr. John C. Merriam, Hon. R. Walton Moore, and the Secretary, Dr. Charles G. Abbot.

The Secretary announced the changes in the personnel of the Board, noted above, and stated that Mr. Moore had been given an ad interim appointment as a member of the executive committee, which the Board, by resolution, made permanent.

The Secretary then presented his annual report, calling particular attention to the publications issued by the Institution during the year. Mr. Delano presented the report of the executive committee, a compilation of the financial statistics of the Institution, and the Secretary then submitted the annual report of the National Gallery of Art Commission.

The Secretary presented a special report, reviewing the oustanding events of the year, following which Dr. Wetmore, Assistant Secretary, gave an account of recent exploring and collecting expeditions of the National Museum.

The Board adopted a resolution recording its appreciation of the bequest to the Institution of $100,000 received through the will of the late Hon. Dwight W. Morrow. The meeting then adjourned, and the regents viewed the special exhibit in the Secretary's office illustrating various phases of the Institution's activities.

FINANCES

A statement will be found in the report of the executive committee, page 188.

MATTERS OF GENERAL INTEREST

JOHNSON-SMITHSONIAN DEEP-SEA EXPEDITION

One of the most extensive programs of oceanographic investigation ever entered into by the Institution was initiated during the year under the name "Johnson-Smithsonian Deep-Sea Expedition." Mr. Eldridge R. Johnson, of Philadelphia, offered the use of his yacht *Caroline*, to be completely equipped at his expense with the most modern devices for oceanographic work. It is expected to make cruises in several following years. The work is under the direction of Dr. Paul Bartsch, curator of the division of mollusks in the National Museum, and the personnel of the first cruise included T. T. Brown, Naval Research Laboratory, physicist; E. W. Price, Bureau of Animal Industry, United States Department of Agriculture, zoologist; Charles Weber, student at George Washington University, assistant zoologist; Elie Cheverlange, artist; G. R. Goergens, United States Department of Agriculture, photographer; and A. W. Wilding, Bureau of American Ethnology, secretary. The Institution was materially assisted in preparation for the cruise by the Navy Department, the Department of Agriculture, the Carnegie Institution of Washington, George Washington University, the Zoological Society and the Oceanographic Institution of Woods Hole.

The first cruise began at New York, January 21, 1933, and ended at the navy yard dock in Washington, March 14, most of the nearly two months being spent in exploring the Puerto Rican deep. The results of the cruise came fully up to expectations. Dr. Bartsch reports that the work was concentrated upon the rim of the deep and that marvelous catches were made, representing all the various groups of marine organisms from vertebrates down to protozoa, as well as aquatic plants. About four truckloads of specimens were carried to the museum.

In addition to actual specimens gathered, three lines of soundings, 235 miles long, were made through the long axis of the deep 20 miles apart with a sounding station at every 5-mile interval. Some of the former depths reported were slightly in excess of those which the *Caroline* obtained in the same location. It is possible that the discrepancy may be due to the bending and deflecting of the wire formerly used in sounding. All the work in this direction was accomplished by means of the echo sounding device installed through the courtesy of the Navy Department. In using the sonic sounding machine a vibrant note is sent out by an oscillator, which, upon reaching the bottom, is reflected therefrom and caught by microphones installed on the ship and then carried to the observer. The interval between sending out the note and the arrival of the echo gives data easily translated into the desired depth. By this means it is easy within a limited number of seconds to determine even the greatest depth found, which was 4,400 fathoms, that is, about 5 miles. Then, also, the expedition gathered samples of water from various depths and temperature readings by thermometers specially designed for the purpose.

Dr. Bartsch states that "this expedition has been the finest in which I have had the opportunity to take part. Mr. Johnson and his son and the invited guests, Mr. Douglass and family, the members of the staff, and every individual from the captain to the cabin stewards did everything in their power to help and thus bent each moment to a purpose. Aside from the splendid surroundings in which the work was done, their esprit de corps made the expedition a memorable one. It will take weeks before all of the elements will have been separated into the component groups, after which they will be turned over to specialists for report. Mr. Johnson deserves great credit for sponsoring this enterprise."

The preliminary results of this first cruise, particularly the descriptions of the many new forms found, are now being written up and will be published in the Smithsonian Miscellaneous Collections.

REMOVAL OF GELLATLY COLLECTION TO WASHINGTON

Four years after its presentation to the American people through the Smithsonian Institution, the Gellatly collection of paintings and art objects was transferred from New York to Washington on April 30, 1933, and opened to the public in the National Gallery of Art on June 23. Ralph Seymour, curator of the collection for many years while it was in the possession of Mr. Gellatly, came to Washington to assist in its unpacking, classification, and preparation for exhibition.

The assembling of this collection, valued at more than $4,000,000, formed the lifework of Mr. John Gellatly. It comprises more than 1,600 separate pieces, including 145 American paintings in oil, water color, and pastel; a notable collection of paintings by European masters; and many interesting and valuable examples of various types of art objects, including ancient glass, jewelry, period furniture, sculpture, and tapestries.

MARTIN GUSTAV AND CAROLINE RUNICE HANSON FUND

On March 13, 1933, Dr. Adolph M. Hanson, of Faribault, Minn., executed a legal assignment to the Smithsonian Institution of all royalties accruing to him under a patent on his discovery, the isolation of the parathyroid hormone (extract of parathyroid gland and process of preparing the same). In making this offer, Dr. Hanson, a lieutenant colonel in the Medical Reserve Corps, United States Army, stated that he wished the gift to appear as a memorial to his father, Martin Gustav Hanson, and his mother, Caroline Runice Hanson, and that he wished the income to be applied "to some scientific purpose, preferably in chemistry or medicine." He added, "I hope that my example may serve as an inspiration for others in the future and add to the interest in our National Institution."

The Institution accepted the gift, and already considerable sums have been received from royalties. These will be applied to the scientific work of the Institution, giving preference wherever practicable to researches in chemistry or medicine, in accordance with the wishes of the donor.

SECOND ARTHUR LECTURE

In 1931 a bequest was received from James Arthur for the promotion of a series of lectures at the Institution dealing with various aspects of the relation of the sun to the planets, the stars, the weather, and human life. The second Arthur lecture was delivered by Dr. Ernest William Brown, professor of mathematics at Yale University, on January 25, 1933, under the title "Gravitation in the Solar System." The lecture will appear later in one of the Institution's series of publications.

WALTER RATHBONE BACON TRAVELING SCHOLARSHIP

Mr. Alan Mozley, of the department of zoology of Johns Hopkins University, was awarded the Walter Rathbone Bacon scholarship for 1932 and 1933, and later this award was extended to cover 1934 also. Mr. Mozley is pursuing a faunistic study of the Siberian nonmarine mollusks. Regarding the importance of this work, Mr. Mozley says:

"The study of this problem is especially important, since in the sub-Arctic we have the unique opportunity of investigating a fauna in the making. The whole of this region has only recently become habitable for mollusks, so that we are dealing, as it were, with an experiment in zoogeography, and there is an absolutely unparalleled opportunity for studying geographic distribution without the host of unknown geologic and geographic factors which often result in speculations which belong more in the realm of nature study or natural mythology than in science."

At the close of the year Mr. Mozley was still engaged in field work in Siberia.

SMITHSONIAN EXHIBIT AT THE CENTURY OF PROGRESS EXPOSITION, CHICAGO

The general theme of the Federal exhibits at the Century of Progress Exposition was the portrayal of the contributions made by governmental agencies toward the advancement of science and the progress of civilization during the past 100 years. To be in unison with this theme the exhibit of the Smithsonian Institution was made up of two parts; first, a brief pictorial account of the Institution's founding and of some of its outstanding achievements in the past, and second, a representation with original material of some of the current activities of the Institution and its seven branches.

The first or pictorial part of the exhibit consists of nine oil paintings, 40 by 30 inches in size. The first of these entitled "President Jackson Notifies Congress of the Smithsonian Bequest, December 17, 1835" shows President Jackson sitting at his desk in the White House in the act of writing a letter while his secretary and nephew, Andrew Jackson Donelson, stands in the background waiting to receive the missive. The second shows the building of the Smithsonian Institution as completed in 1851, and the third is an air view of the portion of the Mall in Washington containing the original buildings and the four additional ones composing the Smithsonian group today. The six remaining paintings, arranged chronologically, depict a few of the many activities undertaken "for the increase and diffusion of knowledge among men." The titles of these are: "Professor Henry Posts Daily Weather Map in the Smithsonian, 1858", "Major Powell Descends the Colorado River Through the Grand Canyon, 1869", "Secretary Langley Tries Out Aerodrome No. 5, 1895", "President Roosevelt Leads Smithsonian African Expedition, 1909–10", "Astrophysical Observatory Established at Montezuma, Chile, 1918", "Division of Radiation and Organisms Established, 1929."

The second part of the exhibit on the Institution's current activities includes seven exhibition cases, an exhibit booth, and an automatic lantern slide projector, distributed over the floor. Five of the exhibition cases contain a group of original specimens indicative of some current research work in biology, geology, anthropology, ethnology, and radiation. The biology exhibit, for example, tells the story of the progressive experiments in evolution with the land mollusk, Cerion, begun in 1912, while the exhibit on anthropology, consisting of carved ivory artifacts, gives an indication of current archeological investigations of the prehistoric Eskimo cultures of northern Alaska and around Bering Strait. The sixth case indicates very briefly the scope of the National Gallery of Art, and the seventh represents the National Zoological Park. For this latter exhibit the interior of the case was modeled to represent a desert with real sand floor, growing cactuses, and a painted scenic background, and during the whole period of the fair a large variety of live lizards is to be displayed.

The exhibition booth contains three separate exhibits as follows: Part of the apparatus used in the Division of Radiation and Organisms in researches on plant growth; a light spectrum with filters to screen different rays such as are used in radiation researches; a group of fluorescent minerals subjected to ultraviolet light with their resultant beautiful coloring. Lastly, the automatic lantern slide projector with two series of 70 lantern slides, changed twice a week, reveals present-day scenes in the many workrooms and laboratories of the Institution.

GRANTS

Blue Hill Meteorological Observatory.—A grant of $500 from the Hodgkins fund was made to the Blue Hill Meteorological Observatory of Harvard University for the purchase of solar radiation instruments, balloons, and hydrogen for use in making a continuous daily record of solar and sky radiation at Blue Hill Observatory. This research, in charge of Dr. Charles F. Brooks, director of the observatory, was undertaken in connection with the International Polar Year.

Davis and Elkins College.—Two researches under way in the department of chemistry of Davis and Elkins College were aided by a grant of $100 for the purchase of equipment. Under the direction of Prof. R. B. Purdum, it was proposed to investigate (1) the solubility of lead sulphate in the presence of sodium sulphate and other electrolytes, and (2) the solubility of benzidine sulphate and of benzidine hydrochloride in various solvents.

Barro Colorado Island Biological Laboratory.—The Institution continued its annual subscription of $300 for a table at the Barro Colorado Laboratory. This laboratory offers unusually favorable opportunity for studies of the fauna and flora of tropical America, and its facilities are used by members of the Institution's staff or associates.

EXPLORATIONS AND FIELD WORK

In addition to the Johnson-Smithsonian Deep-Sea Expedition already described, the Institution sent out or took part in 24 expeditions to gather specimens and data essential to the scientific investigations in progress. Smithsonian field parties worked not only in an unusually large number of States of the United States—29—but also in Alaska, Canada, Cuba, Puerto Rico, Yucatan, Panama, Ecuador, and Siam. All these expeditions are briefly described in the illustrated pamphlet entitled "Explorations and Field Work of the Smithsonian Institution During 1932", Smithsonian publication no. 3213, but to illustrate the aim of Smithsonian field expeditions I may here mention one or two. In Alaska Dr. Aleš Hrdlička carried on anthropological and archeological research on Kodiak Island, excavating sites at Uyak Bay, Chief's Point, and other localities, making an archeological survey of the whole island, and taking measurements and photographs of the few remaining fullbloods on the island; and James A. Ford conducted archeological work in the vicinity of Barrow, furnishing a basis for a cultural chronology of the north Alaska coast. In the West Indies, where in recent years the Institution has centered intensive anthropological and biological researches, H. W. Krieger visited Cuba with a view to determining the northern and southern affiliations of early Cuban cultures, and Gerrit S. Miller, Jr., searched in the caves of Puerto Rico for evidence that some of the members of the ancient fauna of the Antillean Islands continued to exist until the time when the Indians made their settlements.

PUBLICATIONS

The Institution's various series of publications constitute the chief means of carrying out one half of its stated purpose, "the increase and diffusion of knowledge among men." Since the reorganization of the editorial department 2 years ago, all the series—Smithsonian proper, National Museum, Bureau of American Ethnology, Astrophysical Observatory, and Freer Gallery of Art—have been issued from one central office under the general supervision of the editor of the Smithsonian Institution, with the joint aims of greater accuracy and promptness, more uniformity in editorial style, and greater efficiency in administration.

During the year 100 volumes and pamphlets were published, 43 by the Institution proper, 48 by the National Museum, 8 by the Bureau of American Ethnology, and 1 by the Freer Gallery of Art. Details regarding these publications will be found in the report of the editor, appendix 10. The number of publications distributed was 177,572.

LIBRARY

The Smithsonian library accessioned during the year 6,319 volumes and 4,625 pamphlets and charts, most of them coming as exchanges for Smithsonian publications, although, as usual, many gifts also were received. In addition to the routine work of the staff, considerable progress was made on the union catalog, the order department of the library was reorganized, the file of exchange relations showed marked progress, and a start was made on the dictionary index to all publications of the Institution and its branches.

Respectfully submitted.

C. G. Abbot, *Secretary*.

APPENDIX 1

REPORT ON THE NATIONAL GALLERY OF ART

Sir: I have the honor to submit the following report on the activities of the National Gallery of Art for the fiscal year ending June 30, 1933.

The retirement on June 30, 1932, of Dr. William H. Holmes, director of the gallery since its creation as a separate unit under the Institution in 1920, was a severe loss and his place will be difficult to fill. His retirement came through an act of Congress which separated from the Government service many others of the retirement age. His death occurred on April 20, 1933, at Royal Oak, Mich.

On July 1, 1932, a large percentage of the gallery space was occupied by exhibits of the National Society of Mural Painters, the National Sculpture Society and by the alumni of the American Academy in Rome, in connection with the George Washington Bicentennial Celebration; they continued officially until Thanksgiving Day, but were extended a few weeks. The removal of the statuary and the American Academy in Rome exhibits made possible the installation of a part of the permanent collections. Certain partitions which the Mural Painters had removed were not replaced and reduced the wall space, already much too small, by about 180 running feet.

Early in January the large mural paintings were taken down. The large central gallery was then used for the special exhibition of 29 colorful paintings of Gaucho life of the Argentine by Señor Don Cesareo Bernaldo de Quiros. It was sponsored by the Argentine Ambassador, Señor Dr. Felipe A. Espil, and the opening on Friday afternoon, January 13, was attended by many notables headed by Mrs. Herbert Hoover. It continued through March 12, 1933, and, judging by the attendance, it was a great success. Later in the spring the Gellatly collection was removed from New York, arriving in Washington May 1. The private opening was held on the evening of June 22, and the collection was thrown open to the public on June 23.

APPROPRIATIONS

For the administration of the National Gallery of Art, including compensation of necessary employees, purchase of books of reference and periodicals, traveling expenses, uniforms for guards, and necessary incidental expenses, $38,220 was appropriated. This was

$7,180 less than the preceding year, and the amount was further reduced by $1,260 through the impounding of the salary of one laborer, who was retired. Some $16,500 of this appropriation goes for the upkeep of the Freer Gallery of Art.

THE NATIONAL GALLERY OF ART COMMISSION

The twelfth annual meeting of the National Gallery of Art Commission was held at the Smithsonian Institution on December 6, 1932. The members present were Dr. Charles G. Abbot, ex officio, Herbert Adams, Charles L. Borie, Jr., James E. Fraser, Joseph H. Gest, John E. Lodge, Paul Manship, George B. McClellan, Charles Moore, and Edward W. Redfield. Ruel P. Tolman, curator of the division of graphic arts, and acting director of the National Gallery of Art, was also present. Owing to the death of Mr. Gari Melchers, chairman, Mr. Gest was elected temporary chairman, and Dr. Abbot was made temporary secretary in the absence of Dr. W. H. Holmes. Resolutions upon the death of Mr. Parmelee, Mr. French, and Mr. Bixby were adopted. The death of Mr. Gari Melchers, chairman of the Commission, on November 30, 1932, was announced. The temporary chairman appointed Mr. Moore, Mr. Lodge, and Dr. Abbot as a committee to draft suitable resolutions. The resignation of Mr. Herbert L. Pratt was accepted with regret, making three vacancies in the membership, and it was resolved that the National Gallery of Art Commission recommend to the Board of Regents of the Smithsonian Institution the election to membership on the Commission of Mr. Andrew W. Mellon, Mr. Frederick P. Keppel, and Mr. Gifford Beal.

The Commission also recommended to the Board of Regents the reelection for the succeeding term of 4 years of the following members: Messrs. John E. Lodge, E. W. Redfield, and Paul Manship. The following officers were elected for the ensuing year: Mr. Joseph H. Gest, chairman; Mr. Frank Jewett Mather, Jr., vice chairman (reelected), and Dr. Charles G. Abbot, secretary. The following were elected members of the executive committee for the ensuing year: Messrs. Charles Moore, Herbert Adams, and George B. McClellan. Mr. Joseph H. Gest, as chairman of the Commission, and Dr. Charles G. Abbot, as secretary of the Commission, are ex-officio members.

The subject of stained glass was discussed, and Mr. Charles L. Borie, Jr., was appointed chairman of a new committee on stained glass, to report at the next meeting. The Commission, acting as the advisory committee, accepted the full-length portrait of John Gellatly, by Irving R. Wiles, N.A., and the portrait of William H. Holmes, by E. Hodgson Smart. Dr. Moore called attention to the fact that Dr. W. H. Holmes had retired on June 30, 1932, and suggested that a written expression of appreciation of his long and faithful service to the National Gallery of Art and its Commission be recorded.

THE JOHN GELLATLY ART COLLECTION

The John Gellatly collection of paintings, carvings, jewelry, enamels, glass, statues, and miscellaneous art objects, offered early in 1929, and accepted June 13 of that year, was transferred from New York City to the National Gallery of Art, May 1, 1933. Its installation was begun immediately and the collection was thrown open to the public on June 23, 1933. The collection consists of over 1,600 specimens. The fixtures, pedestals, and cases, are also a part of the gift.

This collection fills 1 large gallery and 2 smaller galleries adjoining. Mr. Gellatly was catholic in his taste and collected many rare and beautiful specimens of the work of the goldsmiths, the ivory carvers, the makers of statues in wood, bronze, marble, silver, and gold; ancient glass from many countries; fifteenth and sixteenth century stained glass; furniture, and paintings.

There are 142 American pictures, of which 104 are oils, 22 water colors, 12 pastels, and 4 in miscellaneous mediums such as silverpoint, pencil, and charcoal. Five American artists are represented by 84 examples: T. W. Dewing (17), Abbott H. Thayer (23), Childe Hassam (15), J. H. Twachtman (12), Albert P. Ryder (17). Other American artists who are represented by more than one picture are: Henry Golden Dearth (2), John La Farge (3), J. A. McN. Whistler (2), John Singer Sargent (2), Irving R. Wiles (2), Max Bohm (3), Gari Melchers (3), John Noble (2), Lucia Fairchild Fuller (2 miniatures), J. J. Shannon (2), F. S. Church (7). A few of the American painters represented by but one painting are: John Singleton Copley, Frank W. Benson, Frank Duveneck, George De Forest Brush, Edward G. Malbone (miniature), Robert Reid, George Fuller, Paul Dougherty, R. A. Blakelock, George Inness. In all, there are 44 American artists. European paintings are very poorly represented, there being only 22 paintings by 19 artists, 7 of whom are unknown.

On the walls of the large gallery are shown exactly 100 American oil paintings, while around the walls and the floor space are cases containing glass, jewels, oriental specimens, enamels; ancient and modern sculpture in wax, silver, wood and terra cotta; antique furniture, chairs, settees, tables, and much other valuable and interesting material.

A second gallery is filled to overflowing with a great variety of material from Europe and Asia, tapestries, textiles, furniture, rare stained glass, religious crucifixes and charms, sculpture in wood, terra cotta, ivory, jade, emerald, bronze, and marble. Unique items among these are: The Christian necklace of the sixth century consisting of 15 golden disks inlaid with glass mosaic, each disk portraying one of the twelve disciples with the name inscribed in Greek, the central disk being reserved for the Christ and the two end ones each bearing the Constantinean cross; and an emerald cup, a marvel of size and workmanship. There are many objects of unusual interest and value, also paintings, European and oriental.

In a third gallery are displayed 36 water colors, pastels, and drawings by American artists, and 16 fragments of Chinese frescoes from Turfan; 1 bronze and 1 terra-cotta by Augustus St. Gaudens; 1 marble by George Grey Barnard, and miscellaneous furniture, a grandfather clock, a desk, a harp, tables, chairs, etc. One large model of a seventeenth century warship will be found surrounded by many other objects not listed here. One important painting, a 15-foot circular decoration called "Dawn", by T. W. Dewing, which had been rolled for 19 years, was mounted and hung in the rotunda.

The Gellatly collection is undoubtedly the most important gift to the National Gallery since the Freer collection was received. It has great variety and in itself is an art museum.

THE HENRY WARD RANGER FUND PURCHASES

The 12 paintings purchased during the year by the Council of the National Academy of Design from the fund provided by the Henry Ward Ranger bequest, which under certain conditions are prospective additions to the National Gallery collections, are as follows, including the names of the institutions to which they have been assigned:

Title	Artist	Date of purchase, 1932	Assignment
100. Rhododendron	H. Dudley Murphy, A.N.A.	December	
101. Last Snow	Theodore Van Soelen	do	Everhart Museum of Natural History, Science, and Art, Scranton, Pa.
102. Return from the Farm.	Elliott Daingerfield, N.A. (1859-1932).	do	Smith College Museum of Art Northampton, Mass.
103. Etaples-Moonlight	John Noble, N.A	do	Brooks Memorial Art Gallery, Memphis, Tenn.
104. Snow and Haze	Walter L. Palmer, N.A. (1854-1932).	do	Clemson College Library, The Clemson Agricultural College, Clemson College, South Carolina.
105. Pale Light of Dawn	Spencer Nichols, A.N.A.	do	Society of Liberal Arts, Joslyn Memorial, Omaha, Nebr.
106. Path of Light	Malcolm Humphreys	do	Fine Arts Club of Arkansas, Little Rock, Ark.
107. The Blue Jar	Cullen Yates, N.A	do	Portland Art Association, Portland, Oreg.
108. Room in Arlington Where Lee was Married.	Charles Bittinger, A.N.A.	do	Montgomery Museum of Fine Arts, Montgomery, Ala.
		1933	
109. Self Portrait	Will H. Lowe, N.A. (1853-1932).	February	Albany Institute of History and Art, Albany, N.Y.
110. Heavy Sea	Paul Dougherty, N.A	do	William Rockhill Nelson Gallery of Art, Kansas City, Mo.
111. The Vase	Francis C. Jones, N.A. (1857-1932).	April	Kansas State College of Agriculture and Applied Science, Manhattan, Kans.

ART WORKS RECEIVED DURING THE YEAR

Accessions of art works by the Smithsonian Institution are as follows:

Portrait of Richard Mansfield as Beau Brummel, by Orlando Rouland (1871–). Gift of Henry Harkness Flagler, Esq., New York City, "for the collection of portraits of eminent Americans."

Two bronze statuettes, The End of Day, and Man of Steel, by Max Kalish. Gift of the sculptor.

Bronze statuette, Faun, by Alice Morgan Wright. Gift of the sculptor.

Bronze statuette of a goat, Nancy Lee (Sag Mal Haroun al Raschid of Kayenne). Gift of the sculptor, Gertrude K. Lathrop.

Eight oil paintings, 4 water colors, and one tapestry, part of "The Adelaide M. Noble collection" presented to the Institution by the Mrs. James S. Harlan estate through Mrs. Cornelia Hand Baird, Yonkers, N.Y.:

Oils, artists undetermined unless specified:

Portrait of Mrs. Adelaide M. Noble, by Francois Flameng (1856–).
The Christ Child.
The Old Spinning Woman.
Saint John.
The Finding of Moses.
Madonna with halo of stars.
Shepherd and Shepherdesses. Signed: Albert Cuyp, 1644.
Sketch of Child with Cross and Torch.

Water colors:

Landscape, by E. Landseer Harris.
Landscape, by an artist not known.
Landscape, by John L. Bennett, 1884.
Landscape, by E. Wachtel.

One tapestry, subject from The Siege of Troy, Hector Carrying Anchises on His Back.

Six paintings, mostly portrait sketches in oil, one alabaster Madonna, and furniture, part of the collection presented to the Institution by the daughters of Mrs. Alice Pike Barney in memory of their mother, through Mrs. Dreyfus-Barney, of Paris, France. The paintings are:

Marguerite in Prison, by T. Grund, 1863–67.
Alice Barney with Jabot, by Alice Barney.
Infanta, by Alice Barney.
Laura in Yellows, by Alice Barney.
Peachbloom, by Alice Barney.
Marianne Girard, by Alice Barney.

Twenty-seven unframed water-color sketches by Ernest Griset (1844–1907), part of the bequest of Miss Lucy Hunter Baird received in 1914 and assigned to the United States National Museum, were transferred to the Gallery.

LOANS ACCEPTED BY THE GALLERY

Four early American family portraits: Joseph Turner, and Elizabeth Oswald Chew, by John Wollaston (middle eighteenth century), John Crathorne Montgomery, and Mrs. John Crathorne Montgomery, by Thomas Sully (1783–1872); lent by Mrs. H. H. Norton (Mrs. Mary Montgomery Norton).

A standing portrait of Abraham Lincoln, painted in London, by Charles Snead Williams in 1931–32; lent by the artist. Returned to his agents, November 21, 1932.

Two portraits in pastel by James Sharples (1751–1811), of Gen. James Miles Hughes, original member of the Society of the Cincinnati, and Mrs. James Miles Hughes, his wife; lent by Madame Florian Vurpillot, through Mrs. R. G. Hoes.

Marble bust of Gen. John J. Pershing, by the late Moses Wainer Dykaar.

Life-size portrait bust in Carrara marble of Col. Charles Hoyt March, Chairman of the Federal Trade Commission, by Louise Kidder Sparrow (with rectangular base); lent by Mrs. Charles Hoyt March.

GALLERY LOANS RETURNED

Mrs. Herbert Hoover returned two paintings borrowed by her from the National Gallery in 1929 for exhibition in the White House. They are Love and Life, by George Frederick Watts (returned Sept. 8, 1932), and Castle Creek Canyon, South Dakota, by Frank De Haven (returned Mar. 1, 1933).

Two portraits, one of George Washington by Charles Willson Peale, the property of John S. Beck, and the other of Dr. William Shippen, Jr., by Gilbert Stuart, the property of Dr. L. P. Shippen, were returned by the Corcoran Gallery of Art at the request of their owners, where they had formed part of the Bicentennial exhibition of portraits of George Washington and his associates, March 5 to November 24, 1932 (returned Nov. 28 and 29, 1932).

The original working model in plaster of the bronze equestrian statue of Lafayette erected in the square of the Louvre, Paris, by the school children of the United States in 1900, which was lent to Mrs. Bartlett in October 1931 for a memorial exhibition of the life work of her husband, Paul W. Bartlett (1865–1925), held in New York City, was returned by Mrs. Bartlett on December 20, 1932.

Four paintings and four busts, exhibited for a number of years at the Cosmos Club, Washington, D.C., were recalled on March 1, 1933. The paintings: Indian Summer Day, by Max Weyl, A Pool in the

Forest, by Benjamin Rutherford Fitz, Fired On, by Frederic Remington, and Interior of Levardin Church, Florence, Italy, by S. Jerome Uhl (property of R. P. Tolman); the busts: Alfred Tennyson, by Partridge, Joseph Henry, by C. V. Burton, Voltaire, by J. A. Houdon, and Elisha Kent Kane, by Saunders.

LOANS BY THE GALLERY

The painting entitled "At Nature's Mirror", by Ralph Albert Blakelock (1847–1919), belonging to the William T. Evans collection, was lent to the Museum of Modern Art, New York City, for an exhibition of American painting of the last 70 years, from November 1, 1932, to February 1, 1933. The painting was returned to the Gallery at the close of the exhibition.

The painting by Francesco Guardi (1712–1783) entitled "Ruins and Figures," part of the Ralph Cross Johnson collection, was lent to the Art Institute of Chicago to form part of its art exhibit at the Century of Progress Exhibition in Chicago, from June to November, 1933.

Twelve water-color sketches and one oil painting were lent to the Corcoran Gallery of Art for a memorial exhibition of the work of the late Dr. William H. Holmes, first director of the National Gallery of Art, from June 15 to July 5, 1933. These were returned at the close of the exhibition.

Three early American paintings were lent to the White House in September 1932, at the request of Mrs. Herbert Hoover: Portrait of Mary Hopkinson, by Benjamin West, A Lady, and Joseph Head, by Gilbert Stuart. These were returned to the Gallery in March 1933.

SPECIAL EXHIBITIONS

The exhibition of paintings, sculpture, plans of Washington City, etc., which opened on March 26, 1932, in honor of the bicentennial of the birth of George Washington, mentioned in the last report, closed on November 24, Thanksgiving Day.

An exhibition of 29 large paintings of Gaucho life in Argentina, Province of Entre Rios, 1850–70, by Señor Don Cesareo Bernaldo de Quiros, opened with a private view on January 13, 1933, under the patronage of His Excellency the Argentine Ambassador, Señor Dr. Felipe A. Espil, and continued for the general public through March 12, 1933. Cards for the opening view were issued by the Gallery, and a catalog was supplied through the artist.

The regents and Secretary of the Smithsonian Institution issued cards for the opening view on the evening of June 22, 1933, of the Gellatly art collection, presented to the nation by John Gellatly, Esq. A catalog of the 164 American and European paintings in this collection was issued by the Institution.

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THE NATIONAL GALLERY LIBRARY

Much-needed space was provided for the library by the installation in room 382 of steel book stacks, giving about 250 feet of additional shelving. On May 1, 1933, Miss Ruth Wenger, library assistant, was detailed from the Smithsonian Library, and the organization of the library was begun. At the close of the year considerable progress had been made in rearrangement and shelf-listing of the material and the inauguration of a standardized card catalog. The checking of missing parts of the gallery's serial publications progressed, and the recording of much material was accomplished. During the year 499 volumes and pamphlets were added by gift, exchange, and purchase.

CARE OF COLLECTIONS

The portraits and most of the sculpture which were in the lobby, the northern entrance to the Natural History Building, have been moved to the halls around the rotunda, where both the sculpture and paintings appear to good advantage. Ten statues still remain in the lobby and 10 paintings have been selected from the permanent collection for exhibition there.

CHANGES IN PERSONNEL

Dr. William H. Holmes, Director, was retired June 30, 1932, and Ruel P. Tolman was appointed Acting Director on July 1, 1932.

Ralph Seymour was given a temporary appointment as expert in charge of the Gellatly art collection, May 1 to June 30, 1933.

Miss Ruth Wenger was assigned to the library of the National Gallery of Art, May 1, 1933.

PUBLICATIONS

Holmes, W. H. Report on the National Gallery of Art for the year ending June 30, 1932. Appendix 2, Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1932, pp. 29–33.

Lodge, J. E. Report on the Freer Gallery of Art for the year ending June 30, 1932. Appendix 3, Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1932, pp. 34–38.

Tolman, R. P. Catalogue of American and European Paintings in the Gellatly Collection. Smithsonian Institution, National Gallery of Art, pp. 1–19, 7 illustrations.

Catalogue of an Exhibition of Paintings by Cesareo Bernaldo de Quiros. Gaucho Life in Argentina (Province of Entre Rios) 1850–70. Washington, D. C. Smithsonian Institution. National Gallery of Art (January 13–March 12, 1933). Pamphlet; privately printed.

Cesareo Bernaldo de Quiros, by Christian Brinton. An Exhibition of Paintings of Gaucho Life in the Province of Entre Rios, Argentina, 1850–70. The National Gallery of Art, Washington, D.C. Exhibition of Paintings by Cesareo Bernaldo de Quiros, January 13–March 12, 1933. (Printed by order of the

trustees of the Hispanic Society of America, New York, 1932, and cover revised for National Gallery of Art distribution), pp. 1–23, 22 illustrations.

Respectfully submitted.

R. P. Tolman, *Acting Director.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 2

REPORT ON THE FREER GALLERY OF ART

SIR: I have the honor to submit the Thirteenth Annual Report on the Freer Gallery of Art for the year ending June 30, 1933:

THE COLLECTIONS

Additions to the collections by purchase are as follows:

BRONZE

33.2. Chinese, Chou dynasty. A ceremonial vessel of the type *huo*, with attached cover. Decorations incised and in low relief. Smooth gray-green patina. Inside the cover, an inscription of 50 characters; 4 characters on the outside.

CERAMICS

Pottery:

32.58. Chinese, twelfth–thirteenth century. Sung dynasty. *Koyao*. A bowl with flaring sides and a six-notched rim; on a small basal ring. Grayish green glaze with an irregular brown crackle.

33.1. Chinese, twelfth–thirteenth century. Sung dynasty. *T'u ting* type? A wine cup with flaring sides on a small basal ring; luminous deep cream-colored glaze.

Porcelain:

32.63. a–b Chinese, early eighteenth century. Yung Chêng period. Ku Yüeh Hsüan. A small bowl decorated on the outside with a landscape design in blue enamels over glaze. Ivory stand.

JADE

Chinese, Han dynasty. A group of ornamental jades apparently from one source. The substance is for the most part of a translucent greenish gray, with areas of cream-white surface alteration and brown fleckings. The forms are as follows:

32.38. Crescent-shaped pendant (*huang*), with a decoration of tiger heads and the "grain pattern" of small nodules, carved in relief on both sides.

32.39. Pendant of double bird design, with open work carving and the "grain pattern" in relief on both sides.

32.40. Pendant in bird form, with open-work carving and incised details on both sides.

32.41. A small disk (*pi*), with the "grain pattern" in relief on both sides.

32.42. Oblong pendant with the "grain pattern" in relief on both sides.

32.43. Plaque of animal form, with details of the design carved on both sides.

32.44. Plaque of animal form, similar to the preceding one.

MANUSCRIPTS

32.27. Japanese, sixteenth–seventeenth century. An album of 30 poems from the *Genji Monogatari*, written in *hiragana*. Each poem is accompanied by a miniature painting. (See below under Paintings, 32.27a–dd.)

32.29. Persian, early fifteenth century. Mongol (*Dj*alā'ir) period. Poems of Sulṭān Ahmād ibn 'Uways i-*Dj*alā'ir. A book of 337 leaves, bound in brown leather. Text written in *nasta'līq* script. Illuminated title page and eight pages with border decorations. (See below under Paintings, 32.30–32.37.)

32.45. Persian, early sixteenth century. Herat school. Sulṭān Mahmud Nūr, calligraphist. Selected poems (from the *Dīwān*) of Hafiz, with extracts from the works of Ibn Yamīn, Omar Khayyam, and Niẓāmī written on the margins. A volume of 75 leaves, in a seventeenth century Indian binding of red leather with gold tooling; text in delicate *nasta'līq* script. Two illuminated pages, many illuminated head and tail pieces, and seven minature paintings. (See below under Paintings, 32.48–32.54.)

32.55–32.57. Persian, tenth century. Three leaves from a parchment *Qur'ān*. Text written in ornamental *kūfī* script; 1 illuminated chapter heading and 5 gold lection marks.

32.59–32.61. Arabic (Egypt), fifteenth century. Three illuminated pages from a book of selections from the *Qur'ān*. Text written in a handsome THULTH script; illuminations in gold and blue, on paper.

32.62. Arabic (Egypt), eighth century. A leaf from a parchment *Qur'ān*. Recto: a page ornament in gold and slight color; verso: seven lines of text in *kūfī* script in brown ink.

PAINTINGS

32.27. a–dd Japanese, sixteenth–seventeenth century. By Tosa Mitsunori. Thirty miniature paintings executed in ink, slight color and gold, illustrating scenes from the *Genji Monogatari;* bound in an album. Each painting is accompanied by a poem from the same work. (See above under Manuscripts, 32.27.)

32.28. Persian, sixteenth century. Herat school. Portrait of a painter in Turkish dress, painted in opaque colors and slight gold on paper.

Persian, early fifteenth century. Mongol (*Dj*alā'ir) period. A series of eight border illustrations, executed for the most part in ink drawing in the Chinese taste, from the MS. book, *Poems of Sulṭān Ahmād* DJ*alā'ir* (see above under Manuscripts, 32.29):

32.30. A scene of country life in Central Asia.

32.31. A spring scene including the figures of two lovers.

32.32. An autumn scene: philosophers in discourse.

32.33. Angels descending in streams of golden flame. Executed in gold and tints of rose and blue.

32.34–32.35. A nomad encampment in Central Asia, designed, apparently, as one composition on two facing pages.

32.36. Ducks.

32.37. A stream, wild ducks and cranes.

Persian, sixteenth century, Herat school. A series of 9 illuminations and illustrations from the manuscript book, the *Dīwān* of Hafiz (see above under Manuscripts 32.45), painted, with one exception, in opaque colors and gold on paper:

32.46–32.47. Two illuminated pages (*'unwān*).
32.48. A prince holding a feast on a garden terrace in spring.
32.49. A polo game.
32.50. A prince with women of his household in a garden.
32.51. A prince holding an audience.
32.52. A lion with collar and bell chained to a post. Ink, color and gold.
32.53. A scene of wine drinking in a garden.
32.54. Men dancing on a terrace.
32.64. Persian, sixteenth century. Bukhārā school. A young woman with a spray of lilies. Opaque colors and gold on paper.
33.3. Arabic (Egypt), fourteenth century. An ornamental rosette, designed as a frontispiece for a *Qur'ān* (without inscription). Colors and gold on paper.
33.4. Persian, sixteenth–seventeenth century. A women in an orange coat rolling a thread between her palms. Opaque colors and gold on paper.

STONE SCULPTURE

East Indian, early second century, B.C. Śuṅga period. Two blocks of a hard reddish sandstone, which formed two faces of a fence rail of the *Stūpa* of Bhārhut. The designs carved in high relief are as follows:
32.25. King Prasenajit visits the Buddha (Great Miracle of Śrāvastī). Inscription.
32.26. Worship of a *Stupa* (*parinirvāṇa*).

Curatorial work within the collection has been devoted to the critical study of Armenian, Chinese, and Japanese texts associated with recent acquisitions; to the translation and identification of fragments of Arabic and Persian texts on manuscript leaves; and to the preparation of gallery books, containing descriptive notes for the information of visitors. At the time of this writing, those for galleries I–III have been completed; that for gallery IV is in preparation. Other work includes that ordinarily associated with the study, cataloging, and exhibition of recent acquisitions in the field of oriental fine arts. During the past year 979 objects and 325 photographs of objects were submitted to the curator by other institutions, or by private persons, for expert opinion as to their identity, provenance, or historical or esthetic value. Twelve oriental inscriptions were submitted for translation. Reports on these things were made to owners or senders.

Changes in exhibition have involved the rearrangement of seven galleries, as follows:

Gallery I	Near Eastern art: Christian and Islamic Illuminated Manuscripts.
Gallery II	Near Eastern Art: Arabic and Persian, tenth–fifteenth century.
Gallery III	Near Eastern Art: Persian, thirteenth–seventeenth century.
Gallery IV	East Indian Art.
Gallery VIII	American paintings, by Brush, Dewing, Melchers, Metcalf, Thayer, Tryon.

Gallery IX........ Whistler oil paintings: landscapes and figures.
Gallery X......... Water colors by Whistler and W. Homer.

In all, 450 changes in exhibition were made during the year, distributed as follows:

American paintings and prints, 126.
Biblical manuscripts and paintings, 5.
Chinese ceramics, 8.
Chinese jade, 24.
Chinese sculpture, 2.
East Indian manuscripts and paintings, 49.
East Indian scuplture, 6.
Japanese paintings, 35.
Near Eastern book-bindings, 11.
Near Eastern ceramics and glass, 40.
Near Eastern manuscripts and paintings, 144.

PUBLICATIONS

Brown, W. Norman. The story of Kālaka, Smithsonian Institution, Freer Gallery of Art, Oriental Studies, No. 1, 1933.

Bishop, C. W. (ed.), with K. Huang, W. J. Chang, K. Z. Tung (joint authors). Excavations of a West Han Dynasty site, Shanghai, 1932.

ATTENDANCE

The Gallery has been open every day from 9 until 4:30 o'clock, with the exception of Mondays, Christmas Day, and New Year's Day.

The total attendance of visitors coming in at the main entrance was 120,707; the total attendance for week days 78,247; the total Sunday attendance, 38,990. The usual ratio between Sunday and week-day attendance of 3 to 1, was maintained—the Sunday attendance averaging 750, the week-day attendance, 251. The highest monthly total attendances were reached in April (18,822) and August (14,542); the lowest attendance was in December (4,929).

The total attendance of visitors on Mondays was 25, making a grand total attendance of 120,732.

There were 2,082 visitors to the offices during the year. Of these, 118 came for general information, 280 to see objects in storage, 36 to examine the building and installation, 185 to study in the library, 122 to see the facsimiles of the Washington Manuscripts, 36 to make tracings and sketches from library books, 29 to get permission to make photographs and sketches, 250 to examine or purchase photographs, 126 to submit objects for examination, 375 to see members of the staff. Seventy-four groups, ranging from 1 to 80 persons (total, 329) were given docent service upon request, and 18 groups, ranging from 6 to 13 persons (total, 171) were given instruction in the study rooms.

FIELD WORK

Owing to the disturbed conditions in China, the conduct of field work has been greatly limited. However, during the past spring it has been possible to explore a large part of the province of Shansi. It is thought that the data assembled during these explorations will prove to be of value in the making of a preliminary distribution map of culture sites of various ages in that Province.

PERSONNEL

On August 5, 1932, the Freer Gallery suffered a loss in the death of Herbert E. Thompson, of Boston. Mr. Thompson had been associated with the Gallery since 1921 in the work of the preservation of oil paintings.

William Acker, student assistant, was at the Gallery from July 19, 1932, until January 21, 1933, when he was sent to Japan for further study.

Y. Kinoshita, mounter, was granted a 4 months' leave of absence, from June 11, in order to visit his home in Japan.

Respectfully submitted.

J. E. Lodge, *Curator.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 3

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY

SIR: I have the honor to submit the following report on the field researches, office work, and other operations of the Bureau of American Ethnology during the fiscal year ended June 30, 1933, conducted in accordance with the act of Congress approved June 30, 1932. The act referred to contains the following item:

American ethnology: For continuing ethnological researches among the American Indians and the natives of Hawaii, the excavation and preservation of archæologic remains under the direction of the Smithsonian Institution, including necessary employees, the preparation of manuscripts, drawings, and illustrations, the purchase of books and periodicals, and traveling expenses, $66,640.

SYSTEMATIC RESEARCHES

M. W. Stirling, chief, devoted most of his time during the year to office routine and to the preparation of manuscript accumulated from past researches. Several sections of his report on the ethnology of the Jivaro Indians of eastern Ecuador were completed, and considerable progress was made in the preparation of a manuscript describing and illustrating the important finds made by F. H. Cushing, former ethnologist of the Bureau, during excavations in a muck deposit at Key Marco, Fla. A set of excellent photographs illustrating this work was discovered in the Bureau archives, where they had been deposited, unindexed, by Mr. Cushing, whose death took place shortly after the completion of his Florida field work.

Mr. Stirling also gathered a large quantity of unpublished material relating to the career of Sitting Bull, including a new and heretofore unknown hieroglyphic autobiography drawn by Sitting Bull himself, a more important specimen than the famous copy of a Sitting Bull autobiography in the Bureau archives made by Four Horns.

Dr. John R. Swanton, ethnologist, devoted the greater part of his time, beyond that used in answering correspondents, to an extensive paper on the ethnology of the southeastern Indians, mentioned in previous reports. A great volume of material has been added. Progress has also been made in the preparation of a bulletin to include all the linguistic material rescued from the now extinct Coahuiltecan and Karankawan dialects.

Dr. Swanton took part in the "Conference on Southern Pre-History" held at Birmingham, Ala., December 18–20, under the auspices of the Division of Anthropology and Psychology of the

National Research Council, through its committee on State archeological surveys, of which Dr. Carl E. Guthe is chairman. To this he contributed two papers, one entitled "The Southeastern Indians of History" and the other "The Relation of the Southeast to General Culture Problems of American Pre-History." He presided as president of the American Anthropological Association over the sessions of that body at its meeting at Atlantic City, N.J., December 28–30.

Bulletin 108, entitled "A Dictionary of the Atakapa Language", consisting largely of material collected by the late Albert S. Gatschet but systematized and edited by Dr. Swanton, appeared during the year.

Dr. Truman Michelson, ethnologist, was at work among the Cheyenne and Arapaho at the beginning of the year. Among the Cheyenne the prime object was to get an insight into their mythology, though their sociology was not neglected. Among the Arapaho, work was linguistic and sociological. He secured the personal narrative of an aged southern Arapaho woman. An analysis shows clearly that this is almost entirely institutional, closely following the tribal pattern. With but few changes it might be the autobiography of any aged Arapaho woman. On July 22 Dr. Michelson left for Tama, Iowa, to renew researches among the Foxes in that vicinity. New data on ceremonials were obtained and some older data verified. He left Tama on August 8, stopping at Chicago to consult with some anthropologists of that city and to inspect certain collections.

While in the office Dr. Michelson prepared for publication by the Bureau a manuscript entitled "When the War Chiefs Worship the Wolf", which is to be combined with a paper entitled "Fox Miscellany", which was prepared last year. Dr. Michelson worked out a long series of phonetic shifts in Arapaho, which will ultimately be published. He succeeded in finding Algonquian etymologies for a host of Blackfoot words and stems; which contradicts the usual assumption that Blackfoot vocabulary must be largely from outside sources. A grant was made to Dr. Michelson by the National Research Council whereby he could employ a technical assistant to bring the late Dr. Jones' Fox and Ojibwa material into shape for publication, and Mrs. Margaret Welpley, a former student of Dr. Michelson's, was selected for this purpose. At the close of the fiscal year all the Fox ethnological material was virtually ready for publication.

J. P. Harrington, ethnologist, spent the year in an endeavor to rescue before it is too late what can still be learned of the culture of the Indians of southern California and adjacent regions to the north and east. Attention in this field naturally centered about the classic work of Boscana published by Alfred Robinson in 1846, as Boscana's work has never been thoroughly checked with modern Indians.

Father St. John O'Sullivan of San Juan Mission gave invaluable collaboration in a renewed study of the San Juan Indians.

The Fred H. Bixby ranch near Long Beach was identified as the birthplace of the Indian prophet Chinigchinich. All obscure passages in Boscana were completely cleared up as a result of this work and much new ethnological data was secured.

Scarcely a source of information that could be thought of was left untried. Information was gathered by correspondence from universities and professors in this country, Spain, Italy and Mexico. The manuscript, comprising some 800 pages, was completed for publication, and should be a standard source book for the ethnology of southern California Indians. Thorough linguistic, ethnobotanical, and historical studies were made to support the Boscana.

The beginning of the year found Dr. F. H. H. Roberts, Jr., archeologist, in camp 3½ miles south of Allantown, Ariz., engaged in a series of archeological excavations which had been started in June. The work as a whole was a continuation of a program of researches begun during the summer of 1931. In July 1932 a semisubterranean structure of the Pueblo I pit-dwelling type was cleared of accumulated debris. Eight granaries and two surface shelters accompanying the pit remains were also uncovered. This group contributed valuable data on the habits and customs of the people of that horizon. Specimens of the arts and industries obtained from the structures aided materially in determining the culture pattern.

Investigations were shifted to a Pueblo II site late in July, and a 6-room unit house with its adjacent ceremonial chamber or kiva was excavated. Digging was also carried on in the nearby refuse mound. Twenty burials were found and interesting information obtained concerning mortuary customs. A representative collection of artifacts was also made at this location. The investigations demonstrated that the typical unit house was present in a region where it hitherto had not been supposed to exist.

Dr. Roberts returned to Washington in September and spent the winter preparing plans, diagrams, and a report on the summer's activities.

Dr. Roberts left Washington at the end of May 1933 for Arizona. En route he stopped at Norton, Kans., to inspect purported Indian mounds. The formations proved to be entirely natural.

In Arizona investigations were resumed at the site south of Allantown. The work consisted largely of checking notes made in previous seasons and making preparations to abandon the site, the latter move being necessitated by the lack of funds required to carry the researches to a proper conclusion.

From July 1 to 16, 1932, Dr. W. D. Strong, anthropologist, continued his stratigraphic researches at Signal Butte in western

Nebraska. From July 16 to September 2 archeological research was carried on in historic and prehistoric Arikara and Mandan sites in South Dakota. Some ethnological work was also accomplished among the former people. From September 16, 1932, to January 28, 1933, he was in Washington, where the collections were unpacked, classified, and the writing of reports commenced.

On January 28, 1933, Dr. Strong left Washington for 6 months' anthropological research in northeastern Honduras. This included a 6 weeks' expedition up the Patuca River, where archeological sites were mapped, some excavating was carried on, and the Sumu and Miskito Indians were briefly studied. An accident occurring on this trip caused a delay of several weeks at Puerto Castilla for hospital treatment. From April 24 to May 24 an archeological survey of the Bay Islands was accomplished. This yielded unusually valuable results. On June 4 the party made a muleback trip across the mountains to the interior town of Juticalpa. From here they flew to Tegucigalpa to interview officials. On July 1 the party was returning by mule to the coast. Many new archeological sites, some of very large size, were discovered on this trip. Valuable contacts were also made with the Paya Indians in the interior.

Winslow M. Walker, associate anthropologist, resumed investigations in the mound area of the Mississippi Valley from the middle of August to the middle of November 1932. Excavations made on the site of the former great mound at Jonesville, La., revealed evidences of more than one period of occupancy, the earliest containing pottery of a type similar to that found in the Hopewell mounds of Ohio Other interesting features discovered include portions of a log palisade, a kind of stairway of logs, a lone human skull, minus the lower jaw, lying in the mud beneath the lowest step, and great sheets of cane laid down with careful regularity throughout the mound. Other mounds in this group, formerly known as the Troyville group, were examined, and the conclusion was reached that they probably stand on the site of the great Indian town of Anilco visited by De Soto in 1542. A report on this work has been prepared entitled "The Troyville Mounds, Catahoula Parish, La." Mr. Walker also spent some time while in Arkansas endeavoring to locate the sites of the Quapaw villages shown on the Ross map of 1765, but changes in the river course have obliterated all trace of them. A start has also been made on a card catalog listing the locations of early historic Indian villages, to serve as a guide for further profitable archeological work in the Southeast.

J. N. B. Hewitt, ethnologist, devoted considerable time to a study of the probable date of the formation and organization of the League of the Five Iroquois Tribes. This required especial research in the early writings of the first explorers in the valley of the St. Lawrence

River. This study confirmed Mr. Hewitt's earlier estimate that the approximate period was 1559–70.

A study of the Jesuit Relations shows that the organic units of the federal structure of the historical League of the Five Iroquois Tribes differed from those of the Huron in nonessentials only. Mr. Hewitt also established the fact that the Iroquois had not been expelled from the north by Algonquins in prehistoric times.

A new translation with interpretative notes of the Fifth Ritual of the Federal Ceremony of Condolence and Installation, "The Requickening Address", consisting of 8,385 native terms, was made.

Mr. Hewitt represented the Smithsonian Institution on the United States Geographic Board, as a member of its executive committee.

As custodian of manuscripts, Mr. Hewitt has been assisted by Miss Mae Tucker, who has also continued the task of cataloging the thousands of negatives and photographs accumulated since the establishment of the Bureau.

SPECIAL RESEARCHES

The study of Indian music was continued during the past year by Miss Frances Densmore, a collaborator of the Bureau. Seven manuscripts were submitted, with the following titles: "Winnebago, Iroquois, Pueblo, and British Columbian Songs"; "Seminole Songs Connected with Legends and Dances"; "Dance Songs of the Seminole Indians"; "Choctaw Songs of Dances and Games"; "Songs of the Alibamu Indians"; "Alibamu Songs of the Buffalo and Other Dances"; and "Chitimacha, Choctaw, and Seminole Music, with a Comparative Survey of Indian Music in the Gulf States." Seven manuscripts previously submitted on the music of British Columbian Indians have been combined and retyped.

An extended field trip in the Gulf States was begun in December 1932 and concluded in February 1933. The first tribe visited was the Alibamu in Polk County, Tex., more than 60 songs being recorded. The Chitimacha at Charenton, La., were next studied. About 80 songs were recorded from the Choctaw near Philadelphia, Miss. The Seminole in Florida were revisited and about 70 songs were recorded.

EDITORIAL WORK AND PUBLICATIONS

The editing of the publications of the Bureau was continued through the year by Stanley Searles, editor. The status of the publications is presented in the following summary.

PUBLICATIONS ISSUED

Forty-ninth Annual Report of the Bureau of American Ethnology to the Secretary of the Smithsonian Institution, 1931–32. vi+8 pp.

Bulletin 99. The Swimmer manuscript: Cherokee sacred formulas and medicinal prescriptions (Mooney and Olbrechts). xvii+319 pp., 13 pls.

Bulletin 106. Ethnographical survey of the Miskito and Sumu Indians of Honduras and Nicaragua (Conzemius). vii+191 pp., 10 pls., 1 fig.

Bulletin 108. A dictionary of the Atakapa language, accompanied by text material (Gatschet and Swanton). v+181 pp., 1 pl.

Bulletin 109. A dictionary of the Osage language (La Flesche). v+406 pp.

Bulletin 110. Yuman and Yaqui music (Densmore). xviii+216 pp., 31 pls., 7 figs.

Bulletin 111. The village of the great kivas on the Zuñi Reservation, New Mexico (Roberts). ix+197 pp., 64 pls., 34 figs.

List of publications of the Bureau of American Ethnology, with index to authors and titles. iv+55 pp.

PUBLICATION IN PRESS

Forty-eighth Annual Report. General index, annual reports of the Bureau of American Ethnology, vols. 1–48 (Bonnerjea). v+1220 pp.

The number of publications distributed was 29,889.

LIBRARY

The reference library has continued under the care of Miss Ella Leary, librarian. The library consists of 30,391 volumes, about 16,993 pamphlets, and several thousand unbound periodicals. During the year 320 books were accessioned. There were also received 126 pamphlets and 3,440 serials, chiefly the publications of learned societies. Books loaned during the year numbered 960 volumes. In the work of cataloging 4,840 cards were added to the catalog. A considerable amount of reference work was done in the usual course of the library's service to investigators and students, both those in the Smithsonian Institution and others.

ILLUSTRATIONS

Following is a summary of work accomplished by E. G. Cassedy, illustrator for the Bureau.

Maps (colored)	9
Tracings	12
Mechanical drawing	1
Preliminary drawings	50
Line drawings	54
Sketches (color)	6
Photographs retouched	33

COLLECTIONS

Accession number

114181. Archeological material from various sites between the Rio Salado and the Rio Dulce, known as Mesapotonua Santiaguena, Argentine, and presented to the Bureau by E. R. Wagner, Museo Arcaico Provincial, Santiago del Estero, Argentine.

120252. Collection of human skeletal material found by Dr. F. H. H. Roberts, Jr., while conducting archeological researches for the Bureau at a site on the Zuñi Indian Reservation, N.Mex., in the summer of 1930.

121548. Two boxes of mammalian and bird remains from a stratified archeological site at Signal Butte, Nebr., collected during the summer of 1932 by Dr. W. D. Strong.

Accession number

121824. Seventeen daguerreotypes, thirteen ambrotypes, and one tintype of Indian subjects which had accumulated in DeLancey Gill's office.

122561. One lot of turkey bones (*Meleagris gallapavo*), nymph of bug of family Reduviidae, and two fragments of swamp cane collected by W. M. Walker from the Jonesville mound, La.

122696. Decorated potsherd from Weeden Island mound, Tampa Bay., Fla., presented to the Bureau by D. I. Bushnell, Jr.

122697. Coiled pottery jar and several decorated potsherds from Keams Canyon, Ariz., transferred to the Bureau by the Office of Indian Affairs.

122701. Pottery bowl and pottery tobacco pipe made by the Tule Indians of the village of Mulatupa on San Blas coast of Panama, sent to the Bureau by A. G. Cleveland.

122704. Collection of ethnological specimens from the Jivaro Indians of the Upano, Santiago, Chinganasa and Alto Maranon Rivers of eastern Ecuador; archeological and ethnological objects from the Chama Indians of the Ucayali River in Peru; two copper and two stone axes from Mendez, Ecuador, and one stone ax from the Upper Yaupe River, Ecuador; and a collection of land snail shells from the Upper Paute River in the vicinity of Mendez, Ecuador, collected by M. W. Stirling in 1932.

122705. Slab of shell-tempered pottery used as part of a grave lining from an Indian grave near Nashville, Tenn., sent to the Bureau by P. E. Cox.

122979. Quirt and beaded bag collected by George R. Cassedy at Pawnee Junction, Nebr., in 1869 from Buckskin Charlie (a Sioux) and presented to the Bureau by E. G. Cassedy.

124507. Six projectile points from Yuma County, Colo., sent to the Bureau by Everett Harte of Wray, Colo.

MISCELLANEOUS

During the course of the year information was furnished by members of the Bureau staff in reply to numerous inquiries concerning the North American Indians, both past and present, and the Mexican peoples of the prehistoric and early historic periods. Various specimens sent to the Bureau were identified and data on them furnished for their owners.

Personnel.—E. G. Cassedy was appointed illustrator on November 25, 1932.

Respectfully submitted.

M. W. STIRLING, *Chief.*

Dr. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 4

REPORT ON THE INTERNATIONAL EXCHANGE SERVICE

SIR: I have the honor to submit the following report on the operations of the International Exchange Service during the fiscal year ending June 30, 1933.

The appropriation granted by Congress for the system of international exchanges during the year was $47,529, a decrease of $6,531 from the appropriation for the preceding year. Of this decrease, $1,250 was on account of certain savings in forwarding shipments to Great Britain, and the remainder, $5,281, was to meet the 10 percent reduction made by Congress in its economy program. The repayments from departmental and other establishments aggregated $5,228.29, making the total available resources for conducting the service during 1933 $52,757.29.

The total number of packages handled was 720,209, a decrease of 38,826. The weight of these packages was 634,707 pounds, a falling off of 25,943 pounds.

The following table gives the number and weight of the packages passing through the service arranged under certain classifications:

	Packages		Weight	
	Sent	Received	Sent	Received
			Pounds	*Pounds*
United States parliamentary documents sent abroad	387,004		148,677	
Publications received in return for parliamentary documents		9,519		31,375
United States departmental documents sent abroad	139,638		143,523	
Publications received in return for departmental documents		8,017		28,892
Miscellaneous scientific and literary publications sent abroad	135,751		191,885	
Miscellaneous scientific and literary publications received from abroad for distribution in the United States		40,280		90,355
Total	662,393	57,816	484,085	150,622
Grand total	720,209		634,707	

During the year 2,688 boxes were shipped abroad, an increase of 36 over the number for the preceding 12 months. Of the total number of boxes, 603 contained full sets of United States official documents for authorized depositories abroad, and the remainder (2,083) were filled with publications for miscellaneous establishments and individuals.

The number of packages sent abroad by mail was 79,630, a decrease of 5,805 from the number mailed the previous year.

FOREIGN DEPOSITORIES OF GOVERNMENTAL DOCUMENTS

The total number of sets of United States official publications sent to foreign depositories is 112, of which 62 are full and 50 partial.

The depository in Austria has been changed from the Bundeskanzleramt to the National-Bibliothek, Wien. A complete list of the depositories is given in the report for 1931.

INTERPARLIAMENTARY EXCHANGE OF THE OFFICIAL JOURNAL

The number of foreign legislative bodies and other governmental establishments to which the Congressional Record is forwarded under the terms of the convention for the immediate exchange of the official journal is 104. A list of the States taking part in this immediate exchange, together with the names of the establishments to which the Record is mailed, will be found in the report for 1931.

FOREIGN EXCHANGE AGENCIES

The Austrian Exchange Service, which has been conducted under the direction of the Bundeskanzleramt, is now under the National-Bibliothek and its address is Internationale Austauschstelle, National-Bibliothek, I Augustinerbastei 6, Wien.

The Belgian Service of International Exchanges, formerly conducted under the Ministry of Sciences and Arts, is now under the Royal Library of Belgium and its address is Rue du Musée 4, Bruxelles.

A list of the agencies abroad through which the distribution of exchanges is effected is given below. Most of these agencies forward consignments to the Institution for distribution in the United States.

LIST OF EXCHANGE AGENCIES

ALGERIA, via France.

ANGOLA, via Portugal.

ARGENTINA: Comisión Protectora de Bibliotecas Populares, Calle Callao 1540, Buenos Aires.

AUSTRIA: Internationale Austauschstelle, National-Bibliothek, I Augustinerbastei 6, Wien.

AZORES, via Portugal.

BELGIUM: Service Belge des Échanges Internationaux, Bibliothèque Royale de Belgique, Rue du Musée, 4, Bruxelles.

BOLIVIA: Oficina Nacional de Estadística, La Paz.

BRAZIL: Serviço de Permutações Internacionaes, Bibliotheca Nacional, Rio de Janeiro.

BRITISH COLONIES: Crown Agents for the Colonies, 4 Whitehall Gardens, London.

BRITISH GUIANA: Royal Agricultural and Commercial Society, Georgetown.

BRITISH HONDURAS: Colonial Secretary, Belize.

BULGARIA: Institutions Scientifiques de S.M. le Roi de Bulgarie, Sofia.

CANADA: Sent by mail.

CANARY ISLANDS, via Spain.

CHILE: Servicio de Canjes Internacionales, Biblioteca Nacional, Santiago.

China: Bureau of International Exchange, Academia Sinica, Brenan and Yuyuen Roads, Shanghai.

Colombia: Oficina de Canjes Internacionales y Reparto, Biblioteca Nacional, Bogotá.

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

Cuba: Sent by mail.

Czechoslovakia: Service Tchécoslovaque des Échanges Internationaux, Bibliothèque de l'Assemblée Nationale, Prague 1–79.

Danzig: Amt für den Internationalen Schriftenaustausch der Freien Stadt Danzig, Stadtbibliothek, Danzig.

Denmark: Service Danois des Échanges Internationaux, Kongelige Danske Videnskabernes Selskab, Dantes Plads 35, Copenhagen V.

Dutch Guiana: Surinaamsche Koloniale Bibliotheek, Paramaribo.

Ecuador: Ministerio de Relaciones Exteriores, Quito.

Egypt: Government Press, Publications Office, Bulaq, Cairo.

Estonia: Riigiraamatukogu (State Library), Tallinn (Reval).

Finland: Delegation of the Scientific Societies of Finland, Kasärngatan 24, Helsingfors.

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

Germany: Amerika-Institut, Universitätstrasse 8, Berlin, NW. 7.

Great Britain and Ireland: Messrs. Wheldon & Wesley, 2, 3, and 4 Arthur Street, New Oxford Street, London W.C. 2.

Greece: Bibliothèque Nationale, Athens.

Greenland, via Denmark.

Guatemala: Instituto Nacional de Varones, Guatemala.

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

Honduras: Biblioteca Nacional, Tegucigalpa.

Hungary: Hungarian Libraries Board, Ferenciektere 5, Budapest, IV.

Iceland, via Denmark.

India: Superintendent of Government Printing and Stationery, Bombay.

Italy: R. Ufficio degli Scambi Internazionali, Ministero dell' Educazione Nazionale, Viale del Re, Rome.

Jamaica: Institute of Jamaica, Kingston.

Japan: Imperial Library of Japan, Uyeno Park, Tokyo.

Java, via Netherlands.

Korea: Sent by mail.

Latvia: Service des Échanges Internationaux, Bibliothèque d'État de Lettonie, Riga.

Liberia: Bureau of Exchanges, Department of State, Monrovia.

Lithuania: Sent by mail.

Lourenço Marquez, via Portugal.

Luxemburg, via Belgium.

Madagascar, via France.

Madeira, via Portugal.

Mexico: Sent by mail.

Mozambique, via Portugal.

Netherlands: International Exchange Bureau of the Netherlands, Royal Library, The Hague.

New South Wales: Public Library of New South Wales, Sydney.

New Zealand: Dominion Museum, Wellington.

Nicaragua: Ministerio de Relaciones Exteriores, Managua.

Norway: Service Norvégien des Échanges Internationaux, Bibliothèque de l'Université Royale, Oslo.

Palestine: Hebrew University Library, Jerusalem.

Panama: Sent by mail.

Paraguay: Sección Canje Internacional de Publicaciones del Ministerio de Relaciones Exteriores, Estrella 563, Asunción.

Peru: Oficina de Reparto, Depósito y Canje Internacional de Publicaciones, Ministerio de Fomento, Lima.

Poland: Service Polonais des Échanges Internationaux, Bibliothèque Nationale, Ul. Rakowiecka 6, Warsaw.

Portugal: Secção de Trocas Internacionaes, Biblioteca Nacional, Lisboa.

Queensland: Bureau of Exchanges of International Publications, Chief Secretary's Department, Brisbane.

Rumania: Bureau des Échanges Internationaux, Institut Météorologique Central, Bucharest.

Salvador: Ministerio de Relaciones Exteriores, San Salvador.

Siam: Department of Foreign Affairs, Bangkok.

South Australia: South Australian Government Exchanges Bureau, Government Printing and Stationery Office, Adelaide.

Spain: Servicio de Cambio Internacional de Publicaciones, Paseo de Recoletos 20, bajo derecha, Madrid.

Sumatra, via Netherlands.

Sweden: Kongliga Svenska Vetenskaps Akademien, Stockholm.

Switzerland: Service Suisse des Échanges Internationaux, Bibliothèque Centrale Fédérale, Berne.

Syria: American University of Beirut.

Tasmania: Secretary to the Premier, Hobart.

Trinidad: Royal Victoria Institute of Trinidad and Tobago, Port-of-Spain.

Tunis, via France.

Turkey: Robert College, Istanbul.

Union of Socialist Soviet Republics: Academy of Sciences, Tuchkova 2 Leningrad.

Union of South Africa: The Government Printer, Box 373, Pretoria, Transvaal.

Uruguay: Oficina de Canje Internacional de Publicaciones, Ministerio de Relaciones Exteriores, Montevideo.

Venezuela: Biblioteca Nacional, Caracas.

Victoria: Public Library of Victoria, Melbourne.

Western Australia: Public Library of Western Australia, Perth.

Yugoslavia: Ministère des Affaires Étrangères, Belgrade.

Respectfully submitted.

C. W. Shoemaker, *Chief Clerk.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 5

REPORT ON THE NATIONAL ZOOLOGICAL PARK

Sir: I have the honor to submit the following report on the operations of the National Zoological Park for the fiscal year ending June 30, 1933:

The regular appropriation made by Congress for the maintenance of the Park was $228,880, a decrease of $26,660 from that available during the fiscal year 1932. The 8⅓ percent reduction on salaries from July 1, 1932 to March 30, 1933 and the 15 percent reduction on salaries from April 1 to June 30, 1933 reduced the total expenditures by $15,403.89. There were further reductions—mainly impoundage for positions vacant—totaling $10,702.34. The total expenditures for the year were about $202,760.

ACCESSIONS

Gifts.—A number of important gifts during the year have enriched the collection appreciably. From the United States Bureau of Fisheries, through Henry O'Malley, were received 2 northern fur seals and 16 Aleutian rosy finches. The Pennsylvania Game Commission, through Vernon Bailey, of the Biological Survey, presented a female and 3 young American beavers Dr. E. R. Dunn, of Haverford College, collected in Panama some remarkable frogs, *Atelopus varius zeteki*, and presented the Park with two dozen. This is the first time these frogs have been exhibited. Dr. Charles E. Burt, of Winfield, Kans., has continued his field work and sent in frequent shipments of southwestern lizards. An electric catfish from West Africa and 6 *Rasbora heteromorpha* were purchased through the Frances Brinklé Zerbee Memorial Fund. From the Frederic D. Barstow Fund, there were purchased one dozen zebra finches and a shama thrush.

DONORS AND THEIR GIFTS

E. Ross Allen, Silver Springs, Fla, alligator.
W. E. Anderson, Washington, D.C., ocelot.
G. M. Baker, Riverdale, Md., wolf.
Dr. Thomas Barbour, Cambridge, Mass., 5 Cuban turtles, 2 Cuban tree boas.
Ellsworth Barrett, Washington, D.C., mantis.
Frederic D. Barstow Fund, 12 zebra finches, shama thrush.
Dr. Paul Bartsch, United States National Museum, Washington, D.C., 6 hawksbill turtles, 150 hermit crabs, 5 collared lizards, rough-scaled green snake.
Miss B. Beard, Washington, D.C., raccoon.

Howard Beckett, Lanham, Md., Cooper's hawk.
Joseph E. Benjamin, Washington, D.C., fence lizard.
Mrs. John R. Blake, Washington, D.C., hermit crab.
J. S. C. Boswell, Alexandria, Va., western bullsnake, 2 chuckwallas, 3 sand lizards.
M. K. Brady, Washington, D.C., Mediterranean gecko, marginated salamander.
Tom Brooks, Dumfries, Va., American merganser.
Messrs. E. J. and S. K. Brown, Eustis, Fla., coral snake.
James Brown, Washington, D.C., eared grebe.
Dr. J. H. Bullock, Washington, D.C., orange-fronted parrot.
Dr. Charles W. Burt, Winfield, Kans., 2 collared lizards, American bittern.
Mrs. Rebecca Cannon, Silver Spring, Md., double-yellow-head parrot.
V. F. Cannon, Washington, D.C., soft-shelled turtle.
Wayne Carney, Washington, D.C., 2 sparrow hawks.
F. G. Carnochan, New York City, blue goose, white-fronted goose, snow goose, 2 Canada geese, 4 Muhlenberg's tortoises.
E. W. Clark, Detroit, Mich., 2 massasauga rattlesnakes.
Warren Clements, Washington, D.C., 8 garter snakes.
Charles S. Cole, Washington, D.C., 3 robins.
Mrs. E. S. Conn, Washington, D.C., Petz's paroquet.
James Cooke, Athens, Tenn., great horned owl.
F. C. Craighead, Washington, D.C., skink, pilot snake.
Mrs. W. S. Crawford, Washington, D.C., yellow-naped parrot.
Senator Porter H. Dale, Washington, D.C., tree frog.
Mrs. R. W. Daniels, Bethesda, Md., Canada goose.
Mrs. Belle Davis, Washington, D.C., raccoon.
Charles F. Denley, Glenmont, Md., Reeve's pheasant, Bell's silver pheasant.
Mrs. W. C. Dexter, Takoma, Md., orange-fronted parrot.
Roy A. Dillon, United States Biological Survey, Washington, D.C., skunk, wood duck.
Mrs. W. M. Dougherty, Atlantic City, N.J., 2 long-tailed paroquets, quaker paroquet.
Mrs. Peggy Douglas, Washington, D.C., 3 horned lizards.
Mrs. B. M. Dugdale, Ashland, Va., coatimundi.
E. B. Edelen, Washington, D.C., American barn owl.
Lionel Edwards, Washington, D.C., alligator.
Max Elias, Lawrence, Kans., 10 collared lizards.
Dr. W. O. Emery, Washington, D.C., *Triturus montandoni*, *Triturus cristatus*, *Triturus cristatus carnifex*, Spanish newt, *Salamandra salamandra*.
Franklin Park Zoo, Boston, Mass., 4 horned lizards.
Mr. Fuchs, Washington, D.C., alligator.
H. Shephard Fuller, Washington, D.C., hawks-bill turtle.
Mrs. H. C. Garges, Washington, D.C., raccoon.
W. W. Gingell, Bethesda, Md., horseshoe crab.
B. P. Gray, Washington, D.C., red fox.
W. F. Greaves, Washington, D.C., woodchuck.
Lieut. Col. M. R. Gugenheim, Plains, Va., alligator.
R. E. Haym, Washington, D.C., screech owl.
Mrs. J. A. Heath, Elkton, Md., 4 opossums.
Bernard Hewitt, Washington, D.C., alligator.
I. Hoffman, Washington, D.C., loon.
F. W. Holt, Washington, D.C., banded rattlesnake.
Perry B. Hoover, Silver Spring, Md., capuchin monkey.
Theodore Horydczak, Washington, D.C., Florida gallinule.

Philip R. Hough, National Park Service, Wakefield, Va., red-bellied cooter, snapping turtle, 4 musk turtles.
Dr. W. H. Hough, Washington, D.C., great blue heron.
J. A. Hyslop, Jr., Silver Spring, Md., 3 pilot snakes.
F. N. Jarvis, United States Biological Survey, Department of Agriculture, Washington, D.C., 2 Canadian porcupines.
Dr. Howard Kelly, Johns Hopkins University, Baltimore, Md., indigo snake, corn snake, 2 chicken snakes, coachwhip snake, king snake, Cuban tree boa.
O. L. Keys, Alexandria, Va., barred owl.
E. H. Kirkland, Fort Washington, Md., fox squirrel.
Edward Layton, Florence, S.C., rough-scaled green snake.
Ervin H. Leeth, Chevy Chase, Md., 2 bald eagles.
Albert Lopkoff, Washington, D.C., 3 canaries.
Mrs. Lukes, Washington, D.C., red, blue, and yellow macaw.
Dr. Frank E. Lutz, American Museum Natural History, 12 Panama cockroaches.
J. K. Magee, Silver Spring, Md., pied-billed grebe.
Dr. W. H. Mann, Hopewell, Va., 2 raccoons.
Billy McCann, Washington, D.C., 2 alligators.
E. A. McIlhenny, Avery Island, La., pintail duck, 7 ring-necked scaups.
Mrs. Frank McManany, Washington, D.C., screech owl.
Charles K. Meinbert, Washington, D.C., 3 American crows.
William Mitchell, Jr., Middleburg, Va., alligator.
H. B. Mohler, Washington, D.C., ferret.
Robert Montgomery, Takoma Park, D.C., ring-necked snake.
Dr. Terrell Moody, Washington, D.C., 3 Virginia opossums.
Dewey Moore, Bureau of Plant Industry, Indio, Calif., western bullsnake, desert rattlesnake.
H. C. Moore and A. Snyder, Hayfield, Va., banded rattlesnake.
John R. Morrison, Washington, D.C., coot.
Mrs. R. M. Mullican, Washington, D.C., purple gallinule.
Museum of Comparative Zoology, Cambridge, Mass., tree frog, garter snake, *Anolis porcatus*.
R. H. Noack, Oakland, Calif., 6 triangular-spotted pigeons.
Mr. Pear, Washington, D.C., goat.
F. A. Peckham, Washington, D.C., pilot snake.
Pennsylvania Game Commission, through Vernon Bailey, 4 American beavers.
J. H. Pilling, Falls Church, Va., alligator.
C. J. Poiesz, Washington, D.C., diamond-back terrapin.
G. F. Pollock, Skyland, Va., banded rattlesnake.
M. S. Powers, Athens, Tenn., barred owl.
Miss Nancy Ralls, Chevy Chase, Md., painted turtle.
Mrs. Mary Roberts Rinehart, Washington, D.C., yellow-naped parrot.
President Franklin D. Roosevelt, The White House (deposit) 2 fan-tailed pigeons 2 white rabbits, 2 archangel pigeons, 4 alligators.
Mrs. G. W. Root, Washington, D.C., canary.
Paul G. Rose, Mt. Olive, N.C., 50 small snakes.
Louis Rueger, Richmond, Va., 2 raccoons.
Louis Ruhe, Inc., New York City, 2 grooved-bill toucanettes.
Wm. K. Ryan, Washington, D.C., 2 hooded weavers.
Lieut. F. H. Samuel, Washington, D.C., great horned owl.
Mrs. Garret Sange, Washington, D.C., flicker.
Michael Sanitorios, Washington, D.C., boa constrictor.
Melvin Schaeffer, Washington, D.C., pilot snake.
Mrs. Nellie Schroeder, Washington, D.C., 2 grass paroquets.

Mrs. Shelby, Washington, D.C., 2 prairie dogs, 2 bullsnakes, coachwhip snake, king snake.
Dr. A. N. Skinner, Washington, D.C., green snake.
W. Smith, Washington, D.C., alligator.
Smithsonian Institution, through Dr. A. Wetmore, Washington, D.C., 2 ferruginous rough-legged hawks.
A. Snyder and H. C. Moore, Hayfield, Va., banded rattlesnake.
Mr. Sonder, Washington, D.C., great horned owl, diamond-back rattlesnake.
Miss Daisy R. Spradling, Athens, Tenn., bullsnake, hog-nosed snake, timber rattlesnake.
Storrs Agricultural College, through Walter Landauer, Storrs, Conn., Ancon sheep.
Capt. Parker G. Tenney, United States Army, 4 bean geese.
M. R. Thompson, Chevy Chase, Md., red-bellied terrapin.
F. M. Uhler, United States Biological Survey, Washington, D.C., 2 red-bellied cooters, Carolina box turtle.
United States Biological Survey, Department of Agriculture, whistling swan.
United States Bureau of Fisheries, Department of Commerce, through Henry O'Malley, Washington, D.C., 2 northern fur seals, 16 Aleutian rosy finches, 12 large-mouthed bass.
United States National Museum, Washington, D.C., 11 rhinoceros iguanas.
Frank J. Vejtasa, Fairdale, N. Dak., snowy owl.
Dick Walker, Washington Grove, Md., flying squirrel.
Walsh Auto Co., Richmond, Va., coatimundi.
James Washington, Washington, D.C., ring-necked snake.
Mrs. L. Waxter, Washington, D.C., 4 painted turtles, musk turtle, 4 red-bellied newts, 2 grass paroquets, 2 least parrotlets.
Neal A. Weber, Cambridge, Mass., bald eagle.
Mrs. R. Whitmer, Washington, D.C., raccoon.
Miss Grace O. Wiley, Museum of Public Library, Minneapolis, Minn., 4 fox snakes.
Samuel B. Wilson, Washington, D.C., snapping turtle.
Frances Brinklé Zerbee Fund, electric catfish, 6 *Rasbora heteromorpha*.
Donors unknown, muskrat, gray fox.

Exchanges.—Four doves, 2 Malpelo lizards, 2 red-footed boobies, 8 blue-faced boobies, 4 Galapagos penguins, 2 flightless cormorants, 2 Farallon cormorants, collected by the San Diego Zoological Society-Hancock Expedition, were obtained by exchange from the San Diego Zoological Society, through Dr. Harry M. Wegeforth. From the South Australian Acclimatization Society, Adelaide, Australia, were received a trio of Bennett's wallabies and 5 laughing jackasses or kookaburras.

Purchases.—Ross Freeman, formerly an employee of the United States Rubber Co. in Sumatra, arrived in New York in July and brought with him a large collection of East Indian species. The park was able to select specimens desired at prices that made them practically gifts, and through this source were added to the collection a pair of orang-utans, 2 Siamang gibbons, a pair of Sumatran tigers, and several other interesting mammals and birds, as well as some very rare snakes.

The Alaska Game Commission, through H. W. Terhune, executive officer, carried out all details relative to the purchase and shipment to the park of a young mountain goat.

Births.—There were 53 mammals born, 71 birds hatched, and 12 reptiles hatched or born in the park during the year. These include the following:

MAMMALS

Scientific name	Common name	No.
Ammotragus lervia	Aoudad	1
Axis axis	Axis deer	2
Bison bison	American bison	4
Callorhinus alascanus	Northern fur seal	1
Canis nubilus	Plains wolf	6
Capra hircus	Angora goat	2
Cercocebus fuliginosus	Sooty mangabey	1
Cervus elaphus	Red deer	4
Choeropsis liberiensis	Pigmy hippopotamus	2
Connochaetes taurinus albojubatus	White-bearded gnu	1
Dama dama	Fallow deer	4
Dolichotis magellanica	Patagonian cavy	1
Equus przewalskii	Mongolian wild horse	1
Equus quagga chapmani	Chapman's zebra	1
Felis onca	Jaguar	2
Lama glama	Llama	4
Macaca mulatta	Rhesus monkey	1
Ovis canadensis	Rocky mountain sheep	2
Ovis europaeus	Mouflon	2
Pecari angulatus	Collared peccary	2
Poephagus grunniens	Yak	2
Procyon lotor	Raccoon	2
Sika nippon	Japanese deer	4
Taurotragus oryx	Eland	1

BIRDS

Scientific name	Common name	No.
Anas platyrhynchos	Mallard duck	20
Branta canadensis occidentalis	White-cheeked goose	12
Chen caerulescens	Blue goose	3
Columba palumbus	Wood pigeon	1
Guara alba+G. rubra	Ibis (hybrid)	1
Larus novaehollandiae	Silver gull	10
Nycticorax nycticorax naevius	Black-crowned night heron	25

REPTILES

Scientific name	Common name	No.
Crotalus horridus	Banded rattlesnake	5
Eunectes murinus	Anaconda	7

REMOVALS

Deaths.—Okero, the mountain gorilla presented to the Park by Mr. and Mrs. Martin Johnson, died October 7, 1932, from an intestinal tumor.

Old Ben, the Bengal tiger, died on June 20, 1933. He had been in the Park for 19 years 2 months and was probably about 21 years old at the time of his death.

ANIMALS IN COLLECTION THAT HAD NOT PREVIOUSLY BEEN EXHIBITED

MAMMALS

Scientific name	Common name
Colobus caudatus	White-tailed guereza.

BIRDS

Anthracoceros convexus	Sumatran black and white hornbill.
Centropus sinensis	Sumatran coucal.
Cranorrhinus cassidix	Bare-throated hornbill.
Geophaps smithi	Bare-eyed partridge pigeon.
Otis cafra	Denham's bustard.
Rhytidoceros corrugatus	Malay wreathed hornbill.
Spheniscus mendiculus	Galapagos penguins.

REPTILES

Acrochordus javanicus	Elephant trunk snake.
Dasypeltis scabra	Egg-eating snake.
Diploglossus hancocki	Malpelo Island lizard.
Elaphe taeniura	Striped rat snake.
Gerrhosaurus validus	Robust plated lizard.
Gonyosoma oxycephala	Green rat snake.
Homalopsis buccata	Sumatran water snake.
Trimeresurus wagleri	Wagler's viper.

AMPHIBIANS

Atelopus varius zeteki	Yellow atelopus.
Bufo superciliaris	Leaf toad.
Pseudis paradoxus	South American green frog.

FISHES

Malopterurus electricus	Electric catfish.

Statement of the collection

(Accessions)

	Presented	Born	Received in exchange	Purchased	On deposit	Total
Mammals	41	53	4	27	35	160
Birds	108	7	44	214	1	438
Reptiles	205	12	17	185	6	425
Amphibians	13		14	97		124
Fishes	12					12
Arachnids	4					4
Crustaceans	152					152
Mollusks				3		3
Insects	12					12
Total	517	136	79	526	42	1,330

Summary

Animals on hand July 1, 1932	2,302
Accessions during the year	1,330
Total animals in collection during year	3,632
Removed from collection by death, exchange, and return of animals on deposit	1,136
In collection June 30, 1933	2,496

Status of collection

	Species	Individuals		Species	Individuals
Mammals	193	547	Crustaceans	1	40
Birds	341	1,125	Mollusks	1	4
Reptiles	162	578	Insects	1	12
Amphibians	32	104			
Fishes	30	82	Total	763	2,496
Arachnids	2	4			

Visitors

July	281,500	March	167,825
August	332,600	April	350,900
September	272,400	May	285,300
October	202,250	June	229,300
November	90,775		
December	43,220	Total visitors for year	2,463,350
January	123,250		
February	84,030		

The attendance of organizations, mainly classes of students, of which we have definite record was 30,547 from 628 different schools in 21 States and the District of Columbia, as follows:

State	Number of persons	Number of parties	State	Number of persons	Number of parties
Alabama	25	1	New Jersey	2,094	36
Connecticut	226	4	New York	2,336	35
Delaware	165	6	North Carolina	396	10
District of Columbia	9,626	204	Ohio	285	6
Georgia	65	1	Oregon	31	1
Illinois	19	1	Pennsylvania	5,940	132
Kansas	250	1	Rhode Island	32	2
Maine	169	4	South Carolina	67	2
Maryland	5,575	99	Virginia	2,665	67
Massachusetts	244	9	West Virginia	98	4
Michigan	201	2			
Nebraska	38	1	Total	30,547	628

IMPROVEMENTS

No funds were available for such major improvements as buildings or large cages, but a large number of minor improvements were made during the latter part of the year, chiefly through the use of labor supplied by the Work Planning and Job Assignment Committee, all labor having been paid for from the emergency relief fund. The work that was carried out in this manner was of a character which had been much needed to improve the appearance of the Park, for the convenience of the public and to facilitate proper care of the animals, but which had been delayed owing to shortage of funds.

The outstanding major improvement of the year was the laying of an 8-inch water main from the Connecticut Avenue main to the end of the 6-inch main near the Japanese deer, the laying of a 3-inch main from the 8-inch line to the great flight cage, and the laying of a 2½-inch main to the bear yards. This installation provides the entire west side of the Park with an adequate supply of water under good pressure and lessens the use through the 6-inch Harvard Street main to such an extent that the pressure and volume on the east side of the Park is better than before. This also provides excellent fire protection and the installation should prove adequate for all future developments within the Park.

Thirteen thousand two hundred and fifty linear feet of concrete curb was laid on both sides of 6,625 linear feet of walks, and the walks resurfaced with 53,000 square feet of bitulithic paving, laid hot.

One of the buffalo yards that had seriously eroded was regraded, and three low rock walls were laid to produce a terrace effect and prevent further wash. New fences were constructed around both the buffalo and elk paddocks.

A bank immediately west of the bird house which had been left in an unfinished state from previous construction work was partially cut away. When this work is finally finished, additional cages will be constructed on the site. The earth from the cutting was used to make needed fills about the Park.

In those portions of the Park adjacent to roads and walks and most frequented by the public, dead trees likely to fall and endanger life and property were cut down or the menacing portions removed, and the grounds were extensively cleaned.

Fifty-one cords of wood were gathered and turned over to the municipal wood yard in connection with the cleaning of the grounds. The wood was used by the District committee on employment for the relief of destitute people of the city. In addition to the crews working under the immediate supervision of the Park, the municipal wood yard asssigned a foreman and crew to do certain cutting of trees and cleaning of the grounds, in order that they might obtain the wood more rapidly than it was possible for the Park to supply it. In this manner 127 cords were obtained in addition to that turned over to them by the Park from crews operating under its own foreman.

Oak, maple, beach, elm, and other valuable shade trees have been planted in the buffalo yard, the elk yard, near the office, near the bird house, and other locations. Many banks that had eroded were repaired and sodded with honeysuckle or myrtle, and other minor planting work was carried on, including certain plantings adjacent to the reptile house. A screen of shrubbery has been planted near the office to hide an unattractive service area.

Much more extensive painting of a maintenance character was carried out than has heretofore been possible, owing to the plentiful supply of labor for cleaning surfaces preparatory to painting. Such painting work included the outside of the lion house and exterior cages, the cages outside the monkey house, and the bear yards. Also, about 400 park benches were repaired and painted.

No new construction has been attempted with the exception of the wiring of three cages that had been started in the previous fiscal year and left unfinished and the construction of 20 small cages for the bird house. These are to house a collection of the smaller cage birds.

The blueprints, tracings, and maps of the Park had outgrown the original system of filing and were suffering seriously from lack of proper care. With the use of labor supplied by the Work Planning and Job Assignment Committee, they were sorted, classified, and filed.

No satisfactory map of the Park has been available for several years, and the developments of recent years have emphasized the need for a good map. The preparation of a topographic map on the scale of 50 feet to the inch has been undertaken by using the 1906 topographic base of this scale and bringing it up to date by inserting thereon the changes in topography and structures that have come about since the map was prepared.

NEEDS OF THE ZOO

I wish again to call attention to the inadequate police force and to the need for suitable buildings.

Respectfully submitted.

W. M. Mann, *Director*.

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 6

REPORT ON THE ASTROPHYSICAL OBSERVATORY

SIR: I have the honor to submit the following report on the activities of the Astrophysical Observatory for the fiscal year ended June 30, 1933:

PLANT AND OBJECTS

This observatory operates regularly the central station at Washington and two field stations for observing solar radiation on Table Mountain, Calif., and Mount Montezuma, Chile. The observatory controls a station on Mount Wilson, Calif., where occasional expeditions are sent for special investigations, one of which is mentioned below.

The observatory is continuing the measurements of the solar constant of radiation referred to in former reports and forming the principal theme of volumes II, III, IV, and V of its annals.

WORK IN WASHINGTON

With the publication of volume V of the annals there was available a long series of solar-constant measurements adapted for study of the variation of the sun and the dependence of terrestrial temperatures thereon. Seven regular periodicities were discovered in the variation of the sun, having intervals of approximately 7, 8, 11, 21, 25, 45, and 68 months. The observations reported in volume V of the annals closed with the year 1930. A revision of the periodicities based upon observations from 1924 to 1932 was undertaken by Dr. Abbot. The periodic terms when summed up represented the fluctuation within an average departure of less than one tenth of 1 percent. He ventured to forecast the fluctuation of the solar radiation to the end of the year 1934 as based on this analysis. The observations followed the prediction as closely as could be expected up to about May 1, 1933, when a divergence of about three fourths of 1 percent began to disclose itself: The results came higher than expected. Whether this divergence is due to a slight change of scale of the instruments at Table Mountain from whence the observations are alone available at present, to a failure of the empirical method of reduction there on account of the very unusual humid and hazy summer, or to a real divergence of solar radiation from the trend indicated by former observations cannot yet be determined. As soon as the revision of the method of reduction of observations from Montezuma, Chile, now in progress, is completed, it will be possible to decide.

Having found the variation of the sun so obviously periodic in character, Dr. Abbot and Mrs. Bond spent a great deal of time on the study of the departures from normal temperature of Bismarck, N.Dak. This station was chosen as one with a long record, published in World Weather Records, and situated in a region subject to the most direct influence of the sun without near-by interference of oceanic and mountain climates. The data have been studied for the interval 1875 to 1925 with a view to determining therefrom whatever periodicities might be contained. It is hoped that, based upon this analysis, a prediction might be made of the march of departures from normal temperature at Bismarck for the period 1925 to the present which could be immediately compared with observation so as to see if such prediction would be verified. The study is not yet completed but indicates clearly that the seven periodicities found in solar variation are of importance in the control of the temperature at Bismarck, although for reasons not fully understood changes of phase and amplitude confuse effects. A hopeful line of study of the causes of these changes of phase and amplitude is in progress.

Mr. Aldrich, besides attending to the routine of the observatory and the demands of the field stations in California, Chile, and Egypt, has reconstructed the delicate parts of the double-barreled water-flow pyrheliometer, has taken part in the preparation of an exhibit for the Century of Progress Exposition in Chicago, and has undertaken the revision of the method of reduction of the observations at Montezuma.

Mr. Fowle's work has been largely confined to the preparation of the eighth edition of the Smithsonian Physical Tables.

The instrument maker, Mr. Kramer, has had under construction apparatus for the continuation of the study of the solar spectrum at great wave lengths, to be noticed below, as well as the rebuilding of certain apparatus used by the stations at Table Mountain, Montezuma, and Mount St. Katherine.

MOUNT ST. KATHERINE EXPEDITION

Financed by the generosity of Mr. John A. Roebling, an expedition under the charge of Harlan H. Zodtner, assisted by Frederick A. Greeley, was prepared and dispatched to occupy Mount St. Katherine near Mount Sinai in Egypt. The expedition went forward in March 1933. Arrangements had been made with the Convent of Mount Sinai to construct trails, protect the springs from pollution, and prepare the buildings for observing and quarters for the observers at the summit of Mount St. Katherine. A recent report indicates that the preparations are far advanced.

MOUNT WILSON EXPEDITION

Messrs. Abbot and Aldrich continued the occupation of the station at Mount Wilson up to September 1932 for the purpose of attempting measurements of the solar spectrum for very long wave lengths, from 8 to 30 microns, far down in the infrared. The ultimate object of these studies is to determine the transparency of the atmosphere for these long wave lengths and its dependence on the atmospheric humidity, but more especially on the quantity of atmospheric ozone. It is believed that the temperature of the earth may probably depend intimately on the absorption of outgoing earth rays produced by the ozone of the atmosphere. Measurements made in the ultraviolet spectrum have indicated that the ozone content of the atmosphere is variable and that the variations are associated with the sun-spot numbers. Inasmuch as an important band of absorption by ozone occurs at exactly the only region of the terrestrial spectrum where the atmosphere is otherwise highly transparent, it is very probable that the variation in the atmospheric ozone is an important weather phenomenon. The difficulties of observing in this region are very great. The solar spectrum there is extremely feeble compared with regions of lesser wave length, and a great deal of the shorter wave length rays are scattered into the long-wave region which must be studied. Accordingly a double spectroscopic arrangement must be provided to produce a better spectrum. This not only complicates the apparatus but requires exceedingly sensitive radiation-measuring devices to observe the feeble indications of energy. Computation showed that neither the bolometer, the thermopile, nor the radiometer appeared adequate for the purpose. Dr. Abbot was fortunate in recalling the special radiation-measuring device which he invented about 25 years ago, and in very greatly improving its construction so that it becomes of the very highest sensitiveness. The description of this instrument which he prepared and used at Mount Wilson was published in 1932 under the title "The Kampometer, a New Instrument of Extreme Sensitiveness For Measuring Radiation."

Considerable time at Mount Wilson was occupied in devising and constructing and learning to use this instrument, but Messrs. Abbot and Aldrich before their departure were able to make certain preliminary measurements in the solar spectrum at very long wave lengths which indicated that sufficient sensitiveness is available.

Attempts are under way to improve the kampometer by the substitution of bimetallic strips composed of cadmium and molybdenum and by more exact construction. Also the double spectroscope is being rebuilt, and it is believed that an expedition in 1934, if that be possible, may add valuable knowledge of the extreme infrared solar spectrum.

OTHER FIELD STATIONS

The volcanic eruption in southern Chile early in the year 1932 having temporarily spoiled the atmosphere for observing at Montezuma, we took advantage of the break in continuity of observations to improve the apparatus by substituting pyrheliometers of the newest type, a new pyranometer with improved sun shade, and have undertaken to revise the method of computing in accordance with the latest method developed at Table Mountain. These extensive alterations in apparatus and procedure prevent the working out of the solar-constant values until the method is fully complete and tested. When that occurs the values from the Montezuma station will be available back to about the middle of the year 1932, leaving a break of only 2 or 3 months when the volcanic ash was at its maximum.

Meanwhile telegraphic observations have been received from the station at Table Mountain and communicated to interested parties as heretofore. They are not regarded as of so high a degree of accuracy as those formerly obtained from Montezuma and are regarded, furthermore, as provisional values subject to revision when all the evidence becomes available.

PERSONNEL

M. Keith Baughman was employed as bolometric assistant at Table Mountain from November 21, 1932, to May 31, 1933. A. F. Moore returned from detached service to be director at Table Mountain. Harlan H. Zodtner and Frederick A. Greeley were released from duty at Table Mountain for detached service on the Mount St. Katherine Expedition.

SUMMARY

Valuable progress has been made on the study of the dependence of terrestrial temperature departures on the variation of the sun. Interesting studies have begun on the dependence of terrestrial temperature departures on the ozone content of the atmosphere; solar-radiation observations have been continued at Table Mountain, Calif., Montezuma, Chile, and the cooperating private station at Mount St. Katherine in Sinai Peninsula is being equipped. A new radiation measuring instrument of highest sensitiveness called the kampometer has been devised and used with success in preliminary measurements of the extreme infrared solar spectrum.

Respectfully submitted.

C. G. Abbot, *Director*.

The Secretary,
Smithsonian Institution.

APPENDIX 7

REPORT ON THE DIVISION OF RADIATION AND ORGANISMS

SIR: I have the honor to submit the following report on the activities of the Division of Radiation and Organisms during the year ending June 30, 1933:

This branch of the operations promoted by private funds has for its primary purpose the study of the dependence of plant growth on radiation in various circumstances of temperature, humidity, and carbon dioxide concentration in the air. The division was started May 1, 1929, by the assistance of the Research Corporation of New York, which has furnished an average of about $20,000 a year in grants to promote its progress. To these sums have been added sums from the income of the private endowment of the Smithsonian Institution, so that an average expenditure somewhat exceeding $25,000 annually has been made.

The investigations proposed required considerable laboratory space and office space. These were secured by clearing a part of the western basement of the old Smithsonian Building and equipping it with water, gas, and electricity, cementing the floor, and finishing and painting the walls. Office space was obtained by finishing the interior of the north tower and providing an elevator, whereby eight excellent though small office rooms were made available.

The earlier years of the investigation were very largely given over to the invention and construction of special apparatus under the direction of Dr. F. S. Brackett and Dr. Earl S. Johnston. Much glass apparatus has been prepared by L. B. Clark, and in the shop equipped by the funds of the Research Corporation L. A. Fillmen has constructed many instruments of special design. Dr. E. D. McAlister has been engaged in the preparation of thermocouples of high sensitivity, the measurement of the energy distribution of absorption spectra, and the preparation of spectroscopic apparatus, and has assisted in the different researches as required.

In addition to the personnel above named, W. H. Hoover has been assigned to the special work on radiation and plant growth, Dr. Florence E. Meier, a fellow of the National Research Council, has been assigned to the study of the life and health of algae under different conditions of radiation, and R. M. Clagett has assisted with the wood work of special devices.

During the earlier part of the fiscal year, six pamphlets were published under the following titles:

Lethal action of ultra-violet light on a unicellular green alga, by Florence E. Meier.

A spectrophotometric development for biological and photochemical investigations, by F. S. Brackett and E. D. McAlister.

The functions of radiation in the physiology of plants. I. General methods and apparatus, by F. S. Brackett and E. S. Johnston.

The functions of radiation in the physiology of plants. II. Some effects of near infrared radiation on plants, by Earl S. Johnston.

Carbon dioxide assimilation in a higher plant, by W. H. Hoover, Earl S. Johnston, and F. S. Brackett.

Absolute intensities in the visible and ultra-violet spectrum of a quartz mercury arc, by E. D. McAlister.

An outstanding exhibition was prepared for the Atlantic City meeting of the American Association for the Advancement of Science in December 1932, which attracted wide and favorable notice. Also an interesting exhibit for the Century of Progress Exposition at Chicago was prepared in cooperation between the division, the Astrophysical Observatory, and the Division of Mineralogy of the National Museum.

In March 1933 a reorganization of the division took place. The Secretary, Dr. Abbot, who has been engrossed in the preparation of volume 5 of the Annals of the Astrophysical Observatory and volume 12 of the Smithsonian Scientific Series, having finished these tasks, undertook the general charge of the division. Dr. F. S. Brackett received a part-time appointment as consulting physicist with opportunity to devote himself entirely for the division on the investigation of absorption spectra of organic substances such as contribute to the chemical activity of plants. Dr. E. S. Johnston was appointed assistant director of the division.

Having completed his share of the preparation of the two exhibits, Mr. Hoover carried through a study of the growth of wheat under measured concentrations of water vapor and carbonic acid with fixed temperature and illuminated by measured quantities of light from helium discharge tubes. This research showed that the helium discharge produces approximately 30 percent greater assimilation of carbon dioxide than does equally intense white light. By means of filters some progress was made by Mr. Hoover in separating the effects of the several monochromatic rays of which the light of the helium discharge tube is composed.

Dr. McAlister, at the request of Dr. Abbot, undertook to devise a better means of producing substantially monochromatic light of any desired wave length for use in plant-growth experiments. After devising a spectroscopic method which seemed feasible, he made experiments with the so-called Christiansen filter, which are exceedingly promising. This apparatus consists of a parallel-walled, transparent cell in which some organic liquid, as benzene is almost completely filled with granulated optical glass. At that wave length where the index of refraction of the liquid is equal to the index of refraction of the glass, the rays pass directly through, whereas those of surrounding wave length are scattered to more or less wide angles. It is easily possible with this apparatus to secure a nearly pure spectrum band not more than 200 angstroms wide. The band may be moved from one part of the spectrum to another by changing the temperature of the apparatus. Dr. McAlister, however, by mixing two liquids, has arranged to alter the wave length of the transmitted band by varying their relative concentration. With Mr. Hoover he has developed an excellent method for illuminating with this source of monochromatic light the wheat experiments and the experiments with algae such as Dr. Meier is conducting. Quite sufficient intensities of energy may be obtained by the devices proposed, and it is expected soon to undertake the growth of wheat and of algae under selected rays of nearly monochromatic light of suitable and controlled intensity.

Dr. Meier made two series of check experiments on the propagation of unicellular algae under 12 different varieties of light. These experiments gave well-according results, but their interpretation as regards wave-length data is not yet quite complete.

Dr. Johnston is continuing the experiments on phototropism and has attempted the growing of wheat under outdoor conditions with different concentrations of carbon dioxide. Considerable difficulties were encountered in this latter experiment, so that no definitive results have yet been obtained, but it is believed that the way is now open to more successful operations next season.

Dr. Brackett has completed the installation of the rock-salt spectrograph for investigations of the absorption energy spectra of organic substances in the extreme infrared, and has obtained some beautiful preliminary photographic records of certain bands of absorption. He has also completed the installation of a quartz spectrograph for the study of absorption spectra through a wide range of wave lengths, and has obtained beautiful records with it also.

Mr. Clark has undertaken the preparation of suitable bimetallic strips of cadmium and molybdenum for use in the construction of a kampometer, that excessively sensitive radiation-measuring instrument invented by Dr. Abbot and used by him on Mount Wilson in 1932.

Respectfully submitted.

C. G. Abbot, *Director.*

The Secretary,
Smithsonian Institution.

APPENDIX 8

REPORT ON THE INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE

SIR: I have the honor to submit the following report on the operations of the United States Regional Bureau of the International Catalogue of Scientific Literature for the fiscal year ending June 30, 1933.

The regular routine work of the Bureau was continued, consisting mainly of recording necessary data of current scientific literature published in the United States to be immediately available for indexing and classifying purposes whenever international conditions make it possible to resume publication. In addition to this routine work efforts to reorganize and refinance the organization were continued but without success as, owing to the long continued financial depression, it was impossible to obtain from the other cooperating countries the necessary monetary commitments. Efforts were also made to obtain, in this country, a capital fund to meet the whole cost of printing, a plan having been formulated showing that with a revolving fund of $75,000 available, publication could be resumed and publishing thereafter become self-supporting. The time, however, was not ripe for obtaining necessary financial aid from either private donors or endowed foundations. Therefore, Congress having failed to provide the usual funds to continue the work of the Bureau, the work was suspended at the end of the fiscal year. As all the records and accumulated data are still intact in the Smithsonian Institution, it is hoped and expected that it will still be found possible to reorganize this important, unique international enterprise, as nothing has appeared to take its place and the want of the classified catalogue to the world's literature of science is keenly felt alike by librarians and workers in all fields of science.

Interest in and aid to bibliographies of scientific publications was one of the first and has always been one of the main interests of the Smithsonian Institution. Since 1901 these interests have centered in the International Catalogue of Scientific Literature, which through international cooperation then began the publication of a complete catalogue and index of the current scientific literature of the world. War chaos made it necessary to suspend operations in 1922.

It was through the influence of the Royal Society that the catalogue was begun, and it stood financial sponsor for the enterprise from the beginning. Each country taking part in the work bore the total cost of indexing and classifying its own publications. This cost was met, as a rule, by direct governmental grant. The United States was represented through the Smithsonian Institution, an appropriation being made each year by Congress for the maintenance of the Bureau. The Central Bureau in London bore the expense of editing and publishing the data prepared by the regional bureaus and depended for its support entirely on funds received from subscribers to the work.

The aim of the International Catalogue was not only to cite the titles of scientific papers published since 1901, but briefly to supply an analytical digest of the subject contents of each paper. This was successfully accomplished in the following manner: To each one of the sciences was assigned one of the letters of the alphabet, and to each of the subheadings in these sciences was assigned a number. In classifying the subject contents of a paper or book, instead of writing an abstract, a letter and number referring to the classification schedules were added to the citation for each important subject treated, thus not only analyzing but classifying the author's work. The printed volumes were arranged first as author catalogues and second as subject catalogues. In the subject catalogues the classified references were assembled and grouped under each of the common heads to which they appertained, and furnished a ready means of learning at a glance all that had been written on a given subject of scientific investigation.

The International Catalogue of Scientific Literature was more than an index; it was a condensed digest of the world's scientific literature.

No such bibliographical service exists or ever existed until the International Catalogue appeared, and when it is realized that the most expensive part of the undertaking was furnished free through the classified index references supplied by the 30 or more regional bureaus, it is apparent that no private enterprise could hope to produce such a catalogue.

Revolutionizing advances in many of the arts, industries, and trades are often made by means of scientific research, and what today appears to be an abstract investigation in pure science tomorrow becomes a stepping stone to some epoch-making invention, which either entirely changes an old or establishes a new trade or industry. Hence a knowledge of the world's scientific literature is not a luxury but a necessity.

Today the field is only partially covered by other publications, which, when assembled, are bulky, expensive, lack uniformity in methods of reference, and in the aggregate leave many branches of science unrepresented, all of which came within the scope of the International Catalogue.

This is the situation today for current literature, and unless reorganization of the International Catalogue can be accomplished, it is hard to imagine what the future condition will be unless today's records are all indexed and classified in some uniform and available form.

The World War stopped the publication of the catalogue, yet the backbone of the undertaking, namely, international cooperation of numerous self-supporting classifying bureaus, is still available. This indispensable contribution is worth several hundred thousand dollars a year.

The situation is now far simpler than it was when the organization was founded in 1900, for then no precedent existed for such an international cooperative enterprise. Now, the successful publication of 238 volumes aggregating some 140,000 pages of the International Catalogue is substantial and convincing proof that the original plan was feasible. War and disorganized international conditions alone were responsible for the necessity of suspending publication.

It would be difficult to find an object more worthy of endowment than this unique, international cooperative organization, when worthwhile projects are being considered by individuals or foundations desiring to aid the advance of knowledge and the welfare of mankind.

It is believed that abeyance of the great service formerly rendered by the International Catalogue of Scientific Literature is temporary only and that the work can eventually be resumed when the universal upheaval now convulsing world affairs has somewhat subsided.

Respectfully submitted.

Leonard C. Gunnell,
Assistant in Charge.

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 9

REPORT ON THE LIBRARY

Sir: I have the honor to submit the following report on the activities of the Smithsonian library for the fiscal year ended June 30, 1933:

THE LIBRARY

The library, or library system, of the Smithsonian Institution comprises considerably more than 800,000 volumes, pamphlets, and charts. These are chiefly in the Smithsonian deposit in the Library of Congress and the libraries of the United States National Museum and the Bureau of American Ethnology. The others are in the Smithsonian office library, Langley aeronautical library, radiation and organisms library, the libraries of the Astrophysical Observatory, Freer Gallery of Art, National Gallery of Art, National Zoological Park, and the various sectional libraries of the National Museum. While the collections have to do with nearly all subjects, they concern themselves largely with the natural sciences and technology.

EXCHANGE OF PUBLICATIONS

The exchange work of the library showed a falling off from the previous year, due to the world-wide economic depression and the consequent curtailment of funds of learned institutions and societies for research and publication. Only 22,821 packages of publications—21,103 by mail and 1,718 by the International Exchange Service—were received, as against 24,651 in 1932. A corresponding decrease was apparent in the number of items in the packages. For instance, there were 4,592 dissertations, while the year before there were 5,340. The library obtained 3,664 volumes and parts in response to special requests from the various Smithsonian libraries—fewer by 469 than in 1932. The new exchanges were 198, while the year before they were 280. There was a very noticeable decrease in the want cards for which favorable responses were received, the number from the Smithsonian deposit and the Langley aeronautical library being scarcely more than one half those for which publications were obtained in 1932. Unusually important sendings came from the Académie des Sciences, Belles-Lettres et Arts, Clermont-Ferrand; the Botanical Society of South Africa, Cape Town; the Dansk Ornithologisk Central, Viborg; the Landesmuseumsverein für Vorarlberg, Bregenz; the

Sodalitas Amicorum Universitatis Reg. Hung. Francisco-Josephinae, Szeged; and such universities as California, Harvard, Manchester, Pavia, Pennsylvania, and Yale. Dissertations were received from the Academy of Freiberg, the Universities of Basel, Berlin, Bern, Bonn, Braunschweig, Breslau, Budapest, Cornell, Erlangen, Freiberg, Giessen, Greifswald, Halle, Heidelberg, Helsingfors, Jena, Johns Hopkins, Königsberg, Leipzig, Louvain, Lund, Marburg, Neuchâtel, Pennsylvania, Rostock, Strasbourg, Tübingen, Utrecht, and Zürich, and technical schools at Berlin, Braunschweig, Delft, Dresden, Karlsruhe, and Zürich.

GIFTS

There were many gifts, as usual, but only a few can be mentioned here. From His Excellency, Eamon de Valera, President of the Irish Free State, came a welcome copy of Hugh Lane and His Pictures, by Thomas Bodkin, accompanied by a letter from the donor. From Mrs. Frances F. Cleveland Preston came a copy of A True Story of Some Eventful Years in Grandpa's Life, by Henry E. Perrine—a rare work of botanical interest; from William K. Vanderbilt, a copy of West Made East with the Loss of a Day, by the donor—a worthy companion to other books previously presented by Mr. Vanderbilt; from Mr. and Mrs. Lowell Brentano, a handsome 70-volume set of Voltaire in the original; and from Mosho Kawabata, a collection of Gyokusho's works, in 2 volumes. Other gifts were the Handbook of Museums (6 copies), issued by the American Association of Museums, from the association; Reports, in 11 volumes, of the President's Conference on Home Building and Home Ownership, from the editors; Archaeologia Orientalis, volume 2, from the Far Eastern Archaeological Society; The New Conquest of Central Asia, by Roy Chapman Andrews, from the American Museum of Natural History; The Monasteries of the Wâdi 'n Natrûn, Part II, by Hugh G. Evelyn White, from the Metropolitan Museum of Art; The Elephant, in 2 volumes, by Etsujiro Sunamoto, from the author; An Introduction to Egyptian Religion, by Alan W. Shorter, from the author; La Fayette, a Bibliography, by Stuart W. Jackson, compiler, from William Edwin Rudge; Selected Relics of Japanese Art, volumes 1–5, edited by S. Tajima, from Mrs. Charles D. Walcott, who also gave the library many other publications. From Mrs. Isabel Brackenridge Hendry was received a collection of letters written by John Torrey, Asa Gray, Charles Pickering, Capt. Charles Wilkes, and others to William D. Brackenridge, botanist of the United States Exploring Expedition of 1838–42, which added substantially to the manuscript material on the expedition already in the library. Still other gifts included 2,000 or more publications, chiefly on ethnology and archeology, which had belonged to the late Dr. J. Walter Fewkes, former Chief of the Bureau of American Ethnology, from Mr. and Mrs. E. R. Stabler;

550 from the Biological Society of Washington; 283 from the Geophysical Laboratory; 235 from the American Association for the Advancement of Science; 195 from the National Institute of Health; 66 from the International Catalogue of Scientific Literature; and 31 from the American Association of Museums. There were also gifts, as usual, from many members of the Smithsonian staff, notably the late Dr. William H. Holmes, who gave the library more than 600 publications.

SMITHSONIAN DEPOSIT

The Institution's main library of 40,000 was in 1866 deposited in the Library of Congress. There it has grown, by almost daily additions from the Smithsonian, to well over 500,000. The collection relates especially to the natural sciences and technology, being particularly strong in monographs and journals and in the reports, proceedings, and transactions of learned institutions and societies.

In the course of the last fiscal year the Institution added to the deposit 2,744 volumes, 10,202 parts of volumes, 3,117 pamphlets, and 109 charts. Among the items were 3,315 dissertations. Among them, too, were 2,202 publications which the Smithsonian library obtained in exchange in response to requests from the Smithsonian, periodical, and order divisions of the Library of Congress—a decrease of 243 from the year before. The number of foreign documents received by the library and forwarded to the documents division of the Library of Congress was much smaller than usual, as more of these government publications, it is gratifying to report, are each year being sent directly to the Library through the International Exchange Service and fewer by way of the Smithsonian library. Portraits of the Founder and five Secretaries of the Institution were presented to the Library of Congress late in the year, to be hung in the Smithsonian division with those of other scientists of note.

NATIONAL MUSEUM LIBRARY

The library of the United States National Museum numbers 84,580 volumes and 110,748 pamphlets. The additions in 1933 were 2,436 volumes and 786 pamphlets. The staff entered 10,458 periodicals—1,433 more than the previous year. These included 1,296 volumes and parts that they obtained in exchange as the result of checking sets and writing special request letters. Owing to a reduction in the allotment for binding, they sent only 895 volumes to the bindery, although more were prepared. They cataloged 3,077 publications, and added 20,242 cards to the catalogs and shelf lists. They also did, as usual, most of the routine work for the library of the National Gallery of Art. They forwarded to the files of the sectional libraries 5,901 publications, and lent to the curators and their associates 8,344.

Of the latter, 2,359 were borrowed from the Library of Congress and 535 from 20 other libraries. Publications were likewise lent to many libraries throughout the United States and Canada. The publications returned to the Library of Congress numbered 2,527 and to other libraries 608. The reference work of the staff was extensive and at times complicated and difficult, much of it being in response to requests from members of the scientific staff, but more than usual in answer to questions from visiting scientists and from correspondents.

The sectional libraries to which the staff found time to give special assistance were those of mammals, botany, ethnology, and physical anthropology. These libraries, 35 in number, are as follows:

Administration
Associate director's office
Agricultural history
Anthropology
Archeology
Biology
Birds
Botany
Echinoderms
Editor's office
Engineering
Ethnology
Fishes
Foods
Geology
Graphic Arts
History
Insects
Invertebrate paleontology
Mammals
Marine invertebrates
Medicine
Minerals
Mollusks
Organic chemistry
Paleobotany
Photography
Physical anthropology
Property clerk's office
Reptiles and batrachians
Superintendent's office
Taxidermy
Textiles
Vertebrate paleontology
Wood technology

OFFICE LIBRARY

The office library contains many standard reference works, the publications of the Smithsonian and its affiliated bureaus and of some of the older foreign societies and institutions, and several thousand volumes of general interest. The library was increased during the year by 114 volumes, 812 parts of volumes, and 9 pamphlets. The staff made 809 catalog cards and filed 1,492, answered 241 reference questions, and loaned 2,091 publications. There were about 3,000 visitors.

BUREAU OF AMERICAN ETHNOLOGY LIBRARY

The library of the Bureau of American Ethnology consists of 30,391 volumes, 16,993 pamphlets, and a large number of unbound magazines, chiefly on the North American Indian and other early inhabitants of the Western Hemisphere. It also has some important manuscripts, Indian vocabularies, and photographs. During the last fiscal year the library was increased by 320 volumes and 126 pamphlets. The staff entered 3,440 periodicals, added 4,840 cards to the catalog, loaned 2,134 publications, and rendered the usual reference service, especially in connection with the scientific work of the Bureau.

ASTROPHYSICAL OBSERVATORY LIBRARY

The library of the Astrophysical Observatory has 4,487 volumes and 3,726 pamphlets, largely on the major subjects of interest to the Observatory. The additions in 1932 were 130 volumes and 259 pamphlets. The staff entered 1,209 periodicals and prepared 607 cards for the catalog. The loans numbered 117.

RADIATION AND ORGANISMS LIBRARY

The library of radiation and organisms, which is the working collection of the most recently established division under the Smithsonian, numbers 194 volumes, 10 pamphlets, and 6 charts. The accessions for the year were 4 volumes, 300 parts of volumes, and 1 pamphlet.

LANGLEY AERONAUTICAL LIBRARY

The Langley aeronautical library, the nucleus of which came from the third Secretary of the Institution and such of his associates as Alexander Graham Bell, Octave Chanute, and James Means, numbers 1,954 volumes, 1,116 pamphlets, and 5 charts. Since 1930 most of it has been deposited, under its own name and bookplate, in the Library of Congress. The collection, while small, contains many rare items, among which are sets of early aeronautical magazines. It also has files of letters, photographs, and newspaper clippings. During the last fiscal year the library was increased by 46 volumes, 519 parts of volumes, 30 pamphlets, and 5 charts.

NATIONAL GALLERY OF ART LIBRARY

The library of the National Gallery of Art was given special attention late in the year, in connection with the work of reorganizing the Smithsonian library system that has been going on for some time. Increased space was provided for it and steel shelving installed, the collection was sorted and roughly grouped, the sets were checked for missing numbers and the numbers written for, and other steps were taken preliminary to the making of a shelf list and catalog. This will be the chief work of the staff during the coming year, that the Gallery may have at the earliest possible moment library machinery adequate to its needs.

The accessions during the year were unusually large, numbering 344 volumes, 428 parts of volumes, and 93 pamphlets. The collection now has 1,678 volumes and 1,509 pamphlets, chiefly on the art of the United States and Europe.

FREER GALLERY OF ART LIBRARY

The library of the Freer Gallery of Art is concerned mainly with the art and culture of the Far East, India, Persia, and the nearer East. It has a number of works on American painters, particularly James McNeill Whistler, and on the Washington Manuscripts, the well-known Biblical manuscripts of the fourth and fifth centuries, which the Gallery owns. The main collection was increased during the year by 180 volumes and 88 pamphlets and now numbers 4,857 volumes and 3,399 pamphlets. The field collection has about 800 volumes and 500 pamphlets. The staff entered 147 periodicals, sent 31 volumes to the bindery, added 2,730 cards to the catalog and shelf list, and made many analytical index cards for articles in important art journals.

NATIONAL ZOOLOGICAL PARK LIBRARY

The additions to the library of the National Zoological Park were 1 volume and 11 parts of volumes, increasing this collection on animals and their care to 1,222 volumes and 410 pamphlets.

SUMMARY OF ACCESSIONS

The accessions for the year may be summarized as follows:

Library	Volumes	Pamphlets and charts	Total
Astrophysical Observatory	130	259	389
Bureau of American Ethnology	320	126	446
Freer Gallery of Art	180	88	268
Langley Aeronautical	46	35	81
National Gallery of Art	344	93	437
National Zoological Park	1	0	1
Radiation and Organisms	4	1	5
Smithsonian Deposit, Library of Congress	2, 744	3, 226	5, 970
Smithsonian Office	114	9	123
United States National Museum	2, 436	786	3, 222
Total	6, 319	4, 623	10, 942

In the library system of the Institution there were on June 30, 1933, approximately the following:

Volumes	591, 183
Pamphlets	201, 454
Charts	26, 640
Total	819, 277

There were also a great many uncataloged, unbound, and uncompleted volumes.

SPECIAL ACTIVITIES

The staff arranged and classified the Berlandier manuscripts on the natural history of Mexico; sorted out hundreds of publications that had ceased to be useful to the Institution or its bureaus and transferred them to the Library of Congress, Patent Office, and Howard

University, or sent them back to the Superintendent of Documents; checked the University of California publications in the library and returned about 600 duplicates; sent consignments of Smithsonian duplicates to Harvard University, Yale University, and the Marine Biological Laboratory at Woods Hole, in special exchange for recent publications of these institutions that were needed by the library; arranged for the return of many publications of the Institution and its branches from libraries in which they were duplicates, that they might again become available for exchange; and made notable progress in reorganizing the technological library, in which 1,134 linear feet of steel shelving were installed during the year.

FOUR IMPORTANT PROJECTS

The union catalog was advanced considerably, as the following statistics will indicate:

Volumes cataloged	4, 297
Pamphlets cataloged	2, 382
Charts cataloged	129
Typed cards added to catalog and shelf list	14, 000
Library of Congress cards added to catalog and shelf list	18, 780

The reorganization of the order department of the library was practically completed, with the result that the accuracy and efficiency of its procedure were greatly increased.

The file of the library's exchange relations, begun early in the year, showed marked progress, thanks to the cooperation of the publications offices of the Smithsonian and Museum with the library. It is expected that the file will be well along by the close of the next fiscal year. It becomes more and more useful, especially as an aid in determining the value of each exchange to the work of the Institution.

A noteworthy beginning was also made on the dictionary index to the publications of the Institution and its bureaus referred to in the report for 1932. Library of Congress cards for the Smithsonian Annual Report volumes to date and part of the Proceedings of the National Museum were obtained and most of them filed. The next Smithsonian series to receive attention will be the Miscellaneous Collections. It may be added in this connection that the preparation of a manuscript index to the first 36 volumes of the Proceedings—which, when the task was undertaken early in the year, were the only volumes issued by the Institution or its bureaus for which no Library of Congress cards were available—was finished by the staff and sent to the Library. Already cards have been printed for half or more of the volumes in question.

Respectfully submitted.

William L. Corbin, *Librarian.*

Dr. C. G. Abbot,

Secretary, Smithsonian Institution.

APPENDIX 10

REPORT ON PUBLICATIONS

SIR: I have the honor to submit the following report on the publications of the Smithsonian Institution and the Government bureaus under its administrative charge during the year ending June 30, 1933:

The Institution published during the year 14 papers in the series of Smithsonian Miscellaneous Collections, 1 annual report and pamphlet copies of the 26 articles contained in the report appendix, and 2 special publications. The United States National Museum issued 1 annual report, 3 volumes of proceedings, 3 complete bulletins, 2 parts of bulletins, and 39 separates from the proceedings. The Bureau of American Ethnology published 1 annual report, 6 bulletins, and 1 special publication. The Freer Gallery of Art issued 1 publication in the series Oriental Studies.

Of these publications, there were distributed 177,572 copies, which included 37 volumes and separates of the Smithsonian Contributions to Knowledge, 25,784 volumes and separates of the Smithsonian Miscellaneous Collections, 31,034 volumes and separates of the Smithsonian Annual Reports, 3,161 Smithsonian special publications, 85,550 volumes and separates of the National Museum publications, 29,889 publications of the Bureau of American Ethnology, 56 publications of the National Gallery of Art, 1,265 publications of the Freer Gallery of Art, 79 Annals of the Astrophysical Observatory, 34 reports of the Harriman Alaska Expedition, and 683 reports of the American Historical Association.

SMITHSONIAN MISCELLANEOUS COLLECTIONS

Of the Smithsonian Miscellaneous Collections, volume 87, 9 papers were issued, and of volume 89, 5 papers, making 14 papers in all, as follows:

VOLUME 87

No. 7. Preliminary classification of prehistoric Southwestern basketry, by Gene Weltfish. 47 pp., 19 text figs. (Publ. 3169.) July 12, 1932.

No. 10. Lethal action of ultraviolet light on a unicellular green alga, by Florence E. Meier. 11 pp., 2 pls., 1 text fig. (Publ. 3173.) August 17, 1932.

No. 11. Report on archeological research in the foothills of the Pyrenees, by J. Townsend Russell. 5 pp., 8 pls. (Publ. 3174.) August 26, 1932.

No. 12. A spectrophotometric development for biological and photochemical investigations, by F. S. Brackett and E. D. McAlister. 7 pp., 3 pls., 5 text figs. (Publ. 3176.) September 26, 1932.

No. 13. The functions of radiation in the physiology of plants. I. General methods and apparatus, by F. S. Brackett and Earl S. Johnston. 10 pp., 1 pl., 3 text figs. (Publ. 3179.) November 14, 1932.

No. 14. The functions of radiation in the physiology of plants. II. Some effects of near infrared radiation on plants, by Earl S. Johnston. 15 pp., 4 pls., 2 text figs. (Publ. 3180.) November 15, 1932.

No. 15. An improved water-flow pyrheliometer and the standard scale of solar radiation, by C. G. Abbot and L. B. Aldrich. 8 pp., 1 pl. (Publ. 3182.) November 11, 1932.

No. 16. Carbon dioxide assimilation in a higher plant, by W. H. Hoover Earl S. Johnston, and F. S. Brackett. 19 pp., 2 pls., 8 text figs. (Publ. 3186.) January 16, 1933.

No. 17. Absolute intensities in the visible and ultraviolet spectrum of a quartz mercury arc, by E. D. McAlister. 18 pp., 4 text figs. (Publ. 3187.) January 16, 1933.

VOLUME 89

No. 1. Amphibians and reptiles collected by the Smithsonian Biological Survey of the Panama Canal Zone, by Karl Patterson Schmidt. 20 pp. (Publ. 3181.) March 16, 1933.

No. 2. The latitude shift of the storm track in the 11-year solar period. Storm frequency maps of the United States, 1883–1930, by C. J. Kullmer. 34 pp., 6 figs., 49 maps. (Publ. 3188.) March 3, 1933.

No. 3. The kampometer, a new instrument of extreme sensitiveness for measuring radiation, by C. G. Abbot. 5 pp., 1 fig. (Publ. 3211.) February 8, 1933.

No. 4. Scouting for a site for a solar-radiation station, by A. F. Moore. 23 pp., 4 pls., 9 text figs. (Publ. 3212.) April 4, 1933.

No. 5. Forecasts of solar radiation, by C. G. Abbot. 5 pp., 2 text figs. (Publ. 3214.) March 27, 1933.

SMITHSONIAN ANNUAL REPORT

Report for 1931.—The complete volume of the Annual Report of the Board of Regents for 1931 was received from the Public Printer in October 1932.

Annual Report of the Board of Regents of the Smithsonian Institution showing operations, expenditures, and condition of the Institution for the year ending June 30, 1931. xiii+592 pp., 87 pls., 94 text figs. (Publ. 3142.)

The appendix contained the following papers:

Twenty-five years' study of solar radiation, by C. G. Abbot.
The composition of the sun, by Henry Norris Russell.
Sun spots and radio reception, by Harlan T. Stetson.
An evolving universe, by Sir James Jeans.
The rotation of the galaxy, by A. S. Eddington.
Stellar laboratories, by Theodore Dunham, Jr.
Present status of theory and experiment as to atomic disintegration and atomic synthesis, by Robert A. Millikan.
Assault on atoms, by Arthur H. Compton.
Two-way television, by Herbert E. Ives.

Research Corporation awards to A. E. Douglas and Ernst Antevs for researches in chronology.
Shaping the earth, by William Bowie.
The earth beneath in the light of modern seismology, by Ernest A. Hodgson.
Coming to grips with the earthquake problem, by N. H. Heck.
Growing plants without soil, by Earl S. Johnston.
Some aspects of the adaptation of living organisms to their environment, by H. S. Halcro Wardlaw.
The utilization of aquatic plants as aids in mosquito control, by Robert Matheson.
Our friends the insects, by W. V. Balduf.
Evolution of the insect head and the organs of feeding, by R. E. Snodgrass.
The debt of agriculture to tropical America, by O. F. Cook.
Some wild flowers from Swiss meadows and mountains, by Casey A. Wood.
The antiquity of civilized man, by Prof. A. H. Sayce.
The discovery of primitive man in China, by G. Elliot Smith.
The culture of the Shang Dynasty, by James M. Menzies.
Totem poles: A recent native art of the northwest coast of America, by Marius Barbeau.
Brobdingnagian bridges, by Othmar H. Ammann.
Albert Abraham Michelson, by Forest R. Moulton.

Report for 1932.—The report of the executive committee and proceedings of the Board of Regents and the report of the Secretary, both forming parts of the annual report of the Board of Regents to Congress, were issued in December 1932.

Report of the executive committee and proceedings of the Board of Regents of the Smithsonian Institution for the year ending June 30, 1932. 12 pp. (Publ. 3184.)

Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1932. 89 pp., 4 text figs. (Publ. 3183.)

The report volume, containing the general appendix, was in press at the close of the year.

SPECIAL PUBLICATIONS

Explorations and field-work of the Smithsonian Institution in 1932. 96 pp. 98 figs. (Publ. 3213.) May 6, 1933.
Brief guide to the Smithsonian Institution. Second edition. 80 pp. April 17, 1933.

FREER GALLERY OF ART PUBLICATIONS

Oriental Studies, No. 1. The story of Kālaka. Texts, history, legends, and miniature paintings of the Śvetāmbara Jain hagiographical work. The Kālakācāryakathā. By W. Norman Brown. 4°. 149 pp., 15 pls. (Publ. 3137.) March 29, 1933.

PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM

The editorial work of the National Museum has continued during the year under the immediate direction of the editor, Paul H. Oehser. There were issued 1 annual report, 3 volumes of proceedings, 3 complete bulletins, 2 parts of bulletins, and 39 separates from the proceedings.

The issues of the bulletin were as follows:

Bulletin 39, part N (6th rev.). Directions for preparing specimens of mammals, by Gerrit S. Miller, Jr.

Bulletin 100, vol. 12. The fishes of the families Banjosidae, Lethrinidae, Sparidae, Girellidae, Kyphosidae, Oplegnathidae, Garridae, Mullidae, Emmelichthyidae, Sciaenidae, Sillaginidae, Arripidae, and Enoplosidae collected by the United States Bureau of Fisheries Steamer *Albatross*, chiefly in Philippine seas and adjacent waters, by Henry W. Fowler.

Bulletin 158. The Copepods of the Woods Hole Region, Massachusetts, by Charles Branch Wilson.

Bulletin 163. American and European swords in the historical collections of the United States National Museum, by Theodore T. Belote.

Bulletin 164. The Canadian and Ordovician formations and fossils of South Manchuria, by Riuji Endo.

For a list of the proceedings papers, see the report on the National Museum, part 2 of this report.

PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY

The editorial work of the bureau has continued under the immediate direction of the editor, Stanley Searles. During the year 1 annual report and 6 bulletins were issued, as follows:

Forty-ninth Annual Report of the Bureau of American Ethnology to the Secretary of the Smithsonian Institution, 1931–32. vi+8 pp.

Bulletin 99. The Swimmer manuscript: Cherokee sacred formulas and medicinal prescriptions (Mooney and Olbrechts). xvii+319 pp., 13 pls.

Bulletin 106. Ethnographical survey of the Miskito and Sumu Indians of Honduras and Nicaragua (Conzemius). vii+191 pp., 10 pls., 1 fig.

Bulletin 108. A dictionary of the Atakapa language, accompanied by text material (Gatschet and Swanton). v+181 pp., 1 pl.

Bulletin 109. A dictionary of the Osage language (La Flesche). v+406 pp.

Bulletin 110. Yuman and Yaqui music (Densmore). xviii+216 pp., 31 pls.

Bulletin 111. The village of the great kivas on the Zuñi Reservation, New Mexico (Roberts). ix+197 pp., 64 pls., 34 figs.

There was also issued one special publication:

List of publications of the Bureau of American Ethnology, with index to authors and titles. iv+55 pp.

REPORT OF THE AMERICAN HISTORICAL ASSOCIATION

The annual reports of the American Historical Association are transmitted by the association to the Secretary of the Smithsonian Institution and are communicated by him to Congress, as provided by the act of incorporation of the association.

The annual reports for 1930, volume 3, and 1931, volume 1, and the supplemental volume to the report for 1929 were issued during the year. The annual reports for 1930, volume 4, and 1932, and the supplementary volume to the report for 1930 were in press at the close of the year.

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REPORT OF THE NATIONAL SOCIETY, DAUGHTERS OF THE AMERICAN REVOLUTION

The manuscript of the Thirty-fifth Annual Report of the National Society, Daughters of the American Revolution, was transmitted to Congress, in accordance with law, December 12, 1932.

ALLOTMENTS FOR PRINTING

The congressional allotments for the printing of the Smithsonian report to Congress and the various publications of the Government bureaus under the administration of the Institution were virtually used up at the close of the year. The appropriation for the coming year ending June 30, 1934, totals $5,500, allotted as follows:

Smithsonian Institution	$1, 000
National Museum	4, 500

Respectfully submitted.

W. P. True, *Editor.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

PART 2. REPORT ON THE PROGRESS AND CONDITION OF THE UNITED STATES NATIONAL MUSEUM FOR THE FISCAL YEAR ENDED JUNE 30, 1933

By ALEXANDER WETMORE

Assistant Secretary of the Smithsonian Institution, in Charge of the National Museum

CONTENTS

OPERATIONS FOR THE YEAR

APPROPRIATIONS

PROVISION for the maintenance of the United States National Museum for the fiscal year ended June 30, 1933, made by appropriations carried in the Executive and Independent Offices Act approved June 30, 1932, was subsequently affected by the Economy Act (legislative appropriation act for 1933). Funds available for Museum operations were as follows:

Preservation of collections	$617, 760. 00
Impounded deductions (returned to Treasury)[2]	74, 031. 60
Amount available	543, 728. 40
Maintenance and operation	148, 370. 00
Impounded deductions (returned to Treasury)[2]	12, 995. 74
Amount available	135, 374. 26
Printing and binding	22, 354. 00
Total appropriation available	701, 456. 66

[1] The complete list of accessions to the collections during the year, which appears in the pamphlet "Report of the Secretary of the Smithsonian Institution, 1933", pp. 134–183, is here omitted in the interests of economy.

[2] Legislative appropriation act of June 30, 1932.

For the Museum, the appropriations for 1933 were $8,960 less than those for 1932, the reduction under preservation of collections being $2,750 and under maintenance and operation $6,210. Under preservation of collections, the reduction was taken from the amount available for supplies, and under maintenance and operation from the funds provided for repairs and replacements to buildings.

Under the Economy Act (pt. 2, legislative appropriation act for 1933), approved June 30, 1932, provision was made for the impounding of certain items connected with the funds allotted for personnel. Total amounts so impounded during the year under the National Museum were $87,027.34, of which $74,031.60 came from the appropriation preservation of collections and $12,995.74 from maintenance and operation. Under preservation of collections, $56,252.54 came from stipulated salary reductions and was thus made up by the personnel included under this appropriation. The remaining funds impounded under this heading totaled $17,769.05 and consisted of salaries of vacant positions. The latter amount therefore was a direct reduction in appropriation, since it lowered the amount available for temporary personnel and made impossible the utilization of savings on the salary roll for the purchase of miscellaneous supplies, the allotment for which has always been inadequate. Under maintenance and operation, $8,230.74 was impounded as a result of salary reductions, while $4,764 resulted from the impounding of salaries of vacant positions. The latter amount was a direct reduction of the appropriation, since it lowered the amount available for temporary services and the purchase of supplies and equipment for the mechanics. The impounding of salaries for vacant positions thus withdrew $22,534.06 from funds usually available.

The sum available for printing and binding was decreased $27,646 below the amount of the previous year. This reduction is a serious one, since the printing of manuscripts is now greatly in arrears, and additional funds for this purpose are much needed.

No additions to the personnel of the Museum were made during the year, and a serious condition resulting from an undermanned force continued. More help is urgently needed in the clerical service and the guard and labor forces and also in the scientific personnel. The Museum is greatly overcrowded, and under present conditions the proper exhibition and care of the collections with the available personnel are becoming increasingly difficult.

Arrangements looking toward additional space for the Museum have been outlined in previous reports. Congress has authorized appropriations of $6,500,000 for building wings at each end of the Natural History Building, but this authorization like all others was reduced 10 percent (legislative act for 1933, 212, sec. 320). Plans for the additions have been made by the Allied Architects, Inc., of

Washington, D.C., under an appropriation of $10,000 in the second deficiency bill of 1931 and have been approved by the Fine Arts Commission. The building of these wings has been submitted as the principal construction project recommended for the Smithsonian Institution under the National Industrial Recovery Act. If the required funds are allotted, the first major step in the plan for adequate museums and galleries under the Institution will be under way, and work can begin on the construction without delay.

COLLECTIONS

Steady addition of excellent material to the collections continued throughout the year, the new accessions including hundreds of specimens of the most valuable kind. They came in 1,698 separate accessions, with a total of 348,012 specimens, divided among the various departments as follows: Anthropology, 4,877; biology, 295,782; geology, 37,555; arts and industries, 4,261; history, 5,537. Statement regarding some of the important additions will be found in the reports of the departments that follow, and they are all included in the accession list. The total increase for the previous year was 157,870 specimens of all kinds.

For examination and report 1,575 lots of material were received, including much of a botanical and geological nature, and many individual specimens. Part was returned by request to the senders, when it was not consumed during analysis, and part retained for the collections under arrangement with the donors.

Gifts of specimens to schools and other educational organizations numbered 5,558 specimens, including collections of mollusks and fishes, sets to illustrate rock weathering and soils, and illustrative groups of rocks, ores, and minerals. Exchanges of duplicate materials with other institutions and individuals totaled 45,872 specimens, and 12 specimens were transferred to other departments. Loans to workers outside of Washington numbered 24,552 individual specimens.

Following is a summary of specimens now covered in the Museum catalogs:

Anthropology	672, 022
Biology	10, 815, 307
Geology	2, 127, 718
Arts and industries	115, 467
History	488, 788
Total	14, 219, 302

EXPLORATIONS AND FIELD WORK

Investigations in the field covered the usual wide range of interests connected with man, the lower animals, and plants, both living and extinct. The work was carried on mainly through grants from the general income of the Smithsonian Institution, assisted by contributions from individuals, while certain projects were financed through the income of special funds held as endowments by the Smithsonian. Financial assistance in field expenses from the annual governmental appropriations for the National Museum was small and concerned only part of the various projects. Funds to assist in these matters, especially from private sources, are one of the definite needs of our organization.

Archeological work in northern Alaska was continued during the summer of 1932 by James A. Ford under the general direction of Henry B. Collins, Jr. Mr. Ford arrived at Point Barrow late in August 1931, when the ground was beginning to freeze. He found ice conditions in the Arctic the worst in many years, and so remained at Barrow through the winter in order to allow a full season of excavation in the summer of 1932. He returned to Washington in November 1932. Barrow seems the most promising locality at which to find dependable evidence of the relationship between the old Bering Sea culture and the Thule, the dominant prehistoric Eskimo culture of the eastern Arctic regions. In addition to archeological material Mr. Ford obtained the skull of a bowhead whale and a series of birds.

From February 18 to June 5, 1933, Frank M. Setzler, assistant curator of archeology, continued archeological investigations in southwestern Texas, restricting this year's work to the Pecos River area, to trace the eastern limits of the cave culture. One large cave overlooking the Pecos and a medium-sized shelter near Deadmans Canyon were completely excavated. It is not yet practicable to evaluate the results of this third season in the Big Bend area, but the cultural material recovered obviously belongs to the same horizon as that found farther west. Though a general relationship to the Basket Maker culture of the Southwest is apparent in the material collected both in 1932 and 1933, enough distinct characteristics appear in the remains that Mr. Setzler has exposed in Texas to warrant a temporary designation as the Big Bend cave culture. Neither pottery nor any other class of artifact commonly used by archeologists in establishing a relative chronology has yet been found in association with remains peculiar to these cave dwellers of ancient Texas, and no bond has been discovered to connect them definitely with any other primitive group known in the Rio Grange drainage. One result of the 1932 expedition was the finding of 27 bones of the California condor (*Gymnogyps californianus*) associated with human remains in a cave on the south tip of Mule Ear Peaks. This is the first indication of the former existence of this bird in Texas and is the largest collection of bones recovered outside its present range. In his 1933 investigations, as in those of previous years, Mr. Setzler was greatly assisted by the staff of the United States Bureau of Plant Quarantine at San Antonio.

On his way to Washington late in May, Mr. Setzler spent a week in east-central Louisiana investigating mounds and village sites that available data indicated might be related to the so-called "Hopewell culture" of the northern Mississippi Valley. The results of this brief examination are such as to warrant more intensive research.

In order to complete the enormous task of reorganizing its collections and exhibits, the division of Old World archeology deferred actual field work for the year. Assistant Curator J. Townsend Russell, however, spent a brief period in France during midsummer in connection with the cooperative investigations inaugurated in November 1931 between the University of Toulouse and the Smithsonian Institution.

Dr. Aleš Hrdlička conducted an anthropological and archeological survey of Kodiak Island and made extensive excavations at Uyak Bay, Alaska. These excavations, which have already yielded much valuable and new material, are now more than a third finished.

Dr. R. S. Bassler, head curator of geology, spent several weeks in the Mississippi Valley collecting Silurian and Mississippian echinoderms for the Springer collection. Several hundred crinoids and blastoids and many specimens of other classes of fossils were obtained, and some interesting facts in silicification and related phenomena were checked.

Under the auspices of the Canfield fund, E. P. Henderson spent 4 months collecting minerals, rocks, and ores in the Rocky Mountain States, assisted by F. A. Gonyer, of Harvard University. Among the districts visited were the geode region about Keokuk, Iowa; the Black Hills of South Dakota; Butte and Helena, Mont.; Coeur d'Alene, Idaho; Park City, Bingham, Thomas Range, and other localities in Utah; the carnotite fields of Colorado and Utah; and Leadville, Breckenridge, Alma, and Cripple Creek, Colo. Among the material obtained were a huge quartz geode, numerous well-crystallized copper minerals, and rare vanadium minerals.

Dr. W. F. Foshag, accompanied by James Benn, visited the mica and gem mines about Amelia, Va., and collected a number of rare minerals. Mr. Benn also explored a newly discovered cave near Beaver Creek, Md., and obtained unusual stalagmitic growths of beautiful and perfect form.

Explorations for the division of stratigraphic paleontology were made by Dr. G. A. Cooper during 6 weeks spent in the richly fossiliferous country on Gaspé Peninsula, Quebec, resulting in the acquisition of many fine fossils. Following this Dr. Cooper made stratigraphic studies in New York State's classical sequence of Devonian rocks. Though supplementary to previous studies by Dr. Cooper in this State, this year's task was to trace the stratigraphic units eastward from the Unadilla Valley. The needed columnar sections were prepared, and many specimens, some new to science, were obtained.

As the field expedition under C. W. Gilmore, curator of vertebrate paleontology, extended well into the present year, only brief mention was made of it in last year's report. This expedition in the Oligocene of Montana, western Nebraska, southeastern South Dakota, and eastern Wyoming brought gratifying results in the acquisition of a large and representative collection of this important fauna. Outstanding among many valuable specimens is a nearly complete skeleton of an eagle of a type distinct from any hitherto known.

An important accomplishment of the department of biology was the organization of the Johnson-Smithsonian Deep-Sea Expedition, under the direction of Dr. Paul Bartsch, curator of mollusks and Cenozoic invertebrates, and the successful completion of the first of a series of cruises planned for oceanographic work. Eldridge R. Johnson in the fall of 1932 placed his palatial yacht *Caroline* at the disposal of the Smithsonian Institution for the purpose of deep-sea exploration, together with funds for equipment of the vessel, necessary gear and instruments, and an adequate scientific staff. At the suggestion of Dr. Bartsch an oceanographic survey of the Puerto Rican Deep was undertaken. Various agencies of the Government interested in oceanographic work, including bureaus in the Navy, Agriculture, and Commerce Departments, rendered valuable assistance in the way of suggestions and material, as did the authorities of the Carnegie Institution of Washington, the Oceanographic Institution of Woods Hole, the American Museum of Natural History, Dr. William Beebe, and others. The gathering of equipment and its installation began in October, and on January 21, 1933, the *Caroline* left New York.

The program for the cruise was carried out successfully, and on March 14 the *Caroline* returned to Washington loaded with valuable collections, embracing many forms of life unknown to science, and with extensive observations in the various branches of oceanography, all of which are now in the hands of specialists for study. During the cruise more than 900 soundings were made, and serial gatherings of water samples and temperatures were taken down to 3,200 fathoms. Collections were made at 109 stations, mostly at depths below 200 fathoms, with gear ranging from tangles to dredges, beam trawls, otter trawls, and intermediate nets. Several cores were taken, and morning and evening observations of air draft were made by means of pilot balloons observed through a theodolite. It is planned to continue the work during another cruise in the same general area.

Another important marine expedition was that of Dr. Waldo L. Schmitt, curator of marine invertebrates, to the Galapagos Islands on the yacht *Velero III*, through invitation of Capt. G. Allan Hancock, owner of the ship and leader of the expedition. Dr. Schmitt embarked at Los Angeles on December 28, 1932, and returned on March 25, 1933. Fully equipped for scientific work both on land and sea and with a staff representing several branches of zoology, the expedition visited 11 of the 16 principal islands of the Galapagos Archipelago and 13 other places on the coasts of South and Central America and Mexico, including the Malpelo, Cocos, and Isabel Islands. The expedition obtained large series of invertebrates of which a first set of Crustacea, to which Dr. Schmitt paid special attention, becomes the property of the National Museum. Many additions to scientific knowledge in this group are included in these collections.

Dr. Hugh M. Smith continued explorations in Siam covering various parts of the country not previously visited. The work included a trip up the tortuous Pasak River, which marks the boundary between central Siam and the eastern plateau, journeys to Sam Roy Yot (Three Hundred Peaks) in western Siam, and to the mountain-forest jungle of the northwestern corner of Siam. The large collections of mammals, birds, reptiles, and mollusks received testify to Dr. Smith's continued interest in the Museum and will yield many scientific novelties.

Collections received from Dr. D. C. Graham indicate that he has safely returned to his old field in western China and has resumed his zoological activities in behalf of the Smithsonian Institution. Continuation of his former explorations has been planned in cooperation with the recently established West China Museum.

Dr. Alan Mozley, awarded the Walter Rathbone Bacon traveling scholarship under the Smithsonian Institution for study of the land and fresh-water molluscan fauna of Siberia, had a successful season during the summer of 1932. Through the cooperation of local authorities he was enabled to carry out plans for a visit to the Akhmolinsk Steppe and to the taiga north of Tomsk. Thanks to the generous assistance of the director of the limnological station at Lake Baikal, he was able to spend nearly 2 months in the Baikal region, where he circumnavigated the lake in the motor yacht of the station and made various land excursions. During the winter Dr. Mozley worked on his collections at the University of Edinburgh, where facilities were generously provided him.

Dr. Herbert Friedmann, curator of birds, through the courtesy of Hobart Ames, visited Grand Junction, Tenn., to study a curious red phase among the quail found in that locality. Dr. A. Wetmore, assistant secretary, during a trip to New Mexico and Arizona, collected series of bird skins and skeletons.

The beginning of the year found Dr. J. M. Aldrich, curator of insects, west of the Rocky Mountains collecting Diptera, work that was completed the middle of August. P. W. Oman, of the Bureau of Entomology, made an extended trip by automobile through the northwestern United States to obtain specimens of leafhoppers and other homopterous insects, and returned with many valuable additions to the Museum collections.

Dr. Waldo L. Schmitt spent the first 6 weeks of the year at the marine laboratory of the Carnegie Institution of Washington at Dry Tortugas, Fla., in continuation of studies of the crustacean fauna of the region. A comprehensive collection of marine invertebrates, mainly crustaceans, was brought back.

During the early part of the year Dr. Paul Bartsch continued studies of *Cerion* colonies on the Florida Keys, with the financial assistance of the Carnegie Institution of Washington. On his return he collected mollusks on several mountain peaks of the southern Alleghenies.

Austin H. Clark made several trips to the region included in the proposed Shenandoah National Park in furtherance of a project for coordinating and extending knowledge of the biology of the area, in cooperation with the National Park Service, the United States Bureau of Public Roads, and the Virginia State Commission on Conservation and Development.

In July and August 1932, J. R. Swallen, assistant botanist in the section of grasses, collected in Yucatan under a cooperative arrangement between the United States Department of Agriculture, the University of Michigan, and the Carnegie Institution of Washington, in connection with a biological survey of the Mayan area. The collection obtained, about 1,000 specimens, has increased the known grass flora of the region by more than 50 percent. C. V. Morton, aid in the division of plants, left in March for a 3-months' botanical exploration in Oaxaca. Because of an unfavorable season and Mr. Morton's illness, this work, which was conducted with the kind assistance of Dr. Emil Makrinius, of Pochutla, had to be considerably curtailed. The 2,000 specimens collected, however, will prove valuable, since they come from a region little represented in the National Herbarium.

During the summer of 1932, Prof. C. E. Burt, of Southwestern College, Winfield, Kans., carried on field work in herpetology designed to obtain series of turtles in the region of the upper reaches of the Cumberland and Tennessee Rivers. The Museum has long needed material from that portion of the Appalachian system. The trip, made by automobile, was eminently successful and resulted in large and important collections.

During the Peary Memorial expedition to the west coast of Greenland, under command of Capt. R. A. Bartlett, arranged by the Peary family, Arthur D. Norcross, and friends, Captain Bartlett obtained a large collection of marine invertebrates mostly from the vicinity of Cape York, which with customary generosity he presented to the Museum.

W. G. Sheldon and Richard Borden, during July, August, and September 1932, undertook a second expedition to the mountain region in east-central British Columbia, reaching Mount Selwyn on the Peace River on July 17 and Hudson Hope on August 1. The Sukunka River, which drains the mountains just south of Pine Pass, was investigated to its source, and a grizzly bear was collected. The expedition, difficult and arduous, terminated at the railroad at Dawson Creek, and was highly successful in its collections, which included a moose, a grizzly bear, mountain goats, wolves, red fox, marten, weasels, marmots, rabbits, squirrels, and various smaller mammals.

EDUCATIONAL WORK

The National Museum during the year continued its customary activities in educational lines. Our exhibition halls display great series of objects so arranged as to demonstrate facts of many kinds, on subjects ranging from the tools and dress of primitive man to complicated modern machinery, examples of the life of strange lands, of the elements that compose the earth, fossil animals and plants of former ages, and many other things. Descriptive labels accompany all these, and there is constant change to keep them properly arranged and up to date. The whole serves as a compendium of reference to the student or as an attractive display to the one of more casual interest, from which all may profit according to their desires.

In addition, the Museum is constantly active in the dissemination of knowledge in response to many hundreds of inquiries that come by mail or from visitors. Classes from the city schools are guided through the halls, and groups of students from a distance are given similar service. Although the Museum does not maintain regular series of lectures, members of the staff are called on regularly to address meetings. Students throughout the country interested in definite problems come to work with our collections and libraries, and frequently workers from abroad are engaged in investigations here that sometimes continue for months. Thus it may be seen how widely varied is the range of our educational activities and how extensive the field that they cover.

VISITORS

The Museum buildings were open to visitors during the year on week days from 9 a.m. to 4:30 p.m. and on Sundays from 1:30 to 4:30 p.m., except the Aircraft Building, which was open only on week days. All the buildings were closed all day on Christmas and New Year's Days, and part of the day on December 24, 26, and 31, January 2, and March 4.

The total number of visitors to the various Museum buildings during the year was 1,427,358, or 202,672 less than during 1931–32, a decrease clearly reflecting economic conditions throughout the country. The average attendance for week days was 3,825 and for Sundays 4,571. The number of visitors to the Smithsonian Building on week days was 183,928, a daily average of 591, and on Sundays 40,561, an average of 780; to the Arts and Industries Building 478,160 on week days (average, 1,537) and 103,642 on Sundays (average, 1,993); to the Natural History Building 426,514 on week days (average, 1,371) and 93,463 on Sundays (average, 1,797); and to the Aircraft Building 101,091, a daily average of 325.

Table 1 shows the number of visitors during each month for the past year.

TABLE 1.—*Visitors to Museum buildings during the year ended June 30, 1933*

Year and month	Smithsonian Building	Museum buildings			Total
		Arts and Industries	Natural History	Aircraft	
1932					
July	28, 251	70, 878	53, 540	13, 426	166, 095
August	33, 310	90, 225	66, 900	15, 967	206, 402
September	21, 250	54, 857	42, 911	9, 420	128, 438
October	15, 018	39, 861	38, 270	5, 947	99, 096
November	11, 024	27, 586	30, 397	4, 429	73, 436
December	6, 942	16, 422	17, 292	3, 516	44, 172
1933					
January	8, 503	21, 368	28, 925	4, 449	63, 245
February	8, 138	20, 302	23, 807	3, 787	56, 034
March	20, 538	45, 437	47, 853	8, 886	122, 714
April	33, 114	84, 684	65, 146	12, 457	195, 401
May	18, 863	56, 337	57, 388	9, 075	141, 663
June	19, 537	53, 845	47, 548	9, 732	130, 662
Total	224, 488	581, 802	519, 977	101, 091	1, 427, 358

PUBLICATIONS

The publications issued during the year include nine volumes, as follows: The Annual Report for 1932; Bulletin 39, part N (6th rev.), Directions for Preparing Specimens of Mammals, by Gerrit S. Miller, Jr.; Bulletin 100, volume 12, The Fishes of the Families Banjosidae, Lethrinidae, Sparidae, Girellidae, Kyphosidae, Oplegnathidae, Gerridae, Mullidae, Emmelichthyidae, Sciaenidae, Sillaginidae, Arripidae, and Enoplosidae Collected by the United States Bureau of Fisheries Steamer *Albatross*, Chiefly in Philippine Seas and Adjacent Waters, by Henry W. Fowler; Bulletin 158, The Copepods of the Woods Hole Region, Mass., by Charles Branch Wilson; Bulletin 163, American and European Swords in the Historical Collections of the United States National Museum, by Theodore T. Belote; Bulletin 164, The Canadian and Ordovician Formations and Fossils of South Manchuria, by Riuji Endo; and small editions for office use of the complete volumes 79, 80, and 81 of the Proceedings of the National Museum. Forty-one separate papers published include 2 in the Bulletins and 39 in the Proceedings.

The distribution of volumes and separates to libraries and individuals on the regular mailing lists aggregated 71,294 copies; while in addition 14,256 copies of publications issued during this and previous years were supplied in response to special requests. The mailing lists have been revised to avoid loss in distribution.

During the year 504,770 forms, labels, and other items were printed and 970 volumes were bound.

LIBRARY

In the library system of the Smithsonian Institution, the National Museum Library is second in importance only to the Smithsonian deposit in the Library of Congress. Its collections, concerned chiefly with natural history and technology, were increased during the year by 2,436 volumes and 786 pamphlets, and now number 84,580 volumes and 110,748 pamphlets. The accessions came, as usual, from four sources: Purchases, gifts, exchanges, and binding periodicals.

Gifts were received from many members and associates of the Museum staff. Mrs. Charles D. Walcott gave the library many publications, as did also the late Dr. William H. Holmes, former director of the National Gallery of Art, his gifts for the year totaling more than 600. Important gifts also were received by assignment from the Smithsonian Institution. One was a collection of letters written by Asa Gray, John Torrey, Charles Pickering, Capt. Charles Wilkes, and others of the United States exploring expedition, 1838–42, to William D. Brackenridge, a prominent botanist of the expedition. The collection was presented to the Institution by Mrs. Isabel Brackenridge Hendry, acting for the grandchildren of Mr. Brackenridge. It constitutes a valuable addition to the manuscript material on the subject already in the library.

The staff kept the current work up to date and performed certain extra activities. They entered 10,458 periodicals, or 1,433 more than in 1932. Among these were 204 volumes and 1,092 parts that they obtained by special exchange letters in the process of completing standard sets. They also began 86 new exchanges for the Museum; sent 795 volumes to the bindery; cataloged 2,108 volumes, 954 pamphlets, and 15 charts; and added 20,242 cards to the catalogs and shelf lists. Until toward the close of the year the library work for the National Gallery of Art was done, as usual, by the main library staff; it consisted of entering 428 periodicals and cataloging 344 volumes and

93 pamphlets. The number of volumes and parts sent to the sectional libraries for filing was 5,901. The number of intramural loans was 8,344, of which more than a third were made at the loan desk in the Arts and Industries Building. Of these, 2,359 publications were borrowed from the Library of Congress and 535 from other libraries, including those of the Department of Agriculture, Geological Survey, Army Medical Museum; and the Boston Public Library, Cleveland Public Library, John Crerar Library, Newberry Library; the libraries of the Academy of Natural Sciences of Philadelphia, American Museum of Natural History, Arnold Arboretum, Field Museum of Natural History, Museum of Comparative Zoology, Peabody Museum; and Columbia, Harvard, Johns Hopkins, Michigan, Pennsylvania, Princeton, and Yale Universities. In all, 42 publications were borrowed from libraries out of town, and 30 lent to them. The number of publications returned to the Library of Congress was 2,526 and to other libraries 608.

The staff filed the Wistar Institute cards to date and sorted and distributed the systematic set of the Concilium Bibliographicum cards to the sectional libraries. They began the rearrangement and classifying of the contents of the manuscript case, taking up first the Berlandier manuscripts, consisting of several thousand pages mainly on the natural history of Mexico. They returned hundreds of publications no longer needed to the Superintendent of Documents, and transferred other hundreds to the Library of Congress, the Patent Office, and Howard University.

One of the most important tasks of the staff during the year was making analyticals for the first 36 volumes of the Proceedings of the National Museum. This work was undertaken in cooperation with the Library of Congress, to which the 1,694 manuscript cards prepared were sent for printing, and completes the analysis of this well-known set of Museum publications. Library of Congress printed cards will soon be available for all the publications that have been issued by the Smithsonian Institution and its bureaus. Several sets of these cards are being received by the library, of which two are being filed in the union and Museum catalogs. One is also being used as the basis of the dictionary index that was begun at the Smithsonian early in the year. Finally, the difficult task of reorganizing the technological library in the Old Museum was notably advanced. The wooden shelving in the north gallery on the third floor was replaced by steel to the extent of 1,134 linear feet, the collections were reshelved, and a careful reading of the shelves was begun, preparatory to taking an inventory.

As time permitted, the staff continued to render special assistance in solving the problems of the sectional libraries, including those of the divisions of mammals, botany, and physical anthropology.

PHOTOGRAPHIC LABORATORY

The photographic laboratory made during the year 3,025 negatives, 20,037 prints, 867 lantern slides, and 104 enlargements; developed 98 rolls of film and 48 film packs; and dry-mounted 39 prints. This work represents a slight increase over last year in the number of negatives and prints made, and was required by the National Museum and by the National Gallery of Art and the Bureau of American Ethnology, whose photographic needs are supplied by the laboratory through a cooperative arrangement.

BUILDINGS AND EQUIPMENT

Repairs and alterations.—Among the more important repairs and alterations to Museum buildings performed during the year are the following:

The exterior walls of the Natural History Building were washed by a detail of firemen from the District of Columbia Fire Department.

The plaster ceiling and side walls in the north lobby, Natural History Building, were given three coats of paint, and other painting was done as needed, both interior and exterior, including the tin roofs of the Arts and Industries Building and the Smithsonian Building.

The women's comfort room in the Natural History Building was thoroughly renovated.

The large second-floor east-corner room and the small room adjoining it, in the Arts and Industries Building, were remodeled in the spring of 1933 for the occupancy of the associate director and his assistants. The small anteroom was also renovated. Also, room 90 was remodeled for the use of the new illustrator.

The cafe dining room in the Arts and Industries Building was remodeled, the walls and ceiling covered with composition board, and new fixtures installed.

Work was completed on the installation of the pneumatic collecting and conveying system in the two woodworking rooms in the carpenter shop for removing sawdust.

The work of dismantling the George Washington Bicentennial Art Exhibit was completed in January. The two stone lions on the pedestals at each side of the south steps, Natural History Building, were removed and shipped to Newport News, Va., for permanent exhibition. Several of the plaster figures remained in the rotunda, having been presented to the National Gallery of Art.

Heat, light, and power.—The heat, light, and power plant, located in the Natural History Building, was in continuous operation for about 8 months of the year. The consumption of coal was somewhat more than it was last year, but not above the average for the past few years. For heat, light, and power production 3,297.1 tons of bituminous coal were purchased at $4.62 a ton.

The electric current purchased for the Arts and Industries Building during the year amounted to 124,790 kilowatt-hours and cost $2,849.66, while the current purchased during the summer for the other buildings was 264,310 kilowatt-hours and cost $4,645.08, which makes a total of 389,100 kilowatt-hours purchased at a cost of $7,494.74. The rate per kilowatt-hour was 1.93 cents, which is materially less than for last year, owing primarily to the fact that the current for the Arts and Industries Building was on a different schedule. The current generated in the Museum plant was 621,384 kilowatt-hours, produced at a cost of 1.63 cents a kilowatt-hour.

When the new lead-covered cables were purchased last year for enlarging the connection between the Museum lines and the Potomac Electric Power Co. cables where they enter the Natural History Building on the north side, the central line was not increased. To make this connection safe, a new 500,000 circular mils cable was bought and will be installed during the coming year.

A good deal of electrical repair work has been done during the year, including not only regular repair and upkeep, but also installation of new wiring systems where the old wires have been found to be overloaded or defective.

Repair work too has been necessary on some of the elevators, especially the automatic push-button elevator in the east end of the Smithsonian Building, which for safety's sake should be replaced by a manually operated car at the earliest possible time.

New electric-light equipment to be installed includes 191 ceiling fixtures purchased for the third floor of the Natural History Building.

The lighting of the stamp collection, in the Arts and Industries Building, which has been desired for a long time, has now been completed. This consists of white porcelain-lined inverted trough reflectors supported from the tops of the cases in such a way as to deflect the light down against each surface of the slides on which the stamps are mounted. The method has proved very satisfactory and efficient.

To provide convenient connections for the twelve 500-watt reflectors purchased last year for added interior illumination of the dome of the Natural History Building, 12 outlet boxes with twin receptacles have been installed around the rotunda on the fourth floor, with direct control in the engine room.

The installation of small, low-voltage lamps for microscopic work in the National Herbarium has gone forward. This method of furnishing light for such work was begun last year, and has proved so satisfactory that it has been called for by other workers.

The new heating system at the north front of the Smithsonian Building was completed and was in operation throughout the year. Further improvement in heating efficiency was effected by replacing with new low radiators, in various offices in the Natural History

Building, the radiators of the taller type, some of which were badly situated. Work has progressed, too, on the installation, begun last year, of new pipe in the hot-water system in the Natural History Building. This pipe, brass instead of galvanized iron, will tend to retard the accumulation of scale and dirt and thus aid in the proper flow and distribution of the water. Because of the congested location of the old equipment, the tank and other new apparatus are to be placed in the east end of the engine room.

Ice production.—The refrigerating machine, located in the basement of the Natural History Building, for manufacturing ice for all the Museum buildings, was operated a total of 4,058 hours during the year and produced 413.9 tons of ice at a cost of $827.68, or at the rate of $2 a ton (35 cents a ton less than for last year). During the extremely hot weather, it was necessary to purchase 12½ tons of ice, at a cost of $3.80 a ton.

Fire protection.—The fire alarms in the various Museum buildings have been regularly inspected and tested, the fire hose examined and the plugs flushed, and the sprinkler system in the Aircraft Building properly cared for.

In the Arts and Industries Building some progress was made in reducing fire hazards along lines recommended by the Federal Fire Council. The improvements include filling window openings and open arches with plaster block, replacing wooden partitions with plaster block, replacing old electric wiring with modern wiring, and replacing wooden library shelves with steel shelves. Although many of the fire hazards still remain, especially in the Smithsonian Building and the Arts and Industries Building, they are being removed as rapidly as funds permit, and fire protection is being generally improved.

Furniture and fixtures.—The furniture added during the year included 10 exhibition cases, 365 pieces of storage, office, laboratory, and other furniture, and 2,373 drawers, boxes, and frames of various kinds. During the same period, 19 exhibition cases and bases, 93 pieces of storage, office, and laboratory furniture, and 112 wooden drawers were condemned as unfit for further use.

An inventory of furniture on hand June 30, 1933, showed 3,743 exhibition cases and bases, 17,001 pieces of storage, office, and laboratory furniture, and 103,062 drawers, boxes, and frames.

MEETINGS AND RECEPTIONS

The facilities of the auditorium and lecture room are offered by the Museum to scientific and educational organizations for regular and special meetings, and whenever possible it assists in carrying out their programs. Ninety-five such meetings were held in the auditorium and lecture room during the year by a wide range of societies and organizations.

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Memorial meeting.—To commemorate the many years of service in the Smithsonian Institution of Prof. William Henry Holmes, who died on April 20, 1933, a memorial meeting was held on the morning of April 22, Dr. Abbot presiding. The meeting was widely attended by his coworkers and friends.

Receptions.—On the evening of January 26, 1933, a reception was held by the Washington Real Estate Board in connection with the convention in Washington of the National Organization of Real Estate Boards. The foyer and all the first floor of the Natural History Building were open for the occasion.

About 1,775 persons attended an informal reception given on the evening of March 28, 1933, in the Natural History Building by the American Chemical Society, convening in Washington at that time. Music was furnished by the United States Marine Band, and motion pictures on chemical subjects were shown in the auditorium.

The Congress of Physicians and Surgeons held a reception for Members of Congress on the evening of May 9, 1933, in the rotunda, art gallery, and auditorium of the Natural History Building. Nearly 1,500 persons attended.

Gellatly Art Collection opening.—The official opening of the Gellatly Art Collection took place in the Natural History Building on the evening of June 22, 1933. Secretary and Mrs. Abbot, Assistant Secretary and Mrs. Wetmore, and the Acting Director of the National Gallery of Art and Mrs. Tolman received.

Special exhibits.—The annual forestry notebook contest, under the auspices of the public schools of the District of Columbia, was held in the foyer of the Natural History Building, November 16 to 28, 1932. Some of the notebooks were attached to Museum floor screens, while others were exhibited on temporary tables furnished by the Museum.

The wooden screens forming alcoves on both sides of the foyer in the Natural History Building were used from December 10, 1932, until January 10, 1933, for an exhibit of architectural drawings from the architectural departments of colleges and schools in the District of Columbia, which was held under the auspices of the Washington Chapter of the American Institute of Architects. The exhibition was opened on the evening of December 10, with a reception in the foyer. Drawings were exhibited by the following institutions: George Washington University, University of Maryland, Central High School, Catholic University of America, Gallaudet College, and McKinley High School.

From March 30 to April 14, 1933, four alcoves on the west side of the foyer were assigned for an exhibit of material collected under the direction of Dr. Paul Bartsch on the Johnson-Smithsonian Deep Sea Expedition. The deep-sea specimens, in jars, were placed on plain wooden shelves installed on the semipermanent screens.

The foyer was occupied from April 17 until May 5, 1933, for an exhibition of public school art under the auspices of the Eastern Arts Association, and from May 8 to 20 part of the foyer was given over to an exhibition of colored posters on wild-flower preservation, under the auspices of the Wild Flower Preservation Society.

CHANGES IN ORGANIZATION AND STAFF

The changes this year in organization and staff were caused chiefly by the compulsory retirement on June 30, 1932, of a number of employees in key positions. The retirement of W. deC. Ravenel deprived the department of arts and industries of its director and the division of history of its administrative supervisor. The duties of both of these offices were on July 1, 1932, temporarily assumed by J. E. Graf, associate director of the Museum. On September 6, 1932, the position of director of the department of arts and industries was replaced by a new position of head curator—bringing the department in line with the natural history departments—and Carl W. Mitman, curator of engineering, was advanced to the head curatorship. Frank A. Taylor, assistant curator of engineering, succeeded Mr. Mitman as curator of the division of engineering. The division of history continued to remain an independent division, reporting to the head of the Museum through the associate director.

In the department of biology, the assistant curatorship of the division of fishes, vacated by the retirement of Barton A. Bean on June 30, 1932, was filled on January 3, 1933, by the appointment of Dr. George S. Myers. Dr. Horace G. Richards, assistant curator in the division of mollusks, resigned on September 10, 1932.

In the department of anthropology, the position of scientific aide that had been held by Richard A. Allen was abolished, and the clerical force was strengthened by the appointment of an assistant clerk-stenographer for the division of ethnology.

In the department of geology, James Benn was made scientific aide on March 1, 1933, taking over part of the work formerly done by Miss Margaret W. Moodey.

In the mechanical shops, H. C. Taylor, head of the paint shop, who retired on June 30, 1932, was succeeded on September 6, 1932, by William Crossingham, who had been associated with this branch of the Museum work for over 30 years.

In the administration office, James G. Traylor, appointment clerk, was retired on June 30, 1932, but he continued as clerk to the Board of Regents of the Smithsonian Institution. On January 16, 1933, the appointment work of the Smithsonian Institution was consolidated with the classification and retirement work, and Miss Helen A. Olmsted, from the administrative office of the Museum, was made personnel officer of the Institution.

On August 29, 1932, Carl W. Mitman was appointed contact officer to represent the Smithsonian Institution in its participation in the Century of Progress Exposition, Chicago, June 1 to November 1, 1933. On June 15, Roderic F. Davis was made special agent under Mr. Mitman for work in Chicago.

Honorary connections with the national collections were conferred on several scientists of note. David I. Bushnell, Jr., long associated with the ethnological and archeological work of the Institution, was given an honorary appointment as collaborator in anthropology on July 27, 1932. J. Townsend Russell, who had for several years held an honorary position as collaborator in Old World archeology, was made honorary assistant curator of that subject on May 13, 1933.

In the department of biology, the work of Dr. Charles Branch Wilson, who has collaborated on Museum collections for a quarter of a century, was recognized by his honorary appointment on June 30, 1933, as collaborator in Copepoda.

In the department of geology, the active interest for many years of Dr. August F. Foerste was again recognized, this time by his honorary appointment on September 29, 1932, as associate in paleontology. Dr. Foerste served the Museum in an honorary capacity as collaborator in paleontology from April 16 to December 31, 1928.

The Smithsonian was fortunately able, after her retirement from active Government service, to take advantage of Miss Margaret W. Moodey's long experience in identifying, classifying, and cataloging geological specimens by procuring her services under the income of the Springer fund as aide for work on the Springer collection of fossil echinoderms.

Four employees were retired during the year under the provisions of the Civil Service retirement act. Of these Frank T. Wright, laborer, was retired for disability on August 31, 1932. Others were retired because of age limitation, as follows: Margaret W. Moodey, aide in the department of geology, on December 31, 1932, after over 30 years of service; Ambrose Green, guard, on March 31, 1933, with nearly 38 years of service; and Walter A. Barkley, guard, on January 15, 1933, after 2 years at the Museum but with other civil and military service for the Government.

The Museum lost through death 2 active workers and 3 others long associated with its activities. George Emmert, guard, died on February 1, 1933, and John J. Veit, guard, on April 26, 1933, after services of 14 and 15 years, respectively. The death should be recorded, also, of Dr. Marcus Benjamin, retired, for many years editor of the National Museum, on October 22, 1932.

DETAILED REPORTS ON THE COLLECTIONS

REPORT ON THE DEPARTMENT OF ANTHROPOLOGY

(Walter Hough, *Head Curator*)

Many things of exceptional value came to the department of anthropology during the year, mostly by gift. Though exploration, the source of first-grade scientific material, was curtailed, archeological work on Kodiak Island and at Point Barrow, Alaska, and exploration of caves in Texas was continued; a reconnaissance was made of remains of Indian irrigation projects and house structure in southern Arizona; and cooperative archeological investigations were pursued in Europe.

ACCESSIONS FOR THE YEAR

The division of ethnology received 48 accessions and 961 specimens, compared with 60 accessions and 931 specimens last year. Noteworthy among them is a series of Philippine material, including Moro and other Malay textiles collected by Gen. Tasker H. Bliss while Governor of Moro Province, 1905–9, and presented by Mrs. Bliss; textiles and beadwork of the Moro, Bagobo, and Igorot Tribes collected by the late Capt. Lewis Patstone and presented by Miss M. A. Patstone; and several embroidered garments of Pina cloth, donated by Miss Sarah S. Metcalf. From Cambodia, Indo-China, came a crossbow and from China and Japan large and artistic collections of lacquer, porcelains, brasses, bronzes, ivory carvings, and many objects of minor art. Africa is represented by an inscribed gold ring from the Gold Coast and by a miscellaneous ethnological collection from the Kivu district, Belgian Congo, presented by Miss Ellen I. Burk. A headdress and war club from Rapa Island, Society Group, came as the gift of Stanley W. Bird. Russia is the source of a small collection of brasses, including an excellent samovar, teapot, and tray, the gift of Mrs. F. Ostrach. Mexican material received includes Guadalajara earthenware, the gift of Miss Susan P. Keech, and horse trappings of braided horsehair.

By transfer from the Bureau of American Ethnology, a unique collection was received from the Chama Indians of the Ucayali River area of Peru and from several Jivaro groups of eastern Ecuador. This material was obtained by M. W. Stirling, chief of the Beurau, while a member of the Latin-American expedition to eastern Ecuador and Peru, and scientifically is the outstanding collection of the year, though intrinsically the gift of imperial Chinese porcelains, brasses, and other objects of high art secured in Peiping by Gen. Charles A. Coolidge in 1900, and presented by Mrs. Coolidge, is of first rank. The Mrs. Alexius McGlannan collection of Japanese, Chinese, and European folk and minor arts is likewise highly valuable.

The bequest to the National Museum by the late Osage chief, Tom Baconrind, of his personal belongings and ceremonial paraphernalia aroused unusual interest, as Chief Baconrind was prominent in Oklahoma and learned in the ceremonial lore of his tribe. He assisted the late Francis La Flesche, of the Bureau of American Ethnology, in his studies of the Osage language. The Baconrind gift includes decorative embellishments of native Indian, peyote, and Christian cult elements. A valuable addition to the collection of historical and comparative religious art is the large gift from the estate of Mrs. Alice Pike Barney.

In the division of archeology 64 new accessions, totaling 2,737 specimens, were added, as against 69 accessions and 6,712 specimens during the previous year. The following are worthy of special notice: 339 stone, bone, and wooden implements, basketry, and other materials collected by Frank M. Setzler from six caves in Brewster County, Tex.; 477 flint implements from Aurignacian, Upper Paleolithic, and other early cultural horizons in two caves at the foot of Mount Carmel, Palestine, collected by the American School of Prehistoric Research and received as a loan from the Archaeological Society of Washington; 789 stone, bone, and ivory implements and ornaments collected by Dr. Aleš Hrdlička on Kodiak Island, Alaska; 58 specimens of stone and copper implements and pottery collected in Ecuador by M. W. Stirling; 218 stone artifacts from Monasukapanough and other Indian village sites, mostly in Albemarle County, Va., collected and presented by D. I. Bushnell, Jr.; 58 stone, shell, and earthenware objects from five village sites in Puerto Rico, collected by Gerrit S. Miller, Jr.; 26 earthenware vessels and stone implements from Ometepe Island, Lake Nicaragua, presented by Corp. Emil M. Krieger; 9 wood carvings, copper pins, and an earthenware effigy collected at Pachacamac and other prehistoric sites in Peru and presented by George Hewitt Myers; a quipu, or knotted string record, and 15 fragments of textiles from Pachacamac and Trapiche ruins, Peru, a gift from Mrs. J. P. Compton; 38 lots of potsherds, bone projectile points, and implements from the Gran Chaco of Argentina, from E. R. Wagner, Museo Arcaico Provincial, Santiago del Estero, Argentina.

In the division of physical anthropology 18 accessions, 658 specimens, included important skull and skeletal material from Kodiak Island, Aleutian Islands, Point Barrow, and St. Lawrence Island, Alaska, and from California and New Mexico. A series of 262 photographs of Filipinos came from Dr. R. B. Bean.

Two accessions were received in the section of musical instruments; 7 (378 specimens) in the section of ceramics, including 80 pieces of older glass and pottery and 143 pieces of Irish and American Belleek ware; and 8 (141 specimens) in art textiles, including noteworthy embroideries and laces.

INSTALLATION AND PRESERVATION OF COLLECTIONS

New exhibits were arranged for each of the major exhibition halls assigned to ethnology. South American exhibits were enriched by a large collection of Chama pottery from a group once believed not to practice pottery manufacture. The collection shows them to be the equal of the Coneba in producing a thin-walled, creamy-textured ware. This and three additional exhibit units resulting from the Latin-American expedition to eastern Ecuador have been installed. Material included is from various groups of Jivaro and comprises blowguns, looms and weaving apparatus, woven textiles, decorated pottery, and potterymaking implements, objects of personal adornment, and various objects representing decadent stages in the art of head-hunting. Mexican folk pottery and examples of the folk arts of Mexican, Nicaraguan, and Guatemalan peoples were assembled to form a new exhibit in the Mexican alcove. This includes textiles, wood carving, model figures in wax, and objects of personal adornment. The Colombian and Panamanian exhibits were improved through the addition of the W. W. Archer Choco collection and the M. W. Stirling Tule and Choco material.

A case was arranged to show historical Indian sculpture from modern Indian tribes. Masks and figurine carvings in wood collected by Gibbs, Stuckley, and Wilkes from tribes of the Columbia Valley and the Pacific Northwest are shown, as well as a portrait bust of himself modeled by the Ute, Chief Shem, and the famous Haida slate carving known as the "Bear Mother."

During the year the division of archeology concentrated its efforts on complete revision of the hall devoted to Old World prehistory. An important feature is the synoptic series, portraying diagrammatically the cultural evolution of man in relation to geological events, from Pliocene times to the period of modern civilization, and including type artifacts, charts showing environmental conditions, and water-color sketches suggesting characteristic human activities and industries of the successive periods. Other major exhibits installed deal with the following cultures: Eolithic, pre-Chellean, Chellean, Acheulian, Micoqien, Mousterian, Aurignacian, Magdalenian, Azilian, Final Capsian, Maglemosian, the Proto-

Neolithic of France and Italy (Campignian), of Scandinavia (Ertebølle), and of Central Africa and India, the Neolithic of western, northern, and Alpine Europe, of North Africa, Indo-China, Ja and Siberia, and the later Sumerian-Babylonian.

Five charts tracing the correlation between cultural and geological events in the Old World, 5 illustrations for the synoptic series, 13 maps showing cultural distributions, and 6 maps depicting the range of glacial advance and retreat were prepared and incorporated in the exhibits.

Study collections of the Paleolithic and Neolithic periods were reclassified and the accompanying records corrected wherever necessary to include new information. These have also been regrouped into cultural-geographical series, so that students may examine the material with greater ease and effectiveness. The collection from Casa Grande, southern Arizona, secured early in the present century by the late Jesse Walter Fewkes, was reexamined, and the exhibit illustrating the material culture of this famous ruin was greatly improved.

In the division of physical anthropology a temporary exhibit of 6 cases was arranged from the newly recovered Alaska (Kodiak Island) materials, and 3 cases of new exhibits were added to the permanent display. A case of exhibits prepared for the National Academy of Sciences meeting in April remained for 2 weeks on view in the academy. Two cases of exhibits were prepared for the meeting of the American Surgical Association.

INVESTIGATION AND RESEARCH

In ethnology, Henry B. Collins, Jr., continued the study of Eskimo archeology, particularly on materials collected by himself, J. A. Ford, and M. B. Chambers. For several years the Smithsonian Institution has conducted archeological studies along the west Alaskan coast, to obtain data on the chronological sequence of certain early phases of Eskimo culture. During this year and last the scene has been shifted to the north Alaska coast in the vicinity of Point Barrow. Here the problem involved concerns the historical sequence of Punuk and Thule phases of Eskimo culture. James A. Ford spent the winter of 1931–32 at Point Barrow on the Arctic coast and devoted the following summer to excavating at several old Eskimo sites in the region. Point Barrow has for some time been recognized as one of the most important places archeologically in Alaska, since it was the westernmost limit of the extinct Thule culture, which centered in northern Canada, and also the most eastward point to which the Old Bering Sea culture extended. Mr. Ford's excavations were the first of a systematic nature to be carried on at this strategic point, and the material obtained throws light on the relationships between the Thule, Punuk, and Old Bering Sea cultures. Mr. Collins also devoted some time to research on southeastern archeology, and participated in the conference on southern prehistory held by the National Research Council at Birmingham, Ala., in December.

Phases of Arawakan occupation of the Greater Antilles have become known through five seasons of active field work by Smithsonian expeditions sponsored by Dr. W. L. Abbott in the Dominican Republic, Haiti, and Cuba. Problems involved concern the interrelationships among Ciboney, Arawak, Carib, and perhaps other tribal cultures in central and western Cuba. H. W. Krieger during the year studied material assembled on these expeditions and belonging to these tribal cultures. The greater problem of northern and southern affiliation of the prehistoric Antillean cultures is much nearer a solution, but much work remains to be done in Venezuela, Puerto Rico, the Bahamas, and perhaps Florida. The 1932 season's work, during which Mr. Krieger investigated mounds, earthworks, and kitchenmiddens in central and western Cuba, has confirmed the belief of students that Mayan influence did not reach western Cuba. It was also found that pre-Arawak cultures of the Ciboney type are much more extensive than had previously been known. The principal evidence for this is the large number of village sites yielding no pottery.

Art design areas of North America and of Oceania and certain problems connected with the distribution of aboriginal application of design were other topics of research by Mr. Krieger. The quilled and painted designs on the George Catlin collection of Indian costumes from unidentified northern Plains tribes, and the costumes displayed in the Indian portraits by George Catlin, also received his attention. The culture of the historic tidewater Indians of Virginia, Maryland, and the Carolinas continues of major interest. The strictly prehistoric cultures and the physical anthropology of this area are receiving the attention, respectively, of Frank M. Setzler and Dr. T. Dale Stewart.

The curator of archeology, Neil M. Judd, continued work on his report on the Pueblo Bonito explorations of the National Geographic Society. Assistant Curator Setzler studied archeological material he had previously collected in the Big Bend region of Texas and published a description of certain fragmentary vessels from east-central Louisiana collected in 1926 by the late Gerard Fowke. The importance of these fragments lies in their definite resemblance to a type of pottery generally designated by archeologists as "Hopewell" and heretofore reported only from the northern Mississippi Valley.

Research by the curator of physical anthropology, Dr. Aleš Hrdlička, was concentrated on his field work in Alaska and on study of the skeletal materials brought back. He also finished an extensive work on "The Anthropology of the Pueblos", measured the collection of Chinese skeletons, and prepared for publication a monograph on "Ear Exostoses: Contribution to Racial Pathology." The assistant curator, Dr. T. D. Stewart, measured the tympanic plate and external auditory meatus in the Eskimo, California Indians, and related groups; tested the skull-capacity machine and studied the skull-capacity problem in general; studied the vertebral column in the Eskimo; and continued research on the hair directions of primates.

DISTRIBUTION AND EXCHANGE OF SPECIMENS

Four gifts made to other institutions included 72 specimens. One lot consisted of prehistoric Eskimo objects collected in duplicate by Dr. Hrdlička and Mr. Collins. Two small gifts representing the history of the Japanese Red Cross Society were made to the National Red Cross Museum of Washington, D.C., and a large collection was sent to the City Museum of Talladega, Ala. Sixteen specimens were transferred to the divisions of textiles and archeology.

During the year eight lots of archeological material (612 specimens) were sent out in exchange or as gifts to educational institutions, as follows: 104 specimens (gift) for scientific purposes to Rev. David C. Graham, Suifu, Szechwan, China; 167 specimens (gift) to the City Museum of Talladega, Ala.; 1 cast of a slate tube to Dr. Charles Back, Montezuma, Ind., in exchange for permission to make and retain a cast of the original; 4 lots of potsherds (gift) to the Antelope Valley Museum, Lancaster, Calif.; 3 casts of Easter Island wooden tablets as a gift to the Musée d'Ethnographie, Palais du Trocadero, Paris; 4 casts (2 sendings) to W. J. Curtis, Piqua, Ky., in exchange for permission to make similar replicas; 329 Old World archeological specimens (gift) to the Hastings College Museum, Hastings, Nebr.

NUMBER OF SPECIMENS UNDER DEPARTMENT

During the year the department received 131 accessions, a total of 4,877 specimens. Of these, 4 accessions comprising 510 specimens were loans. The material was distributed as follows: Ethnology, 48 accessions (961 specimens); archeology, 64 accessions (2,737 specimens); physical anthropology, 18 accessions (658 specimens); musical instruments, 2 accessions (2 specimens); ceramics, 7 accessions (378 specimens); and art textiles, 8 accessions (141 specimens).

On June 30, 1933, the total number of specimens in the department of anthropology was as follows:

Ethnology	187, 919
Archeology	440, 817
Physical anthropology	33, 497
Musical instruments	2, 074
Ceramics	6, 178
Art textiles	1, 528
Anthropology (not assigned)	9
Total	672, 022

REPORT ON THE DEPARTMENT OF BIOLOGY

(Leonhard Stejneger, *Head Curator*)

The past year promises to open a new era in the development of the divisions which deal with marine fauna, especially of the deeper waters of the ocean. Thanks to Eldridge R. Johnson's initiative and offer of the use of his yacht *Caroline*, together with generous funds for its equipment for oceanographic work, the first Johnson-Smithsonian Deep-Sea Expedition, under the direction of Dr. Paul Bartsch, curator of mollusks, made a successful cruise of exploration of the Puerto Rican Deep, which resulted in greatly enriching the Museum collections, in addition to giving observations bearing on biological, chemical, and physical problems of the ocean.

Capt. G. Allan Hancock generously offered the Museum participation in the Hancock Galapagos expedition on the yacht *Velero III* during a 3-months' oceanographic cruise to the Galapagos Islands and the western coast of Central America. Dr. Waldo L. Schmitt, curator of marine invertebrates, was detailed for this service and returned with much valuable material, chiefly crustacean, for the Museum collections.

ACCESSIONS FOR THE YEAR

There were 1,200 accessions for the year with a total of 295,782 specimens, more than double the number received during the previous year. Through the two expeditions alluded to, the scientific importance of the invertebrate material is probably greater than that of the vertebrate, though the high scientific value of some of the fish collections should be emphasized, as well as the acquisition of material of various classes from French Indo-China, important on account of the locality being hitherto poorly represented in the Museum. Dr. Hugh M. Smith's collections of Siamese mammals, birds, and mollusks maintain their standing as first-class contributions, and the first collections from Dr. D. C. Graham after his return to his old field in China are coming up to the expectations raised by previous experience. Many of the plant collections accessioned during the year are scientifically of a high order.

Mammals.—The outstanding accession was the skull, with six blades of baleen, of the bowhead whale (*Balaena mysticetus*), collected by J. A. Ford at Point Barrow, Alaska. This is the first skull of its kind to come to any museum from the Pacific side of the Arctic Ocean, and the only bowhead in any American museum, while in European museums the species is represented by less than half a dozen specimens. From Dr. Hugh M. Smith in Siam 151 mammals, supplementing the large collections of previous years, were received. By exchange with H. J. V. Sody, Buitenzorg, Java, 59 mammal skins with skulls from Java and Celebes, were obtained, mostly forms new to the Museum. W. G. Sheldon and Richard Borden presented 63 specimens collected in British Columbia. Dr. R. K. Enders collected in Panama 51 mammals for the Museum, two species being new to the region. Noteworthy among the many specimens obtained from the National Zoological Park by transfer were a young mountain gorilla, *Cacajao calvus*, *Hylobates agilis*, and a young fur seal born at the park. Two gibbons (*Hylobates hoolock*), a species new to the Museum, were obtained in exchange, and a skeleton of a dugong, from Australia, by purchase.

Birds.—The 456 birdskins and 2 skeletons from Siam sent by Dr. Hugh M. Smith take first place. James Ford collected 169 birdskins in Alaska, and Dr. A. Wetmore 95 skins and 38 skeletons in the southwestern United States, besides about 100 local birds. A number of species and genera new to the Museum were obtained by exchange, including an Hawaiian honey creeper (*Paroreomyza flammea*), 10 forms of hummingbirds, and 13 of other birds. A skin and skeleton of the rare Hawaiian goose (*Nesochen sandvicensis*) were presented by the Commissioners of Agriculture and Forestry at Honolulu, and the first known nestling wandering tattlers (*Heteroscelus incanus*), collected by Joseph S. Dixon, came from the National Park Service. Among transfers of specimens from the National Zoological Park was an egg of the California condor. Eggs of 148 forms hitherto not represented in the Museum were obtained in exchange. Percy Shufeldt placed a valuable collection of 2,316 birdskins on deposit in the division.

Reptiles and amphibians.—The largest additions of the year came from Dr. C. E. Burt, the most important being collected for the Museum during a trip to the upper reaches of the Tennessee and Cumberland Rivers, when he obtained 1,491 specimens. He also donated 1,325 specimens from the West. An important collection from Puerto Rico containing topotype material of some recently described frogs was the result of G. S. Miller's visit to that island early in 1932. Three small herpetological collections obtained from French Indo-China are highly important as the locality was not represented in the Museum collections previously, except for a few specimens recently received. From the National Zoological Park the division received by transfer an unusually interesting lot of animals, among which is a series of the pipa, or Surinam toad. A splendidly preserved series of Californian *Batrachoseps* is of great value for the study of that difficult group of salamanders. A good collection of reptiles and amphibians from Kansas was contributed by H. K. Gloyd.

Fishes.—Of special importance was the fine collection of fishes obtained by the Johnson-Smithsonian Deep-Sea Expedition off Puerto Rico, containing many remarkable deep-sea forms, among them a new genus and species of Triacanthidae, the second one of the family to be recorded from the New World. Another collection of great interest is a lot of 67 specimens presented by Dr. George S. Myers, assistant curator of fishes, consisting mostly of type specimens of West African and South American fresh-water fishes described by the donor and others. Holotypes of 2 species, cotypes of 8, and paratypes of 13 are included. Altogether this accession brings to the Museum 26 species, 13 genera, and 1 family hitherto not represented in its collections. From the United States Bureau of Fisheries a fine series of 1,177 fishes from the Catawba and Tuckasegee Rivers, N.C., including the type of a new darter, and another lot consisting of 3 type specimens from the Gulf of Mexico, were received by transfer. C. R. Aschemeier obtained 1,959 fresh-water fishes in Florida, partly collected for the Museum, partly as a gift. The British Museum presented two paratypes of *Notobranchius kiyawensis*. Two paratypes of a new smelt were a gift from Dr. L. P. Schultz, of the University of Washington. A specimen of *Gempylus serpens*, a species new to the Museum, was presented by Eastham Guild, Papeete, Tahiti. From Dr. D. C. Graham came a collection of fishes from Szechwan, China.

Insects.—The outstanding accession of the year was the Edward T. Owen collection of Lepidoptera, comprising about 40,000 beautifully preserved specimens and including many species new to the Museum. The collection represents the life work of Professor Owen and was received from the executor of his estate. Frank Johnson, of New York City, made several gifts of rare species of Lepidoptera of great value, numbering in all 1,030 specimens, of species not previously in the Museum or poorly represented. Two important donations of Microlepidoptera, including about 600 specimens each, were obtained from the British Museum and Edward Meyrick. M. W. Stirling, Chief of the Bureau of American Ethnology, brought back from his South American trip 350 Lepidoptera from Peru. The collection of the late Prof. P. R. Lowry, Durham, N.H., comprising 908 slides of insects, mostly plant lice, was donated by his widow. By exchange with O. Ringdahl, Haelsingborg, Sweden, 273 named Diptera of the family Anthomyiidae, in which he is a distinguished specialist, were obtained, an accession furnishing a large representation of the northern European fauna. Two lots of miscellaneous insects, comprising about 3,800 specimens, came from Indo-China, an important addition as the Museum has little material from that region. L. D. Christenson, Wellsville, Utah, donated a collection of 4,550 Cuban insects, and D. S. Bullock of Angol, Chile, continued his liberal contributions. About 15,000 insects were transferred to the Museum by the United States Bureau of Entomology, being miscellaneous material received for identification from field workers.

Marine invertebrates.—The total number of specimens received was 15,160, of which the following accessions were of special interest: From the estate of the late Dr. Charles Dwight Marsh, his important collection of 3,307 slide mounts of copepods was acquired, including representative material of 26 new species. Capt. Robert A. Bartlett, New York City, presented a large collection of miscellaneous marine invertebrates taken in northwest Greenland waters. Dr. Waldo L. Schmitt collected series of specimens at the Tortugas, Fla., and also a large collection of Crustacea from the Galapagos Islands, during the cruise of the *Velero III*, of which mention has already been made. The collections brought home by the Johnson-Smithsonian Deep-Sea Expedition, under direction of Dr. Paul Bartsch, were highly important. Dr. R. E. Coker, University of North Carolina, presented alcoholic specimens of copepods, comprising holotypes, paratypes, and other important material representative of species to be described by him. P. Hummelinck, of Utrecht, Holland, contributed 85 crustaceans, including types, from the Dutch islands off the coast of Venezuela. The deposition of type specimens of new species included the type of a new sponge, by Dr. James T. Penney, University of South Carolina; the type of new species of crab, described by Dr. Mary J. Rathbun, donated by the Museu Paulista, Sao Paulo, Brazil; and the type and 3 paratypes of a new species of parasitic copepod by Wilbur M. Tidd, Ohio State University. An important collection of 60 microscopic slide mounts and 49 alcoholic specimens of isopods was obtained from Dr. K. W. Verhoeff, Pasing, Bavaria.

Mollusks.—One of the most important accessions of the year is that of 5,550 mollusks taken principally from the Puerto Rican Deep, during the Johnson-Smithsonian Deep-Sea Expedition. Four accessions, 100,500 specimens, are credited to the Frances Lea Chamberlain fund, including material from the Maynard collection of Cerions. Dr. Hugh M. Smith contributed 575 specimens of mollusks from Siam; Brother Daniel, Colegio de San José, Medellin, Colombia, 66 specimens of land, fresh-water, and marine shells; and Walter F. Webb, Rochester, N.Y., 161 specimens from the United States and Australia. A donation from Mrs. Isabel B. Hendry, Rosslyn, Va., contains about 3,100 specimens of land, fresh-water, and marine shells, and 1 from Miss Florence S. Gilson, Nyack, N.Y., 1,400 specimens, mostly marine mollusks. From Dr. C. G. Aguayo, Habana, Cuba, were received 67 specimens of land shells from that island, and from the zoological section of the University of Stellenbosch, South Africa, 140 specimens. The type and paratype of a new fresh-water mussel from Florida were presented by Berlin Hart Wright, Penn Yan, N.Y.; 16 paratypes from Santo Domingo by Dr. H. A. Pilsbry, Academy of Natural Sciences of Philadelphia, and 3 cotypes from the Philippine Islands by Dr. Fred Baker, Point Loma, Calif.

Corals.—More than 200 specimens were received, nearly all from the Johnson-Smithsonian Deep-Sea Expedition.

Helminths.—The total number of helminths accessioned is 1,068.

Echinoderms.—The most important of the 10 accessions received during the year is that from the Johnson-Smithsonian Deep-Sea Expedition, including a large number of specimens of species from moderately deep water in the Caribbean region that have not been collected since the explorations of the *Blake* in 1877–80, the *Albatross* in 1884–87, and the *Fish Hawk* in 1899.

Plants.—Accessions for the year comprised 56,125 specimens, most important of which are as follows: 24,124 specimens were transferred by the United States Department of Agriculture, mostly from the Bureau of Plant Industry, 4,062 being grasses and 15,308 Argentine specimens collected by Venturi. About 3,600 duplicate specimens of the historic Mutis Herbarium, received as an exchange with the Botanical Garden at Madrid, Spain, through the efforts of E. P. Killip, will be of great importance in the study of South American plants. A considerable number of South American plants were obtained from the British Museum (Natural History). Several other tropical American collections were received in exchange, among them 765 specimens of the Ecklon-Zeyler expedition from the Natural History Museum at Vienna, Austria; 530 plants from the Royal Botanic Gardens, Kew, England; 984 plants from the Botanical Museum at Copenhagen, Denmark; 1,141 specimens from the Natural History Riksmuseum in Stockholm, Sweden; 1,257 specimens, mainly from Peru, from the Field Museum of Natural History, Chicago; 1,709 specimens from British Honduras, Guatemala, and Sumatra from the University of Michigan. Similarly, 1,619 Chinese plants were received from Lingnan University, Canton, and 500 from the University of Nanking, China; 744 plants collected in the Hawaiian, Fiji, and Society Islands from the Bernice P. Bishop Museum in Honolulu; and 886 mainly Chinese, West African, and Cuban plants from the Arnold Arboretum, Harvard University. C. V. Morton collected 1,897 plants for the Museum at Oaxaca, Mexico, with the assistance of Dr. Emil Makrinius. The University of Vermont gave the National Herbarium 306 specimens collected in Mexico by C. G. Pringle, the lot consisting of numbers not previously represented in the collections. Among the numerous gifts by institutions and individuals were 464 specimens from the Death Valley region, Calif., by the National Geographic Society; 470 specimens from Nicaragua, by the Instituto Pedagógico de Varones, Managua; 449 specimens from the Santa Marta region, Colombia, by Dr. William Seifriz, University of Pennsylvania; 279 specimens from eastern Peru, by Guillermo Klug, Iquitos; 244 specimens from Colombia, by Baltazar Guevara Amortegui; 341 specimens from Panama, by Brother Paul, Colegio de la Salle; and 576 specimens from the State of Washington, by J. William Thompson, Seattle.

INSTALLATION AND PRESERVATION OF COLLECTIONS

The main work of the taxidermists was the mounting of a hippopotamus and the construction of a biological group of the Haitian ground iguana. The District of Columbia faunal exhibit continued under the care of Dr. Bartsch, who kept it current and made additions, notably a mounted specimen of the Louisiana heron.

Additional half-unit cases were supplied in the division of mammals for the rearrangement of the primate skins, all of which are now grouped together. Considerable work was done in rearranging smaller mammal skins, especially rodents and carnivores. The skeleton collection also was rearranged. The carnivore and larger rodent skulls of the Merriam collection, which has hitherto been kept intact as a separate unit, were intercalated in the general collection. Twelve large and medium-sized mammal skins were tanned on outside contract, and 13 skins were tanned by taxidermists of the Museum, who also degreased and made up 79 skins, skinned or prepared for skeletons 26 mammals, and removed 15 sets of gibbon leg bones. Fifty-five skeletons, mostly large, 145 skulls, and 14 sets of leg bones were cleaned. Contract work on small and medium-sized skulls and skeletons resulted in cleaning 695 skulls and 130 skeletons.

About two thirds of the birdskins received during the year were distributed in the study series. Of collections previously held up as separate units awaiting identification and study, the nonpasserine birds of the Roosevelt and Aschemeier African collections were identified and distributed. About one fourth of the large Siamese collections was worked up and distributed, as well as the rest of the Museum's Chinese birds. The skeletal material collected by H. B. Collins, Jr., on St. Lawrence Island was also identified. The work of expanding and rearranging the crowded parts of the study series included many groups of birds. The collection of alcoholic specimens was completely overhauled and all unidentified material culled out. The work of the preparators included skinning 108 birds, degreasing and remaking 158 skins, mounting two birds for the District collection, cleaning 292 skeletons, skeletonizing 220 birds, and blowing 40 eggs.

In the division of reptiles and batrachians, 6,310 newly identified specimens were incorporated in the collection. Dry preparations were added to the turtle collection as follows: 6 skeletons, 121 skulls, 59 shells; 71 study skins were also prepared, and a number of other reptile skins and skeletons made.

The division of fishes, during the vacancy caused by B. A. Bean's retirement on June 30, 1932, was ably cared for by E. D. Reid, under the immediate supervision of the head curator, until Dr. G. S. Myers, the new assistant curator, took charge. The large collection, mostly of *Albatross* fishes, for many years at Stanford University for study by the late David Starr Jordan and Charles Henry Gilbert, was packed and forwarded to Washington by Dr. Myers.

Dr. J. M. Aldrich, curator of insects, whose work was confined to Diptera, considerably improved the arrangement of several families. Dr. Alan Stone transferred all the mosquito collection to standard museum insect drawers and metal-covered cases and further rearranged the family Tabanidae. In the Coleoptera, H. A. Barber rearranged and expanded special groups and made a preliminary rearrangement of Philippine hispids. Dr. M. W. Blackman rearranged the Museum collection of 22 genera of the family Scolytidae. Dr. A. G. Böving continued to supervise the coleopterous larval collection. Nearly 3,000 jars of this material have been prepared and filled in the past 2 years. L. L. Buchanan studied and rearranged specimens of *Hylobius* and *Lepidophorus*, of the carabid genus *Monoferonia*, of the long series of granary weevils of the genus *Sitophilus*, and of the coffee-bean weevil. In addition he selected a synoptic series of the species of the genus *Calendra* and identified and arranged more than 3,000 North American specimens of the weevil genus *Apion*. Dr. E. A. Chapin made progress in arrangement of the scarabaeid beetles of the subfamilies Melolonthinae, Dynastinae, and Cetoniinae. W. S. Fisher completed rearrangement of the Mexican, Central American, and South American species of Cerambycidae and rearranged and to some extent classified the Oriental Cerambycidae.

In Lepidoptera the specialists proceeded with the incorporation of the great Owen collection into the general Museum series. Foster H. Benjamin consolidated all the North American Noctuidae of the subfamily Catocalinae, which now occupies 67 large drawers and 36 standard museum drawers. A similar rearrangement for the North American Noctuidae of the subfamily Agrotinae was partially completed. August Busck completed the incorporation of the Microlepidoptera from the Barnes collection into the general Museum series. Carl Heinrich added the Barnes collection material of the subfamilies Calleriinae and Macrothecinae to the general collection. Dr. William Schaus was active in expanding and rearranging the exotic Macrolepidoptera in order to care for the additional specimens that have become available during the year. He also completed a new arrangement of the family Epiplemidae and did much work on the Owen collection.

In Hymenoptera R. A. Cushman expanded and rearranged some of the groups and subfamilies in the Ichneumonidae. A. B. Gahan undertook some rearrangement due to the addition of material. C. F. W. Muesebeck arranged the Braconidae of the subfamily Aphidiinae and the exotic specimens of the subfamily Microgasterinae. Miss Grace A. Sandhouse completely rearranged the collections of aculeates. In addition, the aculeate Hymenoptera of the old Fitch collection were worked over and incorporated into the regular Museum collections. The North American material of the genus *Pemphredon* was identified and arranged; and the neotropical species of *Trypoxylon* were incorporated in the collection. Many undetermined Psammocharidae were sorted and grouped into genera, and the North American specimens of the genus *Pepsis* were identified and arranged.

In orthopteroids and neuropteroids, A. N. Caudell continued arrangement of the regular Museum material and made some progress in working up the Baker Philippine material. Dr. H. E. Ewing undertook to arrange the spider collection and sorted out and properly segregated various mixed lots of material in the groups assigned to him. In Hemiptera, H. G. Barber rearranged the entire Heteroptera collection. He now has the true bugs in a satisfactory natural order so that material is readily accessible. P. W. Oman rearranged Museum material in the Homoptera, involving various United States and Canadian Fulgoridae, and supervised the transfer of the extensive North American Psyllidae collection to trays and partly rearranged this material. He also arranged the South American species of leafhoppers of the genus *Agallia* and its relatives, as well as a large part of the West Indian and Central American Cicadellidae.

The alcoholic collection in the division of marine invertebrates is in excellent shape, owing chiefly to the efficient services of the laborer recently assigned to the division. Temporary clerical assistance made it possible to bring the cataloging of identified specimens about up to date. Work on the study collection of the division of mollusks has progressed steadily but slowly. Members of the zoological division staff of the United States Bureau of Animal Industry gave the helminthological collection its periodical overhauling. The usual curatorial work was done in the collection of echinoderms.

About 25,000 mounted phanerogams were added to the main herbarium, mostly recent South American material; 33,883 mounted specimens were stamped and recorded, preparatory to incorporation in the collection. The segregation of type specimens of American phanerogams was continued by E. P. Killip and E. H. Walker, 18,768 types of new species and varieties having now been labeled, cataloged, and placed in heavy individual covers. Also 4,225 photographs of type specimens of American plants in other herbaria (chiefly European) were mounted separately on herbarium sheets for distribution into the herbarium. As in previous years, E. C. Leonard, in addition to his ordinary duties, regularly devoted some time to the moss collection, and recently began similar curatorial work on the Hepaticae, of which a large number await incorporation in the herbarium.

The C. G. Lloyd mycological collection has been maintained in accordance with the terms of agreement under which it was deposited. There is great need of a comprehensive index of Mr. Lloyd's mycological writings, which consist to a great extent of scattered notes, the indexes to the separate volumes into which his writings were collected being neither complete nor uniform in style. Manuscript of a detailed index to the seven volumes was therefore prepared during the year and will be issued shortly by the Lloyd Library at Cincinnati. As a further step in clarifying and rounding out Mr. Lloyd's mycological work, a complete list of his new fungus species and new combinations, totaling about 1,500, is being made. This will include for each species (1) citation of place of publication; (2) other references in the literature by Lloyd and other mycologists, with comment; (3) citation of type and other specimens, with accompanying data. This work, to be ready shortly, will also be published by the Lloyd Library.

During the year 22,290 specimens were mounted by adhesive straps, all but 6,100 of these by contract; 3,412 specimens were glued (by contract); and 28,428 fully prepared specimens were turned out, all of which were stamped and recorded and are now ready for incorporation in the herbarium. Of material intended for the herbarium, there are on hand more than 20,000 specimens that are wholly unmounted; also 2,500 that have been glued but not stamped.

RESEARCH BY MEMBERS OF THE STAFF

The research of G. S. Miller, Jr., curator of mammals, was on the primates. The large collection of gibbons (mostly brought together by Dr. W. L. Abbott) was reexamined and reidentified in the light of recent studies by Pocock and Kloss; and a special study of the remarkable color variation was made. A short note on the classification of the gibbons was published. The opportunity to examine a fresh gorilla's foot, afforded by the death of a young mountain gorilla in the Zoological Park, furnished the stimulus to a new study of the problem of the origin of the human foot (whether or not from a mechanical type like that found in the great apes). Dr. Remington Kellogg reexamined and identified the hair seals in the Museum collection; prepared for publication three reports on cetaceans in the Los Angeles Museum of History, Science and Art, the Condon Museum of the University of Oregon, and the Field Museum of Natural History; and cooperated with specialists in other groups in the preparation of a tentative draft of the zones comprising the California Tertiary.

The curator of birds, Dr. Herbert Friedmann, completed work on the birds collected by the Smithsonian African expedition under Theodore Roosevelt, and also the report on the birds collected in Gaboon by the Garner expedition. He also reported on a large collection of bird bones from St. Lawrence Island, and on three smaller lots from the mainland of Alaska and from Kodiak Island; and began work on the remaining parts of Ridgway's unfinished work "The Birds of North and Middle America" and nearly completed the compilation of literature for all the groups remaining to be published on. He also wrote papers relating to the nictitating membrane of the domestic pigeon, to parasitic cowbirds and cuckoos, to early observations on North American birds, to racial variations in certain African shrikes, to the display of Wallace's bird of paradise, and other subjects. The associate curator, J. H. Riley, studied and identified the large collections of Siamese birds sent in by Dr. H. M. Smith and published descriptions and notes on some of the novelties and more interesting forms. A. C. Bent, collaborator, completed the manuscript of the tenth volume of his "Life Histories of North American Birds", on part of the falconiform birds. Dr. Wetmore published on the birds collected by the Parish-Smithsonian expedition in Cuba and Haiti; described several new forms of fossil birds from North America; continued his editorial work on Swann's "Monograph of the Accipitres", part of which was issued during the year; and wrote various other articles.

The curator of reptiles and batrachians, Dr. L. Stejneger, worked on a revision of the Testudinata of North and Middle America; finished a report on some collections from the Galapagos Islands and Polynesia; and in collaboration with Dr. Thomas Barbour, of the Museum of Comparative Zoology, brought out the third edition of their "Check List of North American Amphibians and Reptiles." Dr. Doris M. Cochran, assistant curator, completed a report on the herpetology of Hispaniola and published several descriptive papers on new species.

Dr. G. S. Myers, assistant curator of fishes, nearly completed a revision of the genera of oviparous cyprinodonts, a group of small fishes of great value in the destruction of malarial and yellow-fever mosquitoes in the Tropics. He also began work on the deep-sea fishes obtained by the Johnson-Smithsonian Deep-Sea Expedition and on the fishes from western China collected by Dr. D. C. Graham.

Dr. J. M. Aldrich, curator of insects, prepared a paper on the dipterous family Tachinidae of the Patagonian region, based on our material and that of the British Museum; published several short papers describing new species from various parts of the world and including notes on synonymy and nomenclature; made a catalog of the muscoid flies of the Old World except Europe; and studied the species of botflies of the genus *Cuterebra*, in collaboration with Maj. E. E. Austen, of the British Museum. C. T. Greene worked on a revision of the genus *Anastrepha* of the family Trypetidae, of definite importance because of the discovery of members of the genus in the southernmost parts of the United States, including Florida and the Brownsville area in Texas. Foster H. Benjamin completed a manuscript discussing the classification and biology of the native Trypetidae of Florida, based on extensive collections made during the effort of the Department of Agriculture to exterminate the Mediterranean fruit fly. Dr. Alan Stone undertook a critical revisionary study of the genus *Tabanus*. Dr. A. G. Böving prepared numerous notes on and illustrations of beetle larvae, including two Puerto Rican species of *Phyllophaga*, the coccinellid beetle *Ortalistes rubidus*, and the larvae of *Rhinomacer pilosus*, *Tetrigus fleutiauxi*, and *Nicobium castaneum*. One paper, describing the larva of the coccinellid beetle *Decadiomus pictus*, was published. L. L. Buchanan began a critical revisional study of the weevil genus *Conotrachelus*. Dr. E. A. Chapin prepared a key to the species of *Chlaenobia* present in the Museum collections, and continued his revisional work on various groups of West Indian Scarabaeidae, especially on those of Puerto Rico. W. S. Fisher completed a study on the genus *Exocentrus* from Java, prepared descriptions for a number of new species of Mexican Buprestidae, and made minor studies in various small groups to facilitate identification.

In the section of Lepidoptera, Dr. W. Schaus continued study of the Puerto Rican Macrolepidoptera, in the course of which he prepared descriptions for many new species. Foster H. Benjamin worked on various North American lepidopterous groups, and prepared a number of short papers. August Busck continued work on the family Tortricidae and took up the genus *Aristotelia*, which contains a number of species of economic importance. Carl Heinrich continued study of American Phycitinae. R. A. Cushman undertook a revision of the genus *Polyaenus*, did some work on the tribes Lissonotini and Glyptini, and published one paper on the identity of several Oriental parasitic ichneumonids of economic importance. A. B. Gahan devoted much time to a paper on the parasites of the Hessian fly. C. F. W. Muesebeck worked on a revision of the braconid subfamily Euphorinae and progressed in work on the subfamily Exothecinae and the genus *Rogas*. Miss Grace A. Sandhouse continued studies on the North American Halictinae, particularly on certain subgenera of the genus *Halictus,* during which she made many dissections and from these permanent preparations for the collection. She completed work on the North American *Augochlora* and worked out a synoptic key to the North American *Pemphredon.* William Middleton worked on sawflies and prepared descriptions of some new species.

A. N. Caudell published a report on the Orthoptera of the Pinchot expedition; carried on some investigational work on neuropteroids, in the course of which he prepared a description for one new species; and studied specimens of Decticinae from California. He finished and submitted for publication an alphabetical index to the orthopterous insects of North America published subsequent to the year 1900 to and including 1925.

Dr. H. E. Ewing made taxonomic studies on both mites and sucking-lice during the year, during which he completed for publication four papers on the classification of various genera or groups.

In Hemiptera H. G. Barber carried on investigations in a variety of groups, including Nearctic and Neotropical Phymatidae, Neotropical Coreidae, Notonectidae and Belostomatidae (with the assistance of Prof. H. B. Hungerford), and Halobatinae, in connection with the Carnegie Plankton expedition, and made considerable progress with the study of the races of the chinch bug (*Elissus leucopterus* Say). P. W. Oman undertook preliminary studies in a number of genera in both the Cicadellidae and the Fulgoridae. His most important contribution during the year was an extensive paper on classification of the North American agallian leafhoppers. Dr. P. W. Mason continued his study of the aphid tribe Macrosiphina.

In the division of marine invertebrates, Dr. Mary J. Rathbun, associate in zoology, was actively engaged in the preparation of the fourth of her series of comprehensive monographs on American crabs. In addition she determined nearly all the current sendings of recent Brachyura and fossil Crustacea and submitted for publication a paper describing seven new species from the Gulf of California. Dr. Waldo L. Schmitt, curator, published a review of the distribution of the larger fresh-water shrimps of the United States, and also prepared for publication the new species in his report on the macruran and anomuran Crustacea of Puerto Rico and the Virgin Islands and an account of two new species of pycnogonids. A revision of the genus *Emerita* was likewise submitted for publication. The assistant curator, C. R. Shoemaker, completed several studies on amphipods; others he has in progress, with a view to bringing taxonomic knowledge of these long neglected Crustacea up to date for the east coast of North America. The report being prepared by J. O. Maloney, aide, on the isopods collected in the course of the various expeditions that Capt.

R. A. Bartlett has made to Greenland in the past several years is rapidly approaching completion, while his descriptions of two new species of isopod crustaceans from California appeared in print during the year. Dr. J. A. Cushman, honorary collaborator, made progress on further parts of his monographs of the tropical Pacific foraminifera. In addition to handling a large volume of paleontological material, he identified various lots of recent foraminifera. Dr. W. H. Longley, collaborator, spent nearly 4 months abroad, chiefly in London, Paris, and Berlin, in part in connection with his studies on evolution.

Most of the time of the curator of mollusks, Dr. Paul Bartsch, was required in planning, equipping, and directing the Johnson-Smithsonian Deep-Sea Expedition and in caring for the material obtained. The identification of material sent in for report occupied the time of the rest of the staff not otherwise taken up by curatorial duties.

The curator of echinoderms, Austin H. Clark, continued work on parts 4 and 5 of his monograph of the existing crinoids, with a view to their completion in the near future, and studied and indentified a part of the material collected by the Johnson-Smithsonian Deep-Sea Expedition.

In the division of plants Dr. W. R. Maxon, associate curator, carried on studies of tropical American ferns; E. P. Killip, associate curator, continued work on a monograph of the American species of Passifloraceae, besides studies of certain genera of Urticaceae and Boraginaceae; E. C. Leonard, assistant curator, studied West Indian flora; C. V. Morton, aide, investigated several tropical American families of phanerogams, especially the Solanaceae; and E. H. Walker, aide, practically finished a revision of Chinese Myrsinaceae, besides carrying on bibliographic work. Here may be mentioned also the study by Mr. Killip of a series of about 3,600 duplicate specimens of the historic Mutis Herbarium received from the Jardin Botanico, Madrid, through his active interest. The Mutis collection, made in Colombia between 1760 and 1808, contains specimens upon which many early species were proposed. In return for the valuable duplicates sent to this Institution, Mr. Killip has undertaken to identify the specimens, and to date has reported upon about 2,000 of the 3,600 received.

DISTRIBUTION AND EXCHANGE OF SPECIMENS

Duplicate specimens distributed to museums, high schools, colleges, and similar institutions aggregated 1,351 specimens, and 43,578 exchanges were sent out, of which 1,073 were zoological specimens. The 42,505 plants distributed went to 104 institutions and correspondents, of which 46 were in the United States, and 58 in 22 countries abroad.

NUMBER OF SPECIMENS UNDER DEPARTMENT

The number of specimens under the department of biology, so far as has been ascertained by count and estimate, is now more than 10,800,000. The actual number is probably much greater, since several collections, as the corals, have not been included, nor does the number of plants given below include duplicates and unmounted material of the lower cryptogams. In several of the divisions, such as those of marine invertebrates and mollusks, lots consisting of minute organisms are frequently counted as single specimens though they may contain hundreds or even thousands of individuals, the enumeration of which would serve no useful purpose.

Mammals		221, 425
Birds:		
Skins	252, 456	
Alcoholics	8, 961	
Skeletons	13, 378	
Eggs	87, 562	
		362, 357
Reptiles and amphibians		100, 842
Fishes		741, 341
Insects		4, 141, 686
Marine invertebrates		897, 602
Mollusks		2, 497, 401
Helminths		144, 255
Echinoderms		158, 035
Plants		1, 550, 363
Total		10, 815, 307

REPORT ON THE DEPARTMENT OF GEOLOGY

(RAY S. BASSLER, *Head Curator*)

The past year was notable for the quantity and value of geological material acquired, particularly in the mineralogical division, where several endowment funds were used rather freely to take advantage of favorable market conditions. In quality of specimens acquired through field work and exchange, this has been the most outstanding year in the history of the division of vertebrate paleontology. Explorations were undertaken in both of the paleontological divisions and in the mineralogical division, the latter under the auspices of the Canfield fund. All resulted in the acquisition of desirable material both for exhibition and study.

ACCESSIONS

In both specimens and accessions the aggregate is greater than last year, numbering 255 accessions with an estimated total of 35,555 specimens. The number for the various divisions is as follows: Mineralogy and petrology, 100 accessions, 728 specimens; geology, systematic and applied, 33 accessions, 706 specimens; stratigraphic paleontology, 92 accessions, 33,805 specimens; vertebrate paleontology, 30 accessions, 316 specimens.

The year's accessions include the following minerals not previously represented: Alkansul, alleghanyite, ardealite, bianchite (type), corvusite (type), galaxite, leucophosphite, minyulite, oxykertschenite, pisekite, rilandite (type), rosickyite, and tuhualite.

There were 31 accessions to the Roebling collection through the income from the Roebling fund, totaling 114 specimens. Perhaps the finest item is a 2½-pound pink spodumene (kunzite) of good crystal form and almost flawless. Four fine black opals from Lightning Ridge, New South Wales, are partly polished to show the wonderful fire that makes these Australian stones most highly prized of all opals. Two 1.7-carat diamonds were added to the American series, 1 from Huntsville, Tex., and 1 from the gold washings of Brown County, Ind. A fine cinnamon-brown crystal of topaz from Burma weighs 2¼ pounds. A huge mass of native copper from the Lake Superior region shows numerous unusually large and well-formed crystals. Other noteworthy additions are a specimen of quartz with attached crystals of euclase and topaz from Brazil; 3 specimens of California gold showing unusually fine crystals; a beautiful crystal of pink and green tourmaline from Madagascar; and 2 large loose crystals of the rare silicate euclase from Brazil. Through the interest of Gilbert LaBine, discoverer of the rich radium deposits at Great Bear Lake, Canada, a 75-pound mass of the radium ore pitchblende, crusted with colorful alteration products, and a rich mass of native silver from the same locality, were added.

Several fine-cut gems were acquired through the Roebling fund, including a rare Brazilian rose-red topaz of 18 carats, a Madagascar ruby tourmaline of 30 carats, a flawless Brazilian pink tourmaline of 62 carats, and an unusual pink amethyst of 49 carats.

To the Canfield collection through the Canfield fund came 13 accessions totaling 235 specimens. The outstanding one comprises three masses of crystallized gold from Breckenridge, Colo., the largest being a slab of fine mossy leaf gold weighing 22.6 troy ounces. A large group of brilliant azurite crystals from Aranzazu, Zacatecas, Mexico, was obtained through the interest of Samuel Sokobin, American consul at Saltillo, Coahuila. Other notable specimens are a group of azurite crystals; a crystal of cerussite from Tsumeb, Southwest Africa; the copper oxychloride atacamite from Chile; a rare phosphate of iron, strengite, and the phosphate of lead, pyromorphite, in unusually large crystals, both from Germany; a group of large and brilliant crystals of tin oxide, cassiterite, on a white quartz crystal base, from New South Wales; a huge crystal of pyrite from Arizona; and a rich example of the rare manganese silicate ganophyllite from Franklin, N.J. Over 200 Bolivian minerals, including excellent crystallized cassiterite, ferberite, and bismuthinite also were acquired.

The finest stone added to the Isaac Lea collection, through the Frances Lea Chamberlain fund, is a flawless golden beryl of fine color from Madagascar, weighing 46 carats. Also, 2 red tourmalines from Madagascar, an engraved emerald of 11 carats, an old carving in Burmese amber, a rare ruby-red feldspar, and 2 unusually deep-colored citrine quartzes were added.

Other additions to the gem collection include 3 cabochons of white grossularite garnets, 3 of Whitby jet, 3 of amazonstone, and several pieces of jaspar. The Oregon Agate and Mineral Society contributed an unusual cut agate showing iridescent rainbow colors; Martin L. Ehrmann presented a dish of yellow precious serpentine; and John H. Willing 3 gold stickpins fashioned as a pick, a shovel, and a pan, stated to have been made in 1855 and worn by early California gold miners.

A huge quartz geode, almost 3 feet in diameter and with a crystal-lined cavity 18 inches deep, from Keokuk, Iowa, was presented by William M. Thomas and his son, Beverly Thomas. Mr. Thomas, a veteran geode collector, states that this is the finest geode he has ever seen. W. E. Lockhart gave a huge slab of amazonstone, measuring about 3 feet square, from Colorado. The following persons likewise added unusually fine material to the collection: Ernest Schernikow, a slab of precious opal from Honduras; F. F. Bradley, a fine group of celestite crystals from Clay Center, Ohio; Mark Bandy, a large specimen of the rare iron sulphate quetenite, from Chile; Boodle Lane, a specimen of galena showing parallel growth, and John C. Wells, specimens of new phosphate minerals from the Black Hills.

Twenty-two specimens, including 14 falls new to the collection, were added to the meteorite series. Two of exceptional interest are from Meteor Crater, Canyon Diablo, Ariz., one a complete individual weighing 1,011 pounds, one of the largest masses recovered at this famous crater, the other the mass from which were obtained the first diamonds found in a meteorite. Another example is the largest individual of a shower that fell at Archie, Mo., on August 10, 1932, during the Perseid meteor shower. This is the second known instance of the fall of a meteorite during a meteor shower. Other meteorite accessions are one half (23½ pounds) of the Altonah, Utah, fall; Beardsley, Kans. (945 grams); Bear Lodge, Wyo. (3,120 grams); Bencubbin, Australia (242 grams); Coya Norte, Chile (16 pounds 10 ounces); Henbury, Australia (31 pounds); Huizopa, Mexico (2,774 grams); Melrose, N.Mex. (990 grams); Nagy Vazsony, Hungary (36 grams); New Almelo, N. Mex. (1,550 grams); Oroville, Calif. (262 grams); Pinon, N.Mex. (1,410 grams); and Tlacatopec, Mexico (2,430 grams), acquired through exchanges and gifts.

The United States Geological Survey transferred several described sets of rocks and ores, the following districts being represented: Ellijay quadrangle, North Carolina; eastern Oregon; Squaw Creek, Silver Peak, and Antonio districts, Oregon; and southwestern Idaho. Through the interest of Dr. Josiah Bridge, the Museum obtained from Ramie Inman two large blocks of a handsome diabase porphyry from Fredericktown, Mo. Dr. Robert W. Sayles presented two large exhibition blocks of a glacial conglomerate, the Squantum tillite, and Dr. Tom Barth collected two large exhibition blocks of gneiss in Norway.

The outstanding accessions in economic geology are as follows: A pegmatite dike from Ohio City, Colo., containing large sheets of lepidolite mica obtained through E. B. Eckel, of the United States Geological Survey, from Messrs. Werner and Disberger, of Ohio City; a 600-pound mass of gold ore from the Homestake Mining Co., Lead, S.Dak.; two large and colorful potash ores, sylvinite and carnallite, from the Minas de Potasa de Suria, Spain; several specimens of halite and related minerals from Hallstatt, Austria, sent by Bergrat Karl Krieger; a series of copper ores and minerals including some large specimens from Butte, Mont., presented by A. L. Bigley and A. E. Blair, of the Anaconda Copper Co.; and a number of specially selected Bisbee copper ores from William P. Crawford, of Bisbee, Ariz. Frank L. Hess, honorary custodian of rare metals, continued his interest by adding over 50 specimens of rare metal ores and minerals from Canada, the Kola Peninsula, Karelin, Brazil, and other districts.

Several notable accessions came to the division of stratigraphic paleontology: 26 exchanges arranged largely by the assistant curator to fill gaps in the brachiopod series were received. The British Museum and Dr. R. Kozlowski at Warsaw and Dr. A. Hadding at Lund supplied fine Jurassic and Cretaceous brachiopods. The National Museum at Melbourne and the Dominion Museum at Wellington furnished two fine collections from the Tertiary of the Australian realm, and the Paleontological Institute of Vienna a small collection of rare Triassic forms. From Harvard University was obtained a large suite from the Middle Paleozoic of Bohemia. Collections from the Devonian were furnished by Dr. A. Öpik in Estonia and by the Muséum Royal d'Histoire Naturelle de Belgique, Brussels. Finally, two sizable lots from the Universities of Oklahoma and New Mexico placed in our collection a more adequate representation of Upper Paleozoic brachiopods from these States.

Among the other exchanges were two lots of Bohemian fossils from Charles University, Prague; an excellent representation of the Norwegian Cambrian from Oslo; a series of topotypes of Carboniferous fossils from the University of London; and an interesting series from the University of Adelaide. Dr. H. Justin Roddy again furnished an extraordinary collection from the Lower Cambrian of the Lancaster region in Pennsylvania.

Several valuable collections were presented, most notable being the fifth shipment of the private collection of Dr. A. F. Foerste, numbering some 10,000 specimens of invertebrate fossils of which over 1,000 are types. Particularly notable is the valuable acquisition of several fine fossil starfishes collected by the late Dr. Albert Perry Brigham, of Colgate University, and presented by Mrs. Brigham and Mr. and Mrs. L. V. Roth. Dr. J. Brookes Knight, of Yale University, gave about 125 brachiopods from the Pennsylvanian of Missouri, and Prof. G. M. Kay, at Columbia University, a collection of Trenton brachiopods. Through the interest of Dr. Mary J. Rathbun, six lots of fossil crustaceans were donated, among which those furnished by Dr. Hubert G. Schenck, of Stanford University, and some pinnotherid crabs, including types, gift of E. W. Galliher, Pacific Grove, Calif., were of most importance.

Among other gifts were a collection of Pennsylvanian gastropods from J. Brookes Knight, of Yale University; a small lot of Pennsylvanian fossils from Ralph H. King, University of Texas; a large exhibition slab crowded with the gastropod *Lecanospira* found in Virginia by Dr. A. A. L. Mathews, Oberlin College; examples of the fresh-water limestone crowded with fossils, used to build the new Mormon Church in Washington, secured through the builders; and finally a valuable lot of Tennessee Cambrian fossils collected by Prof. George M. Hall, University of Tennessee.

The Springer fund purchased the important Keyte collection of Paleozoic fossil crinoids from Colorado. The assistant curator during his field expedition obtained 10,000 to 15,000 fossils in Gaspe and New York. These supplied many important specimens for the biologic and stratigraphic series and also needed material for exchange. A trip into the Ohio Valley by the head curator also furnished a valuable lot of late Paleozoic fossils.

Of the eight accessions of fossil plants, mention may be made of those received from Prof. Ralph Chaney, University of California, which contain many counterparts of types described in several papers. Prof. G. R. Wieland, of Yale, donated two examples of the interesting fern *Tempskya*, and the Santa Barbara Museum of Natural History gave some Pleistocene plants excellently preserved in asphalt.

Material resulting from the field expedition of 1932 is of first importance in the division of vertebrate paleontology, especially benefiting the mammalian collections. Specimens worthy of especial mention are: Much of the skeleton of a hawklike bird, of which the skull, lower jaw, pelvis, sternum, and other bones are present, unquestionably the most perfect skeleton of a bird yet collected from the Oligocene of North America; a skull and skeletal parts of *Eusmilus*, a rare saber-toothed cat of which only three or four specimens were previously known; two articulated skeletons of *Mesohippus;* two articulated skeletons of *Merycoidodon;* one skeleton each of *Leptomeryx* and *Ischyromys;* 120 skulls, many partial skeletons, articulated limbs and feet, in all representing more than 20 genera of vertebrates. Some forms new to science will probably be found when a study is made of these materials.

Through exchanges arranged with various institutions, the division obtained a number of specimens of outstanding merit. From the American Museum of Natural History came a mountable skeleton of *Moropus*, a rare mammal from the Miocene of Nebraska, and a skeleton of the giant reptile *Gorgosaurus libratus* from the Upper Cretaceous of Canada. The former has all the broken and missing bones restored so that the skeleton is ready for mounting. Both genera were previously unrepresented in our collections. The Los Angeles Museum of History, Science and Art furnished a mountable composite skeleton of *Equus occidentalis*, from the famous Rancho La Brea asphalt deposits; and the Colorado Museum of Natural History, Denver, a composite skeleton of the Oligocene rhinoceros, *Trigonias osborni*. From the Royal Ontario Paleontological Museum were obtained two duck-billed dinosaur skulls (*Edmontosaurus* and *Prosaurolophus*), both new in the collections, and from the National Museum of South Africa four skulls and limb and foot bones of *Lystrosaurus* and *Dicynodon*, extinct reptiles from the Triassic. Remains of these genera are rarely found in paleontological collections of North America. A beautifully preserved skull of *Equus alaskae* Hay from Point Barrow, Alaska, was collected for the Museum by James A. Ford. A fossil frog skeleton from the Miocene of Nevada, the most perfect example of an extinct frog yet found on this continent, was presented by R. M. Catlin. A skull of a large cetacean from California, presented by Dr. A. P. Ousdal, forms a valued addition to the series of cetacean remains. By purchase from George F. Sternberg a beautiful example of the extinct fish *Ichthyodectes hamatus* was obtained, and similarly the mosasaur series was enriched by a mountable skeleton of the large sea lizard *Platecarpus*.

INSTALLATION AND PRESERVATION OF COLLECTIONS

A rearrangement of the systematic mineral collection, reported last year as under way, was completed, and much new and striking material from the Roebling and Canfield collections was incorporated. The 2,892 specimens of this series include 837 distinct mineral species and comprise high-quality material only. The new arrangement permitted the introduction of some new exhibits in refractories, lithium, beryllium and rare-earth ores. Several large specimens of ores from important mining districts were installed on new bases. Five large meteorites, previously exhibited on individual bases, were reinstalled on a single long base to harmonize with previous installations. Some striking exhibits on individual pedestals include a large geode from Iowa fitted with interior lighting, radium ore from Canada, and a group of carved corals.

The head curator prepared a new set of slides on geological subjects for the stereomotorgraph, assembled a set of small, polished samples of foreign building stones, both ancient and modern, and prepared various sets of Cenozoic and recent bryozoans for exchange with the British Museum, in the course of which many specimens were identified and added to the collections. He also continued building up a library of pamphlets on general geology, stratigraphy, and invertebrate paleontology.

In revising the exhibition series of ores it was found necessary to expand the study series to accommodate material removed from exhibition, during which the classification, cataloging, and distribution of the important collection of rare metal ores assembled during many years' collecting by Frank L. Hess were completed by the assistant curator. This is probably the finest collection of rare-metal ores extant.

Dr. W. F. Foshag, assisted by James Benn, selected material for an exhibit illustrating the fluorescence of minerals under ultraviolet light. Since only an occasional specimen shows a satisfactory degree of fluorescence, it was necessary to examine hundreds of samples before the best possible effect could be achieved. A satisfactory lighting system was devised by L. B. Clark, of the Division of Radiation and Organisms.

The head curator completed the preparation and installation of the biologic series of fossil plants, a case illustrating the geology of a coral island, one showing various types of geological structures, another with imitative forms of fossils, and one each of the peculiar extinct merostome crustaceans and unusual cephalopods. He likewise installed on a single exhibition base large, showy examples of various kinds of conglomerates and glacial boulder clays.

Dr. C. E. Resser, with the help of Dr. Josiah Bridge, assembled an exhibit illustrating the life of the Ozarkian and Canadian periods, thus filling a long-existing gap. In cooperation with Dr. Roland Brown and Dr. C. B. Read, of the United States Geological Survey, available material also was assembled to illustrate fossilized fruits and flowers.

Dr. G. A. Cooper placed 30 lithologic samples in the stratigraphic exhibition series, revised the exhibit of stromatopores, and, at the close of the year, went over the entire exhibition series in preparation for the International Geological Congress. Dr. C. B. Read continued his voluntary rearrangement of the Lacoe plants. Dr. Charles Butts arranged his extensive collections of Paleozoic fossils so that they are readily available.

Following her retirement from the Government service at the end of December 1932, Miss Margaret Moodey was appointed, under the Springer fund, to take up the long-delayed work of cataloging the unrivaled Springer collection of echinoderms. Two months were spent in bibliographic work and 4 months in checking and cataloging. At the end of the year, 8 families of the Camerata, comprising 115 standard drawers, were completed.

The exhibition series in vertebrate paleontology was increased by the addition of a 5-foot skeleton of *Ichthyodectes hamatus*, skulls of *Edmontosaurus regalis* Lambe and *Prosaurolophus maximus* Brown; skull and lower jaws of *Hyrachodon* and a skull of *Ovibos*.

Assistant Curator C. L. Gazin continued his rearrangement of the mammal collection. The Cumberland Cave collection, consisting of several hundred specimens, is now completely cataloged, labeled, and arranged in standard trays; the *Plesippus* materials have been assorted and, with the exception of the skulls, assembled as a single unit; the Cook collection from Idaho and the Gidley collection from Florida were assorted, labeled, and many of the specimens cataloged. Dr. Gazin also has identified many of the Bridger specimens.

INVESTIGATION AND RESEARCH

By members of the staff.—The head curator completed the preliminary study and illustrations of the Hederellidae, a new group of fossil Bryozoa; brought up to date his bibliographic index of Paleozoic Ostracoda, being published by the Geological Society of America; prepared an address on the development of invertebrate paleontology in America; and forwarded for publication a monograph of the Tertiary Bryozoa of Australia, prepared in collaboration with the late Ferdinand Canu.

Dr. W. F. Foshag completed investigations on the rare minerals searlesite, bakerite, ganophyllite, and sulfohalite and continued work on the borate minerals of the West, in which it was necessary to analyze a number of marls. Several doubtful minerals were studied and their true nature determined.

E. P. Henderson announced two new mineral species, corvusite and rilandite, and nearly completed work on two other new species. Many partial analyses were made for identification, and some material was found worthy of more detailed examination.

Dr. C. E. Resser assisted R. Endo in preparing a paper on the Cambrian of Manchuria. He completed a paper presenting a preliminary generalized time scale for the Cambrian and began a description of the fossils from the *Olenellus* zone in the Appalachians. These last papers were presented at the Boston meeting of the Geological Society of America.

Dr. G. A. Cooper prepared a preliminary paper on the results of his field work in eastern New York and another, written jointly with Dr. Lawrence Whitcomb, of Lehigh University, describing a new genus of brachiopod.

Dr. E. O. Ulrich continued his studies of early Paleozoic faunas. A grant from the Geological Society of America made possible the temporary employment of Dr. H. S. Ladd, who since February was engaged in labeling and photographing fossils and in organizing materials so that Dr. Ulrich's many uncompleted manuscripts, including joint papers with Drs. Foerste, Cooper, Bridge, and others, may finally be printed.

Dr. A. F. Foerste continued his cephalopod studies, unearthing much important information. He will soon reach the point when the cephalopod series can be generally overhauled and classified.

C. W. Gilmore completed a manuscript describing dinosaurian remains from the Cretaceous of Mongolia, which has been sent to the American Museum of Natural History for publication. A beginning was made on a study of turtle specimens from Mongolia for that institution. This will complete our part of the cooperative arrangement between the two institutions whereby for work done

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on the Mongolian fauna, Dr. G. G. Simpson will study and describe the Museum's collection of Paleocene mammals.

Dr. C. L. Gazin completed his extended study of the Cumberland Cave Pleistocene fauna and submitted it for publication. Two papers, "A New Shrew from the Upper Pliocene of Idaho" and "The Status of the Extinct American Eland", were published, and a manuscript, "New Felids from the Upper Pliocene of Idaho", was submitted for publication. Some progress was made on his study of the *Plesippus* materials, as well as a beginning in the study of other portions of the Idaho collections, particularly the mustelids and lagomorphs.

Dr. Remington Kellogg, as in previous years, continued his researches on the cetacean collection, this past year being more particularly applied to the zeuglodonts.

Research by outside investigators aided by Museum material.—During the year 1,767 specimens were lent for study, and 463 lots of material were received for examination and report.

In the paleontological division, Dr. David White was engaged on a description of the Pottsville flora of Illinois. Dr. R. W. Brown continued the study of the Fort Union flora and wrote papers describing the flora of the Miocene of the Blue Mountains, Oreg., and of the Salmon, Idaho, region. Jointly with Dr. C. B. Read, he nearly completed a revision of the Cretaceous fern genus *Tempskya*. Dr. Read prepared papers on the floras in the Mosquito Range, Colo., and in the New Providence shale and on *Trichopitys*. Dr. L. W. Stephenson was engaged in a study of the Navarro fauna of the Texas Cretaceous, and Dr. Edwin Kirk continued his studies on crinoids and completed several papers.

Dr. T. Kobayashi remained here throughout the year continuing his studies of Korean and Manchurian fossils. Much new information of critical importance is constantly coming to light in his studies.

Abbé Georges Le Maitre, the Belgian scientist, studied the meteorite collection; Dr. M. K. Elias, of the Kansas State Geological Survey, spent some weeks studying Carboniferous and Tertiary plants. A. L. Morrow, of Yale University, R. W. Imlay, of the University of Michigan, and Prof. H. A. Meyerhoff, of Smith College, studied the Mesozoic collections; Dr. A. R. Barwick, of Catholic University, studied the invertebrate fossil collection in general; Dr. J. A. Cushman the foraminifera; Dr. Cecil Kindle, of the College of the City of New York, and Dr. Lawrence Whitcomb, of Lehigh University, the Paleozoic invertebrates; and Prof. P. E. Raymond and Henry C. Stetson, of Harvard University, spent a few days working on certain Burgess shale specimens.

Dr. George G. Simpson made considerable progress in his study of the Paleocene mammal collection. A locality map, printed as a result of his field trip to Montana for the Museum this past summer, adds greatly to the value of the collection in definitely locating all the specimens both geologically and geographically. Dr. R. S. Lull, director of the Peabody Museum of Natural History, utilized the horned dinosaur collections in connection with his monographic revision of the Ceratopsian dinosauria. Barnum Brown, of the American Museum of Natural History, likewise made use of the collections in connection with his study of the armored dinosauria.

Assistance to Government bureaus and private individuals.—Mineralogical material was furnished to members of the Geological Survey, the Department of Agriculture, and the Geophysical Laboratory, and Dr. Resser continued his services to the Geological Survey as adviser on Cambrian questions. Requests from Prof. George M. Hall, of the University of Tennessee, for identification of age and species in Cambrian collections necessitated considerable study of the Nolichucky fossils. Thereby, for the first time, definite information was obtained regarding the faunal characteristics of this widespread southern Appalachian formation. A large series of highly important Cambrian fossils was obtained by the Princeton Summer School, at Red Lodge, Mont., and forwarded to the Museum for preliminary identification.

DISTRIBUTION AND EXCHANGE OF SPECIMENS

The following distribution of geological specimens was made: Gifts, 3,456 specimens; exchanges, 2,278; loans for study, 1,767. As transfers to other Government bureaus, 21 specimens were sent.

NUMBER OF SPECIMENS UNDER DEPARTMENT

The estimated total of specimens in the department is as follows:

Mineralogy and petrology	140, 736
Geology, systematic and applied	95, 493
Stratigraphic paleontology	1, 864, 167
Vertebrate paleontology	27, 322
Total	2, 127, 718

REPORT ON THE DEPARTMENT OF ARTS AND INDUSTRIES

(Carl W. Mitman, *Head Curator*)

For the first 2 months of the year, following the retirement of W. deC. Ravenel on June 30, 1932, the department of arts and industries was administered by J. E. Graf, associate director. On September 6, 1932, the office of head curator was established and an administrative set-up created similar to that of the natural science departments of the Museum. C. W. Mitman, who had spent 3 months of the summer in a general survey of technical, industrial, and science museums of western Europe, was advanced from the position of curator of engineering to the new position; and Frank A. Taylor was promoted from assistant curator of engineering to curator.

ACCESSIONS FOR THE YEAR

Valuable historical specimens of textiles, engineering, and graphic arts that never would have come to light in boom times were brought to the department's attention during the year and acquired when possible. Slack business, on the other hand, practically prevented the acquisition of new industrial exhibits, but permitted many who had cooperated with the Museum in the past to renew their exhibits.

Specimens added to the department's collections during 1933 totaled 4,261, about one third more than in 1932. The distribution of these among the divisions and sections was as follows: Engineering, 312; textiles, 708; organic chemistry, 764; wood technology, 365; foods, 2; history of agriculture, 252; medicine, 425; graphic arts, including photography, 1,433.

Engineering.—The 312 specimens included in the 82 accessions of this division were assigned to the sections as follows: Aeronautics, 174; mechanical technology, 130; mineral technology, 8.

In aeronautics, the most prominent object acquired was the gondola, or car, of the *Pilgrim*, the first dirigible designed for inflation with helium gas. It is complete with the Laurence 3-cylinder radial engine and the 4-blade metal propeller used with it, and was presented by the Goodyear Tire & Rubber Co.

The collection pertaining to the early history of balloons was augmented by the gift of Miss Emma Durant, of New York City, of a number of original illustrations and records describing the work of her father, Charles F. Durant, the first professional American aeronaut, who made his first ascent from Castle Garden, New York City, in 1830. Two structural sections from the airships *Shenandoah* and *Akron*, showing two forms of trusses, came from Howard Minker, Washington, D.C., and the Goodyear Tire & Rubber Co., respectively.

To the collection of aircraft engines the Pratt & Whitney Co., Hartford, Conn., added a sectioned operating example of their "Wasp" engine. Seven airship propellers were transferred from the War Department; an adjustable metal airplane propeller of 1914 was presented by Inglis M. Uppercu, Keyport, N.J.; and a modern hollow steel blade from a Dicks propeller was given by the Pittsburgh Screw & Bolt Corporation. A departure from the usual form of lift and propulsion is illustrated by a wind-tunnel model of a rotary airfoil, presented by its inventor, I. B. Laskowitz, Brooklyn, N.Y.

Although several full-size airplanes were offered to the Museum during the year, none could be accepted because of limited space. To the collection of airplane models, however, many new types were added, including a beautifully constructed miniature of a "Travelair" biplane of 1930, one eighth size and half skeletonized to show the construction. It is one of the finest models in the collection and was loaned by its maker, Herbert Atkinson, of New Bedford, Mass. The acquisition of a Curtiss pusher model of the 1908 type and a Curtiss "Hawk" model of 1928, both made to the same scale, permits an interesting contrast of airplane design over a 20-year period. These models were received from Edward Reeves and Richard Hooper, respectively, of Washington, D.C. Another model received from Mr. Reeves illustrates the old "Antoinette" type, a French monoplane of 1909, which made remarkable flights in the early days of aviation. A German World War bombing airplane is represented by a model of a "Gotha", made and presented by Isaac H. Henry, of Easton, Md. Modern military types are shown by a "Condor" bomber model from Harris Taylor, Clarendon, Va.; a Boeing low-wing monoplane model from Robert McGregor, Clarksburg, W.Va.; and a Navy Vought "Corsair" model made by Edwin Geigan, Washington, D.C., and received from Miss E. M. Luers, Bowie, Md. The series of models illustrating the winners of the famed Schneider trophy for seaplanes was increased by a miniature of the Supermarine *S-6-B*, which won the trophy in 1931 at a speed of 340 miles an hour. The model was made and presented by Ivan Lettner, Anacostia, D.C.

With the assistance of the War Department, A. G. Spalding Co., New York, Sternheimer Bros., Richmond, Va., and the Transcontinental and Western Air, Inc., Kansas City, Mo., a display of fliers' helmets was prepared showing the evolution of pilots' headgear from the old crash helmets of the early days to the uniform cap of the modern transport pilot.

The Beverly Hills (Calif.) Chamber of Commerce presented the parachute with which the flier Rodman Law made a demonstration jump from an airplane in 1912, one of the first instances of its kind. This accession provides the Museum with an example of the old "bundle" type of parachute, antedating the several pack types already exhibited.

Col. Charles A. Lindbergh added to his previous gift of the *Spirit of St. Louis* the maps and personal equipment that he carried during his Pan American flight of 1927–28. Much of this material was intended for emergency use in event of a forced landing in the jungles of Central America.

The largest single group of accessions in the section of mechanical technology was in the class of material relating to land transportation. The sole full-size vehicle added this year was a Columbia electric buggy of about 1903–6, the gift of Mrs. Sewell M. Johnson, Washington, D.C. This vehicle is a well-preserved example of the light electric automobile that in its day was so much more dependable than the unperfected gasoline automobile that it was the choice of conservative and professional people. Other automotive material included the steam engine built by the Mason Regulator Co. in 1897 for the first Stanley steam automobile; and a Stanley steam automobile engine of about 1923 from L. J. Hathaway, Cherrydale, Va.

The railroad and locomotive collection was enhanced by the addition of three models of English locomotives of about 25 years ago. They are the gift of Frank A. Wardlaw, Jr., Inspiration, Ariz., and Frank A. Wardlaw, New York City, and include the *Locomotive Greyhound* of the L. & N.W. Ry. Co., and the *Locomotive 146* of the F.C.O. Rr. (Argentine) of 1905, which were made by Mr. Wardlaw, Sr.; and the Caledonian Railroad Co.'s *Locomotive 903.* These locomotives exhibit many features foreign to American practice not heretofore shown in the collections. An unusual railroad item was a Japanese drawing in color of a Norris locomotive, tender, and car of 1853, the gift of C. P. Clausen, Washington, D.C. The Japanese date of the picture indicates that it was made about 1853 and consequently only a year or two after Commodore Perry negotiated the treaty with Japan. Miss Martha Hopkins, Damariscotta, Maine, presented an old single-ox yoke, a type of which not many are known to exist.

The watercraft collection received only one addition during the year—a nicely executed model of the champion ice yacht *Debutante III*, presented by John D. Buckstaff, Oshkosh, Wis., and Douglas Van Dyke, Milwaukee, Wis. The original is the present holder of the Stuart trophy and the world's record over a 20-mile triangular course.

In the class of electrical material the additions to the collection of incandescent lamps are of considerable interest. Frank A. Wardlaw, New York City, an associate of Thomas A. Edison, presented 2 originals of the Edison paper horseshoe filament lamp of 1879, 2 of the bamboo filament lamps of 1880, and an original wooden-screw socket for each type. The paper filament lamps, one of which is intact, are of the first type made after the successful experimental lamp of October 1879, and the bamboo filament lamps, one of which is intact, are the first commercial type. Donald F. Poole, Washington, D.C., presented two early Maxim lamps with sockets. A more modern note in electric lighting is represented in a display panel of eight rare gas discharge tubes, the gift of the Air Reduction Sales Co., New York City. Two fans received show early stages in the development of this electrical appliance. One, made by Leo Daft, electrical pioneer, and dating from before 1890, is the gift of Mrs. Matilda Daft Williams, Albany, N.Y. It is small, with an unguarded fan wheel mounted on the shaft of a small motor with long vertical field coils. The other is a Holtzer Cabot fan of about 1900, in which the earlier type of motor and same general arrangement are still evident though dressed up in a heavy cast-iron base and grilled housing. This fan is the gift of Mrs. Mae I. English and Mrs. L. F Speich, Washington, D.C.

A Merritt typewriter of about 1890, one of the first few machines made by the Merritt Typewriter Co., Springfield, Mass., and a commercial form of a machine formerly represented in the collection by a Patent Office model only, was the only addition to the typewriter collection. It was presented by C. C. Merritt, nephew of the inventor.

Two Edison phonographs were added to the collections. One, an original of the tin-foil record type, was presented by Frank A. Wardlaw; the other, a nicely preserved "Amberola-50" of about 1915, the gift of Clarence Beyer, Baltimore, Md., represents the final development of the wax-cylinder record type, and is complete with a group of select records.

Among the additions to the collection of surveying and astronomical instruments is the Herschelian reflecting telescope made by Amasa Holcomb, of Southwick, Mass., about 1835. The reflector, about 8 inches in diameter and having a focal length of about 9 feet, is of speculum metal and has a remarkably well preserved surface. It is the gift of Mrs. Grace E. Holcomb Steere and Mrs. Eva C. Holcomb Storey, Southwick, Mass., who also presented an astronomical transit and instrument tripod by the same maker. From the War Department came an interesting form of large reconnoitering telescope and an astronomical transit, both about 60 years old.

Among the watches added to the timekeeping collections is an English silver case watch dated 1794, the movement of which is marked "Effingham Embree, New York." Not many watches in the collection dating from 1800 carry the names of American makers or importers. It is the gift of Mrs. Gertrude O. S. Cleveland, Quinebaug, Conn. Clocks added to the collection include two tall case clocks of the early nineteenth century, one the gift of Mrs. Daniel Gardner, Newburgh, N.Y., the other of Mrs. James R. Van Horn, Washington, D. C. An early electric master-clock system, which was installed in the Arts and Industries Building when erected and which was removed during the past year, was added to the collection for its technical interest.

To the section of mineral technology the Carborundum Co., Niagara Falls, N.Y., gave a model of a carborundum grain sifter as an addition to the splendid models that the same company presented last year to show the processes of manufacture of carborundum abrasive products. A group of lathe tools made with "Firthite" alloy cutting edge inserts, a small piece of "Firthite", and a wire drawing die with a "Firthaloy" insert were added to the metallurgy exhibits by L. Gerald Firth, McKeesport, Pa. Philip McKenna, Latrobe, Pa., presented a lathe tool with a "Vascaloy" insert.

Textiles, organic chemistry, wood technology, foods, history of agriculture, and medicine.—Because of the increasing interest of the public in early American textiles, efforts were made to carry out the plans proposed in last year's report for special exhibitions of home handicrafts in textiles. Mrs. William S. Corby, Chevy Chase, Md., loaned for this purpose part of her collection of early American coverlets. These examples of a household industry, which began in Colonial days and continued until the Civil War, were collected in Virginia, Massachusetts, Pennsylvania, Indiana, Maryland, and Florida. Other coverlets for this exhibition were loaned by Capt. James A. Stader, Neosho, Mo., and C. H. Popenoe, Silver Spring, Md.

Beautiful examples of artistic needlework, made before the days of the sewing machine, were received as gifts as follows: From Mrs. Kate Vinson a silk applique quilt designed and made in Baltimore, Md., 1845, by the donor's mother; from Miss Isabelle M. Erwin and Miss Mildred A. Erwin a white quilted counterpane and a cotton patchwork quilt, pieced in "Irish Chain" pattern, both made in South Carolina in 1850; and from Mrs. Mary E. Lyddane linen samplers made in 1804 and 1833. Mrs. Laurence Stabler, Alexandria, Va., loaned two appliqued cotton quilts, one in "Tree of Life" design made in 1802, the other in 1830; and a small linen sampler worked in 1733. Mrs. Daniel Gardner added 27 miscellaneous textile articles. The Museum is indebted to Miss Susan P. Keech for a cotton coverlet, made of a monochrome copper cylinder print—the so-called "Toile de la Bastile"—which has been in the Keech family of Harford County, Md., for 70 years or more.

The Cotton-Textile Institute continued its valued cooperation by the presentation of two series of modern cotton fabrics produced by American manufacturers. Further additions to the display of seasonal cotton dress goods were made by Galey & Lord, who presented specimens of fancy weave cotton and rayon fabrics. The Celanese Corporation of America contributed a new series of examples of piece-dyed dress materials to replace the specimens presented last year. To the Flatau Fabrics Corporation the Museum is indebted for examples of warp-printed, novelty silk crepe fabrics, finished by a special process to give the material a sandy feel when handled. The cooperation of Sidney Blumenthal & Co. was continued by the gift of specimens of upholstery and drapery pile fabrics, cloaking and velvet dress fabrics, and a printed velour bathmat, these to replace some of the specimens contributed by this firm during the past 19 years.

The Armstrong Cork Co. presented a full series showing the manufacture of linoleum and suggestions for the interior decoration of different types of rooms; the Standard Textile Products Co. specimens illustrating the manufacture of wall and table oilcloth and uses to which these materials may be put; and M. J. Whittall Associates a series of specimens illustrating the manufacture of wool carpet yarns. The Universal Winding Co. sent examples of windings of bare and insulated wires for electrical purposes, which had been wound on winders of different types.

Through the courtesy of T. A. Keleher, a live exhibit of about 300 half-grown silkworms was set up in the textile hall. They were placed on shelves in a special glass case, where they were fed fresh mulberry leaves every few hours until the cocoons were spun, the first week of June.

Specimens of new rubber products and a historical series illustrating the development of rubber pneumatic tires from 1904 to the present time were contributed by the B. F. Goodrich Rubber Co. The United Shoe Machinery Corporation added to its exhibit a new series showing a recently perfected shoemaking method.

For the collections pertaining to agricultural history were received three models of the Cyrus Hall McCormick grain reaper constructed, one eighth size, according to the specifications of United States Patents Nos. 3895 and 5335, issued June 21, 1834, January 31, 1845, and October 23, 1847. The first was the gift of Secretary Abbot; the others of the McCormick Historical Association, which also presented three groups of documents, one relating to the development of two hillside plows, patented by Cyrus Hall McCormick in 1831 and 1833; one to the development of the reaper by Cyrus Hall McCormick; and one to a threshing machine invented by Robert McCormick in 1834.

An interesting specimen was received from Miss Anna Tiede in the form of a blank book of veneer cut from western white pine. The sheets were cut with a slicing knife, but, ingeniously, were not cut entirely through, just enough wood being left at the back to bind them. The sheets are not glued at any point.

Gerrit S. Miller, Jr., collected in Puerto Rico during March and April 1932 for the section of wood technology 74 woods from a region heretofore only scantily represented in the collection. These specimens are backed by herbarium material in the division of plants. The University of Poznan sent a set of 63 samples of the woods of Poland in exchange for a collection of woods of the United States. At the suggestion of Mr. Miller, E. N. Bancroft, surveyor general of Kingston, Jamaica, collected for the Museum wood samples of Jamaican trees, most of which are backed by herbarium material in the division of plants. Most of these are generous trunk sections.

Other woods received from various contributors for the study collection comprise single billets or trunk sections. One is a 17-inch section of the rare Chonta palm from Juan Fernandez Island off the coast of Chili, obtained by Dr. W. L. Schmitt. Prof. T. Jonson, of the Royal Swedish Forestry School, Stockholm, contributed a fine trunk section of European white birch from the demonstration forest of the College of Forestry at Garpenberg, Province of Dalarne, Sweden. In exchange for a study sample of *Ginkgo* wood sent to him in August 1932, F. K. Dalton sent a piece of the wood of kaikawaka, or New Zealand cedar, which burns very slowly and is used locally for fire doors and similar purposes. A piece of German oak cut from a dugout built on the Elbe between 800 and 900 A.D., and attesting the great durability of this species, was received from R. D. Hess as an exchange.

A collection of homeopathic pharmaceutical preparations, from Boericke & Tafel, arranged to illustrate the history and principles of homeopathy, was the largest gift received by the division of medicine during the year. The specimens included consist of pharmaceuticals of all kinds from the animal, mineral, and vegetable kingdoms. The division is indebted to Dr. F. B. Kilmer, of Johnson & Johnson, for the contribution of type specimens of the earliest antiseptic surgical dressings made on a commercial scale in the United States. The first type, carbolated gauze, introduced the new Listerian system of antiseptic dressings. The others illustrate improved forms of dressings with corrosive sublimate and boric acid as the medicinal agents.

The pharmacy collection was improved by the addition of considerable material, including a druggist's mortar contributed by Magnus, Mabee & Reynard, and a series of six photographic enlargements of murals depicting the progress of pharmacy, a gift of the Philadelphia College of Pharmacy and Science.

Accessions for the materia medica section included a gift of a set of photographs especially prepared by Eli Lilly & Co. to illustrate steps in the manufacture of insulin; a contribution of Merck & Co. of a series of cinchona alkaloids and alkaloidal salts; and donations of crude drugs by the United States Department of Agriculture, R. Hillier's Son Corporation, J. L. Hopkins & Co., S. B. Penick & Co., Peek & Velsor, and Johnson & Johnson.

Additions to the section of public health were: A group of models and a panel transferred from the United States Children's Bureau; a partial set of specially prepared placards and a series of strip films received from the Metropolitan Life Insurance Co.; and additional colored transparencies donated by the American Hospital Association.

Graphic arts.—The 51 accessions, 4 more than last year, totaled 1,433 specimens, of which the gifts, purchases, transfers, and deposits made a permanent addition to the collections of 482 specimens. The most important accession was 200 old etchings collected by J. Kay, London, in 1826. The lot contains prints by such famous artists as Rembrandt, Claude, Hollar, Cornelius, Bego, and Castiglione, and many by lesser artists, quite a few of which are of much better quality than those by the more famous etchers. Etchings and dry-points by American artists were received from Joseph C. Claghorn, Mrs. Sybilla M. Weber, and Robert Lawson.

In connection with the new installation of the photomechanical and substitute processes, the following accessions were obtained: Photographs of the inventors Frederic E. Ives, Max Levy, Louis E. Levy, and Karl Kletsch; 36 prints made by the Photogravure and Color Co., of New York, from 3 old photomechanical plates etched about 1860 by Fox Talbot. The Meriden Gravure Co. gave 18 specimens of their work in collotype, and 5 specimens of excellent European work were purchased and incorporated in the exhibit. The Laboratory Press of Carnegie Institute of Technology, Pittsburgh, presented 7 examples of the work being done in the school of printing, and 2 large highlight water-marked samples of paper were the gift of the Japan Paper Co.

Of the 26 accessions received by the section of photography during the year, the most important and valued was the gift of Mary O. Petrocelli, Brooklyn, N.Y., of 86 beautiful bromoil and resinotypia prints made by her late husband, Joseph Petrocelli, between 1921 and 1928. They are all suitably and effectively framed, and were presented in the hope that they would stimulate a desire to carry on this type of work, of which Mr. Petrocelli was a master.

An important addition to the motion-picture exhibit was a complete early Edison projection kinetoscope acquired from John P. Daniels, Crisfield, Md.

Three burnishers used by the late John F. Jarvis, Washington, D.C., the gift of Mr. Jarvis' daughters, Mrs. Mae I. English and Mrs. L. F. Speich, illustrate the development of this once useful article in photography. M. Schneckenberger, chief photographer for the Buffalo Museum of Science, Buffalo, N.Y., loaned two important cameras, one a Kodak No. 210 and the other an E. & H. T. Anthony No. 1025. Dr. Robert Taft gave a portrait of Hamilton H. Smith, the inventor of the tintype, which is a copy of a self-portrait (1889) printed on platinum paper of Smith's preparation.

A 35-mm moving-picture film, the gift of Geophysiches Institut, Prague, illustrates the copying of books in this compact form, each page being copied on one frame and projected onto a screen for study. Libraries are using this method to copy rare old books, thus to preserve the originals and make them available for others. Another film acquired from the Universal Talking Newsreel, New York, illustrates the method of locomotion of a walrus in the San Diego Zoo.

Mrs. Hazel Englebrecht, Des Moines, Iowa, specialist in X-ray photography, presented to the section 2 photographs of flowers and 9 negatives of various assorted subjects. DeLancey Gill, Alexandria, Va., for many years illustrator of the Bureau of American Ethnology, upon his retirement on June 30, 1932, gave the collection a Thornton Pickard shutter, a Triplex shutter, an old focusing glass, and a Watkins meter. Eugene Augustin Lauste, Bloomfield, N.J., pioneer inventor of sound and sight motion pictures, presented 22 photographic copies of his early inventions. Ida F. Arnold, Canton, Mass., presented a collection of 4 daguerreotypes, 4 ambrotypes, 2 tintypes, and 1 cabinet portrait.

Loeb collection of chemical types.—Miss Aida M. Doyle, of the section of organic chemistry, devoted 2 days a week to the Loeb collection of chemical types under the head curator's direction, and by the close of the year had made satisfactory progress toward completing a technical catalog of the collection, which now numbers 1,336 specimens.

INSTALLATION AND PRESERVATION OF COLLECTIONS

Engineering.—In the section of aeronautics the erection of the gondola and part of the envelop of the airship *Pilgrim* was the largest new installation. In addition, the collection of kites was installed in metal swinging frames and a complete series of illustrations portraying the evolution of the parachute was added. In mechanical technology the most popular new arrangement was the addition of a horse, harness, and liveried driver to the hansom cab presented last year by Mrs. James Parmelee. Mrs. Parmelee donated a nicely carved wooden horse, the original harness, and the driver's livery. The large tower-clock movement presented last year by the city of Frederick, Md., was installed at the level of the "clock gallery" on the top of a steel tower erected from the main floor, and will be operated during the coming year. The glass and metallurgy exhibits of the section of mineral technology were completely rearranged.

An attractive exhibit portraying the early work of Joseph Wharton in the development of nickel refining and manufacturing processes was installed.

Textiles, organic chemistry, wood technology, foods, and medicine.—In all, 35 installations of new material and 13 rearrangements or reinstallations of specimens received in previous years were made in the textile halls. In the section of organic chemistry 17 exhibits were dismantled and revised, replacing some specimens with new material of more recent manufacture. Three new installations were made in the section of foods. A new colony of bees was installed in the observation hive in the spring, the bees in the old colony having nearly all perished in the previous cold winter.

In wood technology a new cork exhibit was installed from material contributed by the Armstrong Cork Co., the walnut airplane propeller and accompanying parts, received in 1917 from the American Propeller & Manufacturing Co., were rearranged; and parts of the exhibit of the Hammermill Paper Co., illustrating the manufacture and use of sulphite wood pulp for writing papers, were revised. This year 203 woods were received, primarily for the study collection. Of these, 65 were of such size that they could be placed in the regular drawers with little or no cutting, 133 were cut to size and all duplicates put in storage, while 5 await seasoning. A total of 308 hand samples were prepared for the study collection, 2,087 duplicates for distribution and exchange, and 318 thin sections were made for the division of plants.

Important among the new or improved installations in the division of medicine are models illustrating various phases of child welfare; exhibits devoted to the portraying of general hygiene, preventive medicine, and vital statistics; the Arabian period of medical history; the history of pharmacy; the evolution of pharmacopoeias, dispensatories, and formularies; and improved insulin, surgical dressings, and crude drug exhibits.

Graphic arts.—Besides conducting 8 special exhibitions, the members of the staff of the division of graphic arts devoted 4½ months to the arrangement and installation of the photomechanical prints. Many of the early specimens are rare, and to insure their careful preservation they were covered with glass and bound with passe partout. This method, once started, made it necessary to cover all specimens in order to make the exhibition uniform. Nearly all the old material and much new was rematted and covered with glass.

INVESTIGATION AND RESEARCH

Dr. F. L. Lewton, curator of textiles, continued his botanical studies of certain undescribed plants related to the cottons; the assistant curator of wood technology, W. N. Watkins, carried on investigations of the utility of certain tropical Florida woods and gave special study to the anatomy of other species of woods; the assistant curator of medicine, Dr. Charles Whitebread, pursued his studies of Arabian medicine and the history of pharmacy; R. P. Tolman, curator of graphic arts, devoted some time to further research on the artist Malbone; and the assistant curator of engineering, Paul E. Garber, found time to give to his researches in aeronautical history.

Many individuals and industrial organizations made use of the department's collections during the year, some in connection with their studies on various phases of industrial and technologic history and transportation, involving in some cases the comparison of specimens in the collections with privately-owned objects, and others in connection with the preparation of historical exhibits for the Century of Progress Exposition in Chicago. Assistance of this sort was rendered also to a number of Federal agencies, including the United States Shipping Board, the Bureau of Public Roads, the Bureau of Navigation and Steamboat Inspection, and the Aeronautics Branch of the Department of Commerce. Much time too was required to comply with requests for the identification of specimens brought or sent in by individuals and Federal bureaus. Such assistance included identification of woods for the United States Bureau of Plant Industry, the National Committee on Wood Utilization, the Bureau of Standards, and the Bureau of American Ethnology. Seeds of foreign cottons were identified for the Division of Foreign Plant Introduction and rare drugs for the Division of Botany, United States Bureau of Plant Industry. In addition, many lots of material, such as paintings, sculpture, ship models, tools, textile fabrics, machinery, electrical and mechanical equipment, watches and clocks, and scientific apparatus, were identified and appraised.

DISTRIBUTION AND EXCHANGE OF SPECIMENS

The distributions from the department of arts and industries during the year aggregated 2,091 specimens, of which 39 were gifts in aid of education, 8 exchanges for material which has or will be received, and 1,595 loans for educational or research purposes. Also 449 specimens that had been temporarily in the department were returned to their owners.

NUMBER OF SPECIMENS UNDER DEPARTMENT

The number of specimens in the department was 115,467, assigned as follows:

Engineering	15, 025
Textiles	13, 754
Wood technology	8, 294
Organic chemistry and animal products	20, 108
Foods	1, 092
Agricultural history (estimated)	1, 202
Medicine	16, 622
Graphic arts, including photography	38, 034
Loeb collection of chemical types	1, 336
Total	115, 467

REPORT ON THE DIVISION OF HISTORY

(Theodore T. Belote, *Curator*)

In 1921 the division of history was removed from the department of anthropology and placed as a separate unit under the department of arts and industries, its report since 1925 for convenience having been combined with that of that department. With a reorganization during the present year, the division of history now renders a separate account of its activities.

The historical collections have been divided into the following units: Art, antiquarian, costume, military, naval, numismatic, and philatelic. These terms refer to the intrinsic character of the historical materials and indicate categories for the classification, installation, preservation, and future development of the immense mass of objects of various types now in the care of the division. The arrangement of the material in each of these groups has been greatly facilitated during recent years by the assignment of suitable exhibition and storage space in the Arts and Industries Building for the entire historical collections. Much of the time of the historical staff has been occupied with transferring materials from the Natural History Building to the Arts and Industries Building, but the rearrangement of all this material has not yet been completed.

ACCESSIONS FOR THE YEAR

Additions to the collections during the year were smaller in numbers than in recent years, chiefly because of lack of exhibition and storage space for new specimens of bulky size, the necessity of depending upon gifts for material that has become comparatively scarce and valuable, and the adoption of a high standard for material accepted. Specimens added numbered 5,537, or 519 less than for the previous year.

In the antiquarian collections several objects of special interest were added. One of these is a small compass in a leather case which was carried by William Clark during the Lewis and Clark expedition to the Pacific coast, 1804–6, and presented by Miss Mary McCabe. Another is a silver vase given to Maj. Gen. Silas Casey, when captain of the Second Infantry, United States Army, in recognition of his services during the War with Mexico. It was lent to the Museum by Miss Sophie Pearce Casey. Seven pieces of chinaware owned during the early part of the nineteenth century by President James Madison were presented by John H. Gray. Mrs. Daniel Gardner added 77 specimens of china, glass, and miscellaneous tableware to the antiquarian material presented by her in 1931.

An interesting collection of feminine wearing apparel of the latter part of the nineteenth century was donated by Mrs. Gertrude O. S. Cleveland. A frock coat and vest worn by William McKinley, prior to his election as President of the United States in 1896, were presented by George A. Troll.

A United States flag carried on the boat *Emma Dean* by Maj. J. W. Powell and his party during their exploring expedition down the Green and Colorado Rivers, 1871–72, was presented by Frederick S. Dellenbaugh.

Two military belt buckles of more than the usual historical importance were received. One of these, presented by Virginia B. Lewis and Emily B. Leaf, was owned during the War of 1812 by Maj. Gen. Jacob Brown. The other, a gift of B. F. O'Rourke, was worn by Thomas O'Rourke, Company E, Eighty-eighth New York Volunteers, during the Battle of Cold Harbor, Va., and bears on its surface a rifle bullet that was embedded in it during that engagement. The military collection was also increased by a saber carried during the Civil War by Lt. Thomas D. Jellico, One hundred and sixty-ninth New York Volunteer Infantry, presented by Mrs. Clara Jellico Bevers, and by a Spanish carbine and sword of the period of the Spanish-American War, presented by Mrs. Arthur Foraker. The Polish Government presented a series of uniforms and accessories of types now used in the Polish Army.

A number of relics of unusual historical interest relating to the career of Commodore Thomas Macdonough, added to the naval collection, include a gold watch owned by him; a silver pitcher and six goblets presented to him by the citizens of Lansingburg, N.Y., in commemoration of his victory on Lake Champlain, September 11, 1814; and a handsome gold-mounted sword, a scabbard, and belt presented to him by the crew of the U.S.S. *Guerriere*, July 8, 1819. These items were lent by Rodney Macdonough. A naval sword, received as a gift from Mrs. J. A. Starkweather, was owned during the early part of the nineteenth century by Dr. Thomas Williamson, United States Navy.

Among the additions to the numismatic collection was a Portuguese half-dobra gold piece struck in Brazil in 1761, presented by Phillip Elting. From the International Nickel Co. came a collection of 48 nickel coins illustrating the types of coins of this metal now circulating in Albania, Austria, Belgium, Ecuador, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Montenegro, Morocco, Poland, Siam, Switzerland, Turkey, and Vatican City. The United States Mint transferred two examples each of the gold, silver, and

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bronze coins struck in the Denver, Philadelphia, and San Francisco Mints during 1932.

Two bronze copies of the medal of award of the United States George Washington Bicentennial Commission, 1932, were presented by the commission. The directors of the French Mint presented an exceptionally artistic medal commemorating the tercentennial anniversary of the birth of Benedict Spinoza. A special collection of 186 British medals commemorating the exploits of Admiral Edward Vernon, R.N., during his expedition against the Spanish possessions in the Caribbean Sea, 1739–41, was lent for temporary exhibition by L. McCormick-Goodhart.

A number of additions were made to the collection of military decorations. From the War Department came two examples of the recently reestablished United States military decoration, the Purple Heart. From the New Mexico National Guard, through Maj. Frederick R. Lafferty, the Museum received two examples of the long-service medal and drill-attendance medal of the type awarded to members of that guard. Six military decorations and six exquisitely executed miniatures of these decorations, all owned during the World War by Maj. Gen. George M. Burr, were presented by Mrs. Lydia K. Burr.

The philatelic collections were increased by 3,971 specimens received from the Post Office Department, including examples of many United States and foreign commemorative stamps of more than the usual historical interest.

INSTALLATION AND PRESERVATION OF COLLECTIONS

The transfer of historical materials from the Natural History Building to the Arts and Industries Building has complicated the problem of adequate space and furniture, but the arrangement has been greatly improved by the transfer. The art material has offered the greatest difficulties, as it is difficult to arrange busts, portraits, and historic scenes in a satisfactory manner owing to the architectural features of the walls of the building. Part of the collection of busts is shown on the tops of wall cases.

The only series of paintings now shown with entire success is the Ferris collection of American historical subjects for which special alcoves were provided 2 years ago. This collection makes a splendid showing and harmonizes well with the costumes material exhibited in the same hall.

The antiquarian material has been united and now includes a fine series of china, glass, silverware, and furniture relating to the development of the American home from about 1750 to 1850. The pieces of greatest importance are those associated with noted personages of American history, and material of this character is given the most prominent location in the exhibition scheme. This section includes materials owned by George Washington, Thomas Jefferson, Alexander Hamilton, James Madison, and many other important figures in American history.

An exhibit of unusual historical interest installed during the year included examples of coins, tokens, and paper currency issued by local and State authorities and by private individuals and commercial firms in the United States from the Colonial period to the present time. Of equal importance are many examples of metal currency known as "tokens" that were produced in the United States during the financial panic of 1837 and during the Civil War. This special exhibit also included coins and currency made during the period of the Confederation prior to the establishment of the United States Mint and the first issue by that establishment of the official series of United States coins, which began in 1793.

The value of the philatelic material for exhibition purposes was greatly increased by the installation of a special series of electric fixtures, which not only light the cabinets but also the nearby wall cases containing the Richard Mansfield collection of historical theatrical costumes.

NUMBER OF SPECIMENS UNDER DIVISION

During the past year 5,537 specimens were received and 227 specimens were returned to the owners. The number of specimens included in each of the classes of materials assigned to the division is given below. The library material, which includes documents and publications of historical interest, has received few additions in recent years, as material of this character is no longer included in the field of work of the division.

Art	4, 546
Antiquarian	10, 996
Costumes	4, 090
Library	2, 225
Military	27, 488
Naval	2, 510
Numismatic	45, 802
Philatelic	391, 131
Total	488, 788

PUBLICATIONS ISSUED BY THE UNITED STATES NATIONAL MUSEUM DURING THE FISCAL YEAR 1932–33

REPORT

Report on the progress and condition of the United States National Museum for the year ended June 30, 1932.
8vo., pp. i–vi, 1–181, pl. 1.

PROCEEDINGS

Proceedings of the United States National Museum. Volume 79.
8vo., arts. 1–34, xvi+626 pp., 76 figs., 115 pls.

Proceedings of the United States National Museum. Volume 80.
8vo., arts. 1–23, xii+603 pp., 54 figs., 65 pls.

Proceedings of the United States National Museum. Volume 81.
8vo., arts. 1–18, xii+571 pp., 136 figs., 64 pls.

BULLETINS

No. 39, part N. Directions for preparing specimens of mammals. Sixth edition, revised. By Gerrit S. Miller, Jr.
8vo., pp. i–ii, 1–20, 5 figs.

No. 100, volume 12. Contributions to the biology of the Philippine Archipelago and adjacent regions: The fishes of the families Banjosidae, Lethrinidae, Sparidae, Girellidae, Kyphosidae, Oplegnathidae, Gerridae, Mullidae, Emmelichthyidae, Sciaenidae, Sillaginidae, Arripidae, and Enoplosidae collected by the United States Bureau of Fisheries steamer *Albatross*, chiefly in Philippine seas and adjacent waters. By Henry W. Fowler.
8vo., pp. i–vi, 1–465, 32 figs.

No. 158. The copepods of the Woods Hole region, Massachusetts. By Charles Branch Wilson.
8vo., pp. i–xix, 1–635, 316 figs., pls. 1–41 (colored frontispiece).

No. 163. American and European swords in the historical collections of the United States National Museum. By Theodore T. Belote.
8vo., pp. i–vii, 1–163, pls. 1–46.

No. 164. The Canadian and Ordovician formations and fossils of South Manchuria. By Riuji Endo.
8vo., pp. i–iii, 1–152, pls. 1–38 (including 5 folding maps).

PAPERS PUBLISHED IN SEPARATE FORM

FROM THE BULLETINS

From no. 100, volume 6. Contributions to the biology of the Philippine Archipelago and adjacent regions: Part 7, The Philippine land mollusks *Cochlostyla rufogaster* and *Obba marmorata* and their races. By Paul Bartsch.
8vo., pp. 329–342, pls. 83–86.

From the same: Part 8, The land shells of the genus *Obba* from Mindoro Province, Philippine Islands. By Paul Bartsch.
8vo., pp. 343–371, pls. 87–93.

FROM VOLUME 80 OF THE PROCEEDINGS

No. 2921. Insects of the order Orthoptera of the Pinchot expedition of 1929. By A. N. Caudell.
Art. 21, pp. 1-7.

No. 2923. Revision of the nearctic ichneumon-flies belonging to the genus *Macrocentrus*. By C. F. Muesebeck.
Art. 23, pp .1-55.

FROM VOLUME 81 OF THE PROCEEDINGS

No. 2925. Birds collected in Cuba and Haiti by the Parish-Smithsonian expedition of 1930. By Alexander Wetmore.
Art. 2, pp. 1-40, pls. 1-7.

No. 2927. The marine and fresh-water sponges of California. By M. W. de Laubenfels.
Art. 4, pp. 1-140, 79 figs.

No. 2928. A new trematode of the genus *Urotrema* from bats. By Joseph E. Alicata.
Art. 5, pp. 1-4, 1 fig.

No. 2929. A newly discovered West Indian mollusk faunula. By Paul Bartsch.
Art. 6, pp. 1-12, pls. 1-3.

No. 2930. Decorative designs on Elden Pueblo pottery, Flagstaff, Ariz. By Walter Hough.
Art. 7, pp. 1-11, 1 fig., pls. 1-10.

No. 2931. The fishes obtained by Lieut. H. C. Kellers, of the United States Naval Eclipse expedition of 1930, at Niuafoou Island, Tonga group, in Oceania. By Henry W. Fowler.
Art. 8, pp. 1-9, 3 figs.

No. 2934. The forms of the common Old World swallowtail butterfly (*Papilio machaon*) in North America, with descriptions of two new species. By Austin H. Clark.
Art. 11, pp. 1-15, pls. 1-8.

No. 2935. Report on the hexactinellid sponges collected by the United States Fisheries steamer *Albatross* in the northwestern Pacific during the summer of 1906. By Yaichiro Okada.
Art. 12, pp. 1-118, 16 figs., pls. 1-6.

No. 2936. The trematode parasites of marine mammals. By Emmett W. Price.
Art. 13, pp. 1-68, pls. 1-12.

No. 2937. Two new land shells of the genus *Bulimulus* from Bolivia. By William B. Marshall.
Art. 14, pp. 1-3, pl. 1.

No. 2938. A Miocene mollusk of the genus *Haliotis* from the Temblor Range, California. By W. P. Woodring.
Art. 15, pp. 1-4, pl. 1.

No. 2939. Notes on the helminth parasites of the opossum (*Didelphis virginiana*) in southeast Texas, with descriptions of four new species. By Asa C. Chandler.
Art. 16, pp. 1-15, 5 figs.

No. 2940. The helminths parasitic in the Amphibia and Reptilia of Houston, Tex., and vicinity. By Paul D. Harwood.
Art. 17, pp. 1-71, pls. 1-5.

No. 2941. On a newly mounted skeleton of *Diplodocus* in the United States National Museum. By Charles W. Gilmore.
Art. 18, pp. 1-21, 3 figs., pls. 1-6.

FROM VOLUME 82 OF THE PROCEEDINGS

No. 2942. A remarkable new genus and species of two-winged flies related to the Oestridae. By Charles H. T. Townsend.
Art. 1, pp. 1–4, 2 figs.

No. 2943. A new Paleocene mammal from a deep well in Louisiana. By George Gaylord Simpson.
Art. 2, pp. 1–4, 1 fig.

No. 2944. The Chinese lizards of the genus *Gekko*. By Leonhard Stejneger.
Art. 3, pp. 1–8.

No. 2945. Description of a tick, *Dermacentor halli*, from the Texas peccary, with a key to the North American species of *Dermacentor*. By Allen McIntosh.
Art. 4, pp. 1–6, 1 fig., pl. 1.

No. 2946. New fossil fresh-water mollusks from Ecuador. By William B. Marshall and Edgar O. Bowles.
Art. 5, pp. 1–7, pl. 1.

No. 2947. Two new nematodes, and notes on new findings of nematodes parasitic in Amphibia. By A. C. Walton.
Art. 6, pp. 1–5, 1 fig.

No. 2948. A fossil rhinoceros (*Diceratherium armatum* Marsh) from Gallatin County, Montana. By Horace Elmer Wood, 2d.
Art. 7, pp. 1–4, pls. 1–3.

No. 2949. New fresh-water gastropod mollusks of the genus *Chilina* of South America. By William B. Marshall.
Art. 8, pp. 1–6, pl. 1.

No. 2950. A new species of extinct turtle from the Upper Pliocene of Idaho. By Charles W. Gilmore.
Art. 9, pp. 1–7, 5 figs., pls. 1–3.

No. 2951. A collection of birds from Great Namaqualand, Southwest Africa. By Herbert Friedmann.
Art. 10, pp. 1–12, pl. 1.

No. 2952. Five new species of North American ichneumon-flies. By Frank D. DeGant.
Art. 11, pp. 1–6.

No. 2953. Fossil plants from the Aspen shale of southwestern Wyoming. By Roland W. Brown.
Art. 12, pp. 1–10, 2 figs., pls. 1, 2.

No. 2954. *Camptostroma*, a Lower Cambrian floating hydrozoan. By Rudolf Ruedemann.
Art. 13, pp. 1–8, 2 figs., pls. 1–4.

No. 2955. Descriptions of new ichneumon-flies with taxonomic notes. By R. A. Cushman.
Art. 14, pp. 1–16.

No. 2956. Description of two parasitic nematodes from the Texas peccary. By Benjamin Schwartz and Joseph E. Alicata.
Art. 16, pp. 1–6, 4 figs.

No. 2957. New termites from India. By Thomas E. Snyder.
Art. 16, pp. 1–15, 8 figs., pl. 1.

No. 2958. A new nematode from the rhea. By Everett E. Wehr.
Art. 17, pp. 1–5, 3 figs.

No. 2959. Synopsis of the calanoid crustaceans, exclusive of the Diaptomidae, found in fresh and brackish waters, chiefly of North America. By C. Dwight Marsh.

Art. 18, pp. 1-58, pls. 1-24.

No. 2960. West African snails of the family Achatinidae in the United States National Museum. By Henry A. Pilsbry.

Art. 19, pp. 1-6, pls. 1, 2.

No. 2961. Descriptions of new and imperfectly known species and genera of gobioid and pleuronectid fishes in the United States National Museum. By Isaac Ginsburg.

Art. 20, pp. 1-23, 3 figs.

No. 2962. *Crossochir koelzi:* A new California surf-fish of the family Embiotocidae. By Carl L. Hubbs.

Art. 21, pp. 1-9, pl. 1.

No. 2963. Pottery of the Hopewell type from Louisiana. By Frank M. Setzler

Art. 22, pp. 1-21, 6 figs., pls. 1-7.

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

FOR THE YEAR ENDING JUNE 30, 1933

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds of the Smithsonian Institution, together with a statement of the appropriations by Congress for the Government bureaus in the administrative charge of the Institution:

SMITHSONIAN ENDOWMENT FUND

The original bequest of James Smithson was £104,960, 8 shillings, 6 pence; $508,318.46. Refunds of money expended in prosecution of the claim, freights, insurance, etc., together with payment into the fund of the sum of £5,015 which had been withheld during the lifetime of Madame de la Batut, brought the fund to the amount of	$550, 000. 00
Since the original bequest the Institution has received gifts from various sources, chiefly in the years prior to 1893, the income from which may be used for the general work of the Institution. To these gifts has been added capital from savings on income, gain from sale of securities, etc., bringing the total endowment for general purposes to the amount of	1, 121, 938. 03

The Institution holds also a number of endowment gifts the income of each being restricted to specific use. These are invested and stand on the books of the Institution as follows:

Arthur, James, fund, income for investigations and study of sun and lecture on the sun	$46, 176. 01
Bacon, Virginia Purdy, fund, for a traveling scholarship to investigate fauna of countries other than the United States	57, 846. 04
Baird, Lucy H., fund, for creating a memorial to Secretary Baird	9, 492. 74
Barstow, Frederic D., fund, for purchase of animals for the Zoological Park	878. 26
Canfield Collection fund, for increase and care of the Canfield collection of minerals	44, 162. 63
Casey, Thomas L., fund, for maintenance of the Casey collection and promotion of researches relating to Coleoptera	8, 923. 05
Chamberlain, Francis Lea, fund, for increase and promotion of Isaac Lea collection of gems and mollusks	32, 513. 80
Hodgkins fund, specific, for increase and diffusion of more exact knowledge in regard to nature and properties of atmospheric air	100, 000. 00

Hughes, Bruce, fund, to found Hughes alcove	$17,492.15
Myer, Catherine Walden, fund, for purchase of first-class works of art for the use of and benefit of the National Gallery of Art	21,886.49
Pell, Cornelia Livingston, fund, for maintenance of Alfred Duane Pell collection	2,787.63
Poore, Lucy T. and George W., fund, for general use of the Institution when principal amounts to the sum of $250,000	63,642.83
Reid, Addison T., fund, for founding chair in biology in memory of Asher Tunis	25,725.75
Roebling fund, for care, improvement, and increase of Roebling collection of minerals	139,339.01
Rollins, Miriam and William, fund, for investigations in physics and chemistry	58,779.04
Springer, Frank, fund, for care, etc., of Springer collection and library	14,883.04
Walcott, Charles D. and Mary Vaux, research fund, for development of geological and paleontological studies and publishing results thereof	11,615.48
Younger, Helen Walcott, fund, held in trust	49,812.50
Zerbee, Frances Brincklé, fund, for endowment of aquaria	878.73
Total endowment for specific purposes other than Freer endowment	706,835.18

The capital funds of the Institution, except the Freer funds, are invested as follows:

	U.S. Treasury	Consolidated fund	Separate funds	Total
Arthur, James, fund		$46,176.01		$46,176.01
Bacon, Virginia Purdy, fund		57,846.04		57,846.04
Baird, Lucy H., fund		9,492.74		9,492.74
Barstow, Frederic D., fund		878.26		878.26
Canfield Collection, fund		44,162.63		44,162.63
Casey, Thomas L., fund		8,923.05		8,923.05
Chamberlain fund		32,513.80		32,513.80
Hodgkins (specific) fund	$100,000.00			100,000.00
Hughes, Bruce, fund		17,492.15		17,492.15
Myer, Catherine W., fund		21,886.49		21,886.49
Pell, Cornelia Livingston, fund		2,787.63		2,787.63
Poore, Lucy T. and George W., fund	26,670.00	36,972.83		63,642.83
Reid, Addison T., fund	11,000.00	14,725.75		25,725.75
Roebling Collection fund		139,339.01		139,339.01
Rollins, Miriam and William, fund		58,779.04		58,779.04
Smithsonian unrestricted funds:				
Avery fund	14,000.00	42,995.35		56,995.35
Endowment fund		172,494.45		172,494.45
Habel fund	500.00			500.00
Hackenberg fund		4,645.45		4,645.45
Hamilton fund	2,500.00	466.06		2,966.06
Henry fund		1,396.39		1,396.39
Hodgkins general fund	116,000.00	34,626.90		150,626.90
Parent fund	727,640.00	1,409.48		729,049.48
Rhees fund	590.00	546.19		1,136.19
Sanford fund	1,100.00	1,027.76		2,127.76
Springer fund			$14,883.04	14,883.04
Walcott, Charles D. and Mary Vaux, fund		11,615.48		11,615.48
Younger, Helen Walcott, fund			49,812.50	49,812.50
Zerbee, Frances Brincklé, fund		878.73		878.73
Total	1,000,000.00	764,077.67	64,695.54	1,828,773.21

FREER GALLERY OF ART FUND

Early in 1906, by deed of gift, Charles L. Freer, of Detroit, gave to the Institution his collection of Chinese and other oriental objects of art, as well as paintings, etchings, and other works of art by Whistler, Thayer, Dewing, and other artists. Later he also gave funds for the construction of a building to house the collection, and finally, in his will, probated November 6, 1919, he provided stock and securities to the estimated value of $1,958,591.42 as an endowment fund for the operation of the gallery. From the above date to the present time these funds have been increased by stock dividends, savings of income, etc., to a total of $4,736,907.59. In view of the importance and special nature of the gift and the requirements of the testator in respect to it, all Freer funds are kept separate from the other funds of the Institution, and the accounting in respect to them is stated separately.

The invested funds of the Freer bequest are classified as follows:

Court and grounds fund	$530, 719. 72
Court and grounds maintenance fund	133, 392. 99
Curator fund	540, 030. 57
Residuary legacy	3, 532, 764. 31
Total	4, 736, 907. 59

SUMMARY

Invested endowment for general purposes	$1, 121, 938. 03
Invested endowment for specific purposes other than Freer endowment	706, 835. 18
Total invested endowment other than Freer endowment	1, 828, 773. 21
Freer invested endowment for specific purposes	4, 736, 907. 59
Total invested endowment for all purposes	6, 565, 680. 80

CLASSIFICATION OF INVESTMENTS

Deposited in the United States Treasury at 6 percent per annum as authorized in the U. S. Revised Statutes, sec. 5591		$1, 000, 000. 00
Investments other than Freer endowment (cost or market value at date acquired):		
Bonds (20 different groups)	$368, 873. 41	
Stocks (36 different groups)	430, 252. 66	
Real estate first-mortgage notes	16, 750. 00	
Uninvested capital	12, 897. 14	
		828, 773. 21
Total investments other than Freer endowment		1, 828, 773. 21
Investments of Freer endowment (cost or market value at date acquired):		
Bonds (48 different groups)	$2, 275, 487. 44	
Stocks (37 different groups)	2, 371, 085. 15	
Real estate first-mortgage notes	58, 500. 00	
Uninvested capital	31, 835. 00	
		4, 736, 907. 59
Total investments		**6, 565, 680. 80**

CASH BALANCES, RECEIPTS, AND DISBURSEMENTS DURING THE FISCAL YEAR [1]

Cash balance on hand June 30, 1932		$250, 270. 59
Receipts:		
Cash income from various sources for genera work of the institution	$67, 978. 99	
Cash gifts expendable for special scientific objects (not to be invested)	124, 500. 00	
Cash received as royalties from sales of Smithsonian Scientific Series	2, 500. 00	
Cash income from endowments for specific use other than Freer endowments and from miscellaneous sources (including refund of temporary advances)	58, 373. 59	
Cash capital from sale, call of securities, etc. (to be reinvested)	226, 107. 44	
Total receipts other than Freer endowment		479, 460. 02
Cash receipts from Freer endowment, income from investments, etc	217, 437. 92	
Cash capital from sale, call of securities, etc. (to be reinvested)	1, 190, 648. 13	
		1, 408, 086. 05
Total		2, 137, 816. 66
Disbursements:		
From funds for general work of the Institution:		
Buildings, care, repairs and alterations	$2, 013. 48	
Furniture and fixtures	58. 20	
General administration [2]	24, 384. 37	
Library	1, 882. 75	
Publications (comprising preparation, printing, and distribution)	9, 771. 57	
Researches and explorations	10, 605. 94	
International exchanges	3, 903. 48	
		52, 619. 79
From funds for specific use, other than Freer endowment:		
Investments made from gifts, from gain from sales, etc., of securities and from savings on income	117, 601. 49	
Other expenditures, consisting largely of research work, travel, increase and care of special collections, etc., from income of endowment funds and from cash gifts for specific use (including temporary advances)	161, 978. 87	
Reinvestment of cash capital from sale, call of securities, etc	214, 539. 95	
		494, 120. 31

[1] This statement does not include Government appropriations under the administrative charge of the Institution.

[2] This includes salaries of the Secretary and certain others.

CASH BALANCES, RECEIPTS, AND DISBURSEMENTS DURING THE FISCAL YEAR—continued

Disbursements—Continued.		
From Freer endowment:		
Operating expenses of the gallery, salaries, field expenses, etc	$57,896.01	
Purchases of art objects	166,548.77	
Investments made from gain from sale, etc., of securities and from income	7,525.90	
Reinvestment of cash capital, from sale, call of securities, etc	1,175,697.63	
		$1,407,668.31
Cash balance June 30, 1933		183,408.25
Total		2,137,816.66

EXPENDITURES FOR RESEARCHES IN PURE SCIENCE, EXPLORATIONS, CARE, INCREASE, AND STUDY OF COLLECTIONS, ETC.

Expenditures from general endowment:		
Publications	$9,771.57	
Researches and explorations	20,645.32	
		$30,416.89
Expenditures from funds devoted to specific purposes:		
Researches and explorations	121,629.71	
Care, increase, and study of special collections	15,743.11	
Publications	2,117.28	
		139,490.10
Total		169,906.99

The practice of depositing on time in local trust companies and banks such revenues as may be spared temporarily has been continued during the past year, and interest on these deposits has amounted to $2,020.04.

The Institution gratefully acknowledges gifts or bequests from the following:

Dr. Adolph M. Hanson, income from certain royalties for conducting scientific work of the Institution.

Mr. Eldridge R. Johnson, for deep-sea and other oceanographic explorations.

Research Corporation, for further contributions for researches in radiation.

Mr. John A. Roebling, for further contributions for researches in radiation.

Mrs. Mary Vaux Walcott, for purchase of Indian sand paintings.

All payments are made by check, signed by the Secretary of the Institution, on the Treasurer of the United States, and all revenues are deposited to the credit of the same account. In many instances deposits are placed in bank for convenience of collection and later are withdrawn in round amounts and deposited in the Treasury.

The foregoing report relates only to the private funds of the Institution.

The following appropriations were made by Congress for the Government bureaus under the administrative charge of the Smithsonian Institution for the fiscal year 1933.

Salaries and expenses		$38, 644
Gellatly Art collection		17, 500
International exchanges		47, 529
American ethnology		66, 640
International Catalog of Scientific Literature		5, 650
Astrophysical Observatory		32, 094
National Museum:		
Maintenance and operation	$148, 370	
Preservation of collections	617, 760	
		766, 130
National Gallery of Art		38, 220
National Zoological Park		228, 880
Printing and binding		62, 422
Total		1, 303, 709

There was also an allotment of $12,500 made by the United States Commission of the Chicago World's Fair Centennial Celebration for participation by the Smithsonian Institution in "A Century of Progress."

The report of the audit of the Smithsonian private funds is printed below:

October 4, 1933.

Executive Committee, Board of Regents,
Smithsonian Institution, Washington, D.C.

Sirs: Pursuant to agreement we have audited the accounts of the Smithsonian Institution for the fiscal year ended June 30, 1933, and certify the balance of cash on hand June 30, 1933, to be $185,308.25.

We have verified the record of receipts and disbursements maintained by the Institution and the agreement of the book balances with the bank balances.

We have examined all the securities in the custody of the Institution and in the custody of the banks and found them to agree with the book records.

We have compared the stated income of such securities with the receipts of record and found them in agreement therewith.

We have examined all vouchers covering disbursements for account of the Institution during the fiscal year ended June 30, 1933, together with the authority therefor, and have compared them with the Institution's record of expenditures and found them to agree.

We have examined and verified the accounts of the Institution with each trust fund.

We found the books of account and records well and accurately kept and the securities conveniently filed and securely cared for.

All information requested by your auditors was promptly and courteously furnished.

We certify the balance sheet, in our opinion, correctly presents the financial condition of the Institution as at June 30, 1933.

William L. Yaeger & Co.
William L. Yaeger,
Certified Public Accountant.

Respectfully submitted.

Frederic A. Delano,
R. Walton Moore,
John C. Merriam,
Executive Committee.

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1933

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, during the greater part of its history, this purpose has been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880, induced in part by the discontinuance of an annual summary of progress which for 30 years previously had been issued by well-known private publishing firms, the secretary had a series of abstracts prepared by competent collaborators, 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 1933.

HOW THE SUN WARMS THE EARTH [1]

By C. G. Abbot
Secretary, Smithsonian Institution

[With 6 plates]

James Arthur in 1931 bequeathed a considerable sum to the Smithsonian Institution for the study of the sun. A condition of the gift directed that each year a lecture should be given on some phase of our knowledge of the sun either by a member of the Institution's staff or by some other competent person. The first Arthur lecture was given 2 years ago by Dr. Henry Norris Russell, who discussed the sun's chemical and physical composition. Last year, Dr. Ernest William Brown, in the second Arthur lecture, treated of the sun's gravitational control of the solar system. In this third Arthur lecture I propose to give some account of the sun's radiation, whereby the earth is kept at a habitable temperature.

HEAT EXCHANGE BY RADIATION

Experiment: Here I have a lamp which I can heat more and more by electric current until, as you see, it glows brightly. At the other side of the stage, too far away for direct heating by the lamp, is a concave mirror which forms an image of the lamp upon a sen-

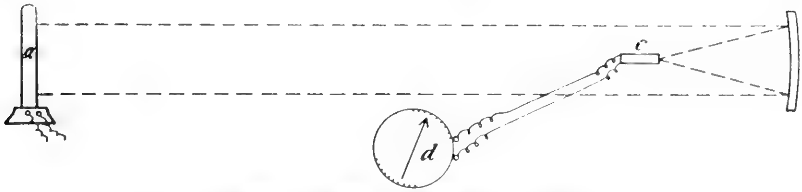


Figure 1.—Heat exchange by radiation.

The lamp, *a*, heated by electricity, sends rays to the concave mirror, *b*, which focuses them on the thermopile, *c*, whose warming is indicated by the galvanometer, *d*.

sitive electrical thermometer called a thermopile (fig 1). That you may all observe its behavior, I record the indications of the electrical thermometer on the screen. Please observe this little spot of

[1] The third Arthur lecture, delivered at the Smithsonian Institution on Feb. 26, 1934.

light upon the scale of the instrument. Now I warm the lamp as before. See the spot of light move. To convince you that rays from the warmed lamp are actually crossing the stage and warming the electrical thermometer by being focused upon it, I insert this card so as to hide the lamp from the focusing mirror. The spot of light immediately falls back. I remove the card. It leaps forward. All this time the lamp, though warmed, has been too cool to glow. But now I heat it to a glowing temperature, as you see. Note how very much wider now is the swing of the recording light spot as again I insert the card.

RAYS MAY TRAVEL IN A VACUUM

Thus we see that not only visible rays from very hot sources, but invisible rays from bodies too cool to glow, are able to cross wide spaces and to produce heat when they are absorbed by blackened receiving surfaces like that of this electrical thermometer. In our experiment the space traversed by the rays was filled with air. That was a hindrance, not a help, to the passage of these rays. They will cross a vacuum even more freely than they will pass through air. When we say that a radio program is "on the air", it is true that the air fills the space between the broadcaster and the listener, but it is not the air that carries the waves. Just as sunlight comes to us across a 92,000,000-mile vacuum, radio rays can also travel in vacuum. They do not employ the air for their conveyance. The nature of the medium that carries light and radio rays is still obscure, but we know that it is not the air.

THE SUN IS THE EARTH'S HEAT SOURCE

The sun's rays are almost the sole source of the heat that warms our earth. They cross the void of space to us just as the rays from the lamp crossed this stage. It requires 8 minutes for the sun's rays to reach the earth, traveling 186,000 miles each second. We noted that the electrical thermometer, when radiated upon by the hot lamp, warmed up to a certain degree of temperature and then stayed constant. The earth, wherever the sun's rays strike it, also tends to warm up. Its temperature would stay constant as the thermopile did when thus warmed, if conditions on the earth remained unchanged. But clouds may form and obscure the sun, dust or smoke frequently intervenes and, most important of all, the earth rotates a complete turn every day. No spot on earth stays fixed underneath the sun beam long enough to come to a constant temperature. The earth is about 8,000 miles in diameter, and 25,000 miles in circumference. Hence at the equator its surface passes under the solar beam about 1,000 miles each hour.

INFLUENCE OF OBLIQUITY

The effect of sun rays in producing heat must always depend on the obliquity of the receiving surface to the rays received. Figure 2 illustrates this point. The rays whose front have the width *ab* must

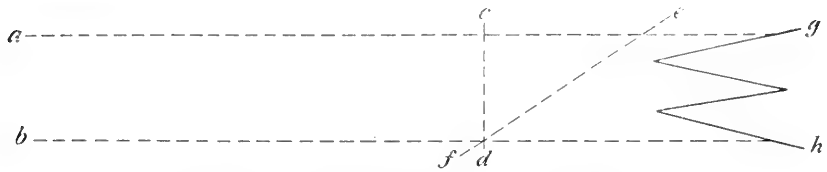


FIGURE 2.—Influence of obliquity by radiation.

evidently produce a greater intensity of heating effect on the surface *cd* at right angles to the beam than on the surfaces *ef* or *gh*, where the same amount of radiation is spread over large areas. Experiment: I can illustrate this readily. (See fig. 1.) Note how the warmth of the thermopile, as measured on the screen, diminishes when I rotate it gradually from being at right angles until it reaches parallelism with the rays it receives from the heated lamp. Let us apply this principle of response to obliquity to our thought of the warming of the earth by sun rays. We see, as in figure 3, that

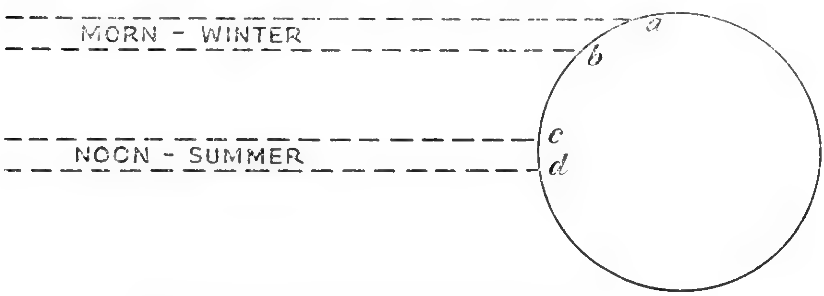


FIGURE 3.—Solar heating of the earth influenced by obliquity.

the intensity of the solar heating is greatest at noon and greatest in summer, because at these times the obliquity is least. This is the reason why, in the United States, July is warmer than January, even though the sun is 3,000,000 miles farther away in July than it is in January. Returning to consideration of the effect of rapid rotation in preventing the surface of the earth from attaining constancy of temperature under solar heating, we now see that, owing to change of obliquity of solar rays, the intensity of the earth's heating continually changes from morning to night. Darting along at 1,000 miles per hour, three times as fast as a racing airplane, the earth's surface never has time to reach a constant temperature under solar heating.

COMPARISON OF THE SOLAR HEATING OF THE EARTH AND THE MOON

On the moon things do not change so rapidly. The moon has no atmosphere, hence no clouds, smoke, or dust. (See pl. 1.) Instead of rotating in 24 hours like our earth, the moon rotates only once in 27¼ days. Being little more than 2,000 miles in diameter, its circumference is less than 7,000 miles. Hence the moon's surface passes under the sun's rays only about 10 miles per hour. Thus there is opportunity for the moon's illuminated surface to warm up to a practically constant temperature. At the center of the moon's bright face its temperature is found to be 250° F., which is about 40° F. above that of boiling water. Compare this with the earth. Even at the Equator there are few stations where the weather records report temperatures above 112° F., which is 100° below the boiling temperature. This is the case even though the sun sends rays equally as intense to the earth as to the moon. The difference in maximum temperatures reached by the two bodies depends partly on the rapid rotation of the earth and partly on its possession of an atmosphere.

ATMOSPHERIC INFLUENCE ON PLANETARY TEMPERATURE

Not only do clouds, dust, and smoke produce their effects, but our atmosphere is a sort of ray trap. On cloudless days, sun rays can pass through it readily. They lose only about one-fourth of their heat before reaching the earth. It is not so with the long-wave rays sent outwards by our earth's surface. About three-fourths of them are restrained by the atmosphere. Hence, like a blanket upon a sleeper, the atmosphere must itself be warmed through before the earth's heat given up to the atmosphere by long-wave radiation and by contact can escape to space. With such an effective blanket keeping the earth warm, it is not surprising that at night, when the solar heating is all cut off, the earth's temperature does not fall as much as that of the moon. Those who have been on high mountains, or in parched deserts, where the atmospheric blanket is so dry as to be less efficient than it is here in the East, know how much more and how much quicker the night air cools than it does near the sea. Indeed, one shivers even in daytime on a high desert mountain the moment he steps into the shade. The following figures [a slide on the screen] exhibit this phenomenon for two places of nearly the same latitude near the Equator and for the moon.

Average range of temperatures between day and night

Port au Prince, Haiti	12° F.
Timbuktu, in the Sahara Desert	27° F.
On Mars	100° F.
On the moon	500° F.

IMMENSITY OF SOLAR RADIATION

I despair of giving you a vivid idea of the immensity of the sun's heat and of the quantity of energy it continually emits. Experiment: I turn on for an instant a 1,000-candlepower Mazda lamp. It seems blindingly bright. But the sun's surface for equal areas emits about five times as blinding a beam as this lamp does, and the area of the sun's surface is about 8 billions of trillions (8×10^{21}) times that of the lamp filament. Plateau, a Belgian physicist, wished to study the after images left within his eyes by a bright light. Looking steadily at the sun for 20 seconds, he lost his sight completely.

Dr. S. P. Langley describes how he made an experiment to compare the rays of the molten steel poured from the Bessemer converter with those of the sun. Into the enormous converter pot there streamed first some 15,000 pounds of molten iron loaded with half a ton of silicon and carbon. Then a blast of air was forced up through the glowing mass, and the chemical action set up a heat which so far surpassed mere iron-melting temperature that when another 15,000 pounds of molten iron was added it looked like chocolate poured into a white cup. The cataract of liquid steel was then discharged, shooting showers of scintillations that seemed sunlike in their brillancy, and spattering the surroundings for a hundred feet with little shooting stars. But there was nothing really sunlike at all in this fierce glare. For when Langley exposed an apparatus which took a balance between the brightness of the surface of the steel and an equal surface of the sun, the sun was found to send out at least 87 times as intense radiation, square foot against square foot, as the dazzling steel. This applies to the total rays, whether visible to the eye or not. But for the light rays only, the sun proved intrinsically not less than 5,000 times the stronger source. And this was near Pittsburgh, where the sun's rays had already lost over half their intensity in the murk of the atmosphere.

SUN RAYS EMITTED IN ALL DIRECTIONS

Some people, possibly of Scotch ancestry, reluctant to contemplate a pitiable waste of good things, have supposed that the sun does not send its rays in every direction, but only in those directions where there lie objects to be shined upon, such as the earth or the planets. This is not true. The sun shines nearly equally in every direction, and for aught we know the rays it is sending out at this instant, if they hit nothing, may go on and on for a million years or even forever, covering 186,000 miles on their journey every single second that they travel. This thesis is proved by the observed fact that the intensity of the sun's rays falls off as the square of its distance increases. Our experiments have proved it by observing the change in solar radiation intensity between perihelion and aphelion of the earth.

TOTAL OUTPUT OF SOLAR RADIATION

How much energy does the sun lose in this prodigal way? Every year it loses heat equivalent to 400 billions of trillions (4×10^{23}) of tons of anthracite coal. Of this prodigious amount the earth intercepts the equivalent of 200 trillions of tons. Compared merely with the small part of solar radiation intercepted by the earth, the total yearly consumption of coal for heat, light, and power in the United States is trifling—only 500 millions of tons.

SOLAR POWER

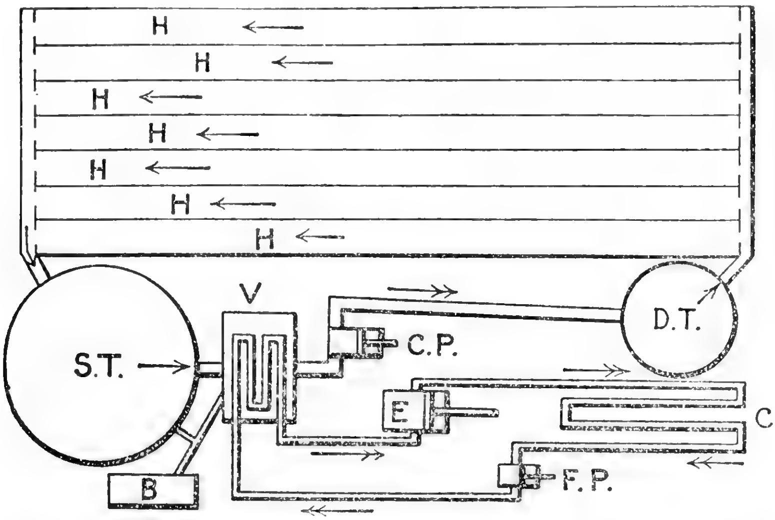
This leads to the inquiry why we depend on coal, oil, and waterfalls for power, when the sun is furnishing to the earth so incomparably much more energy free, gratis, for nothing. There are two reasons. First, clouds and night interrupt the continuity of the supply, and cut it off just at those times when we most need power. Even during the day the rays alter very much in their intensity because they shine through great thicknesses of the atmosphere in the early morning and the late afternoon. Night also varies greatly in length between summer and winter in temperate zones where the most power is used. Unfortunately, night is longest in winter, when we need most power. Second, though sun rays cost nothing to produce, they cost much to capture. If their energy could be fully utilized it would require only about a square yard for 1 horsepower. But the losses unavoidable in using sun rays for power will demand provision of at least 4 and probably 10 square yards per horsepower. In fact, no solar-power plants thus far have reached such efficiency. To install apparatus over 10,000 square yards to obtain 1,000 horsepower, or over 10,000,000 square yards to match Niagara may well give engineers pause.

Nevertheless, solar power may not be hopeless. Two of the most successful solar-power installations made thus far are those of Boyle and Willsie [2] at Needles, Calif., about 1908, and that of the Sun Power Co. (Eastern Hemisphere) Ltd., at Meadi, near Cairo, in Egypt, in the year 1913. These two installations illustrate two contrasting types. In the first the inventors avoided expensive equipment by contenting themselves with a small temperature rise and therefore with low efficiency. The heater consisted of a shallow wooden basin coated with asphalt and divided by strips into troughs. It was covered by layers of window glass and insulated at the sides

[2] Engineering News, May 13, 1909.

and bottom by double air spaces. Each trough of the heater formed a compartment. (The following six paragraphs are taken from the paper cited in footnote 2.)

The heater in the fourth plant was in two sections, separated by a footpath. The first section was covered by one layer of glass and the second section with two layers. Both sections were inclined. The



Water from the distributing tank D. T. after flowing through the glass-covered troughs H.H.H. absorbing solar heat is stored in the storage tank S. T. This hot water gives up its heat in the vaporizer V and is sent back by the circulating pump C. P. to the distributing tank. Single-headed arrows indicate the flow of the water. Emergency steam boiler, B, for cloudy periods.

Sulphur dioxide flows in the direction of the double-headed arrows from the vaporizer coils to the engine E. The exhaust vapor goes to the condenser C. The liquid sulphur dioxide is returned by the feed pump F. P. to the vaporizer.

In practice the distributing tank is small; the storage tank S. T. holding both the hot and cold water.

FIGURE 4.—Diagrammatic plan of Willsie sun-power plant.

heat-collecting liquid ran from the first section into the second section, at a temperature of about 150° F., and from the second section into the storage tank at about 180° F. These temperatures varied with the time of day, wind, cloudiness, and other weather conditions, and especially with the amount of liquid flowing through the heater.

The solar-heated water was stored in a tank, insulated to prevent the loss of heat by radiation. The heated water was then drawn uniformly and continuously from the storage tank and made to give up its heat by circulating it about a boiler or heat exchanger containing some volatile liquid, such as ammonia or sulphur dioxide. The vapor generated by this heat, after operating an engine, was condensed and returned to the boiler to be used again. The water, after giving up its heat to the sulphur dioxide, was sent out through the solar heater to collect again the heat in the sun's rays. Theoretically, the plan meets all the requirements for the transformation of solar heat into continuous, uniform power (fig. 4).

The sulphur dioxide engine used in this experiment was a vertical automatic cut-off, which at times, with a boiler pressure of 215 pounds, probably developed 15 horsepower. The two heater sections exposed an area of about 1,000 square feet to the sun, but as the heat was taken from storage and not directly from the heater, it is not fair to assume the above proportion of heater surface to horsepower developed.

The condenser consisted of 6 stacks of horizontal pipes, 12 pipes to the stack. The cooling water, pumped from a well 43 feet deep, had a temperature of 75° F. Only enough water was allowed to drip over the pipes to keep them wet, and so great was the evaporation in the dry desert breeze that the cooling water left the lower pipes at 64°. By using the cooling water over and over, the condenser gave very satisfactory results. A shade of arrow weed, a straight willowlike shrub abundant along the Colorado River, kept the sunshine from the condenser pipes and permitted a good air circulation.

At times the storage valve would be opened after dark, allowing the solar-heated liquid to flow over the exchanger pipes and thus start up the engine. Up to the year 1910 this was probably the first sun-power plant that was ever operated at night with solar heat collected during the day, and it came nearer than any other plant to the commercial utilization of solar heat for power purposes; it was also the largest sun-power plant of which there was any record.

From the foregoing, the cost of installing a sun-power plant may be estimated:

Heater, 24-hour size	per horsepower	$100.00
Storage, 100-hour size	do	10.00
Engine, pumps, etc	do	20.00
Vaporizer	do	15.00
Condenser	do	15.00
Liquid sulphur dioxide		1.25
Emergency steam boiler		2.75
Total		164.00

At that time the costs of steam-power plants were said to range from $40 to $90 per horsepower. The cost of a Willsie sun-power plant was accordingly from two to four times that of a steam plant, and the interest and depreciation on this excess of cost would offset in some measure the saving of fuel.

In the Egyptian solar-power plant (pl. 2), fairly high temperatures and fairly high efficiency were obtained by concentrating solar rays by a battery of cylindric mirrors onto a system of connecting boiler tubes. In order to follow the sun's daily march through the heavens, the mirrors were rotated from east to west each day at such a rate as to keep the sun rays in focus upon the boiler tubes. The total area of sunshine collected was 13,269 square feet. Each channel-shaped reflector and its boiler was 205 feet long, and there were five such sections placed side by side. The concentration was 4½ to 1. The maximum quantity of steam produced was 12 pounds per 100 square feet of sunshine, equivalent to 183 square feet per brake horsepower, and the maximum thermal efficiency was 40.1 percent. On August 22, 1913, the average power for the 5 hour's run was 59.4 brake horsepower per acre, and the maximum and minimum power on that day were 63 and 52.4 brake horsepower per acre, respectively.

The engineer, Mr. Ackermann, remarks:

> The problem of the utilization of solar energy is well worthy of the attention of engineers, for even now it is very nearly a solved problem where there is plenty of sunshine and coal costs £3 10s. a ton. It is fortunate that where coal is dear, sunshine is often plentiful, and it is to be remembered that coal will gradually get dearer while the cost of manufacture of sun-power plants should decrease. Sun-power plants are admirably suitable for pumping in connection with irrigation, for where there is most sunshine there is need for most irrigation, and the slight variation in the quantity of water pumped throughout the day does not matter. Also, when temporarily there is no sunshine (due to clouds), probably little or no irrigation is required.

A SOLAR COOKER

I have myself dabbled in the enticing solar-power field. As an introductory experiment I designed and constructed a solar cooker on Mount Wilson, Calif. In my experiments I desired to store the heat in a suitable reservoir at such a temperature as would permit all the usual cooking operations, such as stewing, preserving, boiling and baking of meats, and even including the baking of bread, to be carried on for some time after the cutting off of sunlight.

As the most convenient way to combine a solar-heat collector with a suitable high-temperature reservoir, it seemed best to concentrate the solar rays upon a metal tube communicating to a reservoir at some distance above the collector. The scheme is exactly that of a household water heater, merely substituting concentrated sun rays for a fire as the source of heat. In this way, the hot fluid, expanding, rises by the differential action of gravity into the top of the reservoir, while the cooler fluid at the bottom of it flows downward to the heat source in replacement. A continuous circulation of hot fluid would thus maintain the temperature of the reservoir. Water, the cheapest liquid, could not be used in the cooker unless under such pressure as would introduce a costly and dangerous element. Temperatures approaching 200° C. were desired, and if water were used, steam pressures of nearly 15 atmospheres would prevail. Instead of water, therefore, engine-cylinder oil was preferred. This fluid can be heated to temperatures somewhat above 200° C. without boiling, flashing, or strongly evaporating.

I chose the cylindrical reflector of parabolic cross-section for the purpose of collecting and focusing the solar rays. A cylindrical reflector does not require, like a conical one, motions about two axes in order to follow the sun. If the cylindrical mirror is mounted upon an axis parallel to the earth's axis, a rotation from east toward west at the same rate as the earth's daily rotation from west toward east is all that is required. To be sure, the full aperture of the mirror is attained only at the dates of the equinoxes. Yet if the mirror is made rather long from north to south, compared to its width from east to west, this loss is trifling, even in June and December.

The mirror is made 12½ feet long and 7½ feet wide, and is mounted with its long dimension parallel to an axis pointing toward the North Star. For rigidity and cheapness the mirror was framed on five sections of structural steel.

But how should it become a brightly reflecting mirror? This was accomplished by using sheets of glossy rolled aluminum, thick enough to preserve their shape when screwed to the steel. They added very little to the weight of the mirror and were found to reflect about 75 percent of the total solar radiation. Experience shows that aluminum sheets retain their highly reflecting surface for several years if kept dry. Later "Allegheny metal", or stainless steel, was used.

Having thus made a light, rigid, parabolic cylindrical mirror, the next care was to mount it free to turn about an axis parallel to the earth's. It was necessary to provide a driving mechanism to cause the mirror to follow the apparent daily march of the sun from east to west. Much expense might have been lavished on this part, for the combination of an astronomical driving clock and worm-and-wheel mechanism, usually employed by astronomers to drive telescopes of a similar size, often costs hundreds of dollars. A very inexpensive device was used for the mirror of the cooker. A little alarm clock was made master of the situation. It gave a signal which at each 5 minutes allowed the machinery to run. The machinery ran a little too fast, and after a short run was held back for about a minute, awaiting the next pleasure of the little master clock. The whole driving outfit required an outlay of about $15 and 3 days' work. It has operated perfectly satisfactorily for about 8 hours a day through several summers.

The reservoir, 20 by 24 by 36 inches, was made of steel, with welded corners. Two ovens, each 9 by 11 by 16½ inches, were let in at the back. The reservoir stands on a platform about 6 feet above the top end of the mirror. To conduct the heated oil, there is a copper pipe 1¼ inches in diameter, bent so as to pass from the reservoir down under the mirror, returning in the focus of the sun rays through the hollow trunnions.

The reservoir and pipes are protected from loss of heat by brick-work composed of diatomaceous earth. Such bricks are known by the trade name "silocel." Only substances like cotton and silk-fluff are less conducting, and their insulating advantage over the bricks is very slight. As these bricks are perfectly fireproof, they are highly suitable for use around an oil reservoir, heated nearly to the limit of safe oil temperatures.

It remains to speak of the coverings of the mirror, and of the heater tube within it. In order to avoid cooling by air currents, and to prevent the mirror surface from being fouled by dust and other things, the whole top of the mirror frame is covered by sheets of window glass. To prevent the loss of heat by air convection from the very hot blackened heater tube, this metal tube is surrounded by a glass tube, leaving an air space of about three-fourths inch all around it. But the glass tube grows very hot, and itself tends to cool, so that great losses of heat would still occur there. This is hindered by a second concentric tube of glass, larger than the first, and separated from it by the highest practicable vacuum. In this way, the heated inner tube is, like the inner part of a thermos bottle, prevented from cooling by a vacuum jacket. Of course, it is not practicable to coat the inner glass with silver, like a thermos bottle. Complete silvering of it would shut out the sun rays. However, the upper one-third of its surface is silvered, which helps decidedly to prevent the escape of heat and hinders very little the sun rays from entering.

The whole cooker, with all of its coverings, is shown in plate 3. Temperatures of 175° C. are readily attained. This is quite hot enough to bake bread.

Fruit is preserved with great ease. The prepared fruit is put into glass jars, covered over with sirup, and left overnight in the lower oven. In the morning, the jar covers are fastened down while still hot. That is all! Indeed, the cooker is highly convenient. Foods may be prepared in a cool kitchen, having no fire. A beautiful mountain view is seen as they are set into the ovens out of doors.

There is no danger of burning in the well-tempered heat. Foods may be left to cook for many hours without harm. All meats and vegetables are most deliciously prepared.

In short, the solar cooker is a delightful luxury. Whether improvements and simplifications may reduce it to less than a luxury is still questionable. As an experiment in collecting solar heat, it has served a very useful purpose. Several of the devices tried out thereby seem likely to be of value for the greater problem of harnessing the sun rays for power.

CONDITIONS IN THE SUN

Before discussing the influence of the sun on climates and weather, let us devote a few moments to the consideration of the sun itself. As Dr. Russell stated 2 years ago, the sun is composed of the same chemical elements as those found upon the earth, and roughly in the same proportions. The temperature even at the surface of the sun is observed to be of the order of 6,000° absolute centigrade, nearly twice as hot as the arc light. All substances are not only melted, but rendered gaseous, at such temperatures. At lower levels within the sun's body there is every reason to believe that the temperature rapidly rises. Dr. Eddington computes for the sun's central temperature something like 20,000,000° C. The pressure there reaches many millions of atmospheres. Though we have no examples of such extreme conditions on the earth, we may surely infer that the sun's substance except possibly near its center is wholly gaseous. Elements like oxygen and hydrogen, which combine so avidly as to explode together when burned on earth, would not unite at all at solar temperatures. Not only are there no molecular compounds formed there (except in sun spots, where lower temperatures prevail), but even the atoms themselves are largely split to pieces, throwing off electrons and the other recently discovered subatomic constituents.

MEASURING SOLAR RADIATION

For many years the Smithsonian Institution has devoted much attention to the measurement of the intensity of solar radiation. We are concerned not only with its total heating power but with the relative intensity of the rays of the different colors. [Here a spectrum was thrown on the screen.] Not only the rays visible to the eye, but others beyond the violet and beyond the red, which we call ultraviolet and infrared, respectively, are plentifully emitted by the glowing sun.

All rays, whatever their color, or even if they are invisible ultraviolet or infrared rays, give up their total energy to produce heat when they are fully absorbed upon a black surface. Hence we use sensitive blackened electrical thermometers rather than the eye, the photograph, or even the photoelectric cell when we wish to compare

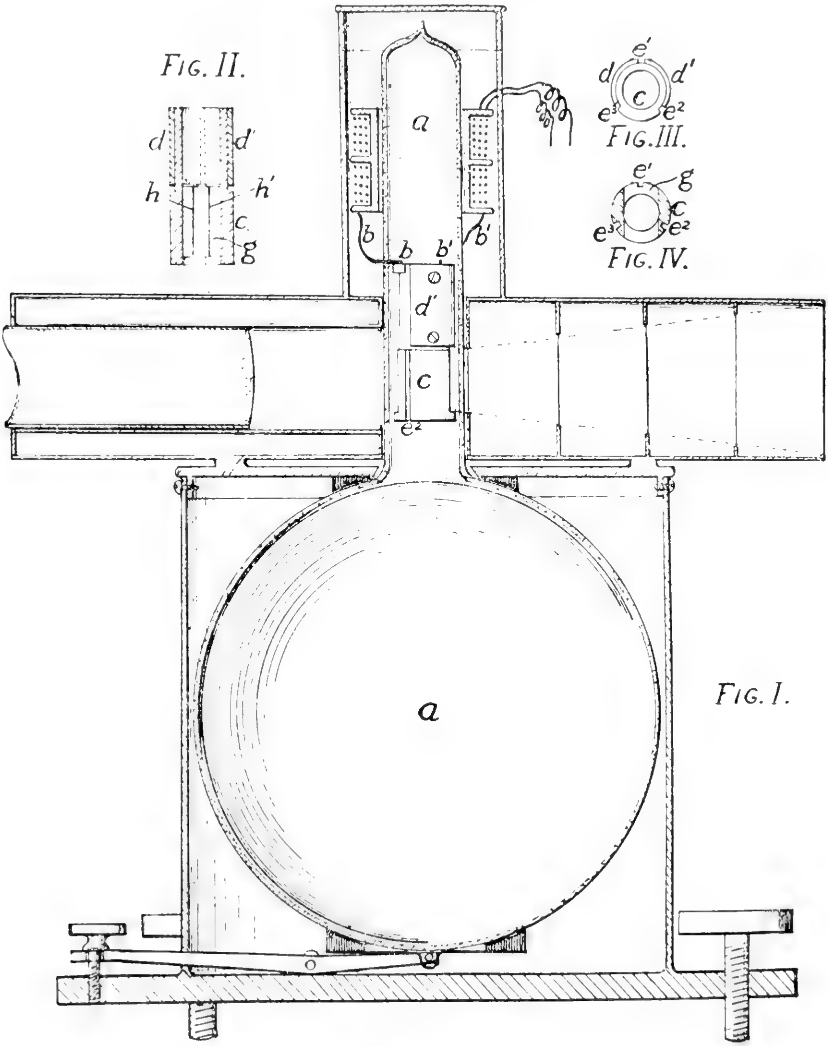


FIGURE 5.—Vacuum Bolometer.

Sensitive strips *h h'*, mounted on the copper blocks *c d'* form two arms of a Wheatstone bridge completed by the two coils *b b'*. Solar spectral rays are admitted by a vestibule with diaphragms and may be adjusted by the eyepiece. The vessel, *a*, is highly evacuated.

accurately the energy of one ray with the energy of another ray of a different color or wave length. My predecessor, Secretary Langley, invented the bolometer (fig. 5), a delicate electrical resistance thermometer, for this purpose about the year 1880. We use the bolometer every day in our three field stations on high desert mountains of California, Chile, and Egypt to measure the energy of the rays that compose the sun's spectrum.

A STATION FOR OBSERVING SOLAR RADIATION

Plate 4, figure 1 shows our station at Montezuma, Chile. It occupies a foothill 9,000 feet in height not far from the Andes Mountains, which rise to 18,000 feet within full view. The station is near the nitrate fields of northern Chile, where neither beast nor bird, reptile nor insect, nor any living plant is to be seen. Darwin, in his book entitled "The Voyage of the Beagle", tells of riding all day in this Desert of Atacama, and seeing no life except a few flies feasting on the dead body of a mule. The observers bring all the water for washing, bathing, cooking, and photography from Calama, a town 10 miles away. They have a piano, Victrola, radio, books and games, and telephonic communication with Calama, but the life there is certainly not a gay one. Every day that is fair (and 80 percent of the days are fair) they observe from about 6 o'clock until 10 o'clock a.m., and compute from 10 o'clock until mid-afternoon, or even later. By evening they are able to telephone out their message, giving the intensity of the sun's rays as they would be found outside our atmosphere. The result reaches Washington early on the next morning and is broadcast by Science Service at 4 p.m. to the world.

Plate 4, figure 2 shows the bleak character of our newly occupied station in the Sinai Peninsula, Egypt. It is on Mount St. Katherine, 8,500 feet in elevation, about 10 miles from St. Katherine Monastery on Mount Sinai. The director, Mr. Zodtner, his wife, and two small children, and the assistant, Mr. Greeley, occupy this station.

SOLAR ENERGY SPECTRA

Figure 6 shows a series of bolometric solar spectral energy curves all obtained on the same forenoon at our station at Montezuma, Chile. You will note first of all that the spectrum visible to the eye makes less than half of the length of the prismatic solar energy spectrum as we observe it. Second, you will observe that at several places in the infrared region there are great vacancies where the spectral energy almost disappears. These bands, named by Langley ρ, ϕ, ψ, and Ω, are produced by the absorption of the sun's rays by water vapor in the earth's atmosphere. Third, you will see many smaller indentations in the visible and ultraviolet regions, which are duplicated on all of the several energy curves shown in the figure. These indentations correspond to the dark lines called Fraunhofer lines seen visually in, or in photographs of, spectra of the sun.

They are produced by absorption of gases such as hydrogen, calcium, iron, magnesium, and others, which are volatilized in the sun itself. Fourth, you may note that though all of the energy curves are of nearly equal height in the highest parts of the infrared spectrum, their heights increase considerably from the bottom energy curve shown to the top one, if observed in the violet or ultraviolet. This indicates how much more transparent our atmosphere is for red and infrared rays than it is for violet and ultraviolet rays. The curves were made successively, the lowest in the early morning, when the sun shone obliquely through a great thickness of atmosphere, causing much depletion of the rays, and the highest near noon, when the sun was nearly vertically overhead and the thickness of air traversed was much less.

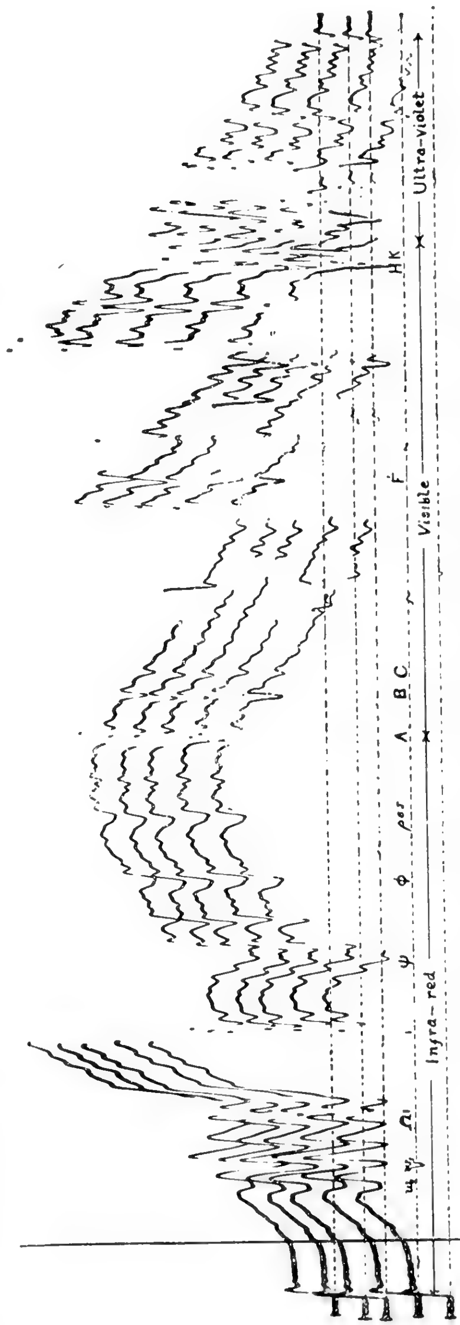


FIGURE 6.—Prismatic solar spectral energy curves. Taken at Montezuma, Chile.

SOLAR ENERGY SPECTRA IN FREE SPACE

By measuring the heights of all of these curves at some 40 points scattered from the ultraviolet to the infrared, and knowing the thickness of atmosphere traversed by the sun rays in each instance, we are able to compute how high the curve would be at all points if taken in free space outside our atmosphere.

Figure 7 shows such a curve, freed from all atmospheric absorption, freed also from all instrumental absorption, and reduced from the prismatic to the normal or wave-length scale. Here the visible

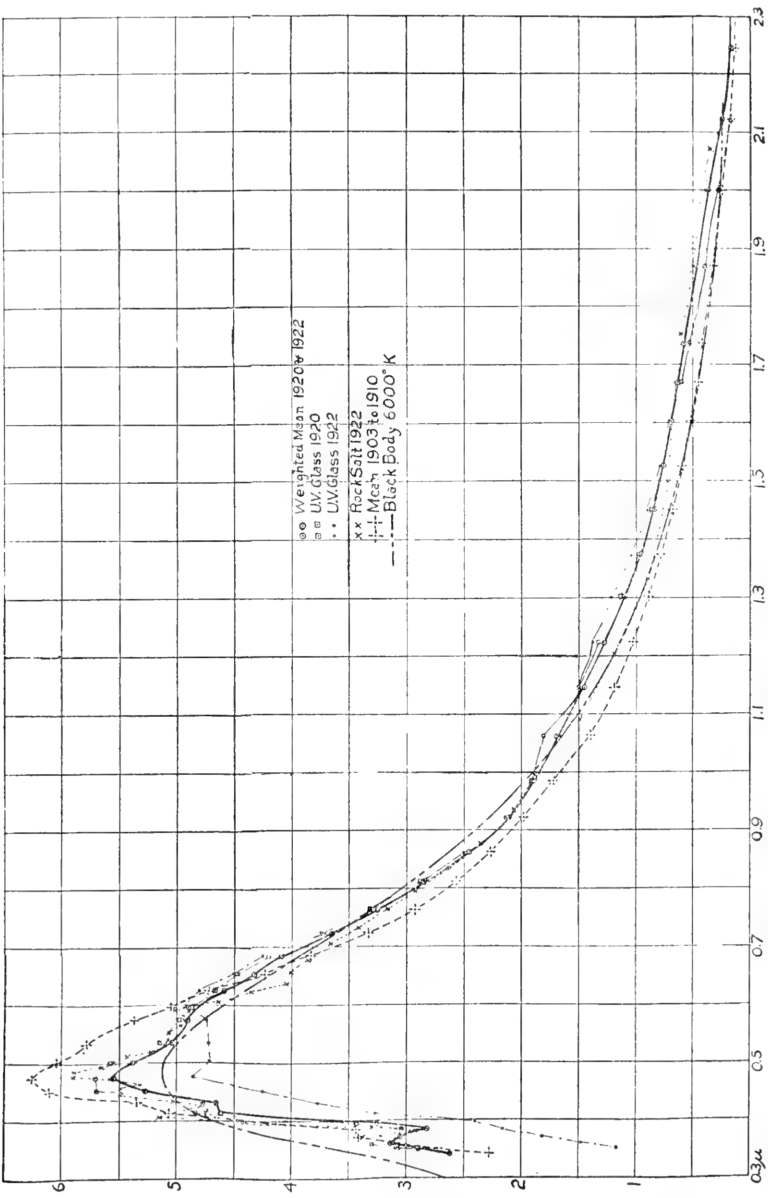


FIGURE 7.—Normal solar spectral energy curve outside the atmosphere. Compared to the energy curve of the perfect radiator at 6000° Abs. C.

part shrinks greatly in length but grows greatly in height relatively to the infrared. Compare this solar energy curve, if you please, with the energy curve of a perfect radiator of the temperature of

6,000° absolute centigrade shown near it. Evidently they are much alike in most parts, but the solar curve falls away from the other in the ultraviolet. This weakness of ultraviolet rays is due mainly to the powerful absorption of the sun's ultraviolet rays by the sun's own gaseous envelop. But you will gather from this comparison of the two curves, I am sure, an indication of one of the ways used to estimate the sun's effective surface temperature as of the order of 6,000° absolute centigrade.

THE SILVER-DISK PYRHELIOMETER FOR MEASURING TOTAL SOLAR RADIATION

Plate 5 shows the silver-disk pyrheliometer. It is an instrument which I invented at the Smithsonian Institution for measuring the total heating power of the whole solar beam. It has been standardized against the water-flow pyrheliometer, also my invention, and over 70 copies of the silver-disk pyrheliometer have been made and calibrated at the Smithsonian Institution and furnished at cost to observers on all the continents of the world. At the front of the pyrheliometer is a tubular vestibule with numerous diaphragms for keeping out sky light and the wind, while admitting the sun's rays to the box beneath. In this box is a blackened disk of silver, as big as a dollar, and about five-sixteenths inch thick, on which the sun's rays shine at right angles. In a radial hole, bored from one side into the silver disk, is sunk the cylindrical bulb of a delicate mercury thermometer. For convenience the stem of the thermometer is bent at right angles and fastened alongside of the vestibule. The observer, with watch in hand, notes the rate of rise of the thermometer when he has admitted sun rays by opening the shutter at the top of the vestibule tube. In this way the heat of the sun's rays is measured.

THE SOLAR CONSTANT OF RADIATION

We cannot carry the silver-disk pyrheliometer to the moon to measure the intensity of sun rays outside our atmosphere. It is true that we did in 1914 send an automatic pyrheliometer into the stratosphere (figs. 8 and 9) and got good observations with twenty-four twenty-fifths of the atmosphere eliminated. Instead of actually observing outside the atmosphere, we measure the area under one of the bolometric spectral energy curves that I showed a few moments ago, and also the area under the computed solar-energy curve outside the atmosphere, which I also referred to. Dividing the latter area by the former, we obtain the factor by which, if we multiply the solar heat observed by the pyrheliometer, we may obtain the heat which that instrument would have measured if we had taken station on the moon and observed the sun there.

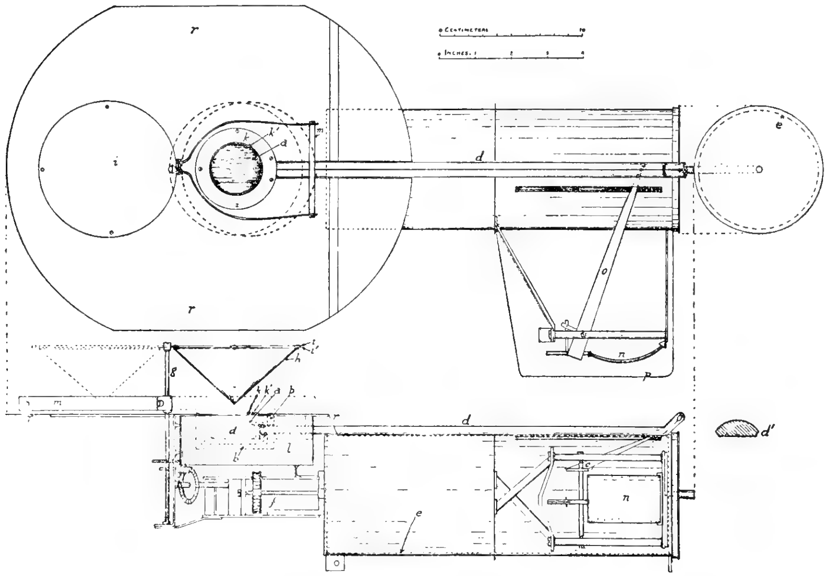


FIGURE 8.—Autographic balloon pyrheliometer and barograph. A photographic record of solar radiation and barometric pressure was obtained at 15 miles elevation.

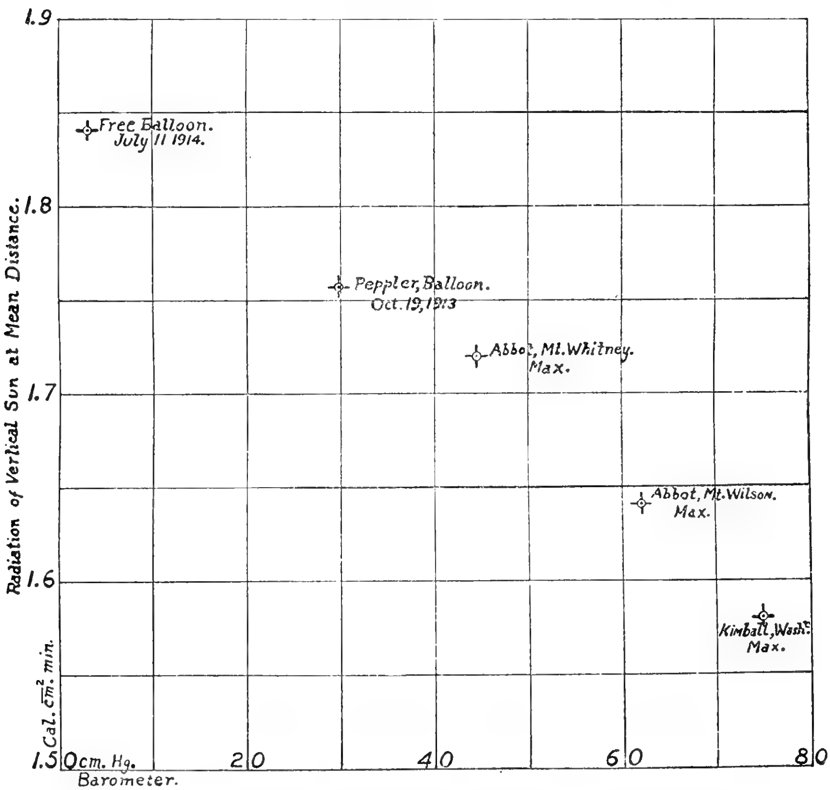


FIGURE 9.—Pyrheliometry from earth's surface up to the stratosphere.

Such is Langley's method for measuring what is called the solar constant of radiation. I can explain its result as follows: Imagine a cube of blackened water 1 centimeter on edge, or about the size of a dice cube. Expose it on the moon with one face at right angles to the sun's rays. Let the experiment be made in March when the earth and moon are at mean solar distance. How much will the temperature of the blackened water cube rise in 1 minute? The answer is 1.94° C. That is called the solar constant of radiation. In usual words, the intensity of solar heating is 1.94 calories per square centimeter per minute at mean solar distance outside our atmosphere.

THE SUN A VARIABLE STAR

For 15 years Smithsonian observers have measured the solar constant on every practicable day on one or more high desert mountains in distant lands. Though called a constant, the value is not a constant. Figure 10 shows how its monthly mean values have been observed to vary from 1920 to 1930. The changes, as you see, are not large. In 1922 there came the largest, reaching a range of 2.5 percent. Figure 11 shows the values measured simultaneously by Smithsonian observers in California, Chile, and South-West Africa. Their results, though not absolutely identical, are so nearly so as to disclose fair agreement as to the variability of the sun. Its variability seems to be altogether irregular. As we see it in figure 10, it seems quite devoid of any wavelike regular periodicity.

PERIODICITIES IN SOLAR VARIATION

In figure 12, however, I show that this first impression of entire irregularity in solar variation is superficial. In reality the sun's variation is a complex summation of not less than seven regularly recurring waves, or periodicities. They are respectively of approximately 7, 8, 11, 21, 25, 45, and 68 months in their periods.

The component periodicity curves are summed up into the curve B, which is plotted in dots upon the original measured curve A. Even in details the agreement of the two curves is striking. Thus we claim that the sun is not a constant star but a variable one, whose apparently irregular variation is really a complex of at least seven periodicities.

The interesting question at once occurs: Do the solar periodicities impress themselves on the earth's weather? They do. Before discussing this subject I must speak of the sun spots.

SUN SPOTS

When Galileo in 1610 first used the telescope he saw that the sun's surface carried dark spots (pl. 6) and that these moved along, indicating that the sun rotates in about 26 days. From 1826 to 1868

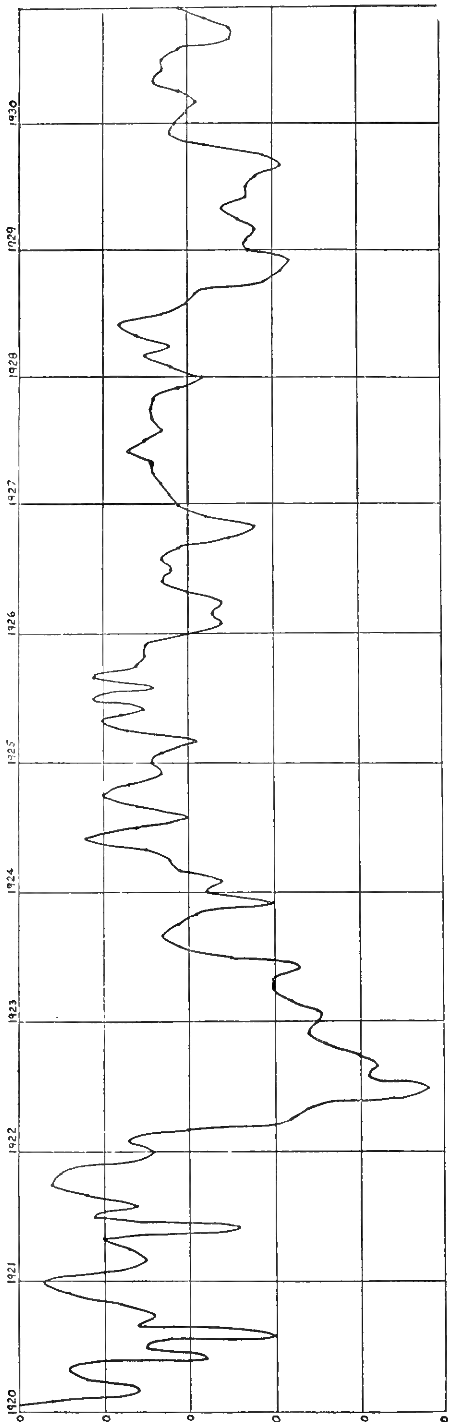


FIGURE 10.—Preferred monthly mean value of the solar constant, 1920 to 1930.

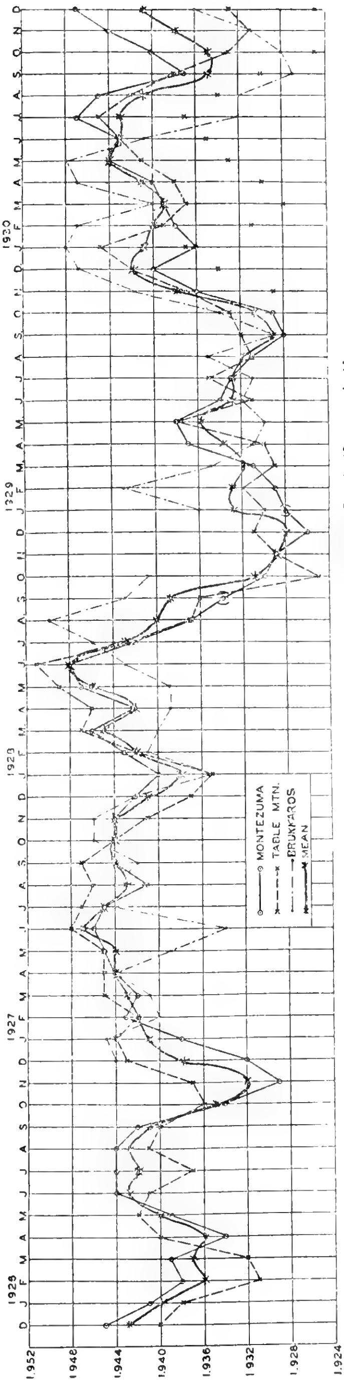


FIGURE 11.—Solar-constant values simultaneously observed at three stations.

H. Schwabe, of Dessau, Germany, kept daily watch upon the sun spots and discovered about 1843 that their numbers wax and wane in a period of about 11 years. His observations were continued by many observers, and old records were consulted which showed that the 11-year periodicity in sun spots has continued for several cen-

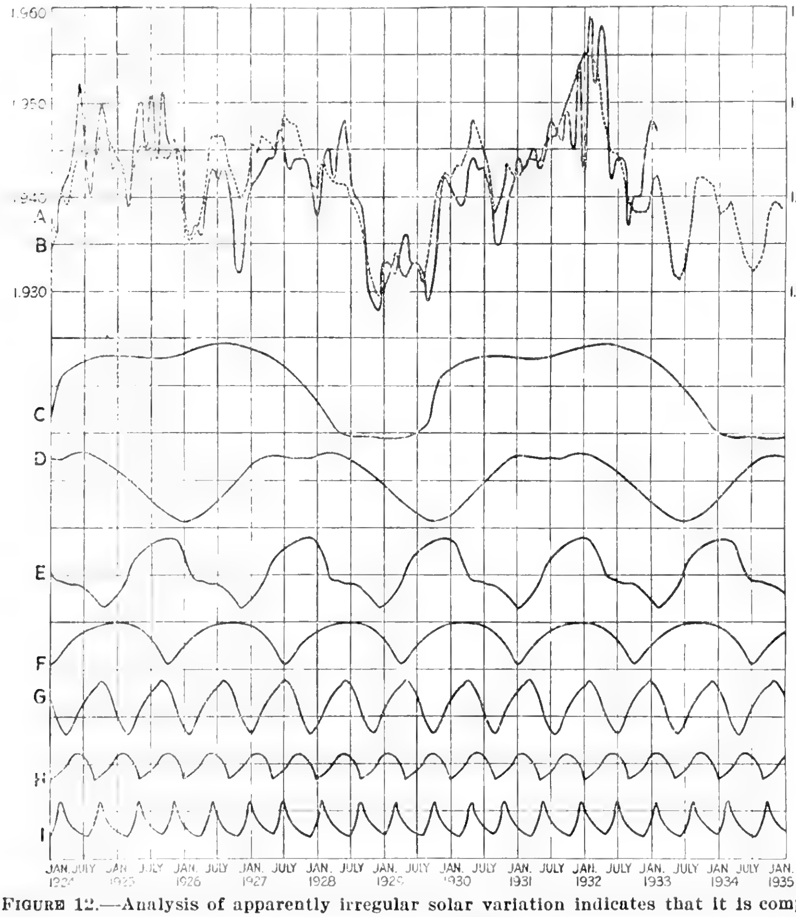


FIGURE 12.—Analysis of apparently irregular solar variation indicates that it is composed of seven regular periodicities.

turies (fig. 13). Recently Douglass, by tree-ring measurements, and Baron de Geer, Antevs, and others, by measuring clay deposits, have found evidences of the sun-spot period for many centuries. About 25 years ago Dr. Hale at Mount Wilson Observatory discovered that sun spots are magnetic. This fell in nicely with the previously observed fact that the earth's magnetism and the aurora borealis are both closely associated with the sun-spot periodicity. Hale soon found that magnetic polarities are opposite in adjacent spots, and he showed later that the magnetic polarity of sun spots passes through

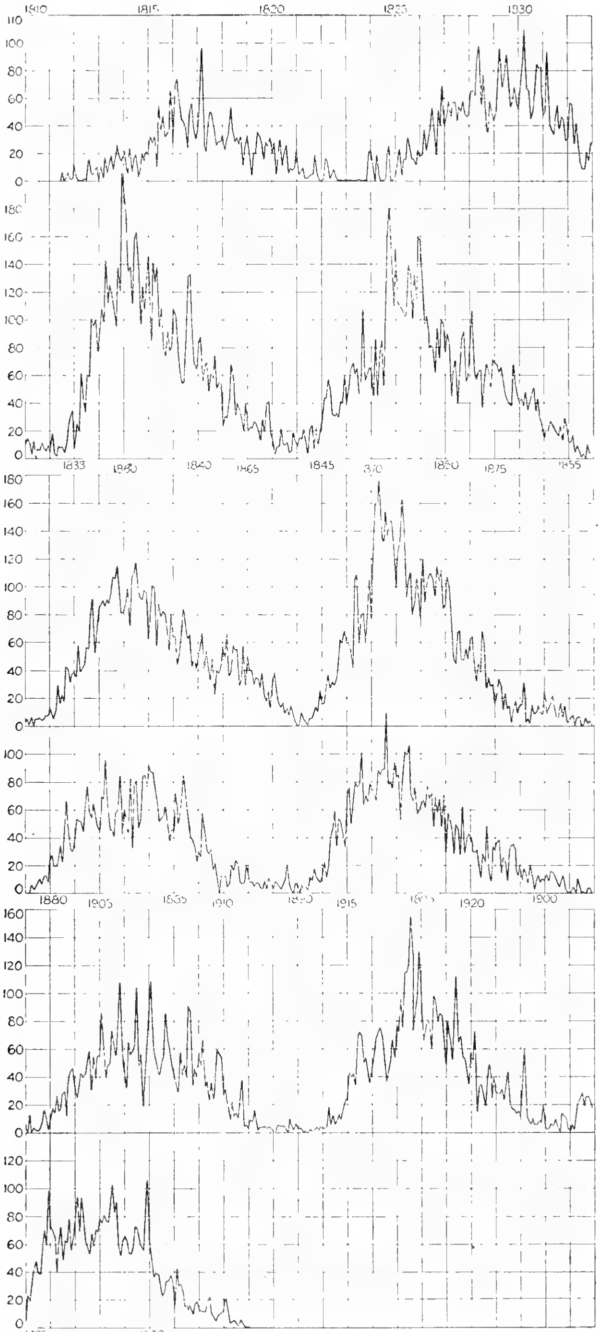


Figure 13.—Curve showing 11-year periodicity in sun spots, 1810–1934.

this interesting course, that the order of the two polarities is opposite in the north and south solar hemispheres and that the order continues unchanged through each 11-year sun-spot period, but reverses at the beginning of the next period (fig. 14). Thus it requires two 11-year periods to bring the sun through a full cycle of magnetic changes.

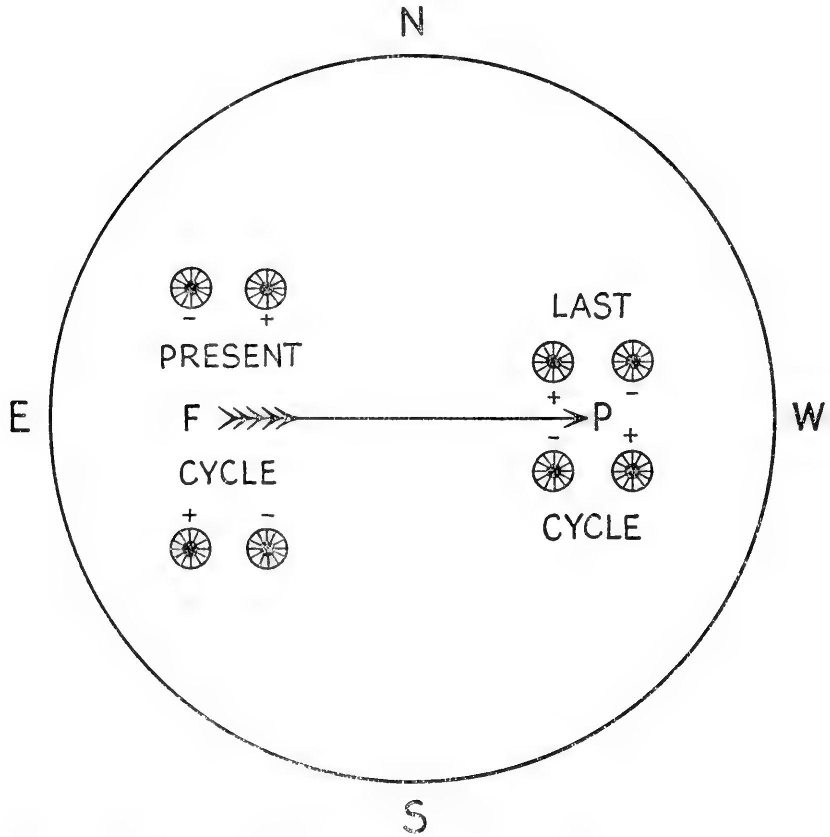


Figure 14.—Diagram of reversal of sun-spot magnetic polarity which occurs at the beginning of a new sun-spot cycle of 11 years.

SUN SPOTS AND WEATHER

For many years we have known that though the solar constant is a little higher when sun spots are most numerous, paradoxically the weather at most stations is a little cooler. The effect is only about 1° F. at maximum. Recently I have found a more important effect than this of sun spots on weather. Figure 15 gives one of the many instances which illustrate it. At Bismarck, N.Dak., I find the solar periodicities plainly shown in the departures from normal temperature, but the phases and the magnitudes of the periodicities change according as sun spots are few or many. The same is true at other places. I shall not detain you with many instances of the periodicities in solar variation reflected in weather but I will ask you to note

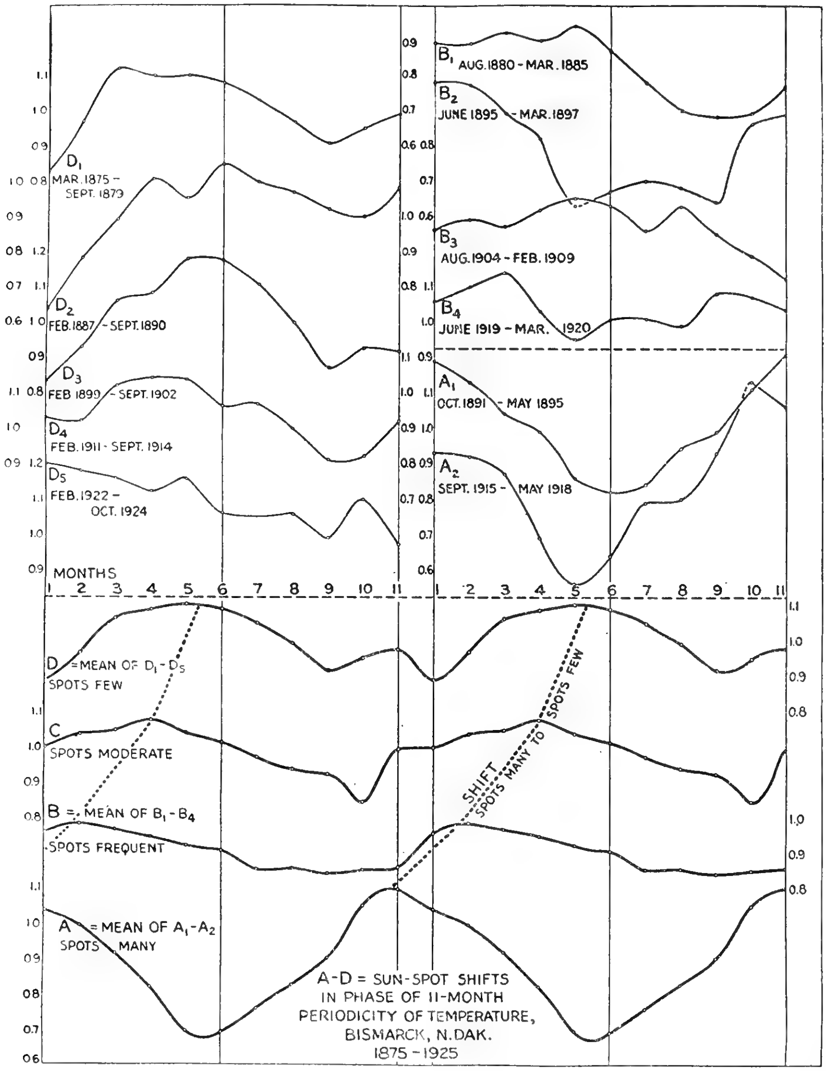


Figure 15.—Phases of weather periodicities changed by sun-spot prevalence.

that the 11-month period in Bismarck temperatures holds practically with unchanged phase from 1875 to 1925, provided we limit ourselves in comparisons to intervals of equal sun-spot numbers. On the other hand the phase of this weather wave reverses if we compare intervals of low with intervals of high sun spots. To reinforce this observation, I shall give one other instance from Cape Town, South Africa, 10,000 miles from Bismarck. Again in figure 16, observing the 11-month solar period as reflected in Cape Town temperature departures, and confining ourselves to intervals of time when Wolf's sunspot numbers did not exceed 30, we find that the 11-month period is so definite and so accurately in the same phase from 1865 to 1925 that we are able to correct the length of the period and detect that it lacks 3 days of a full 11 months. It is in fact 331 days.

I need not detain you to discuss others of the numerous solar periodicities which I have found reflected at numerous stations all over the world, both in temperature and precipitation. I will only state that the cumulative evidence that the solar variations largely control the weather is overwhelming. The regular periodicities that comprise solar variation are all important in governing weather, but their weather effects shift in phase according to the sun-spot numbers prevailing.

THE 23-YEAR PERIOD IN WEATHER

It happens that 7 solar periodicities above specified all come very close to finding their least common multiple in the double sunspot period of 276 months, or 23 years. It may be very significant that this interval, within the error of observation, is equal to Hale's magnetic cycle in sun spots. Since all of the solar periodicities of which it is the least common multiple are influential in governing weather, we need not be surprised to find that the weather tends to repeat itself, detail after detail, at intervals of 23 years.

As an illustration, figure 17 shows the smoothed percentages of normal monthly precipitation found at Nagpur in south-central India from 1856 to 1930. The values are arranged in 23-year cycles, so chosen that the year 1875 begins a cycle so as to fit with most of the lists in World Weather Records.[2] Lines have been drawn to guide the reader's eye to what seem to me to be homologous features in the four cycles illustrated. I would like to call special attention to the regions 1865–70, 1888–93, 1912–17. In 1865, 1868, and 1870 we find 3 pillarlike features of high-percentage precipitation bounding 2 features of subnormal precipitation. Thus there stand out two intervals of 3 and 2 years, respectively, as if guarded by these sentinel features, but embracing nearly a score of subordinate features. The reader's attention is now invited to similar features, 1888–93 and 1912–17, in which nearly all the details seem to be recognizable.

[2] Smithsonian Misc. Coll., vol. 79, 1927; vol. 90, 1934.

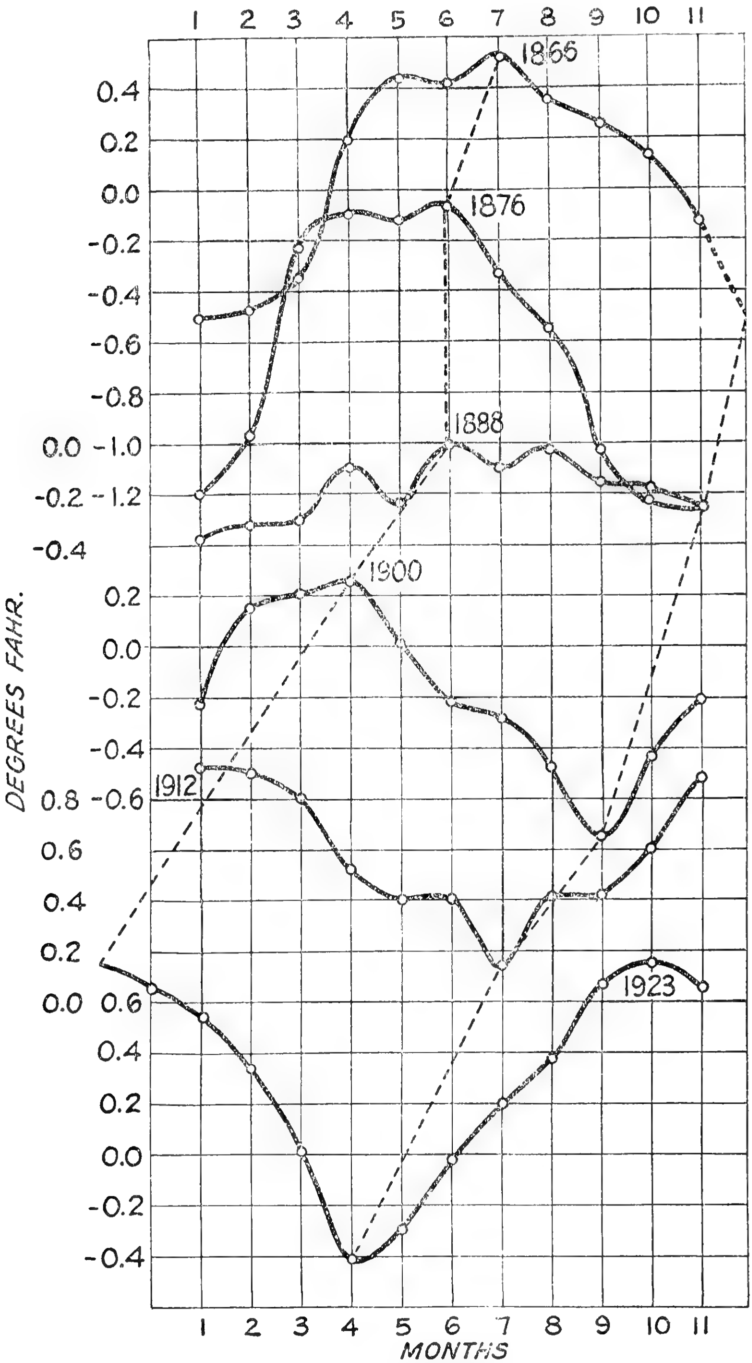


FIGURE 16.—The 11-month period in temperatures of Cape Town, during sun-spot minima only, 1865 to 1925. Shift of phase shows true period 331 days.

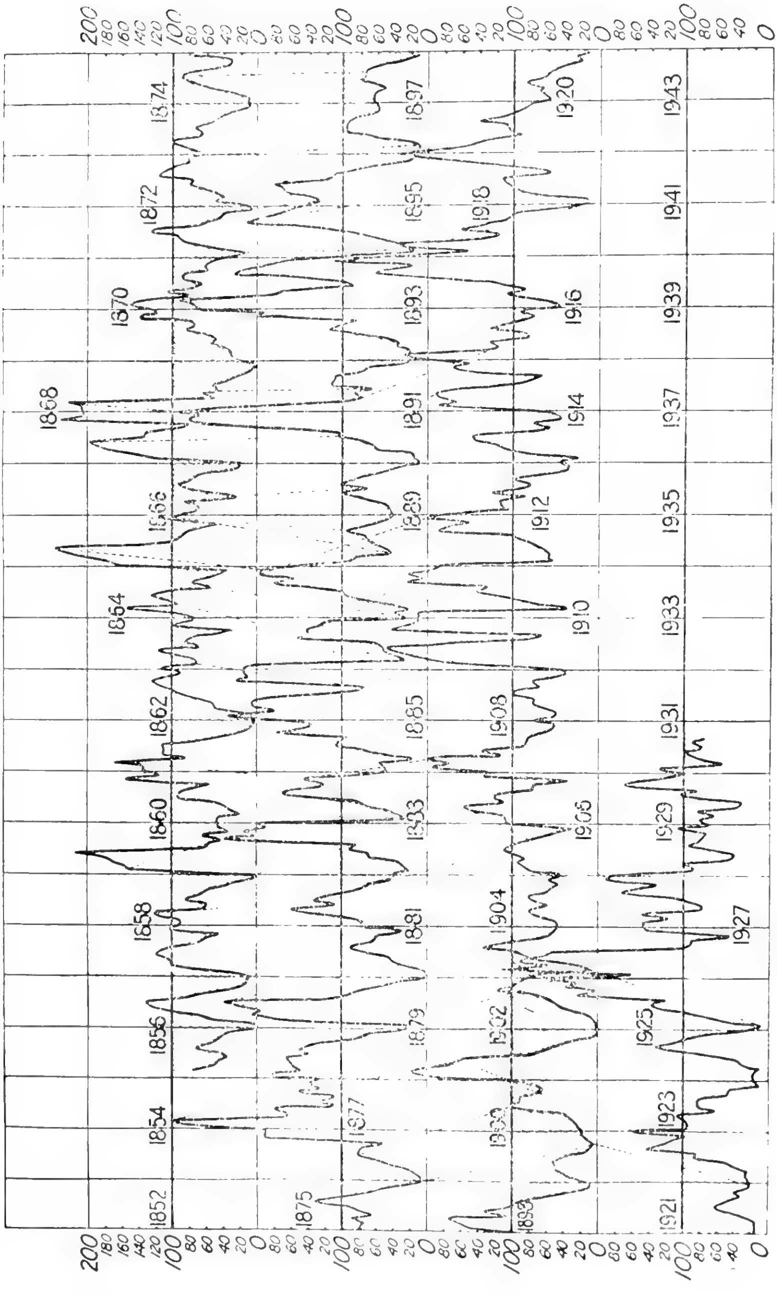


FIGURE 17.—The 23-year cycle in precipitation of Nagpur, Central India.

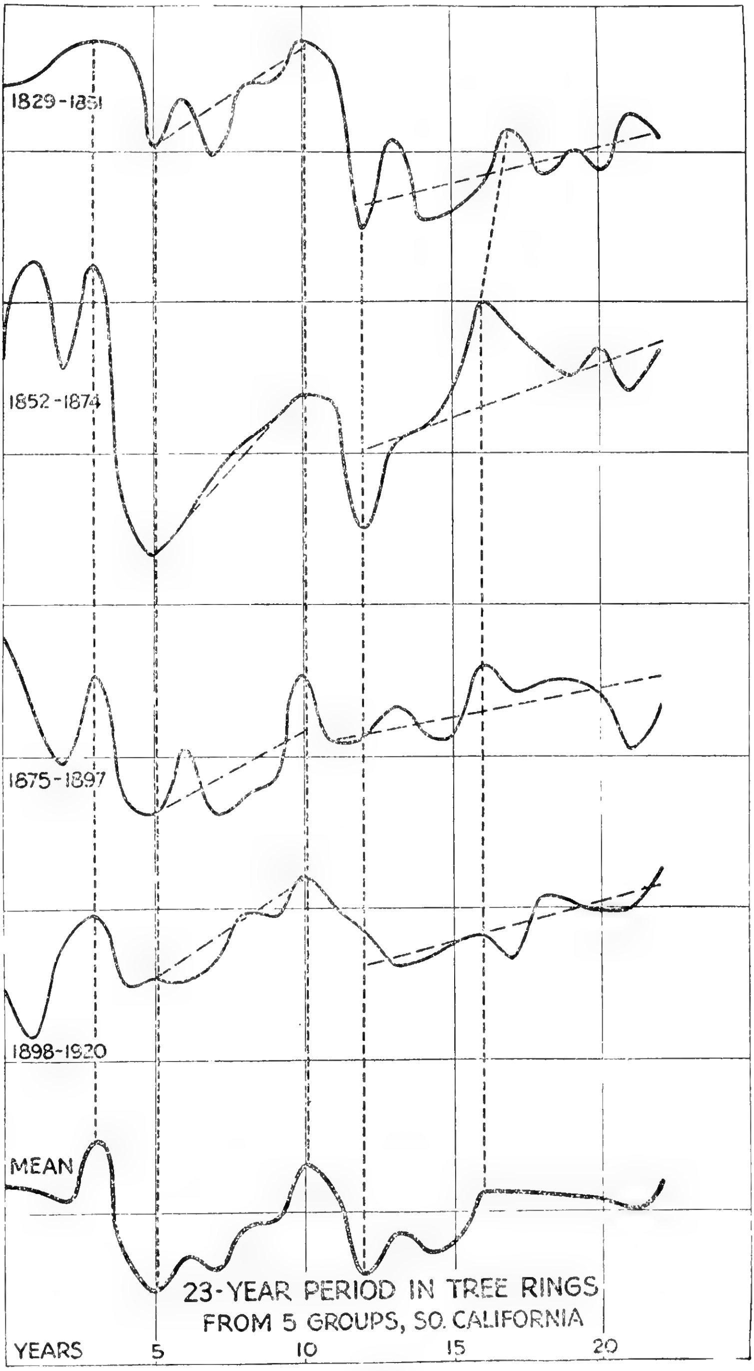

1829-1851
1852-1874
1875-1897
1898-1920
MEAN
23-YEAR PERIOD IN TREE RINGS
FROM 5 GROUPS, SO. CALIFORNIA
YEARS
5
10
15
20

FIGURE 18.

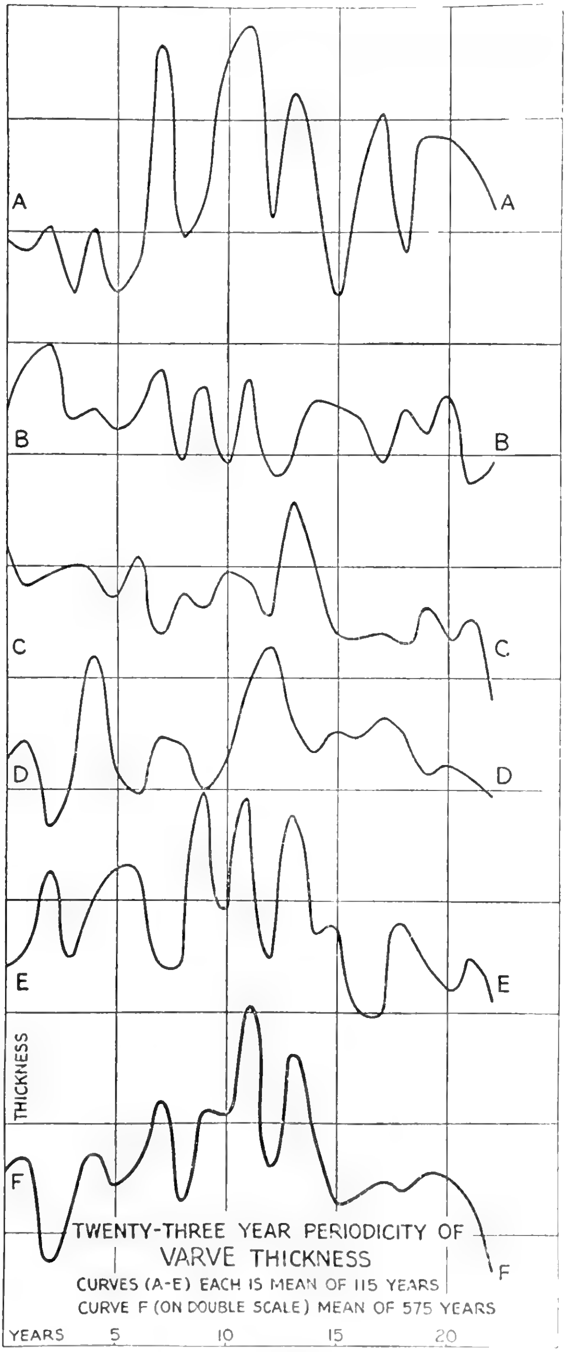
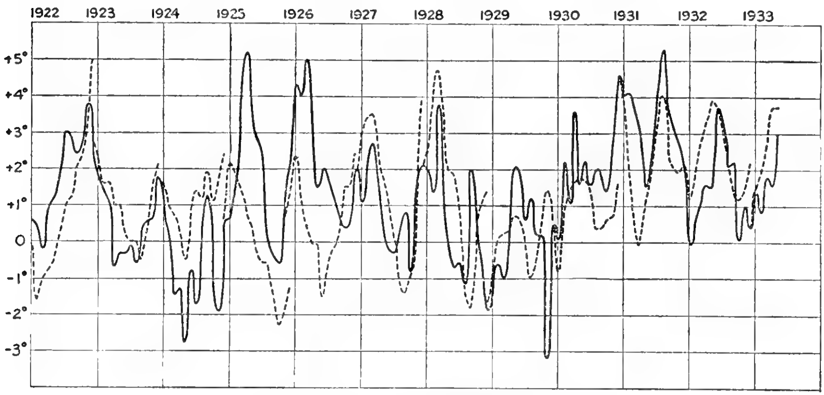

A
B
C
D
E
F
THICKNESS
TWENTY-THREE YEAR PERIODICITY OF
VARVE THICKNESS
CURVES (A-E) EACH IS MEAN OF 115 YEARS
CURVE F (ON DOUBLE SCALE) MEAN OF 575 YEARS
YEARS 5 10 15 20

FIGURE 19.

The separation between the first and second of these occurrences is almost exactly 23 years, but there is a delay of nearly a year in the appearance of the third. A similar delay marks, however, all of the features from 1899 to 1918, after which the cycle returns approximately to its earlier phase-status. Compare, for illustration, the year 1929 with 1860.

The 23-year cycle is recognizable in tree rings and in clay deposits of the glacial period as indicated by figures 18 and 19.



NORTH PLATTE, NEB.
DEPARTURES FROM NORMAL TEMPERATURE
(5-MONTH RUNNING MEANS)

FIGURE 20.

In some cases the 23-year cycle has features of high or low values prevailing over the course of several years and repeated similarly during each cycle. Such cases occur, for example, in the Nagpur precipitation cycles from the twenty-first through to the fifth year, during which 7 years the precipitation is subnormal. This indicates a probability that the subnormal precipitation will be experienced in central India from 1942 to 1948.

When the attempt is made to forecast weather for coming years in more detail than such general statements as these, the embarrassing changes of phase already referred to are encountered. These, though they do not destroy the general sequence of the individual features of the 23-year cycle, produce displacements, sometimes as great as a year, and often several months, in the times of their occurrence. Further research, it may be hoped, will aid in overcoming this difficulty.

A modest forecasting experiment is undertaken in figure 20. Having plotted 2 complete 23-year cycles extending from 1875 to 1920, inclusive, and in addition plotted 1 more year—1921—I pieced onto the last month of 1921, 12 months of forecast based on a study of the 2 preceding cycles. After having drawn this predicted curve, I then drew the curve of actual observation for those 12 months. Similarly, I proceeded, 1 year at a time, from 1922 to 1932, inclusive, as shown in figure 20. Although the fit between forecasted and observed curves is not perfect, the maxima and minima are nearly correctly matched in times, the ranges are usually similar, and the correlation is indeed fairly high.

And now, ladies and gentlemen, having discussed with you radiation, the earth and moon as depending on solar heating, and prospects for solar power, the sun itself in its glowing grandeur, our measurements which prove the sun to be a variable star, the regular periodicities disclosed in the sun's variation, the influence of sun spots on weather, and finally the dependence of weather on the variation of the sun, I conclude the third Arthur lecture.

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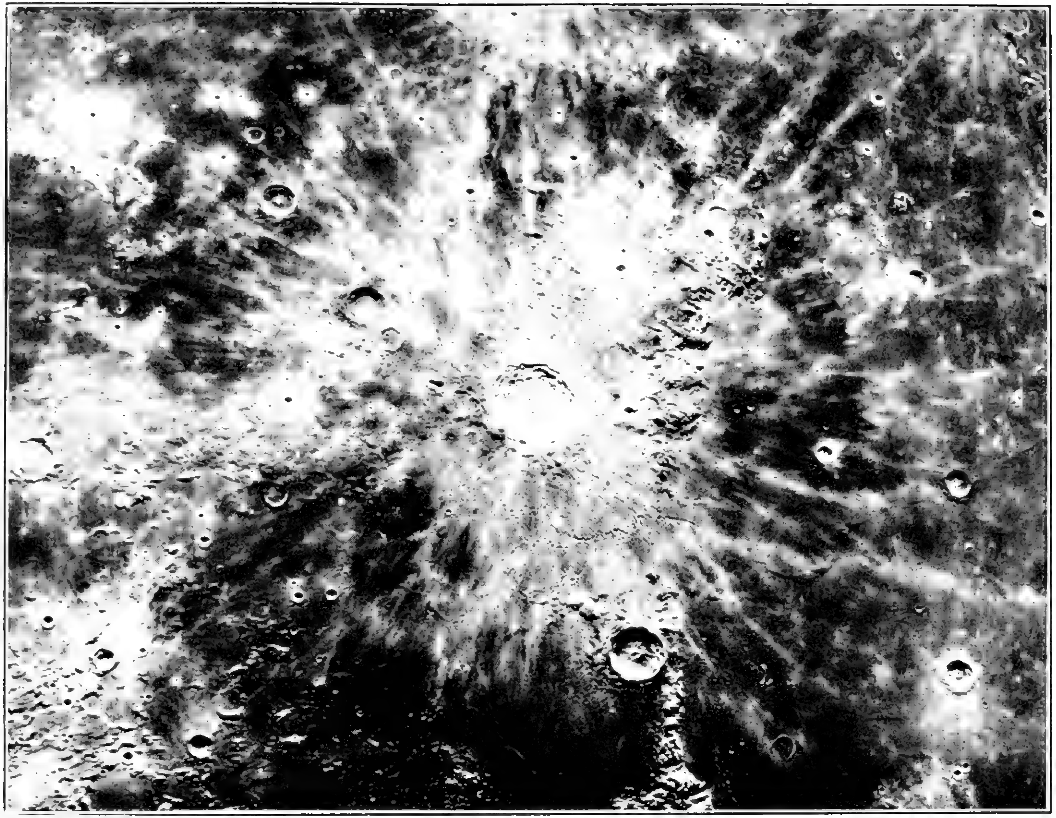
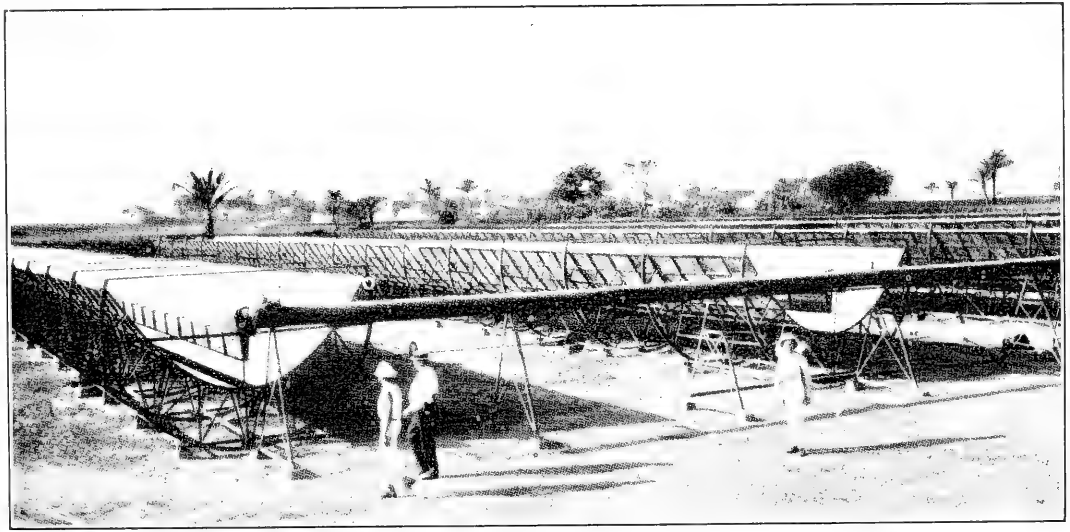


Mount Wilson Observatory.

THE LUNAR CRATER COPERNICUS AND SURROUNDING REGION.

The diameter of this crater is about 50 miles.

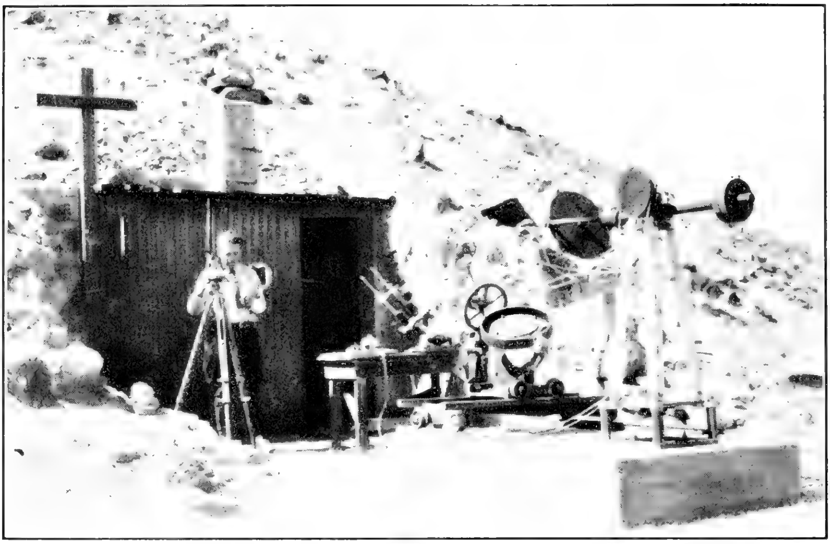


THE SHUMAN-BOYS SOLAR ENGINE.

The gigantic mirrors here shown were employed in 1913 at Meadi in Egypt to collect solar heat for the purpose of driving a steam engine used for pumping water.

THE ABBOT SOLAR COOKER, MOUNT WILSON, CALIF.

Side view showing end of great mirror, reservoir with ovens, and oil circulation tubes.



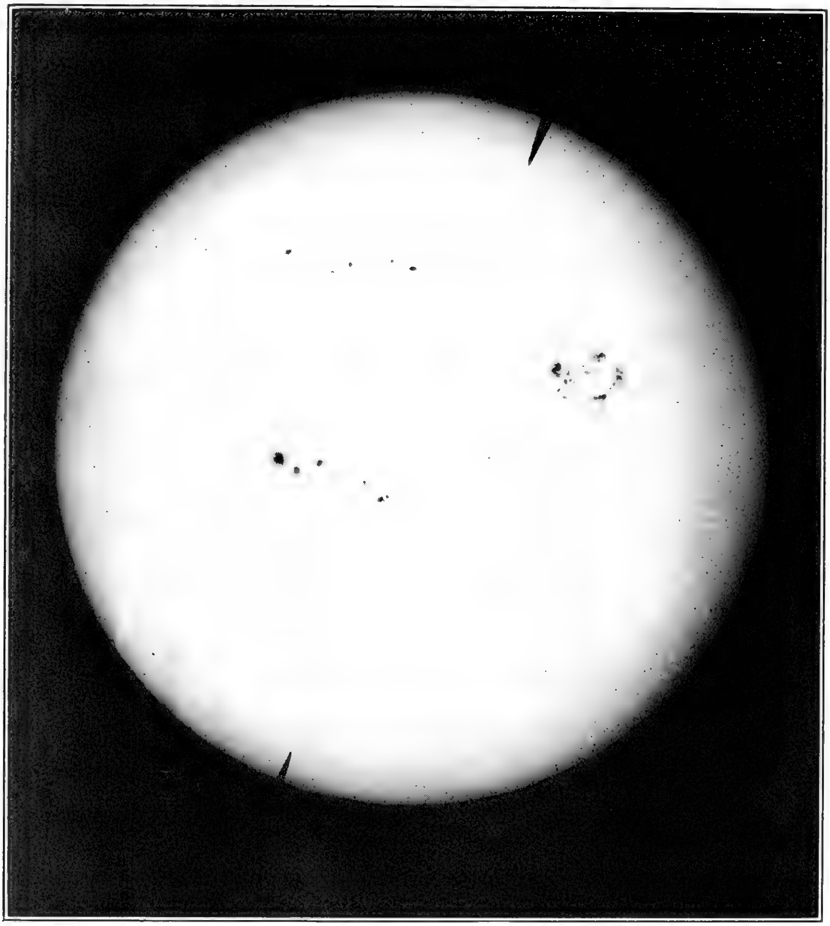
1. MONTEZUMA, CHILE, SOLAR OBSERVATORY, ALTITUDE 9,000 FEET.

The coelostat at right reflects the solar beam into the tunnel to the spectrobolometer. In the center are shown the two silver-disk pyrheliometers for observing total solar radiation. At the left the observer measures the sun's altitude

2. SMITHSONIAN SOLAR OBSERVATORY ON MOUNT ST. KATHERINE, SINAI PENINSULA, EGYPT, ALTITUDE 8,500 FEET.

Observatory on the peak, dwelling below. The director, his wife, two infants, and the assistant occupy this desolate station.

SILVER-DISK PYRHELIOMETER



MOUNT WILSON SOLAR PHOTOGRAPH, SEPTEMBER 25, 1928.

GRAVITATION IN THE SOLAR SYSTEM [1]

By Ernest W. Brown
Yale University

[With 4 plates]

We are apt to regard the sun as important for life on the earth chiefly because it is our main source of heat and light. But it is equally important for the continued existence of life as we know it that the earth shall continue to receive the proper amounts of heat and light, and to do so it is necessary that our planet shall remain at nearly the same distance from the sun at all times. The amount of either that we receive varies inversely as the square of the distance between the two bodies; should this distance vary too greatly or should the earth leave the neighborhood of the sun altogether, existence as we know it would cease. This distance is maintained by the operation of the laws of motion and of gravitation. In this lecture, which is a rapid survey of the problem of the reconciliation of theory with observation, I shall adopt the familiar Newtonian laws as the theoretical basis.

According to the Newtonian view, gravitation is a force which always tends to draw two particles of matter together. This tendency is balanced by the inertial property of matter. The effect of this property is that when deviation from constant velocity in a straight line is caused by such a force as gravitation, the amount of the deviation in a given interval of time, properly measured, is proportional to the force. In the case of the force of gravitation this balancing effect results in the two bodies circling about one another, never exceeding a certain distance apart or approaching nearer than another definite distance, unless they happen to be started moving exactly toward or away from each other, or unless the relative starting velocity is too great. Newton showed that under the usual conditions the curved motion is that of a closed oval—an ellipse—or, if the starting conditions are just right, a circle. In the last case, the balancing effect of the motion is often called the " centrifugal force ", but it is better named the " kinetic reaction ", since it is not

[1] The second Arthur lecture, delivered at the Smithsonian Institution Jan. 25, 1933.

a force in the Newtonian sense but is a result of the motion that balances the centripetal force of gravitation.

In order to solve the problem of the motion of any body, we must know in advance certain features of that motion. In the solar system, for example, we must know whether the motion is nearly circular, like that of the earth around the sun, or highly elliptical, like that of a comet. For this purpose rather rough observations will serve. But when this has become known and an accurate calculation is needed, accurate observations must be used. If observations of the position of a body could be made with perfect accuracy, a very few would suffice. But they are always subject to errors of various kinds, and to diminish the effects of some of these errors the observations must be numerous. Only by continual comparison of the results of theory with the observations can one hope to know the past, and by knowing the past to predict the future.

The working out of the consequences of the laws of motion and gravitation is almost entirely performed by mathematics. When only two particles are concerned the problem is very simple. With more than two it becomes highly complicated, and a considerable number of the most eminent mathematicians from the time of Newton up to the middle of the nineteenth century attacked it. It is easy to find reasons for the comparative neglect of the problem at the present time: The initiation of other problems in mathematics and astronomy, the laborious and intricate calculations now necessary if progress is to be made, and the need for assimiliation of a large heritage of the past have all played a part.

Many astronomical discoveries have been due to the discussion of large numbers of observations. The early tendency of scientific work was to record only the unusual—an eclipse, the appearance of a comet, the time of setting of a bright star or of a planet, and so on. Gravitational astronomy can be said to have made a real start when Tycho Brahe undertook to observe daily over a long period of years sun, moon, planets, and stars, and to record their positions in the sky with all the accuracy his home-made instruments could furnish. Not only so, but he tried to discover all the errors to which his observations were subjected and to correct them accordingly. The next step, that of making deductions from the observations, was taken by Johannes Kepler, who, with some difficulty, managed to get hold of certain of the records left by Tycho after the death of the latter.

Just as Tycho was the forerunner of the tireless routine observer, so Kepler was the first to undertake the discussion of large numbers of observations in order to deduce such laws as he might be able to find. With an immense amount of labor extending over many years he was able to give to the world those that still bear his name.

Briefly, the three laws state that the curves in which the planets move round the sun are ellipses with the sun in one focus; that the time taken to get from one part of the ellipse to another is proportional to the area bounded by the ellipse and the two distances to the sun, and lastly, that the squares of the periods of revolution of the planets around the sun are proportional to the cubes of the longest diameters of the ellipses in which they move. The success of his work was a wonderful achievement, for he had little to guide him; only by persistent trial and error could these results have been obtained at that time.

Kepler died in 1630. Isaac Newton, the third and without any question the greatest of the trio who laid the foundations of celestial mechanics, was born in 1642. Through his work the subject was changed from a mass of hypotheses and guesses into a science which was capable of endless development. Kepler had given a geometrical description of the motions of the planets: he had formulated certain empirical laws which had no apparent connection with one another. Newton gave the bases by which he was able to show that these laws were a necessary consequence of properties that are common to all matter. To do so, he had to take new steps in at least three directions. First, the final formulation of the laws under which all matter will move whatever may be the acting forces. Here he had the aid of the work of Galileo, who had been a contemporary of Kepler, but who does not seem to have been in touch with him. Second, the choice of the law or laws of force which would make the planets move in the manner shown by Kepler. Third, the invention of a mathematical device, which would enable him to deduce the consequences of the laws of motion and of gravitation, and thus to show that Kepler's laws were precisely what could be expected from the operation of these fundamental properties of matter.

We are approaching the two hundred and fiftieth anniversary of the year in which Isaac Newton gave the first demonstration that the orderly progress of the bodies that constitute the solar system was due to the existence of certain simple laws apparently obeyed by all matter. These laws, formulated with admirable lucidity in the Principia, remained unchanged for over two centuries. While the comparison of their effects with the observed motions showed small deviations with the gradually increasing accuracy of the calculations needed to show these effects, and of the observations, only in our own time has the theory of relativity given us a new basis from which these properties of matter may be developed. From the point of view of the astronomer who is interested in the comparison of theory with observation in the solar system, the difference between the two methods of approach is philosophical rather than practical.

The numerical results have been shown to be so nearly the same, that in only one case has it been possible to detect by observations of the positions of the bodies of the solar system a minute difference between the results deduced from the Newtonian laws of motion and gravitation and those deduced from the theory of relativity.

Newton was not content with the bare outlines of the subject but desired to fill in details wherever possible. It is reported that the publication of his work was much delayed because of his difficulty in proving that a uniform sphere would attract an external particle exactly as if all its mass were concentrated at its center. And again he was delayed by an erroneous value of the radius of the earth, a proper value of which was needed in the application of his theory to the motion of the moon, if theory and observation were to agree. Further, he dreaded controversy, and had he given his proofs by the use of calculus, or " fluxions " as he called it, there would probably have been endless debate concerning the validity of this new and unknown method of argumentation. To avoid it, he performed one of his greatest feats, the translation of the whole process into elementary plane geometry—a method of reasoning which was known and acceptable to the scientific men of his time.

For nearly a century after the publication (1688) of the Principia of Newton, progress was slow, perhaps because it demanded considerable development of the calculus originated by Newton and Leibnitz. The geometrical form of argument used in the Principia is much too difficult and complicated for investigation, and it was not until Leonard Euler and some of his predecessors had shown how to deal with the problem by analysis that progress was possible. Most of Euler's work appeared in the third quarter of the eighteenth century. The end of it is marked by the advent of Laplace, whose Traité de la Mécanique Céleste furnished mathematicians with a storehouse of facts that were deducible from the equations of motion, and who gave principles for the development of the solutions, which furnished starting points for many of the investigations of his successors.

The mathematical processes start by translating the laws into algebraic symbols and then equating the gravitational forces to their kinetic reactions. This process—a comparatively simple one—involves the setting up of certain formulas known as differential equations which give the rate of change of the velocity of each body in any direction in terms of the positions of all of them at the moment. What is usually needed is the deduction of the positions at any other moment. This second step requires what is known as the " solution " of the differential equations. It is at this point that the difficulties begin to arise. No method is known for obtaining these solutions exactly. What is actually done is the introduction of modifications made to simplify the mathematical and numerical work; the results so obtained are later corrected to take care, as far as possible, of the changes that have been introduced. This process of gradual approximation is in general use for most of the problems in which mathematical methods are adopted for the study of physical phenomena; for those of celestial mechanics, it is the basis of all the methods which have been devised.

After Laplace's time the increasing accuracy and number of the observations demanded that the calculations giving the positions of the moon and planets be carried out in much greater detail, involving a disproportionate increase in the work. The problem of the moon's motion alone required many years of calculation to carry the approximations to the point where the results appeared to have the same degree of accuracy as the observations. During the nineteenth century only two of the many who started succeeded in getting near the goal, namely, P. A. Hansen and C. Delaunay. Hansen's work, with minor corrections, was used to calculate the positions of the moon given in the Nautical Almanacs for some 70 years. Delaunay's theory was not put into tabular form until the beginning of the present century, at a time when the demand for accuracy exceeded that which his theory was capable of furnishing.

For the great planets two ambitious projects have been carried out successfully. In Paris, Leverrier, with the help of a staff of computers, recalculated the theories of their motions and carried the work through to the formation of tables which were in use for many years to predict their places given in the almanacs. Toward the close of the century, a similar task was undertaken by Simon Newcomb in Washington, but with increased demands for accuracy he found the work too great for one man, even with the computing assistance which he was able to command. He wisely sought and obtained the services of G. W. Hill, the greatest celestial mechanician so far arisen in America, for the most laborious and difficult part of the work, namely, the theories of the motions of Jupiter and Saturn.

With the publication of the works of Hill and Newcomb carried through to the formation of tables so that comparison with observation was rendered comparatively easy, it was evident that the accuracy of the theories had caught up with that of the observations. It thus became possible to discuss, with the hope of making new discoveries, the differences between the theories and the immense store of observations that had been accumulated at many observatories during the nineteenth century. Newcomb undertook this task and proved himself to be a master in marshaling great masses of material and in deducing the best results from them. The details of this work have not been published, but the results are summed up in a small octavo publication entitled "Astronomical Constants."

As stated above, the immediate object of most of the work of the past in this subject has been the deduction of the positions of the known bodies of the solar system at any time in the past or future, from the laws of motion and gravitation. The deduced positions are compared with those observed in the telescope. The desire to achieve the highest accuracy possible has to many been a sufficient objective. Ultimately, it leads to a knowledge of the extent to which the assumed laws will account for the observed phenomena. The study of the differences between the observed and calculated positions has sometimes given unexpected information concerning the operations of the laws; at other times it has furnished information concerning effects other than those produced by the direct action of gravitation. In fact, every considerable increase in accuracy, either of the theory or of the observations, has been followed by discoveries that have stimulated further investigation and the desire for still greater accuracy.

Newcomb's summary shows that most of the definite differences between theory and observation could be accounted for by small changes in the constants that had been used to calculate the theories. It followed that, in general, the Newtonian laws of motion and gravitation were sufficient to account for the observed phenomena. Only one outstanding deviation was found—one that had previously been indicated by Leverrier, namely, an unexplained motion of the perihelion of Mercury. As is now well known, this has received an explanation through the theory of relativity, and, within the probable error of the determination of the motion of Mercury from observation, it is satisfactory. As mentioned above, this is the only difference in the motions of the solar system between the results of the Newtonian and relativity laws that is large enough to be detected at present, and this condition will probably continue for many years to come.

Nearly another half century has passed since Newcomb's results came into general use; and in the interval observations have been accumulating—chiefly at Greenwich and Washington, where they form part of a continuous program. In that time, only minor differences which could not properly be ascribed to errors of observation, have appeared. Some of these could undoubtedly be diminished by a new discussion of the masses and other elements of the orbits; others are possibly due to slight defects in the calculated theories—defects that it is difficult to avoid altogether with long and involved calculations. Some idea of the small magnitude of these differences can be gained from the statement that the mean annual deviations of any of the great planets from their calculated positions during the years 1926–30 have scarcely exceeded two-tenths of a second of time, and the majority of them are smaller. But the problem of accounting for such differences as exist has become more difficult, mainly because they are so much smaller than those to be dealt with in the past. Effects that could previously be laid aside as too small for consideration must now be taken into account. Changes in our measure of time, for example, must be considered, at least in dealing with the inner planets. As far as the outer planets, Uranus and Neptune, are concerned, there is some evidence that the agreement with observation could be improved by a new determination of their theoretical orbits. Although a new planet, Pluto, has been discovered in their neighborhood, the weight of the evidence at present available indicates that its mass is too small to affect their motions to an extent sensibly greater than the errors of observation within the interval during which the planets have been followed.

The latest theory of the moon's motion appears to satisfy the observations when we take account of the changes in our measure of time. It must be stated, however, that as the moon is the chief source for the exact determination of these changes, the argument is not conclusive; it depends as much on the nature of these changes and on the evidence that can be gathered from other sources. There is some difference between the calculated and observed motions of its perigee.

The present theory of the sun's action should be taken to another place of decimals before it can be asserted that this difference is real, but the amount of calculation needed to obtain this increased accuracy is so great that it will hardly be undertaken as long as other influences on its motion are in doubt. The chief of these is the effect produced by the distribution of the moon's mass; the constants adopted for this effect are very doubtful, and a redetermination of them from accurate observations of the librations extending over a long period of years is the first step.

I have mentioned several times the fact that large numbers of observations have contributed mainly to our knowledge of the accuracy of the laws which govern the motions of the bodies in the solar system. Some statistics may be of interest. In his Astronomical Constants (1895) Newcomb gives the following numbers used in his discussion:

Sun	40, 176
Mercury	5, 421
Venus	12, 319
Mars	4, 114

A similar discussion taken up at the present time would probably require the consideration of an additional 10,000 to 15,000.

Observations of the moon at the present time are accumulating at a rapid rate—in 1931 over a thousand were compared with their theoretical values. There are probably some 10,000 available in the 20 years elapsed since the present theory was finished, and the constants of that theory were determined from nearly 30,000.

Up to this point I have dealt only with those bodies in the solar system for which the calculated theories have a degree of accuracy similar to that of the observations. To complete the list one must mention certain of the satellites which have been under observation for long periods of years. Of the large numbers of small planets with diameters ranging from 300 miles down which have been discovered and kept in view since the beginning of the nineteenth century, only one, Vesta, has had its orbit calculated with an accuracy similar to that of the orbits of the great planets. In addition we have some scores of comets which belong to the system, and come into the range of observation at regular intervals.

To sum up the results of this immense amount of calculation and observation, it may be stated that no deviation from the Newtonian or the extended relativistic laws of motion and gravitation has yet been established in the motions of the solar system. Such apparent deviations as have been confirmed have hitherto been found to be due to other sources of disturbance, either in the method of observation or in the calculations, or can be ascribed to a lack of knowledge of the distribution of the matter which may cause the deviation. But the desire for accuracy has done more than merely to give a verification of the laws, for through it remote effects of these laws have been found which could hardly have been discovered in any other way. The amount of the tidal friction, which has played an important part in the past history of the system, the verification of the relativity laws, the changes in the rate of rotation of the earth, may be cited as modern examples. Other cases of more technical interest will occur to the astronomer.

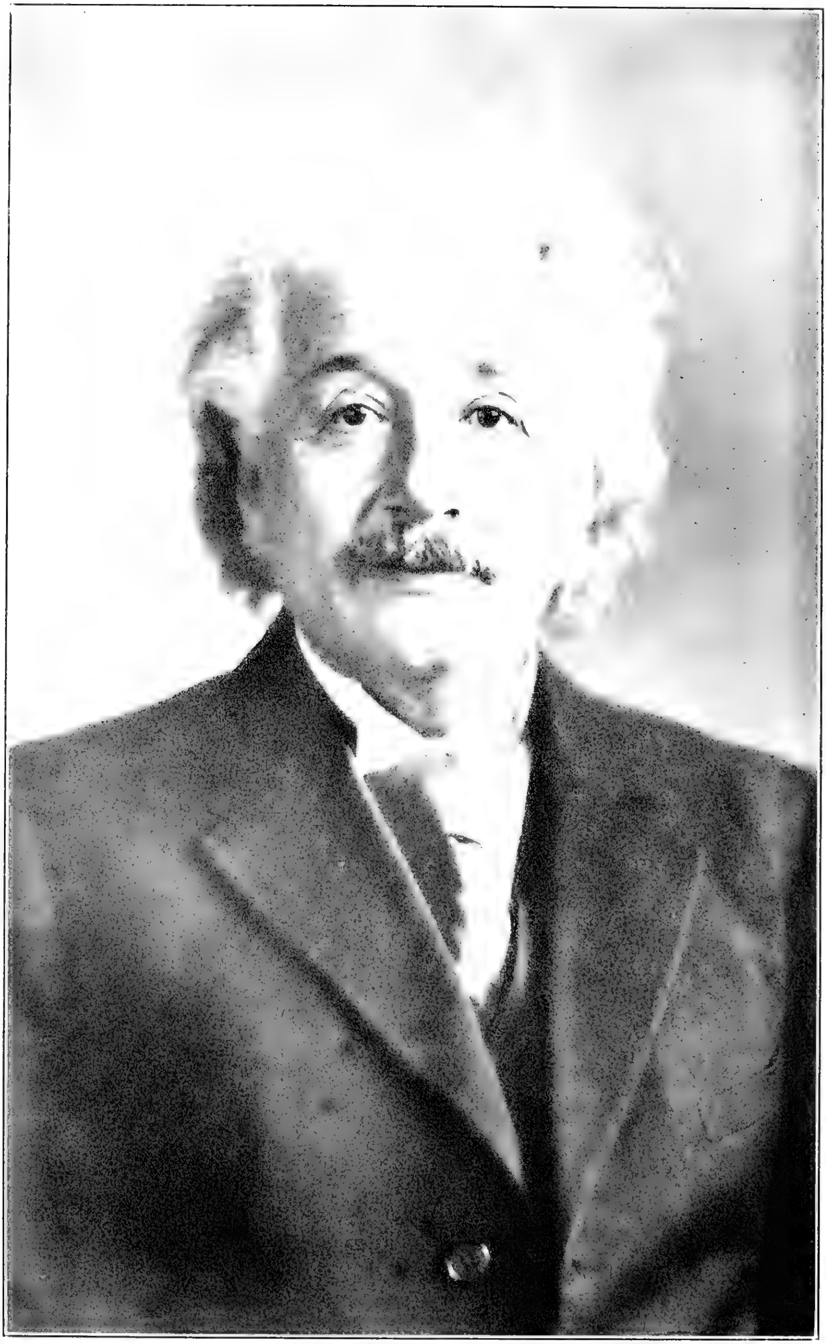
Perhaps the most useful service this work is performing at the present time is the more accurate determination of the motion of the earth relatively to the stars, or what is the same thing mathematically, the motion of the stars relatively to the earth. We can only observe from our moving platform, and to get exact results it is necessary to know how the platform moves. Thus the emphasis shifts from time to time, but the work goes on, and ultimately most of it is found to have value for one purpose or another. This is desirable, for there is no way of recalling the past, and we must capture the present with the hope of benefits in the future.

SIR ISAAC NEWTON, 1642 1727.

Science Service, Inc.

PIERRE SIMON, MARQUIS DE LAPLACE, 1749-1827.

SIMON NEWCOMB, 1835–1909.



Orren Jack Turner

ALBERT EINSTEIN.

THE STRUCTURE AND ROTATION OF THE GALAXY [1]

By J. S. Plaskett

I. THE STRUCTURE OF THE GALAXY

For uncounted generations thoughtful men, philosophers and mathematicians, physicists and astronomers, as well as many other students, have been puzzling over the nature of our surroundings in space. They have not been satisfied, as I am afraid many of us are satisfied, with their merely terrestrial surroundings but have tried to penetrate the almost inconceivable distances that separate the members of our stellar system, to trace the evolution and unravel some of the mysteries of the structure and constitution of the universe. The word "universe", however, is so broad and inclusive in its meaning, it implies something so vast and incomprehensible to our finite minds, as to be quite beyond the possibility of useful definition or discussion in a lecture like this. The term "universe" has frequently been used, and indeed is still used, I believe improperly, as referring to the particular system of stars of which our sun is one insignificant member among thousands of millions of others. A much better designation, however, is "galaxy", and hereafter we will refer to the system in which we are situated as the galaxy. Although it is now almost universally believed that there are countless other stellar systems extending to distances beyond the capacity of the most powerful telescope to penetrate, all of which may justly be included in the universe, yet it is generally recognized that our system is the largest and most complex of any known. The galaxy indeed is more than sufficiently large and complex, with its structure and motions still only partially determined, as to occupy fully our attention for one evening.

It seems hardly necessary to state in this twentieth century that the fundamental problem in the background of all modern astronomical research is the problem of the constitution, the structure, and the motions of the galaxy. While undoubtedly some practical applications of astronomy to the determination of time and to navigation and surveying have little to do with the structure of the galaxy,

[1] A lecture delivered before the Astronomical Society of the Pacific at San Francisco on Apr. 20, 1932. Reprinted by permission from Publications of the Astronomical Society of the Pacific, vol. 44, no. 259, June 1932.

it must be remembered that these applications no longer require astronomical research, nor do they now occupy more than a very small fraction of the time of an astronomical observatory. Whether an astronomer is engaged in determining the positions or measuring the radial motions or distances of the stars, whether he is examining their apparent brightness or investigating their orbital motions, whether he is analyzing the constitution and physical conditions of the stars and nebulae by means of the spectroscope, or whether he is only applying mathematical analysis to the investigation of the dynamical conditions in the galaxy, he is, by every one of these methods and many others, hoping to add something of value toward the solution of the fundamental astronomical problem and to aid in building up a true conception of the structure of the galaxy.

A mere glance at the sky on a clear moonless night shows a luminous belt, the Milky Way, hence the name "galaxy", stretching across the sky, while observations at different times of the year and in both hemispheres show that this Milky Way belt goes clear around the sky, practically in a great circle. The concentration of the stars in the Milky Way seems to indicate unmistakably to us that they must extend to greater distances in that direction but, until comparatively recent times, the prepossession that the earth must be the center of the universe tended to the assumption of a spherical distribution. That the stellar system must have a relatively flattened form was first pointed out by Wright, only about 200 years ago. This idea of the flattened shape of the galaxy was further elaborated by the elder Herschel, who by means of his star-gaging about the end of the eighteenth century stated that the shape of the stellar system approximated that of a grindstone.

Our conceptions of the dimensions of the stellar system have grown with increasing knowledge of the distances of the stars. As the distance or parallax of any star was not measured until 1838 and as by the end of the nineteenth century less than 100 stellar parallaxes had been measured, with many of them very uncertainly determined, it is obvious that the ideas of the dimensions of the galaxy prevalent at the beginning of the present century were based on meager observational data and were little better than guesses. It was not until 1905 that Newcomb and Seeliger, who were the first to apply analytical methods to the problem, arrived at an estimate of 7,000 light years for the diameter of the galaxy.

I hope I may be pardoned at this stage for interpolating some explanatory matter with illustrations about the astronomer's yard-stick, the light-year. While I believe that everyone knows what a light-year means, I am sure that very few have any adequate conception how great a distance it represents and, therefore, I venture to repeat the well-known fact that a light-year, the distance that light traveling at the tremendous speed of 186,000 miles per second will cover in a year, represents about 6 million million miles. To get a concrete illustration, the nearest fixed star, α Centauri, in the Southern Hemisphere and not visible in these latitudes, is 4¼ light-years distant, or 25 million million miles. It is very easy to say 25 million million or to see it as 25 followed by 12 ciphers, but not quite so easy to realize the tremendous distance involved. Some help may be gained by calculating how long it would take an express train traveling 60 miles an hour, day and night, to cover this distance. Such a conveyance would take some 57,000,000 years to complete the journey. Perhaps a still better illustration is that of the spider web, the very fine filament used in the reticles of transits or measuring microscopes, of which it is estimated that 2 pounds would stretch around the earth, 25,000 miles. At this rate it would require no less than 1,000,000 tons of spider web to reach α Centauri and hence 1,600 million tons to span Newcomb and Seeliger's estimate of the diameter of the galaxy.

At the risk of boring you, but in the hope of "getting across" some conception of the immensity of stellar distances, and the sparseness of the stars in space, I shall show some figures made by me some 4 years ago to illustrate the scale of the universe. The first is a table (table 1), starting with the smallest known particle, the electron, and proceeding by 21 steps each 100 times the preceding, to the largest known entity, the Einstein universe. It should be stated, of course, that these dimensions were those extant when the drawings were made, but some of them are quite different now, especially the dimensions of the universe, and in the present rapidly changing state of quantum and relativity theory may be again different next year.

TABLE 1.—*Scale of universe*

—9	.000 000 000 000 06 inch	1.6×10^{-13} cm.	Electron.
—8	.000 000 000 006 inch	1.6×10^{-11}	
—7	.000 000 000 6 inch	1.6×10^{-9}	
—6	.000 000 06 inch	1.6×10^{-7}	Atom.
—5	.000 006 inch	1.6×10^{-5}	Soap bubble.
—4	.000 6 inch	1.6×10^{-3}	Tissue paper.
—3	.06 inch	1.6×10^{-1}	
—2	6.3 inches	1.6×10	
—1	.01 mile	1.6×10^{3}	
0	1 mile	1.6×10^{5}	
1	100 miles	1.6×10^{7}	
2	10 000 miles	1.6×10^{9}	Earth.
3	1 000 000 miles	1.6×10^{11}	Earth–moon.
4	100 000 000 miles	1.6×10^{13}	Earth–sun.
5	10 000 000 000 miles	1.6×10^{15}	Solar system.
6	1 000 000 000 000 miles	1.6×10^{17}	
7	17 light-years	1.6×10^{19}	Nearer stars.
8	1 700 light-years	1.6×10^{21}	Local cluster.
9	170 000 light-years	1.6×10^{23}	Galaxy.
10	17 000 000 light-years	1.6×10^{25}	Nearer spirals.
11	1 700 000 000 light-years	1.6×10^{27}	6 × range 100″ telescope.
12	170 000 000 000 light-years	1.6×10^{29} cm.	Einstein universe.

The dimensions are given in centimeters, inches, miles, and light-years, and for comparison corresponding familiar objects are given to the right. The astronomical end of the scale is illustrated by further figures, each having its side 100 times the length of the preceding and each showing in the right-hand lower corner the size of the preceding figure. Starting with a sketch of the Western Hemisphere just nicely fitting in a square with a side 10,000 miles, it and the next two steps, the earth-moon system 1,000,000 miles and the sun-earth 100,000,000 miles are sufficiently familiar not to need illustrating. The next step (fig. 1), again 100 times the length of the preceding

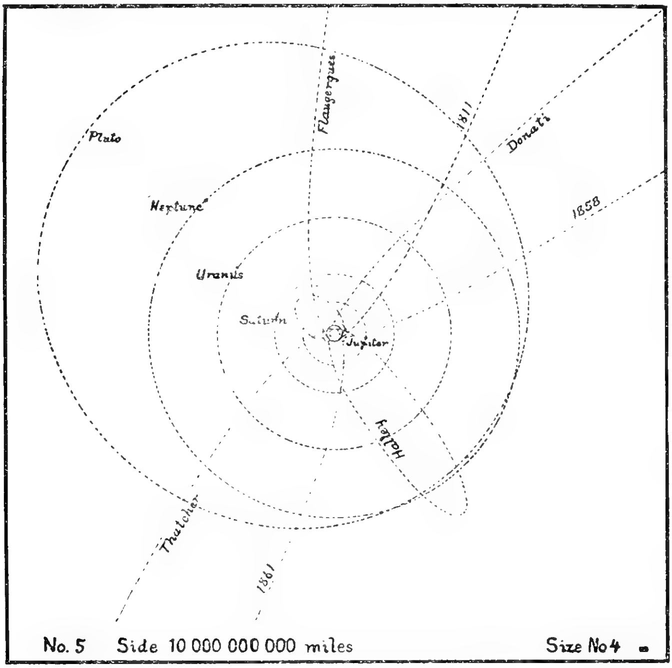


FIGURE 1.—Solar system.

or 10,000,000,000 miles, easily contains the planetary system but only part of the orbits of some of the long-period comets. The next (fig. 2), of 1,000,000,000,000 miles, or one-sixth of a light-year as you will remember, shows the whole planetary system as a dot in empty space. How empty space really is will be better appreciated when it is learned that the sun in this figure would be an invisible dot $\frac{1}{400,000}$ inch in diameter and that you would have to travel 25 times as far in any direction before you would encounter a single star. Yet so tremendous is its extent that it is estimated there are some 200,000,000,000 stars in the galaxy.

The next step (fig. 3), 100,000,000,000,000 miles, or 17 light-years, shows the relative distance and intrinsic brightness of a few of the nearer fixed stars. Please remember that the width of this figure corresponds to a train journey of 230,000,000 years, and yet we see how far we are from anything approaching a galaxy of 200×10^9 stars. If we proceed to the next step (fig. 4), however, scale 1,700 light-years, we are now more nearly approaching galactic dimensions and begin to see what Newcomb and Seeliger were considering when they estimated a diameter of 7,000 light-years with a thickness of about one-fourth the diameter. This group of stars, which is now

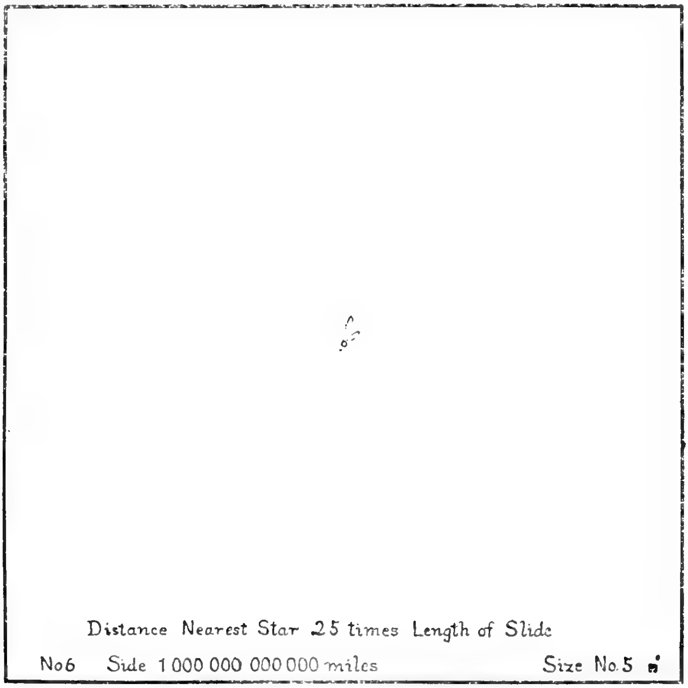


FIGURE 2.—The solar neighborhood.

called the "local cluster", with the sun not quite central, will certainly extend to a diameter of 7,000 light-years or more before the stars become very thinly spaced and probably represents the galaxy of Newcomb and Seeliger.

The dimensions of the galaxy were increased by Walkey in 1914 to a diameter of 14,000 light-years and by Eddington in 1915 to about 15,000 light-years. The most complete investigation of the structure and dimensions of the limited stellar system as then recognized is due to the famous Dutch astronomer, Kapteyn, who in 1920 from long-extended investigations, embracing practically the aim of his life work, gave an idealized representation of the galaxy with the stars thinning out gradually with increasing distance from the sun, more rapidly of course in the direction perpendicular to the plane of the Milky Way. On Kapteyn's system, the diameter along the direction of the Milky Way, where the stars are only one-tenth as thickly spaced as in the neighborhood of the sun, is about 18,000 light-years corresponding to Walkey's and Eddington's dimensions, with a thickness of about 3,500. If, however, one goes farther outward until the stars are only one-hundredth as thickly spaced as near the sun, and hence very sparsely scattered indeed, the diameter would be 55,000 and the thickness 11,000 light-years.

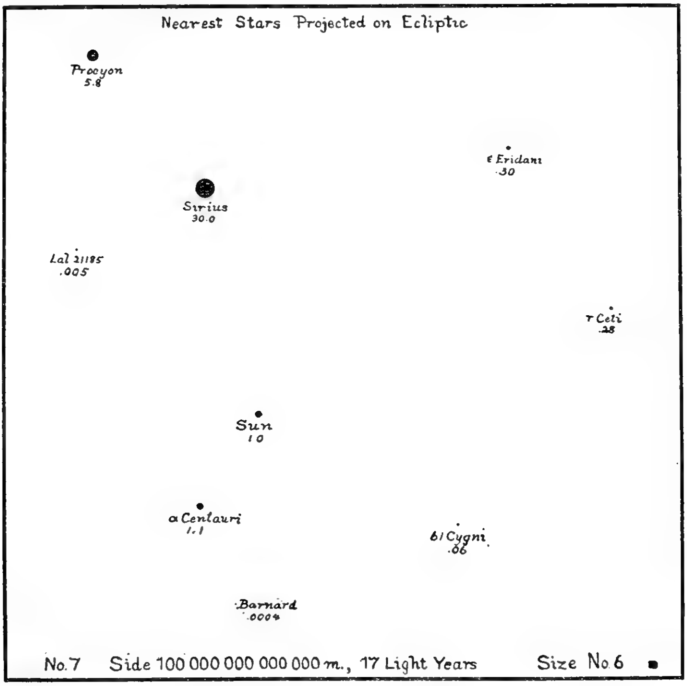


FIGURE 3.—The nearest stars.

But as Kapteyn himself fully realized, all the earlier estimates as well as his own referred to a simplified ideal watch-shaped system of stars, thinning out gradually as you go outward from the sun, which is taken as the center, while the real system is much more complex. Even the most cursory glance at the Milky Way on a clear, moonless night suffices to show that the stellar system has no such regular distribution as that pictured above. It seems rather to be formed of great aggregations of stars, star clouds as they are usually called, separated by sparser regions arranged in the most irregular way, and one is forced to realize, especially when one sees photographs of the Milky Way, how very inadequate were these early conceptions of the galaxy, the distribution being assumed as regular to enable the problem to be treated mathematically. While they probably represent the arrangement of the stars in the neighborhood of the sun, in the local cluster as it is now called—and it should be remembered that it was only these stars whose distances and distribution were then available for analysis—they took no account of the complex and irregular distribution around the Milky Way into the great star clouds, so obvious a feature of its structure.

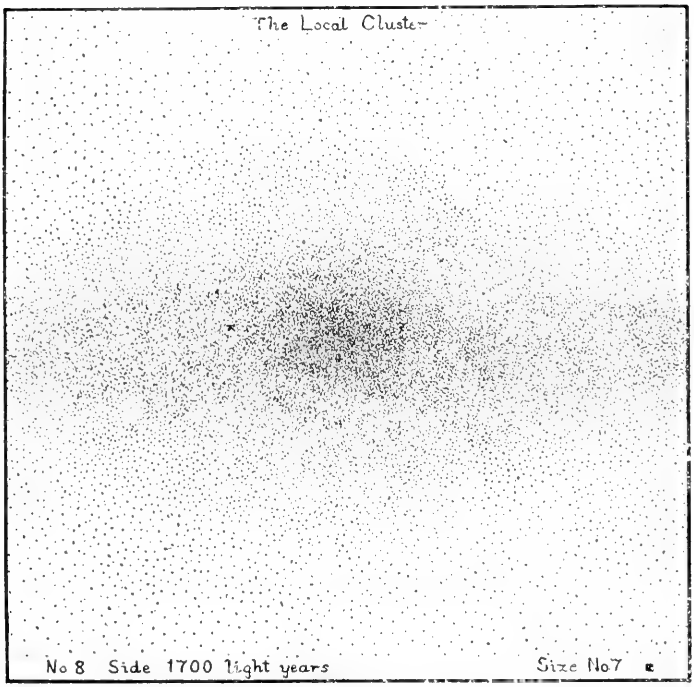


FIGURE 4.—The local cluster.

Even while Kapteyn was preparing his magnum opus and before it was published, a research was under way by Shapley at the Mount Wilson Observatory, which was to supersede Kapteyn's ideal structure and give us a much enlarged conception of the magnitude and complexity of the galaxy. Shapley developed an entirely new method of determining the distances of the stars, depending upon a knowledge of the intrinsic brightness of certain variable stars, the Cepheids. Whereas, by the ordinary trigonometric method, stellar distances beyond a hundred light-years or so are only very uncertainly determined, this luminosity method gives accurate distances to several thousands of light-years. Shapley thus determined the

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distances of the 80-odd globular clusters, curiously distributed over the sky, being nearly all in one hemisphere, which he found to vary from 20,000 to 200,000 light-years. When their positions with respect to the plane of the Milky Way were plotted, the remarkable fact emerged that they were distributed symmetrically with respect to the central plane with the same number on each side, as seen in figure 5, the next step in the scale of the universe. There seems to be no escape from the conclusion that the clusters and the stars belong to the same dynamical organization, that each forms part of the galaxy, and that they must be concentric and coterminous with one another. The central position of our sun in the galaxy forever disappeared when the distribution of the clusters showed that it was about half-way between the center and the edge of the great discoidal system of stars, which Shapley estimated as having a diameter of 300,000 light-years and a thickness of 12,000.

Shapley's conception of the galaxy has been generally accepted with the exception that more recent investigations with more extensive material have shown that Shapley's distances of the clusters, and hence the scale of the galaxy, should be reduced by approximately 40 percent. But even such a reduction leaves the galactic system nearly 200,000 light-years in diameter, of almost inconceivable dimensions, requiring for example 50,000,000,000 tons of spider web to span.

The modern conception of the sidereal system is then not a single watch-shaped cluster of stars surrounding the sun and gradually thinning out toward the edges, but rather a great aggregation composed of this cluster and numerous others, represented by the Milky Way clouds gradually merging into one another at the edges where the stars are thinner, the whole forming one great disklike system roughly circular in outline, but with its thickness only about one-twentieth of its diameter. The globular clusters, though part of the galaxy, are, however, nowhere near the disk (see fig. 5), but form a roughly spherical or spheroidal shell concentric with the disk, a cluster of guardian attendants on each side of the main disklike system—the latter estimated to contain some 200,000,000,000 stars, of which our solar system is but one average member.

A very natural question arises as to the structure and arrangement of the stars in this system. We have seen that, while the stars in the neighborhood of the sun are fairly uniformly distributed in a watch-shaped cluster, gradually thinning out toward the edges, the photographs of the Milky Way clouds show that the structure of adjacent clusters or star clouds as viewed from our position in the disk itself is complex and apparently irregular, without orderly arrangement. But may this not be due to our situation within the plane of the disk where it is impossible to see more than the vertical projection of part of the disk or, in other words, where we cannot distinguish the wood for the trees? As it is impossible for us either to determine the structure of the galaxy from our position within it or to get outside the galaxy to examine it from without, the only recourse is to see if we can find any prototypes outside the galaxy, any outside systems whose structure may legitimately be assumed as similar to our own.

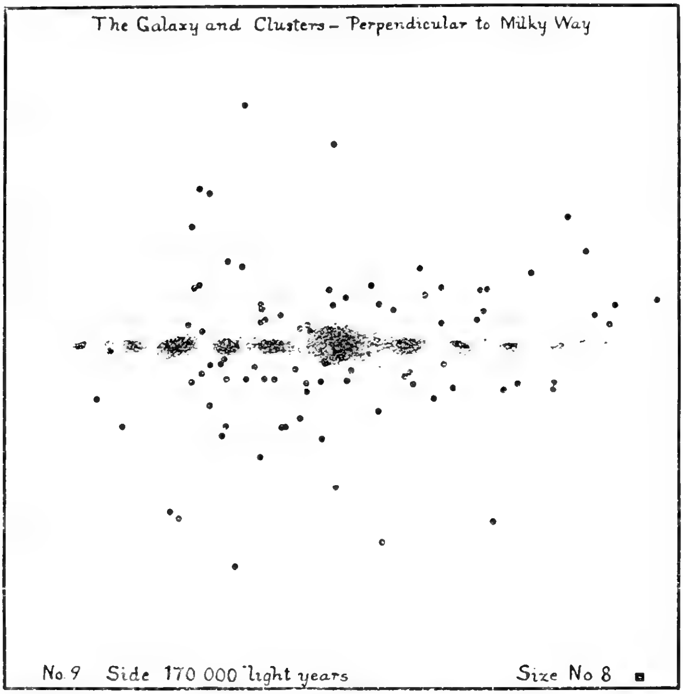

FIGURE 5.—The galactic system.

It is now quite generally believed that the spiral nebulae, of which many thousands or perhaps even millions can be detected by modern telescopes, are external galaxies, are stellar systems, constituted very similarly to our own galaxy. Thanks to the work of Hubble at the Mount Wilson Observatory, who was able, by examining the Cepheid variables in some of the nearer of these nebulae, to determine their distances in the same way that Shapley obtained the distances of the globular clusters in our own galaxy or nebula, we now know the distances and the dimensions of some of the nearer of these external galaxies, these spiral nebulae.

The characteristic form of these external star systems is familiar to all, and we see readily the reason for the name spiral, assigned to these objects, since all show distinctly an extremely flattened disk-like form with a marked central condensation from which spiral arms, with knots or condensations distributed throughout their length, unwind. It surely does not require a very vivid imagination to picture our own galaxy as a great spiral nebula with a flattened disklike form, the local cluster and the Milky Way clouds being the condensations in the arms of this spiral. The main difficulty is the question of size, as our galaxy is undoubtedly four or five times greater in diameter than the largest known spiral, the Great Nebula in Andromeda.

And yet if we examine photographs of the two nearest spirals, Messier 33 in Triangulum and Messier 31, the Great Nebula in Andromeda, we see so many similarities that the essential identity in structure of these spirals and our galaxy can scarcely be doubted. The spiral in Triangulum with a distance of some 900,000 light-years and a diameter of 15,000 is well resolved into stars and star clouds by the 100-inch telescope, and I have always considered this spiral as being a model about one-fifteenth in size of our own galaxy. But the similarity in structural detail is even more marked in the Andromeda nebula, which at a distance of 900,000 light-years has a diameter of 45,000, about one-fifth of the galaxy. A photograph of part of the Andromeda nebula on a large scale with the 100-inch telescope shows so striking a resemblance to the Milky Way clouds that, especially if we remember the difference in scale and that the fainter stars cannot show in the Andromeda on account of the great distance, no one who sees them can doubt the essential similarity of structure.

We can then, I think, legitimately assume that the galaxy is a great discoidal aggregation some 200,000 light-years in diameter and 10,000 in thickness, built up of stars and star clouds which gradually merge into one another at the edges where the stars are thinner. It also seems legitimate to assume, from analogy with the external galaxies, the spiral nebulae, that it has a marked central condensation, indicated by the richness of the star clouds in the direction of the center in Sagittarius, and a definite spiral form with the Milky Way clouds as the condensations along the spiral arms. Our sun is near the center of one of these condensations, the local cluster, situated about halfway between the center and the edge of the whole system. It seems obvious, from our position within the system, that the structure of the adjacent condensations, particularly when complicated by the presence of absorbing matter or clouds, so prominent a feature of both the galaxy and the spirals, could easily reproduce the structure we see in the Milky Way clouds. Although we cannot prove positively that the galaxy is so constituted, any evidence we have is in favor of such a conception, while the essential similarity in structure of all the spirals forms strong presumptive evidence of a similar structure in the galaxy. That the galaxy is essentially a homogeneous unit like the spirals is indicated by the demonstration, based mainly on observational data obtained at Victoria, that the space between the stars is uniformly pervaded throughout by almost incredibly diffuse matter, millions of times more tenuous than the highest vacuum we can produce on the earth, with the molecules about a centimeter apart, and so tenuous that there would be only about 4 ounces of this gaseous matter in the whole volume of the earth. Our conception of the galaxy as a single homogeneous dynamical unit is much strengthened by the proof to be presently given that both stars and diffuse matter are in beautifully ordered rotation in their own plane.

Another view of the galaxy was, however, advanced about a year ago by Shapley, who was the originator of the present conception of its dimensions and structure. Shapley contends that, as the galaxy is five times larger than any other known system, it is not likely to have a similar structure. He analyzes loose clusters of nebulae in Virgo and Centaurus and assumes that the galaxy is built up of a number of discrete nebulae loosely aggregated together. There are, however, many difficulties in this hypothesis, for in the clusters he assumes as analogous there is no trace of discoidal form, while the component nebulae are widely separated from one another in contradistinction to the galaxy, where star clouds merge into one another. But the main objection to Shapley's new hypothesis lies in the demonstrated dynamical unity of the galaxy and in its ordered rotation in its own plane, to which his loose groups of nebulae have not the least similarity.

II. THE ROTATION OF THE GALAXY

The conception we have tried to develop of the structure of the galaxy should enable us to understand better the motions in the galaxy. The name, the "fixed stars", is a misnomer, as it has long been known that motion is a universal property of the stars. The motion of a star, which may be in any direction, can only be measured in two directions—its cross motion, or change of position in the sky, called the proper motion, and its motion in the line of sight, its radial velocity measured by the spectroscope. From these two components, provided the distance is known, we can get the real or space motion of any star. The proper motions are all very small, the largest being a change of position of 10″ per year, or the width of the moon in 180 years, while the majority of proper motions are less than one-hundredth of this, or moon width in 18,000 years. The radial velocities, which will mainly be dealt with in this discussion, vary from zero up to some 40 or 50 kilometers per second, on the average about 20 kilometers, 12 miles, per second, although a few stars have higher velocities, up to 300 or 400 kilometers per second.

The motions of the stars appear in general to be quite at random without trace of regularity, like a swarm of mosquitoes, for example, or a crowd of people holidaying in a park. It was, however, early realized that our sun, if in motion, would give an apparent systematic trend to the motions of the other stars; and Herschel, as early as 1783, from the proper motions of 13 stars, showed that the sun was moving toward the constellation Hercules. The method used may be illustrated from the example of people moving at random in a park. It is obvious that a person going through the park will see the people in front, on the whole, seem to approach, those behind appear to recede, and those at the sides to be moving backward. In this way, from the proper motions and radial velocities of several thousand stars, we know with some precision that the sun is approaching the constellation Lyra, not far from Herschel's first attempt, with a speed of 20 kilometers, 12 miles, per second. Owing to our moving viewpoint on the solar system, it is evident the stars will all have spurious apparent motions, and before we can discuss the real motions of the stars we must first of all correct for the solar motion. Hereafter, when speaking of stellar motions, therefore, we shall be referring to the corrected or real motions of the stars.

The motions of the stars are so nearly at random that it was not until 1905 that Kapteyn found there was a preference of the proper motions for two opposite directions, "star-streaming" as he called it, the effect being as if there were two systems of stars each with random motions, interpenetrating one another. No satisfactory explanation of this phenomenon was forthcoming, though it was generally agreed it must be due to the gravitational attraction of the whole system. A second mysterious systematic effect was discovered by Stromberg at Mount Wilson in 1924. Stromberg showed that the motions of all the stars with velocities greater than 80 kilometers per second, the high-velocity stars, were not at random but were all directed to one hemisphere of the sky. Stromberg was unable to offer any satisfactory explanation for this "asymmetry in stellar velocities" as he called it. It was found, however, that the mean direction was almost exactly at right angles to the direction to the center of the galaxy in Sagittarius.

These two systematic effects in the motions of the stars and the need of some comprehensive treatment of the dynamics of the stellar system have been met only very recently by Lindblad's theory of the rotation of the galaxy in 1926. Although speculations about the rotation of the stellar system about some central star were prevalent during the nineteenth century, they had no observational data to support them and could not survive. Before giving Lindblad's hypothesis, however, there are some general considerations unknown earlier in support of a rotation of the galaxy which may well be cited.

We have already built up our conception of the galaxy as a tremendous discoidal aggregation of stars and star clouds with a diameter of 200,000 and a thickness of 10,000 light-years. Elementary dynamics at once indicates that such a thin disk-shaped system could only be maintained in a flattened form by rapid rotation, otherwise it would assume a more nearly spherical shape. And we have not far to go to find analogues showing rotation. The very structure of the spirals suggests rotation; they are just like a Catherine wheel. Moreover, the spectroscope has demonstrated that several of them are in rapid rotation. Unfortunately, however, we cannot get outside our galaxy to test its rotation spectroscopically, and there did not seem any means of attacking the problem internally from our position within the system, where all the stars we can observe are rotating as well as ourselves.

The way was first pointed out by Lindblad in 1926 in a series of papers to the Swedish Academy. Lindblad postulated that the galaxy was composed of a number of subsystems, approximately concentric with one another, and all in rotation at different rates around a common axis perpendicular to the galactic plane. The subsystem rotating at the highest speed would evidently by centrifugal force be the most flattened toward the central plane and, on Lindblad's hypothesis, is the one containing our sun, the local cluster, the Milky Way clouds, and the vast majority of the stars. Subsystems with a lower rotational speed would be less flattened to the galactic plane. The stars in such a slower-moving subsystem would appear to us to be moving much faster, to have higher radial velocities than the stars in our own system, as our high rotational speed, about 300 kilometers, or 200 miles, per second, would sweep us rapidly past them. The most slowly rotating subsystem is the system of globular clusters which are little flattened toward the plane and whose low rotational speed gives them apparently high velocities in the line of sight with respect to the sun.

Lindblad's hypothesis at once gives an explanation of Stromberg's asymmetry, as the high-velocity stars evidently belong to a slower-moving subsystem and being overtaken by the higher rotational speed of the sun, at right angles to the direction to the center, gives them the appearance of moving in the opposite direction, as has already been shown. The phenomenon of star-streaming, the preferential direction being nearly in the direction to the center of the galaxy, is also explainable though not so directly as a result of galactic rotation. While Lindblad's theory thus successfully accounted for these previously unexplained systematic motions, it did not point the way to any observational means of testing the rotation. A method was developed by J. H. Oort, of Leyden, in a masterly paper about a year later, but before discussing Oort's work, it will be well to consider the general consequences of a rotation and to see what possibility there is of detecting any rotation from our position within the galaxy where the sun and stars are rotating together.

The rotation of a system of stars implies a central attracting force, obviously provided by the matter of the stars themselves, directed toward the center of gravity of the system. The law of force and the manner of rotation will depend upon the distribution of the stars within the system, and two particular cases may be considered, that of uniform distribution and that of a concentration toward the center.

In the case of uniform distribution of the stars or matter throughout the system, it is an elementary principle of dynamics that for stars within the system the attractive force will be directly proportional to the distance from the center, and that all the bodies within the system will revolve around the center in the same time; in other words, such a stellar system will rotate like a solid disk or wheel. For uniform distribution of the stars throughout a system, there will hence be no relative motion between the sun and stars and no possibility of detecting a rotation from observations of the radial velocities or proper motions of neighboring stars. Just as a fly on the spoke of a rapidly rotating wheel could not tell by observing other flies on the rim, hub, or spokes whether the wheel was stationary or spinning.

Although it is impossible to detect a rotation of the galaxy from internal evidence, when the stars are uniformly distributed through the system, the position is more hopeful if there is a concentration of the stars or matter toward the center. Analogy with the spirals, which all show central condensation, makes it highly probable that the stars are more concentrated toward the center of the galaxy. In the extreme theoretical case, with all the matter concentrated at the center, practically true of the solar system, the attracting force is inversely as the square of the distance, and the bodies or stars nearer the center revolve faster, both linearly and angularly, than those farther out. An example is the solar system, where the inner planets move much faster than the outer, and if we were to measure the radial velocities of the planets we could prove that they were in rotation about the sun and be able to find the direction to the sun from these motions even if the latter were or became invisible. This was done by Gyldén as far back as 1871, when from the motions of some of the asteroids he determined the direction to the sun within 6°. Exactly the same relation holds in the stellar system for, even if only part of the matter is concentrated at the center, the revolution will follow some intermediate course between constant angular velocity and planetary motion, and it is obvious that as long as there is any condensation toward the center, there will be relative motion between the neighboring stars which can be measured and the rotation determined. This can be shown perhaps more clearly by a diagram, figure 6.

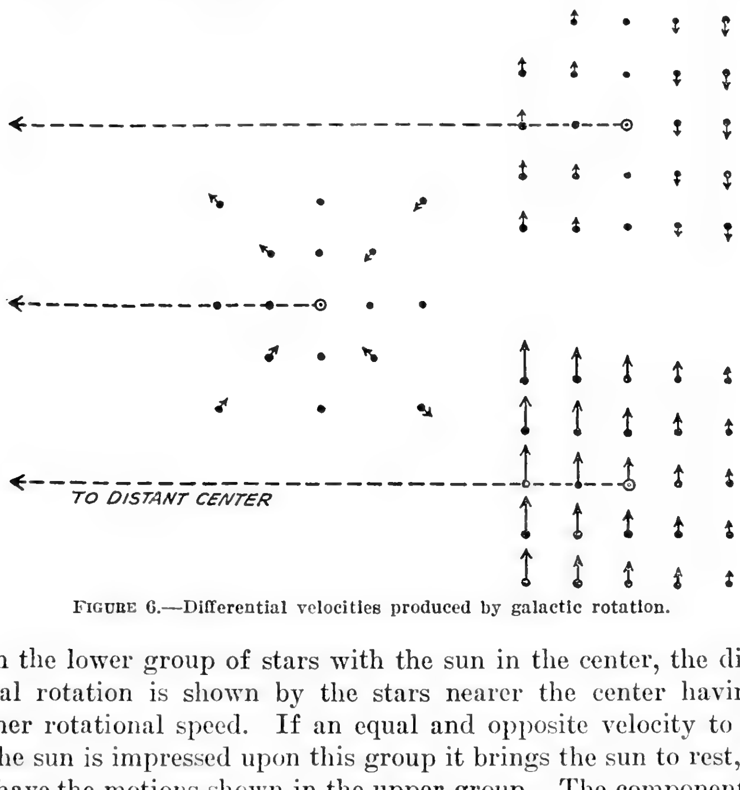

FIGURE 6.—Differential velocities produced by galactic rotation.

In the lower group of stars with the sun in the center, the differential rotation is shown by the stars nearer the center having a higher rotational speed. If an equal and opposite velocity to that of the sun is impressed upon this group it brings the sun to rest, and we have the motions shown in the upper group. The components of these velocities in the direction of the sun, the radial velocities, are shown in the center group. It will at once be seen that the relative motion or the rotational effect depends not only on the angle between the star and the direction to the center but also on the distance of the star from the sun. There is no rotational effect along, and perpendicular to, the direction to the center, while the maximum rotational effects are midway between the zero values.

Oort's great contribution to the problem of the rotation of the galaxy was to translate the foregoing general principles into simple mathematical language and test the resulting expressions from the known motions of the stars. Expressed most simply, this states that the residual velocity of any star, the velocity after the effect of the solar motion has been removed, the actual velocity of the star in the system, is directly proportional to its distance from the sun, provided only that this distance is small compared to the distance of the center, and to the sine of twice the angle between the star and the direction to the center of the galaxy, or

$$\rho = \bar{r}A \sin 2(l - l_o)$$

Oort showed conclusively from an analysis of the then known radial velocities of all the more distant celestial objects such as the O-, B-, and N-type stars, the Cepheids and the " c " stars, the planetary nebulae and the calcium clouds, that the observed velocities of all these objects followed closely those predicted by the galactic rotation. If the observed distribution of the velocities of all these objects is not due to a rotation of the galaxy, the producing cause gives results very similar to galactic rotation.

There are certain limitations and difficulties in conclusively demonstrating the rotation which should be noted. It has been shown that the rotation produces a change in velocity of 1 kilometer per second for stars at a distance of 200 light-years. Since, owing to the effect of the random motions and of errors of observation, a rotational effect of 5 kilometers is the minimum for definite results, this requires a knowledge of the velocities of stars 1,000 light-years distant. Only a very small proportion of the stars at that distance are bright enough for velocity determinations, and the numbers for analysis are hence very small, too small to overcome the disturbing effect of the random motions which only become harmless when averaged out over several stars. Consequently Oort's tests of the galactic rotation were limited by the small number of radial velocities of distant stars available at that time.

Fortunately, at Victoria there were available as a result of about 6 years' work by Dr. Pearce and me, the radial velocities of some 500 O- and B-type stars, the hottest, most massive, most luminous stars in the sky, and hence the most distant that can be spectroscopically observed. As they also have the smallest random motions of any class of stars they are especially suitable for testing the rotation of the galaxy and indeed have provided the most convincing evidence of its reality. It is necessary, however, as the rotational effect is directly proportional to the distance, to arrange these stars into groups at different distances. This is a difficult task, as no reliable parallaxes are available. If the stars were all of the same intrinsic brightness, they could be arranged according to distance by the apparent magnitudes, but this criterion is imperfect on account of the considerable range in total brightness. The criterion eventually used depends on the properties of the diffuse gaseous matter pervading the system which has already been mentioned, whose presence is revealed and its motions determined by the dark absorption lines H and K of calcium in the spectra of these stars. The more distant the star, the greater depth of the diffuse gas the starlight passes through, the greater the absorption, and the stronger the H and K lines. Some 250 of these stars in which the H and K lines are well defined were arranged into three groups of weak, medium, and strong lines, and consequently into groups of stars, as eventually appeared at average distances of 2,000, 3,000, and 5,500 light-years.

As the rotational effect depends also upon the angle between the star and the direction to the center of the galaxy, each of these distance groups was arranged into some 10 subgroups in longitude. This had the further advantage, by combining a number of stars in each subgroup, of diminishing the disturbing effects of random motions. These different groups were then solved by Oort's equation, using the method of least-squares, a mathematical process of getting the most probable values of the unknown quantities. The results of this solution are exhibited in table 2, in which the second and third columns contain the number of stars and the average longitude of each subgroup. The fourth column gives the average observed residual velocity, corrected for the solar motion, of the stars in each subgroup. The fifth column gives the computed velocity that would be produced by the galactic rotation for the mean longitude of each group.

The eye needs only to glance down the pair of columns to be struck by the remarkable agreement between the observed velocities and those that would be produced by a rotation of the galaxy. The coincidence seems even more striking when it is remembered that there are unavoidable errors of observation present in the velocities and that the stars have random motions on the average of about 10 kilometers per second. Considering the small numbers of stars in many of the groups and the disturbing effects of such random motions, the agreement is extraordinary and can certainly not be accidental. If the double wave swing of the residual velocities, from positive to negative and back again to positive, so distinctly shown in every group, is not due to a rotation of the galaxy, it must arise from some cause which gives a distribution of the residual velocities almost exactly similar to that produced by the galactic rotation.

TABLE 2.—*Comparison of velocities*

Group	Number	Mean longitude	Stellar velocities: Observed	Stellar velocities: Computed	Cloud velocities: Observed	Cloud velocities: Computed
		Intensity of interstellar lines 4.4 to 6.9		$rA=+10.22$		$rA=+5.03$
1..................	2	345°	+36. 2	+10. 8	−1. 2	+3. 3
2..................	2	17	+ 5. 9	+14. 0	+4. 9	+4. 9
3..................	14	38	+10. 4	+ 9. 9	+5. 7	+2. 9
4..................	11	61	+ 6. 4	+ 2. 1	−0. 4	−1. 0
5..................	13	75	− 7. 3	− 2. 4	−0. 4	−3. 2
6..................	8	89	− 6. 8	− 5. 3	−6. 0	−4. 6
7..................	8	113	− 2. 1	− 5. 0	−6. 9	−4. 4
8..................	6	131	+ 4. 5	− 0. 5	+2. 7	−2. 2
9..................	8	156	+ 7. 0	+ 8. 0	−1. 7	+2. 0
10..................	13	174	+14. 4	+12. 6	+4. 9	+4. 1
11..................	3	205	− 2. 6	+ 9. 8	+3. 4	+4. 2
		Intensity of interstellar lines 7.0 to 7.9		$rA=+14.53$		$rA=+6.91$
1..................	8	12	+ 5. 5	+14. 3	+ 4. 6	+ 6. 7
2..................	12	38	+ 8. 9	+ 8. 0	+ 6. 3	+ 3. 7
3..................	11	51	+ 7. 2	+ 1. 7	+ 4. 8	+ 0. 6
4..................	10	65	− 1. 5	− 5. 3	− 0. 9	− 2. 6
5..................	4	75	− 7. 8	− 9. 5	− 2. 4	− 4. 7
6..................	8	89	−20. 2	−13. 7	−10. 6	−16. 7
7..................	3	110	−23. 9	−13. 9	− 9. 7	− 6. 7
8..................	3	139	+ 1. 7	− 3. 2	− 0. 3	− 1. 7
9..................	9	160	+10. 6	+ 7. 2	+ 0. 2	+ 3. 3
10..................	10	174	+17. 2	+12. 2	+ 2. 7	+ 5. 6
11..................	1	192	+44. 6	+14. 4	+13. 0	+ 6. 7
		Intensity of interstellar lines 8.0 to 9.5		$rA=+27.52$		$rA=+13.72$
1..................	2	358	+35. 7	+24. 3	+ 8. 2	+ 9. 4
2..................	2	17	+12. 2	+29. 3	+ 6. 1	+11. 9
3..................	6	34	+21. 5	+21. 3	+ 7. 5	+ 7. 9
4..................	2	47	+11. 8	+10. 4	+ 6. 6	+ 2. 4
5..................	12	70	− 3. 4	−10. 4	− 5. 4	− 8. 0
6..................	4	97	−26. 8	−23. 4	−15. 5	−14. 3
7..................	9	107	−28. 4	−23. 5	−17. 7	−14. 5
8..................	4	141	− 4. 1	− 0. 9	+ 1. 2	− 3. 2
9..................	2	169	+13. 6	+16. 0	+ 1. 9	+ 5. 3

It will be noted that the velocities of the diffuse cosmic matter, or cloud, which are obtained from the displacement of the interstellar H and K lines in the same way as the stellar velocities from the hydrogen and helium lines, are given in the sixth column, and that these velocities show an even closer agreement with those that would be produced by a rotation of the galaxy, given in the seventh column, than is the case in the stellar velocities. No one who bears this agreement in mind can have any reasonable doubt that not only the stars but the intervening exceedingly diffuse matter, 4 ounces in the volume of the earth, are rotating around a very distant center in the direction of the constellation Sagittarius. This direction of 328° is determined from the least-squares solutions at the same time as the rotational effect rA. Our conviction of the reality of the galactic rotation will be considerably strengthened when we learn that the geometrical center of the galaxy as determined by Shapley from the distribution of the globular clusters is at galactic longitude 327°, agreeing exactly, within the errors of observation, with that determined dynamically on the assumption of a rotation of the galaxy from the distribution of the velocities.

It will be of interest to derive some more general results of the rotation. I am sure it is not necessary to tell you that the velocities we have been discussing are not the rotational velocities around the galactic center but only the differences in velocity produced by the change in rotational velocity at different distances from the center. The orbital or rotational velocity is much greater, though not yet very rigorously determined. One way of obtaining it is from measures of the radial velocity of the globular clusters, which, as we have seen, have a low rotational motion and whose mean observed velocity should hence give the orbital velocity of the sun. The result shows that the rotational speed is of the order of 300 kilometers, or 200 miles, per second. This becomes greater as we go toward and smaller as we go away from the center. Computing the change, it appears that 5,000 light-years nearer the center the speed will be 335 kilometers per second, and 5,000 light-years farther away, 265 kilometers per second. As you have seen, it is these changes in rotational speed that cause the velocity differences discussed.

As compared with terrestrial velocities, the rotational speed of 300 kilometers per second is tremendous indeed, nearly 2,000 times faster than man has ever traveled on the earth, than the speed attained in the recent Schneider Cup trials of 400 miles per hour, but yet so vast are the dimensions of the galaxy that it will take the sun about 250,000,000 years to complete one revolution. Hence, during the whole span of geologic time on the earth our sun has only made some five or six revolutions in its orbit. This velocity of 300 kilometers per second only corresponds to a change of angle or longitude of ″0.006 per year, hence the hopelessness of detecting the rotation by observing the proper motion of external objects is obvious.

The magnitude of the rotational effect—the value of A, which we have found to be 1 kilometer per second for stars 200 light-years away—and the orbital speed of the sun, 300 kilometers per second, enable us to calculate the distance of the sun from the center and the total mass of the system. The distance of the sun from the center, on the assumption that the main part of the mass is concentrated near the center, comes out as about 40,000 light-years and the total mass of the galaxy as about that of 250,000,000,000 suns. If the orbital speed were smaller or the mass less concentrated to the center, these dimensions would be somewhat reduced, though the order is not changed. Please remember that this distance and the mass are calculated, on the assumption of a rotation of the galaxy, wholly from the radial velocities of relatively few stars without any reference to measures of stellar distances or star counts.

It will be of interest to compare these dimensions with those arrived at in our discussion of the structure of the galaxy and based on the distances of the globular clusters. The diameter arrived at was 200,000 light-years, which, with the sun halfway between center and edge, makes its distance from the center 50,000 light-years, a very satisfactory agreement of geometrical and dynamical values. Seares and Van Rhyn, from the result of star counts, estimated a total of 30,000,000,000 stars in the galaxy. Since dark nebulae obstruct our view, particularly in the direction of the center in Sagittarius, the numbers may well be much greater, while there is in addition the mass of the cosmic cloud and the bright and dark nebulae, so that the dynamical estimate may not be unreasonably higher than the geometrical.

The evidence seems overwhelmingly in favor of a rotation of the galaxy, but before unreserved acceptance two difficulties should be mentioned. In the first place, practically all the velocity data on which the observational test was made covered barely three-fifths of the way around the galactic plane. While it seems highly probable that the lacking velocities from the southern sky will confirm the northern results, we should accept the evidence with some reserve until the actual observations are available. The same difficulty, of the insufficiency of data in the southern sky, is felt in almost every general astronomical investigation and to my mind money spent in the increase of astronomical equipment in the Northern Hemisphere would be much more useful if it could be transferred to the Southern. The second difficulty lies in the shearing effect of the differential rotation on the permanence of such aggregations of stars as the local cluster and the Milky Way clouds. If we take the local cluster as 5,000 light-years in diameter, the differential rotation will cause the inner edge of the cluster to make 8 revolutions while the outer part is making 7. Obviously a compact cluster will be sheared into an elongated form, so that the presence of star clouds in the galaxy must be regarded only as transitory eddies in a whirlpool which form and dissipate continually.

Nevertheless, the evidence in favor of the rotation seems overwhelming and it will be useful to summarize it briefly: (*a*) The spiral nebulae, to which strong evidence points as being replicas of the galaxy on a smaller scale, are by their very appearance obviously in rotation, while rapid rotation has been spectroscopically measured in several of them. (*b*) The extremely flattened shape of the galaxy, with the thickness only about one-twentieth the diameter, is in itself almost indisputable evidence of rapid rotation in its own plane; otherwise it would assume a more nearly spherical form like a globular cluster. (*c*) The very presence of the cosmic diffuse matter, obeying the differential rotational swing exactly as the stars, is in itself a proof of galactic rotation. Only rotation could have kept this gas distended throughout the system and have prevented it from long ago collapsing into a dense nebula at the center. (*d*) The satisfactory manner in which the galactic rotation has accounted for the previously unexplained systematic effect of star-streaming and the asymmetry in the high-velocity stars also counts in its favor. (*e*) The observed residual velocities of the most distant stars and of the cosmic cloud agree so closely with those that would be produced by a rotation of the galaxy as to make any other explanation highly improbable. (*f*) And finally the dimensions of the system and the direction to the center as determined dynamically from the analysis of the velocities agree almost exactly with those determined by the direct geometrical measures of distance and position of the center.

I have been attempting this evening, with I hope some success, to carry you with me in imagination away from our terrestrial limitations, not to the bounds of space which are as yet glimpsed uncertainly, if at all, but only sufficiently far to give a comprehensive view of the galaxy. We should now be able to see it, not as an unorganized aggregation of stars and star clouds, still less as a haphazard collection of widely separated nebulae, but as a great dynamical unit of definite discoidal form rotating in its own plane in a majestic and beautifully ordered way. The galaxy is a wonderful example of the universal reign of law in the physical world and of the beneficent wisdom and power of the Supreme Ruler of the universe.

NOTES ADDED BY AUTHOR, APRIL 1934

Developments in astronomy in the 2 years since this lecture was given have considerably modified some of the dimensions there given and the conclusions reached, and it seemed desirable to incorporate the changes in an appendix rather than modify the text.

The principal development has been the general acceptance by astronomers of the presence of some kind of an absorbing medium in the galaxy, principally in the neighborhood of the central plane, which both dims and reddens the light of distant stars. The effect of such an absorbing medium on the determinations of the dimensions of the galaxy are fairly obvious when it is remembered that these dimensions depend principally upon the known intrinsic brightness of the Cepheid variables. The inverse square law enables the distance of any star to be determined if its intrinsic and apparent brightnesses are known. Any absorbing matter between us and the star will make it appear fainter and its distance will hence be measured too great.

Various determinations of the decrease in apparent brightness produced by the galactic absorbing matter have been made, but the most recent and direct is by Stebbins at Mount Wilson, who by means of a photoelectric photometer determined how much the globular clusters, from whose distribution the estimate of a diameter of the galaxy of 200,000 light-years was made, were reddened by this absorbing matter. The startling conclusion was reached that the presence of this obscuring material had made the previous estimates of the distances of the globular clusters about twice too great and that the actual diameter of the galaxy is only about 100,000 light-years instead of the 200,000 obtained without consideration of the presence of absorbing material.

This decreased diameter has been convincingly confirmed by a development of the theory of the rotation of the galaxy discussed in the last section of the lecture. If the galaxy is in rotation, and this is now almost universally accepted by astronomers, the theory shows, and indeed it follows directly from Kepler's third law, that the distance of the sun from the gravitational center of the galaxy can be obtained from certain constants of the rotation. These constants can be derived from an analysis of the radial velocities and proper motions of distant stars, and this has been done by the author and Dr. J. A. Pearce in collaboration at Victoria for the most distant stars that can be readily observed. Earlier determinations by this method were considerably smaller, but the Victoria value from increased and more accurate material gives the distance of the sun to the center as some 33,000 light-years. The sun, from reliable evidence, is about two-thirds of the distance outward from the center of the edge of the galaxy, which makes the diameter 100,000 light-years. The agreement by these two entirely different and independent methods is strong evidence of the essential correctness of this revised diameter of 100,000 light-years for the galaxy.

This reduces the disparity in size between the galaxy and the Andromeda nebula to a little over 2 to 1 instead of the 4 or 5 to 1 given in the lecture. But this disparity almost entirely disappears by reason of recent measures, which double the apparent size of the Andromeda. Hubble has discovered over 100 objects on photographs of this nebula, which he identifies as globular clusters, and their distribution indicates that the nebula must extend to about twice the size shown by long-exposure photographs. Similarly, within the last few months Stebbins has measured by a photoelectric photometer the outlying regions of the Andromeda nebula and finds that the luminous star clouds extend also to about twice its apparent diameter.

This obviously makes the Andromeda nebula of practically the same dimensions as the galaxy and enormously strengthens the conclusion reached in the lecture of the identity in structure and general characteristics of the two systems. It renders improbable and unnecessary the hypothesis of some astronomers that the galaxy is not a single unit rotating in its own plane, similar to the external nebulae we see all around us, but is a large complex organization of loosely aggregated discrete nebulae. It seems to me that the removal of the disparity in size between the Andromeda and the galaxy has removed the necessity or probability of such hypotheses and that we may now accept readily our inherent belief in the homogeneity of the cosmos.

THE CONTENTS OF INTERSTELLAR SPACE [1]

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[With 3 plates]

Many years ago the late Professor Barnard, whose devotion to celestial photography was extraordinary, found many regions among the multitudes of stars in the Milky Way where stars seem to be absent. Plates 1 and 2 show some outstanding instances of this. To explain these vacancies we must suppose either that there are no stars in these directions, so that we see clear through our system to the void beyond, or else that dark clouds of matter intercept the light of the stars which lie beyond them. Such clouds, as they are supposed to be, are not connected in any way to our earth, as rain clouds are, for however many times one photographs these parts of the heavens the dark starless regions remain unchanged. The results of recent studies, described in what follows, go to show that the dark regions are in fact caused by condensations of a rare medium which fills all space within our galaxy.

Although in the opinion of astronomers the dark-cloud hypothesis was more probable than the star-vacancy hypothesis, it was some years before the proof came. In order to make it clear we must recall that when the light of the sun or of a star is made to pass through a spectroscope, not only does the rainbow band of colors appear, but this band is crossed by numerous dark (or sometimes bright) lines. These lines are the identifying marks of the chemical elements. (See pl. 3.) Hydrogen, for instance, has a line in the red, one in the blue, one in the indigo, and one in the violet, all of which are very conspicuous. Calcium (the metallic part of the familiar compound, lime) has 1 line in the green, 2 in the indigo, 2 very notable ones (often called "H" and "K") in the violet, and

[1] This article is based upon two technical papers, one by Otto Struve (Popular Astronomy, vol. 41, no. 8, p. 423, 1933), the other by J. S. Plaskett and J. A. Pearce (Publications of the Dominion Astrophysical Observatory, vol. 5, no. 3, p. 167, 1933). Although parts of the article are largely in the words of these authors, it was necessary in adapting the material for use in the Smithsonian Report to make slight verbal changes throughout, and for that reason no quotation marks are used. Pages 212 to 215 are based on Plaskett and Pearce, pages 216 to 218 on Struve.

others in the ultraviolet. Recent remarkable progress in atomic physics has proved that the spectrum lines of a chemical element do not all refer to the atoms of that element in a complete state. Atoms when highly excited by intense heat, radiation, or electricity may temporarily lose one or more electrons. Some of their spectral lines refer to the fragments more or less diminished which remain with the nucleus of the atoms so excited. The H and K lines of calcium, for example, represent ionized calcium atoms with one electron gone.

The sun and the stars are all moving rapidly with reference to one another through space. About the year 1910 L. Boss and W. W. Campbell independently showed that the sun is moving at about 12 miles per second toward a well-defined point in the constellation Hercules, about 10° southwest of the bright star Vega. In Campbell's determination the frame of reference was fixed by the positions of 280 bright stars. Later, in 1926, Campbell and Moore employed 2,119 stars in determining the solar motion. Many of the stars form double, triple, or even more complex systems, revolving with respect to the center of gravity of the components, as well as traveling rapidly through space together. All such motions, including the motion of our sun toward Hercules, express themselves in the spectra by shifting the positions of all the spectral lines of the moving luminaries. The lines shift toward the red when the star is receding (see pl. 3), and toward the violet when it is approaching us, or what amounts to the same thing, when we are receding from or approaching the stars. Astronomers, by measuring these line shifts accurately, can estimate the velocities of stars away from or toward the sun, as the case may be. In the case of double stars, with short periods of mutual revolution, the spectral lines shift alternately toward the red and toward the violet, and betray the exact period of rotation, and in some cases the diameter of the star's orbit.

Some 27 years ago Hartmann [2] first observed, in the spectroscopic binary δ Orionis, that the H and K lines of calcium did not share in the orbital velocity oscillations of the hydrogen and helium lines arising in the stellar atmosphere, but remained relatively fixed in position, hence the name "stationary" calcium lines, which has persisted almost to the present time. By far the most suggestive and penetrating early contribution to the problem of the stationary H and K lines was given by V. M. Slipher [3] in 1909.

Slipher measured the velocities given by the stationary calcium lines in 10 bluish stars in the constellations Scorpio, Ophiuchus, Perseus, and Orion. From observations of π and σ Scorpii, double-lined spectroscopic binaries (both components being bright enough

[2] Astrophys. Journ., vol. 19, p. 268, 1904.
[3] Lowell Obs. Bull., vol. 2, p. 1, 1909.

to show spectral lines), he deduced that "the sharp calcium lines must have their origin in an absorbing medium outside the components of the binary systems." This conclusion was, of course, facilitated by the doubling of all the spectral lines belonging to these stars because of their mutual revolution. But his analysis did not end there, for by combining his results with the then recent studies of Campbell on the rapid motion of our sun with reference to 280 of the brighter stars Slipher was able to prove "that the origin of the calcium absorption lines remains fixed with reference to the frame fixed by Campbell's 280 stars, or, at most, has a very low velocity, and therefore that it is outside the solar system, apparently in stellar space." He advances as an hypothesis, "It might then, for the present, be assumed that the calcium absorption has its origin in an interposing cloud covering at least certain extensive regions of the sky." When, in addition, he suggested that the sodium D lines be investigated for their stationary character, it will be evident from what follows how far he was in advance of the time, and how unfortunate for the progress of this subject that this contribution remained comparatively unnoticed.

In 1920, in an investigation by Plaskett,[4] on the massive eclipsing system Y Cygni, it was found that the relative shifting of the calcium spectral lines indicated a difference of 40 kilometers per second in velocity for calcium away from the center of mass of the two stars, as measured by the lines of other chemical elements. This large motion is quite beyond the possibility of explanation as errors of measurement or wave length, and definitely rules out the hypothesis of any limited calcium cloud surrounding the observed stars. For out of such a cloud with such rapid relative motion the eclipsing system would soon escape. Similar velocity differences were soon found, and a new phase of the problem developed in a further research on the O-type stars.[5] It was conclusively shown that these stationary calcium lines were present, not only in spectroscopic binaries but in all stars of the class; and that the velocity given by these lines generally differed, frequently to a marked degree, and up to 50 and 60 kilometers per second, from the velocity given by the lines of hydrogen, helium, etc., arising in the stellar atmosphere itself. This seemed to leave no doubt of the presence in space of diffuse gaseous matter containing ionized calcium, the source of the so-called "H" and "K" lines, through which these high temperature O-type stars were rushing rapidly about in all directions.

Further, when it was shown quite independently of Slipher's earlier work, which was then unknown, that the velocities given by these

[4] Publ. Dominion Astrophys. Obs., vol. 1, p. 213, 1920.

[5] Publ. Dominion Astrophys. Obs., vol. 2, p. 335, 1924; Monthly Not., vol. 84, p. 80, 1923.

" interstellar " lines, as we prefer to call them, were generally equal and opposite to the apparent solar motion, toward Hercules, determined by Campbell, the conclusion was hardly escapable that these high temperature stars were in motion, frequently in rapid motion, through widely extended clouds of ionized calcium which are, comparatively speaking, at rest with respect to the stellar system as that system is represented by Campbell's 280 stars. Further, the D lines of neutral sodium atoms having the same sharpness and stationary character as H and K, which had been predicted by Slipher and had been observed by Miss Heger [6] at the Lick Observatory in some B-type stars, were also shown to be present along with the spectra of some of the O-type stars.

Since both calcium and sodium have been found in interstellar space, there seems then good grounds for the hypothesis that the interstellar matter is of the same general composition as the stars and contains most of the known elements. The sodium D lines and the calcium H and K lines are, however, the lines most likely to be observed in celestial spectra. The principal spectral lines of other elements of sufficiently great relative abundance in cosmic matter to be expected in this connection lie in the far ultraviolet spectrum, and are cut off from our observation by the ozone of the earth's atmosphere. The recognition that the interstellar lines did not generally appear in stars of lower temperature than the very blue ones, taken in conjunction with Hubble's [7] recent theory of the excitation of the gaseous nebulae to visibility by neighboring high-temperature stars, led to the hypothesis, mainly due to H. H. Plaskett, that the calcium and sodium in this widely extended diffuse interstellar matter are rendered absorbing at H and K and at the D lines by the excitation of neighboring stars of very high temperature of the types designated " O " and " B " of the Harvard star classification. This hypothesis,[8] advanced in 1923, required an extensive distribution of this diffuse gaseous matter, nearly stationary with respect to the stellar system, and extending to distances of several thousand light-years throughout the space inhabited by the O- and B-type stars.

A great stimulus to, and a great advance in, the problem of the cosmic diffuse matter in the galaxy was given by Eddington [9] in the 1926 Bakerian Lecture of the Royal Society. He discusses theoretically the physical conditions likely to be present in diffuse matter in interstellar space and showed the probability of uniform distribution except where condensations in this matter gave rise to the

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[6] Licks Obs. Bull., vol. 10, no. 326, p. 59, 1919; no. 337, p. 141, 1921.
[7] Contr. Mt. Wilson Obs., vol. 11, pp. 252, 397, 1922.
[8] Monthly Not., vol. 84, p. 80, 1923.
[9] Proc. Roy. Soc., ser. A, vol. 111, p. 424, 1926.

diffuse nebulae. He was able to derive the probable density of the interstellar matter from considerations of the constitution of the diffuse nebulae. Without following the steps of Eddington's analysis, we may summarize by saying that he arrived at the conclusion that as far as the velocity of their particles was concerned these nebulae would behave as if raised to a temperature of 10,000° Abs.C. The resulting density of the interstellar gases, he found, is of the order of 10^{-24} g/cm^3. This density, as Eddington points out, must be a maximum value, as otherwise the velocities of the stars, owing to the increased mass of the stellar system, would be greater than observed.

The extreme rarity of interstellar diffuse matter, as Eddington showed, was favorable to the high speeds necessary for the splitting off of one or more electrons from calcium atoms when illuminated by the rays of the stars so that they would be in the state to show the H and K lines in their spectra. To explain his point fully would take us into the study of photoelectricity, which would be too far afield. I will therefore only ask the reader to accept the fact that it is the frequency of vibration, not the intensity of rays of light, which determine whether or not they can singly or multiply ionize atoms. The rays of the hottest stars, however distant and thereby enfeebled, possess the tremendous frequency of vibration required.

The property of absorbing, nearly totally, specially selected rays from stars is adapted to give the ionized calcium atoms velocities of interaction far above those of molecules of a solid body situated in interstellar space. Such specially influenced absorbing atoms radiate and absorb as if at very high temperatures. Computed by the ordinary laws of the perfect radiator or "absolutely black body", space has a theoretical temperature of only 3° C. above absolute zero. Calcium atoms at 3° Abs.C. would not be ionized and would not show the H and K violet spectral lines. It is the ionizing influence of high-frequency rays from stars that puts these atoms in condition to absorb H and K rays.

The crucial test of Eddington's hypothesis is that the intensity of the stationary lines must be a simple function of the distance.

The intensity of a stationary calcium line may be measured with a microphotometer. Comparing the contour thus derived with the contour produced by a known amount of calcium vapor in the laboratory, we can determine the total number of ionized calcium atoms between the observer and the star. For a star about 10,000 or 15,000 light-years away we find 10^{15} ionized calcium atoms in a column having a section of 1 square centimeter. Remembering that 1 out of 1,000 calcium atoms is in the singly ionized state competent to produce the observed H and K lines, we conclude that the total number of calcium atoms in all stages of ionization is 10^{18}. If we make the assumption that the composition of matter in interstellar space is similar to that of the earth, we would have to multiply this result by 100 to get the total number of atoms of all elements. This leads to a density of something like 10^{-26} g/cm^3.

It is difficult to comprehend such a state of rarification as this, in which there may be an atom or so per 100 cubic centimeters of space. What is not occupied by the atom itself must be "empty", and just what that means I will leave to the theoretical physicists to explain. I am not sure, however, that it is any easier to comprehend the empty spaces between nuclei and electrons in what we usually regard as dense matter.

The most important recent advance in the study of interstellar calcium is the investigation of galactic rotation of the interstellar medium published last year by Plaskett and Pearce. They have proved statistically that the effective distance of the calcium column between the star and the observer is one-half of the distance between the star and the observer. This proves that, statistically at least, the density of interstellar calcium is approximately constant in all parts of our Milky-Way system up to distances of 3,000 to 5,000 light-years from the sun.

I have some doubt as to whether this constancy may be relied upon in the case of every star. There are indications that condensations of the general cloud are actually present.

So much for the proofs that interstellar space is populated by atoms of calcium and other chemical elements situated so far apart that on the average only one atom is to be found in a cube 2 inches on a face. To see how rare such a gas is compared to our atmosphere, let us recall that at sea level 1 cubic centimeter (about the volume of backgammon players' dice) of air at 0° C. contains 27,000,000,000,000,000,000 molecules.

DUST IN INTERSTELLAR SPACE

Rare gases, however, do not appear to be the sole contents of interstellar space. Particles of dust form haze in the earth's atmosphere, as we well know. In the year 1912, for instance, the eruption of the volcano of Mount Katmai in Alaska so filled the atmosphere of the whole Northern Hemisphere with dust that the direct beam of the sun at noon was weakened by about 20 percent. Photographic exposures had to be increased in landscape photography because of this volcanic haze. Lord Rayleigh showed in 1871 that when the particles are very small, not much larger in diameter than the wave length of light, they produce a much greater depletion of the shorter wave lengths in the spectrum, such as violet and blue, than they do of longer ones, such as the red. Hence, if there are in space minute dust particles, we should expect that not only would distant stars be made fainter but their light would be somewhat redder than if they were near. This effect is known as "Rayleigh scattering."

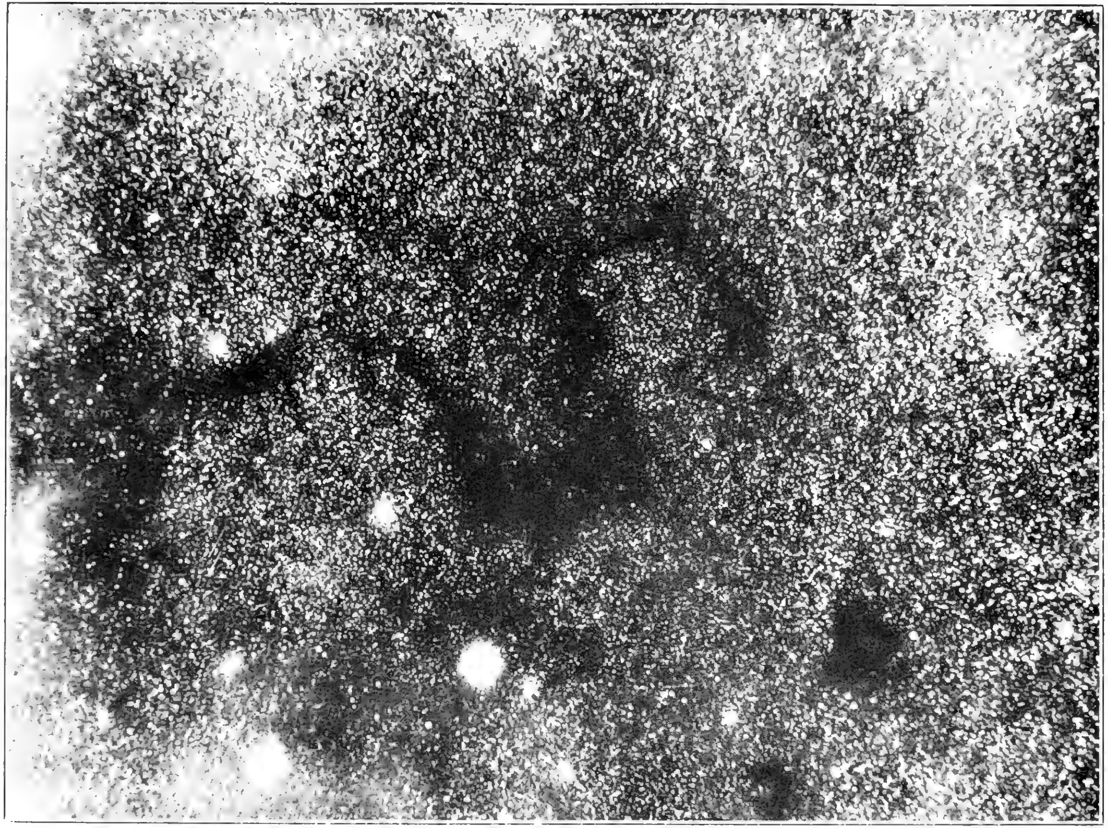
In 1930 Trumpler found evidence in favor of selective reddening of the stars in space. His results have led to a considerable amount of controversy in the astronomical literature of 1931–32, but the prevailing opinion now seems to be that the reddening is actually produced by dust in space. Trumpler concluded that this dust causes a general absorption of starlight weakening the total light received by us from distant stars in proportion to their distance and amounting to 0.7 stellar magnitude per 3,000 light-years. He also observed in addition a selective absorption for blue and violet rays amounting to 0.3 magnitude per 3,500 light-years, which, by eliminating the blue and violet more than the red, produces a marked reddening of the more distant stars. Elvey, Stebbins, Huffer, Van de Kamp, Miss Williams, and others have found a large amount of supporting observational evidence. Schönberg and Gleissberg have worked out the theory of the problem of Rayleigh scattering as applied to the supposed interstellar dust. On the other hand, the Harvard group, notably Gerasimovič and Miss Payne, have found evidence which they regard as being against the hypothesis of Rayleigh scattering. Öpik has tried to reconcile the observations with the theory of scattering, and his results are of great importance.

I think it will be generally agreed upon that the more distant B-type stars (the bluish stars, naturally very rich in blue and violet rays) are actually redder than the nearer ones of the same class. There can be no doubt that the hypothesis of Rayleigh scattering would provide the most attractive explanation of this observation.

There is a great deal of independent evidence that there is an absorbing layer of matter in and near the galactic plane. Hubble has found a well-defined region of avoidance of extragalactic nebulae, which follows roughly the outlines of the Milky Way. Stebbins and Huffer have recently shown that the red B stars—that is, those which may have been weakened as regards their blue and violet rays by their long path through interstellar haze—are concentrated in this region of avoidance. Seares and Elvey have both found indications that space-reddening is related to the regions of obscuration in the Milky Way. Van de Kamp has found from statistical considerations that the existence of a relatively thin absorbing layer is probable. Vyssotsky and Miss Williams, and also Stebbins, have found supporting evidence from the colors of globular clusters.

Not one of the explanations suggested for the various observations made which indicate the existence of interstellar haze is fully satisfactory. While the tendency among astronomers now is to favor the hypothesis of a medium of interstellar dust, which is not coexistent with the cloud of interstellar gas giving rise to stationary absorption lines, we must admit that much work remains to be done, both observationally and theoretically, before we shall be able to definitely accept this interesting hypothesis.

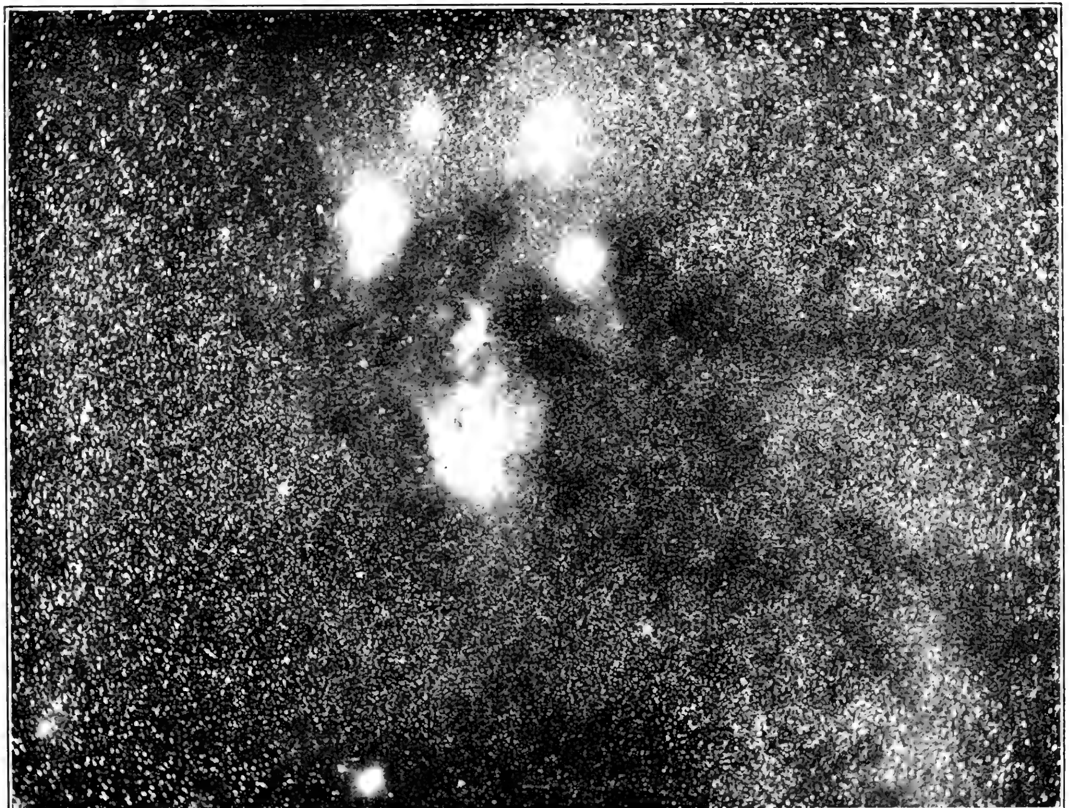
To sum up these recent results of astronomical investigation: Space is no longer to be conceived of as completely empty in those regions not occupied by the individual stars and the bright nebulae. The whole intervening regions are populated by obscuring gases so very rare, it is true, as to be far beyond our best vacuums, but still probably containing about the same mixture of chemical elements that we find in the sun or the earth's crust. Besides these gases astronomers are now generally convinced that there is also in space a very rare dusty haze made up of material particles. It is indeed so very rare a haze that only by refined measurements does its effect of obscuring the stars become manifest. It tends to make the distant stars more reddish.



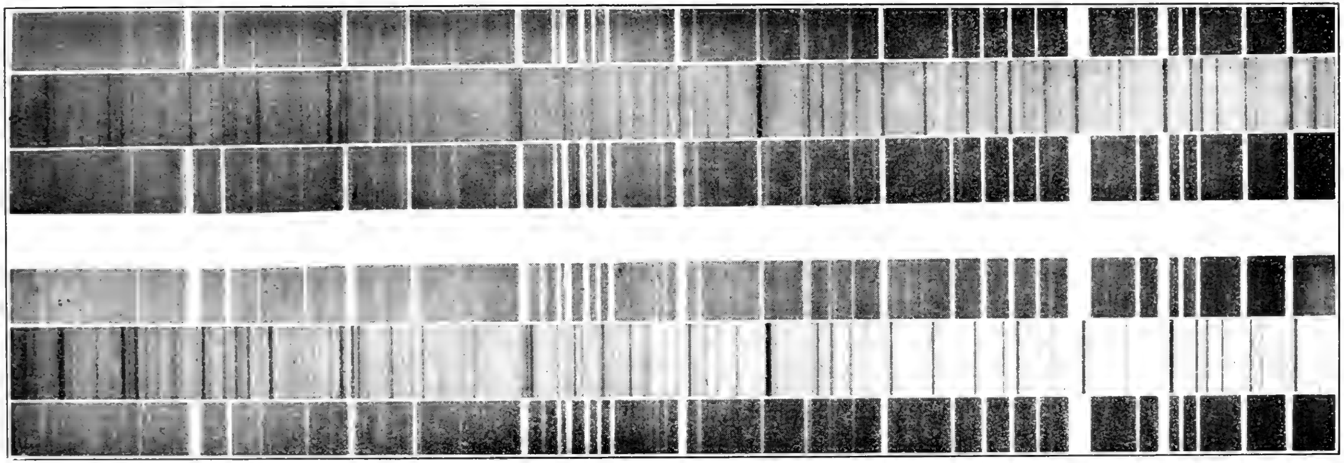
Mount Wilson

DARK LANE IN THE MILKY WAY.

Evidently some nonluminous material between us and the stars hide them from us.



REGION OF GREAT NEBULA OF RHO OPHIUCHI.



SPECTROSCOPIC BINARY MU ORIONIS, SHOWING LARGE DISPLACEMENT OF LINES.

The figure shows the spectrum of this star taken on two different dates. Some of the dark lines in the star's spectrum closely coincide with the comparison lines of titanium. In the upper spectrum the star's lines are only slightly displaced toward the right (toward the red); in the lower spectrum the displacement is in the same direction, but is much larger. This shift of the star's lines is due to the speed of the star in the line of sight, away from the earth (recession), which the measurements on the original show to be 19 kilometers (12 miles) per second on the upper spectrum, and 63 kilometers (39 miles) per second on the lower.

SOME POINTS IN THE PHILOSOPHY OF PHYSICS: TIME, EVOLUTION, AND CREATION[1]

By E. A. Milne, F.R.S.

When I agreed to this lecture I stipulated that I might be allowed to interpret the subject announced so as to let my treatment relate less to the subject in general than to some particular aspects which happen to have been interesting me lately. Professor Whitehead, Sir Arthur Eddington, and Sir James Jeans have given to the world brilliant accounts of the present position of physics in relation to mathematics and philosophy. What I have to say bears to their writings the humble relation of an example to a piece of book work, or of an application of a theorem to the theorem itself.

The particular subject to which I invite your attention is that of time and space, more particularly time, in relation to relativity and thermodynamics, and the time and space of the whole world. The present position in physics of time seems to me to offer difficulties, and it may interest you if I attempt to discuss them for a "short space of time", whatever that may mean!

Strictly speaking, physics has no philosophy. It has method. At any rate physicists, both theoretical and experimental, are rarely philosophers when they are making investigations, but they are acutely conscious of method. Philosophy concerns itself with the justification of these methods, and the ultimate meaning in reality of the results obtained by the methods. Now the methods of theoretical physics seem to be reducible to two species, the method of starting with concepts and the method of starting with things observed. To start with a concept requires two people who agree that they understand what the concept means without giving it an exact definition. They agree that the concept is an entity which, for each of them, stands in the same relation to the things and propositions which are to follow. In some presentations of thermodynamics, energy is introduced as a concept; in Sir James Jeans' recent book, The New Background of Science, space and, possibly, even electrons and protons are regarded as mental concepts, though with respect to the latter most physicists would disagree with him.

[1] An address delivered to the British Institute of Philosophy on Oct. 17, 1933. Reprinted by permission from Philosophy, January 1934.

When a subject is developed from concepts, the concepts play the part of the terms occurring in the axioms of geometry. It may be convenient to have some sort of idea of what the concepts stand for, to give crude illustrations of them, as for example when we make to ourselves a crude picture of a geometrical point or line. But actually no use is made of these crude illustrations. The concepts are undefined save as being governed by propositions of which they are subjects. To say of energy that it is that which is conserved in processes of certain types takes us no further in understanding what energy means, nor has the proposition any content unless a measurement process is specified by which conservation can be tested. As Mr. Bertrand Russell remarks in an oft-quoted sentence, the upshot of this is that—in geometry for example—mathematicians do not know what they are talking about and do not care; they do not care because to care would be irrelevant.

In the other method of procedure, a synthetic process is followed. Things experienced or observed come first, and then combinations of these are constructed which have such aspects of generality that they give insight into the relations between the things observed. The things observed lead to generalizations which involve terms with an observational meaning, and these generalizations sum up many possible observations.

Physical science in its theoretical development tends, not to oscillate between the two methods, but to replace the first method by the second. The method of concepts often requires the greater imagination and the deeper insight to isolate the concepts which are to prove useful. But it is more primitive. In a way, it saves trouble. The method of defining each term in terms of things already observed requires much painstaking analysis. But it has the ultimate merit of avoiding the unnecessary. The method of concepts affords no test as to whether the concepts are essential. Indeed, the method of concepts is a matter of mental economy, but not of logical economy. It is a pioneer method, without which progress would be often slow or impossible. Concepts wisely chosen lead to discoveries, to phenomena previously unsuspected. Often the conceptual character disappears of itself, when things introduced as concepts become objects of observation. At other times unnecessary concepts are only bundled out by a great revolution in thought. The atomic theory of matter and the dynamical theory of gases both started with concepts, the concept of atomic entities of different species and the concept of these atomic or molecular entities in motion interacting dynamically with one another. The atomic theory of matter was not implied by the rules of chemical combination—the conservation of mass and the existence of combining ratios and so on—but was, nevertheless, a grand tool of investigation before individual atoms were observed. The dynamical theory of gases led to relations between observable quantities, like Maxwell's prediction of the independence of gaseous viscosity of pressure, subsequently verified. In each case the starting point was a superb effort of the imagination. Rutherford's discovery of the atomic nucleus led to Bohr's magnificent conception of atomic structure as involving discrete electronic orbits about a center, and Bohr's theory opened up the possibility of unraveling the spectra of the elements and predicting their chemical properties.

Electronic orbits were a hypothesis. Was this a necessary hypothesis? In 1925 Heisenberg answered this question by passing to the other method of theoretical physics, the method of introducing nothing but "observables", to use Dirac's word. Abandoning the mention of orbital sizes and frequencies, Heisenberg showed that the transition relations between the observed energy levels in atoms could be obtained by starting from these levels alone.

This great revolution in thought led to the foundation of the quantum mechanics. But it was not a revolution in method. In 1905 Einstein had applied the same method to the notion of simultaneity of events. He showed that when we examine simply the observations which it is possible to make by which we habitually assign epochs to events, then two events which appear to be simultaneous to a given observer are not in general simultaneous to a second observer in uniform motion with respect to the first observer. Einstein swept out of tenability the concept of an absolute simultaneity, previously uncritically accepted as intuitive. Einstein's method was to tie an observer down to stating his tests for what he was disposed to call simultaneity; unless he came prepared to state tests for simultaneity, a judgment as to the simultaneity or otherwise of two distant events was valueless. It was this necessity for concentrating on evidence, which Einstein forced physics to take into account, that has had so profound an effect on the development of physics. It is true that the statement made above, concerning an observer in uniform motion with regard to a second observer, involves a conventional assignment of epoch to an event and involves, further, a definition of uniform velocity, which, in turn, implies a definition of distance and a definition of uniform time. The definition of distance employed by Einstein involved the introduction of the concept of the rigid body, which cannot be defined, so that Einstein's treatment was not free from conceptual taint. We shall later endeavor to avoid such departures from the purely observational method. Nevertheless, we may with Jeans speak appropriately of the "Einstein-Heisenberg policy" of concentrating only on observables, and regard the fact that this policy is not only practicable but amazingly successful as one of the discoveries of the century.

Once an unnecessary concept is dismissed, it does not return. Nevertheless, new different concepts may then make their appearance. Heisenberg's discoveries were quickly followed by Schrödinger's development of the wave mechanics, which presented a new unobservable ψ, the subject of mathematical propositions but not otherwise defined. Certain aspects of ψ—its absolute magnitude, for example—had physical interpretations and were equivalent to physical measures, but ψ itself remained mysterious. Dirac, in his profound volume, has constructed a complete mechanics which begins by introducing a new set of concepts, not defined in terms of immediate experience. Certain nonnumerical magnitudes typified by symbols ψ (or ϕ) and α are introduced as representing "states" and "observables", respectively, where a distinction is made between the "observable" α and the number that is obtained when an observation of this observable α is made on the system in the state ψ. Thus the state and the observable are conceptual things, capable of being roughly described but not defined or directly experienced. A purely symbolic mathematics is then constructed on the basis of defined operations between observables and states, and formulae are obtained embodying the fact that under certain circumstances observations assign definite numerical values to observables. Probability interpretations are then placed on certain symbols, capable of a meaning whatever systems or observations are in question. Next, in a most beautiful manner the equations of classical mechanics are used to suggest relations between observables which are cases of the general abstract theory, and thus certain operations conducted on them are capable of interpretation. Lastly, the constructed abstract theory and the introduced abstract mechanics are applied to particular physical systems, themselves involving such concepts as the point mass and the point charge, and the predicted properties of these specific physical systems can then be obtained from the interpretation of the abstract relations. This imperfect summary is only intended to illustrate the development of physics by the successive use of old concepts, then things observed, and then, in turn, new concepts, the last being possibly very strange ones.

Though the Einstein-Heisenberg policy is fairly new to physics, it is far from new to philosophy. This was the policy of Locke and Hume. Hume in particular irrevocably damaged the idea of efficient causation by examining the evidence by which a particular "cause" was assigned to a particular "effect." Though we may not accept his solution in terms of habit, we owe a great debt to his exposure of certain fallacies of thought; the philosophy of physics considered as a method is in fact the philosophy of Hume. Again, modern logic, in the works of Whitehead and Russell, is the fearless eradication of things that cannot be observed. The theory of number, both of finite number and of infinite number, is the strict application of such a simple experimental process as that of counting objects.

It is in the domain of microscopic phenomena that the successes of modern physics have been most conspicuous. I should like now to invite your attention to the application of the methods of physics to the less fashionable domain of macroscopic or ordinary-scale phenomena, and to discuss these in relation to certain large-scale phenomena. It is often said that the concepts of space and time may break down in atomic phenomena. But it is no use saying this unless we are clear as to what these concepts mean in larger-scale phenomena, indeed until we are certain that they are only concepts. For example, in order to be able to attach a meaning to the uncertainty principle of Heisenberg we have to give form to the notions of position and momentum, of energy and time, which involve both kinematical and dynamical notions; and the principle implies the transfer to atomic phenomena of notions derived from ordinary experience.

Now, there are two well-defined branches of physical science which concern themselves with the macroscopic phenomena. One is the theory of relativity; the other is thermodynamics. Both of these bring us immediately to *time*. The one makes little of time; the other makes much.

The one, relatively, appears to relegate time to the role of a co-ordinate. It is often represented as claiming to show that time and space, not separately real, are but aspects of a higher reality, " space-time ", which is the true framework of events. The individual is supposed to make his private choice of his resolution of this framework into his own separate space and time, but no one choice is to be preferred to any other. An individual observing two separated distant events may describe one as preceding the other, while another may describe them as simultaneous. The time ordering of the events thus depends on the particular observer, and has nothing to do with the events themselves. As Jeans points out in the book mentioned, this raises acute difficulties concerning the reality of evolution. He mentions that it has been suggested that " the concept of evolution in time may lose all meaning " so that we cannot speak of the universe evolving as a pattern is woven on a loom. If " time is merely a geometrical direction of our own choice in a continuum ", the pattern is already spread out, and future events have the same kind of reality as past ones. " Indeed, an inhabitant of a nebula can wave his 'now' through the continuum until its intersection with the world line of our path passes instantaneously from 1932 to 1942." In fact, the theory of relativity does not imply that the observer on a distant nebula can experience or observe the event, near ourselves, which we shall experience in 1942, at an epoch defined by an event occurring in our reckoning as 1932. In the definite meanings it is possible to attach to the words, we shall experience the events of 1942 sooner than anybody else can have experience of them. We ourselves are first in the field. But the evolution difficulty still remains. If time means different things for two different observers, how can the universe be said to evolve in time? For no meaning can be attached to a unique temporal ordering of the totality of events.

Yet there is one characteristic of the world frequently adduced to show that it is indubitably evolving. That characteristic is an apparent steady increase of entropy. As each observer's time goes on, the universe appears to him to be moving from a less probable state to a more probable state; it appears to be tending to a changeless state, of uniform temperature, a state called "heat death", in which all available mechanical energy has been transformed into forms not available at this final constant temperature. In a section called "The Final State of Maximum Entropy" Jeans says that though general considerations cannot indicate the road by which the final end of the universe is reached, they can tell us something as to the nature of this final state. Though the entropy *might* decrease momentarily, this is enormously improbable, and it is still more improbable that it should go on decreasing for any measurable period. Jeans draws explicit attention to the fact that his examples of change of entropy are confined to finite portions of the universe, such as a boiling kettle or red ink mixing with water, but he applies the same conclusions to the whole universe. "There can be no end to the increase of entropy until these regions [regions of the universe at different temperatures] are all at the same temperature, with radiant energy diffused uniformly through space. Then and only then will the universe have reached its final state, the perfect quiet and perfect darkness of eternal night."

Thus we have the two results: relativity suggests that the flux of time is meaningless, whilst thermodynamics suggests that it is highly significant. These are contradictory. If there is a limiting state of the universe to which we are approaching, then states that are old can be distinguished from states that are young, by the degree of their approximation toward the final state. Not only distinguished, but labeled the one old and the other young. But according to relativity different observers assign different times to different events. Which time is the one indicated by thermodynamics? Does thermodynamics indeed select a special time, which we could call absolute time, and if so what observer experiences this time? Thermodynamics appears to say that the system is ageing to all observers; it does not keep company with relativity. It is not sufficient with Eddington to say that the entropy-increasing property gives a point to time's arrow. It is not merely a question of the time sense, the fact that entropy distinguishes one direction of time from the other; it is that the interval between two states of the universe, corresponding to a given entropy difference, may apparently be different for different observers.

Jeans does in fact conclude that there is for the world an absolute time, though he derives this not from thermodynamics but from the structure of the astronomical universe. His view is that absolute time and absolute space exist in a wider external world than that of pure physics, that this absolute space and time are found in astronomical nature, and that so an escape may be found from the relativity view that evolution is meaningless.

It appears to me, however, that Jeans evades the issue. By astronomical nature he means very large scale phenomena, the outward motions of the spiral nebulae, and his conclusion would be solidly based only if these phenomena disclosed something which contradicts those conclusions to which we have been led by laboratory experiments. Jeans says that absolute time and absolute space do not enter into the nature we study in our physical laboratories. But how? In what sense can a large block of space be absolute whilst a small one is not? If the universe contains an absolute frame of reference, it must also be absolute whatever the scale of the phenomena. We cannot, of course, rule out the possibility that very large scale phenomena might disclose generalizations not found to be valid for smaller-scale experiments. But Jeans is talking not of phenomena but of time and space, elsewhere considered as "mental concepts." And which large scale phenomena are in fact the culprits? But there is another point. The second law of thermodynamics *is* verified for ordinary scale phenomena, so that even for ordinary phenomena we have the apparent conflict between relativity and thermodynamics. Jeans says: "Through our consciousness we break up the space-time product into space and time, whilst electrons and radiations and protons cannot." Yet it is not suggested that it is due to our consciousness that that aspect of evolution which we call the entropy-increasing property does actually exist. These same electrons and protons which cannot break up space-time into its constituents are the very participants in the drama of the ultimate heat death. In spite of relativity, therefore, they know how to behave as if a definite time exists. Jeans is even led to conjecture that " our minds may be in contact with reality by other than purely physical elements ", just because of their consciousness of " a radical distinction between space and time which does not appear to extend to physical phenomena." Yet he emphasizes an apparently fundamental distinction between time and space when he describes that physical phenomenon which is the running-down of the universe.

I want now to suggest that the impasse arises partly from our forgetting the purely conceptual character of space-time and partly from an unjustifiable application of the second law of thermodynamics to the whole universe. Our experience of time is immediate, not a concept; the experiments on which thermodynamics is based are not concepts. But on the one hand " the whole universe " is a concept, as De Sitter has pointed out, save in the case of the uninteresting possibility that the universe contains a finite number of particles. And on the other hand, space-time is a concept of which we have no experience, a mathematical invention, useful solely for correlating experiences. We have no right to foist this invention on nature and then complain that nature contains two contradictory phenomena; for the so-called " possession " of a space-time framework in which time and space merge together is not a phenomenon in nature. Our problem is to correlate the experience of one observer (in which, in his time, the universe increases its entropy) with the experience of another observer with a different time. Jeans is, I think, right in suggesting that very large scale astronomical phenomena afford a means of reconciling these experiences, but not, it seems to me, by pointing to a unique or absolute space or time, which involves grave difficulties in relation to the facts on which relativity is based. We will attempt to remove our difficulties by building up definitions of space and time, or rather building up measures of space and time, from a basis of things experienced. We will pass from concepts of space and time to observables, according to the Einstein-Heisenberg policy.

We begin with the observer. Each observer possesses, for macroscopic phenomena, a definite temporal experience of events at himself. I as an observer and chronicler can say of two events which happen to me which precedes the other. For very small separations of events it may, indeed, occur that I am unable to decide which is earlier, and the indubitability of the time sequence may fail. But this is not an exception in principle. I may suppose myself to have constructed a clock, running no matter how irregularly, and to have graduated it numerically in some perfectly arbitrary way. I can make the graduations as small as is recognizable. Then when an event occurs to me I can prick off on the clock disk the position of the hand, and so attach some definite time number to the event. There is no question of my "resolving my experiences into time and space"—there is no arguing about my own temporal experience. We remark further that the only events the observer actually experiences are events at himself. He may be informed of other events, or infer their existence from his own experience, but he has direct experience only of events at himself.

The observer, myself, is quite unable to superimpose two different intervals on the clock. Once gone, an interval on the clock is gone forever. Thus from my own experience alone I cannot select one particular system of graduation of my clock subdivisions and call them "uniform time." So far uniform time is not definable.

I have certain experience of the relative proximity of objects near me, namely, tactual experience. I can extend my arm, and ascertain that I have to extend it more for one object than for another. I can also walk to an object, and count my paces. But it would be difficult to build up consistent measures of "distances" of objects from these observations. If, on the other hand, I use a meter scale and read off positions of objects against its graduation, either I assume its graduations are equal or that the scale itself is unaltered by displacement—in each case invoking the indefinable concept of the rigid body. As we are endeavoring to proceed without using indefinable concepts, we must exclude the use of the meter scale.

The assigning of a distance to a distant object can be accomplished in principle as follows: I can send a signal (e.g., a light signal) from myself to the object, despatching it at time t_1 by my arbitrary clock. I can then receive back the echo, and note the time of its arrival, say t_2. If necessary I can arrange another observer at the object who returns my signal immediately he receives it. The position now is that I have two data of observation, t_1 and t_2. What can I do with them?

Out of two numerical magnitudes two other independent numbers may be constructed in an infinite number of ways. I want to construct two numbers, one of which I can call the epoch of the event constituted by the arrival of my signal at the object, the other of which I can call the distance of the same event, i.e., the distance of the object at the instant of occurrence of the event. Though the epoch of an event occurring not at myself is completely undefined, so far, it is clear that it will be convenient to assign to this event an epoch or time number which is greater than t_1, the epoch of despatch, and less than t_2, the epoch of return. For in any sense we can reasonably attach to "earlier" and "later", the event is later than t_1, earlier than t_2. Let us adopt as a purely conventional definition of the epoch of the distant event the average of t_1 and t_2, say T. Thus $T = \frac{1}{2}(t_1 + t_2)$. The event is then said to be simultaneous with the event constituted by my clock-reading T. This is a purely conventional definition of simultaneity, but it is compatible with any intuitive ideas we have as to the meaning of simultaneity, provided we could attach a meaning to saying that the clock was running uniformly and the signal traveled at constant velocity. In fact this conventional assignment of an epoch to a distant event is sometimes said to involve the assumption that the forward and backward signal velocity are the same. But we have not yet defined "distance", hence we have not defined velocity, so the limitation would be meaningless. We content ourselves with the epoch T as defined with reference to the arbitrary clock employed.

Having averaged t_1 and t_2, the simplest remaining thing to do is to subtract them. For technical reasons, it is convenient first to choose an arbitrary number, c, and then define the distance of the event at $\frac{1}{2}c(t_2 - t_1)$. This we will call X. In ordinary language we should say that c is the signal velocity, so that $c(t_2 - t_1)$ is just the distance described in the double journey. But in our presentation c is just an arbitrarily chosen number. We have now defined distance X without using a rigid scale. We have used only clock measures made with an arbitrarily graduated clock.

If we wish to assign measures to the relative direction of two distinct objects, we can measure the angles between their directions with the aid of a rigid body equivalent to a theodolite. It should be noticed that the use of a rigid body for measuring angles is fundamentally different from the use of a rigid body for comparing lengths; the right angle and its subdivisions are communicable units, capable of being set up independently, whilst the meter is not a communicable unit. I can explain to a distant geometer what a given angle is, so that he can set one up for himself; I can never explain to him what a meter is without taking one to him, and this assumes that a meaning can be attached to saying that it is unaltered in the process of transport. Once a method has been described for assigning distances and ascertaining angles, a geometry can be adopted and coordinates can be assigned to any distant object. It is not necessary here to go into details. The significant step is that the measure or scale of spatial relationship can be constructed out of clock observations. Space is constructed out of temporal experience—not, that is, its three-dimensional aspect but its scale aspect. In the case of a one-dimensional world, a geometry is not necessary, and space measures can be constructed purely out of temporal experiences. The adoption of a geometry is necessary when we recognize the three-dimensionality of our possible observations; i.e., that we can determine direction in terms of two independent measures.

We now want to correlate or compare the clocks of two different observers. When we repeat our measures of the distance X of an object we may find that X remains constant or that X changes. If X happens to remain constant, it is not difficult to show how, if the object also carries an observer with a clock, the two clocks may be synchronized. And if three observers, A, B, C, by such synchronized clocks agree that they are at constant distances apart, it can be shown that the time numbering of their clocks is unique. This time numbering they will call uniform time. Whether it coincides with what we ordinarily mean by uniform time is another matter, but this unique time numbering is as far as three such observers can get when they pay attention only to the reception time of signals. The unique time numbering they arrive at would coincide with what we ordinarily mean by uniform time when the strength of the signals returned are also constant in time, provided we can say what we mean by comparing the strengths of signals. This involves the construction of a piece of apparatus capable of measuring signal strengths, whose properties remained constant in time. These properties would include length measures of its parts, measured with the same arbitrary clock (now uniquely graduated). Now if another observer, B′, were, in our ordinary language, receding from A, he could be made to appear at a constant distance from A by letting A's clock run slow. This is equivalent to letting the unit of length conventionally adopted by A increase, so that the size of a signal-strength-measuring receiver would appear to decrease and the weaker signals now received would be estimated as weaker simply due to the smaller instrument used. I have not carried out all the mathematical details of this process, but the general inference is clear. Just as it is generally recognized that no observable differences would be produced in the universe if we had a length measure arbitrarily changing, so when we base length measures primarily on time measures, uniform time cannot be defined. Uniform time is a convention based on the simplest description of a set of phenomena occurring in nature—as is obvious when we examine its astronomical definition in terms of the earth's rotation, or in terms of dynamical clocks assumed to remain invariable.

All we can do then is to correlate different ways of time-keeping. The next problem of interest is then to correlate the time-keeping of observers in motion. Suppose, then, that *I*, whom I call observer A, repeat my observations on an object B, and find that X, its distance, changes as T, the assigned epoch, changes. Let us assume for simplicity that its direction remains constant. This assumes that a meaning can be given to invariance of direction; this can be accomplished with the aid of a gyro-compass. I can now repeat my observations as often as I please and as close together as I please, either by using a Morse-code method of signaling or signaling with differently colored lights. I must simply be able to recognize and identify return signals. I can then graph X against T. I can in particular find the slope of this graph at any time T. If this slope happens to be constant, I shall say that the object B is in uniform motion with respect to myself, and call the slope the velocity V, all in terms of my arbitrary clock. The value of V is unaltered by multiplication of the clock readings by an arbitrary factor.

Suppose B, also provided with a clock, performs similar observations on myself, A. He can send me signals and receive them back; choosing the same number *c*, he can assign epochs T′ and distances X′ to the events which are the arrivals of the signals at myself. He can thus determine my velocity with respect to himself.

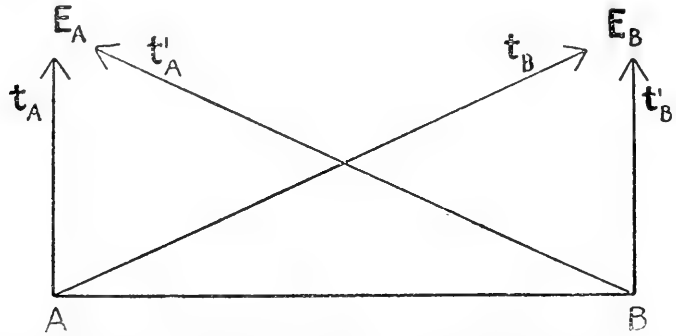
Now suppose that B stands in precisely the same relation to A as A stands in relation to B. Then when A finds B to be moving with a uniform velocity by his clock, there must exist a set of clock graduations for B such that B finds A to be moving with a uniform velocity and, moreover, with the same uniform velocity, for otherwise they would not be equivalent. A and B are then said to possess similar clocks. The possession of similar clocks by the two observers is thus capable of experimental test.

We are thus able to say what we mean by A and B possessing similar clocks without its being required to bring these clocks side by side. The latter test would indeed violate the conditions of the situation, the essence of which is that the two clocks are in relative motion. If we reduced one clock to relative rest, we should have no means of testing whether we had altered the clock in the process. As it is, we have effected a comparison of the clocks whilst they are in motion: what A finds B is doing by his (A's) clock, is described in the same way by A as what B finds is happening to A (by B's clock) is described by B; A describes his experience of B in the same way as B describes his experience of A.

A and B can, however, make one further type of observation. They can read one another's clocks. Or, what is the same thing, B can inform A of the time recorded by his (B's) clock at the epoch of arrival of a signal from A. A can then compare B's reading of B's clock with the reading of his own clock which he has assigned as simultaneous with this event. In ordinary words, A reads B's clock through a telescope, at a certain time by his own clock, corrects this latter time for the time of travel of the signal, and compares his own (corrected) clock reading with his telescopic observation of

B's clock. It is easy to show that the direct reading by A through a telescope is equivalent to the communication of information by B and that the signal velocity is equal to the arbitrarily chosen number c.

It by no means follows that A and B agree on the epoch they assign to the event which consists of reading B's clock. This was Einstein's great discovery. A procedure for correlating the readings, equivalent in the sequel to Einstein's results, is as follows: Consider an event at B to which B assigns the epoch t'_B (by direct reading of his clock); and let A assign the epoch t_B to it by his clock after making the necessary light signals. Consider, secondly, an event E_A at A, to which A assigns the epoch t_A (by direct reading of



Suffixes A and B denote locations of events. Unprimed symbols (t_A, t_B) are A's assignments of epoch. Primed symbols (t'_A, t'_B) are B's assignments of epoch

A's clock); and let B assign the epoch t'_A to E_A by his clock after making the necessary signals. Then, since A and B are supposed to be completely equivalent in all their relationships, if t'_B happens to equal t_A, t_B must equal t'_A. In other words, suppose that A makes a graph of his value for the epoch of E_B, namely, t'_B against B's value for the same event, namely t'_B; then the same graph must result if B plots t'_A, his value for the epoch of E_A, against t_A, A's value. These graphs could be actually drawn and compared. In mathematical language we should have $t'_B=f(t_B)$ and $t_A=f(t'_A)$, where the two f's denote the same function.[2]

Now, it can be shown mathematically that the only possible form of the graph for which this relation holds is represented by

$$t'_B=t_B(I-V^2/c^2)^{1/2}$$

and

$$t_A=t'_A(I-V^2/c^2)^{1/2}$$

[2] When A and B have chosen clock graduations for which the two f's are identical, they may be said to be provided with identical clocks.

provided the clocks were synchronized to read zero at the instant when A and B parted company. In words, B assigns to an event near himself an earlier epoch, by his clock, than A assigns to the same event by his clock. Similarly, A assigns to an event at himself an earlier epoch than B assigns to the same event. To A, B's clock runs slow; to B, A's clock runs slow. The degree of running slow is the more pronounced the faster the relative motion.

This is a well-known result in the theory of relativity,[3] but our presentation of it has a different logical setting. We have not used the concept of a rigid measuring rod, and we have not assumed that A and B are in "empty space." We have not taken the constancy of the velocity of light from observation. We have adopted it as an axiom giving us our definitions of lengths. We have simply assumed that A and B possess temporal experiences and that they stand in completely equivalent relationships to one another. This condition is satisfied if A and B stand in the same relation to the rest of the universe. Our experimental basis is that it is actually possible to realize in experience two equivalent observers in uniform relative velocity.

Let us in fact apply this result to the whole universe. It is well known to everybody nowadays that the universe as a whole is expanding. By this we mean that the extragalactic nebulae are receding from us and from one another, receding from one another, moreover, at rates which are proportional to their separations.

This is the same thing as saying that if we take any nebula and divide its velocity by its distance we get the same result for all nebulae. We do not know from observation how this quotient changes in time. It appears to be the same all over the universe at the present epoch (i.e., for nebulae considered simultaneously in the above sense of simultaneity) as far as is yet observed. Whether at another epoch it will be the same we do not know. Some current theories assume that the coefficient of the proportionality is locally constant in time, and hence that the nebulae are being accelerated. Now, however a nebula is being accelerated, its velocity can never exceed the velocity of light.[4] Thus, if the nebulae were being accelerated outward, each one would ultimately acquire the velocity of light, and the law of proportionality of distance and velocity would cease to be obeyed, for the velocities would tend to become the same for all nebulae, but the distances would be different for different

[3] What are usually called the "Lorentz formulae", connecting A's and B's assignments of epochs and coordinates to any event whatever, can be shown to follow from the above formulae without further assumptions.

[4] Statements sometimes made to the contrary, as for example that nebulae may ultimately possess velocities greater than that of light and so pass out of causal connection with the rest of the universe, are erroneous. The error came in owing to a false identification of "cosmic" time with the time of experience.

nebulae. In that case the velocity-distance proportionality would be an altogether ephemeral thing. There is, however, no observational evidence that the nebulae are being accelerated. I have given reasons elsewhere for supposing that the velocity of each nebula is a constant, apart from effect of irregularities in distribution leading to residual gravitational fields. We may consider a smoothed out model of the universe in which the velocity of each is actually constant, the distance increasing accordingly with the time. Observation and all theories agree in showing that the nebulae were all very close together about 2,000,000,000 years ago, reckoned by clocks at ourselves. The nebulae may then be likened to an army of objects which all parted company at a definite epoch in our own past, and since then have moved each with its own constant velocity.

Now, in all schemes so far proposed for the universe, every particle or nebula in the ideal scheme is equivalent to every other. The relation between itself and the rest of the universe is the same whatever nebula is chosen. The reason that this condition is imposed[5] on world models is that we have only actually observed a very small portion of the universe and we want to build up a model of the whole which will not endow the observed portion with special properties. Removing the last vestige of an anthropocentric view of the universe, we refuse to consider our own viewpoint as special, and we regard any other viewpoint as equally good. If you like, we are extrapolating the observed portion of the universe in the fairest possible way, first by constructing round the edges of the observed portion adjacent portions as similar as possible, then building on to those, and so on, meaning always by " as similar as possible " the possession of the same features as viewed from the viewpoint to which the extrapolation is extended. Distance and epochs of events on the nebulae can then be assigned in principle by the methods given. The space in which they are embedded is a purely constructed entity.

It may seem at first sight that if we construct a world model with the same relation of each particle to the rest, then it must extend indefinitely through infinite space. For the possession of an experienced boundary is impossible. Yet it can be shown that on the procedure we have outlined, in view of any observer the system is of finite radius and the distance of the remotest members of the system cannot exceed a finite length. The apparent paradox is removed by noting that the nebulae form what is called an " open " set of points, infinite in number, having the surface of a sphere for the set of limiting points. The limiting points themselves are not

[5] In most current presentations of relativistic cosmology this condition is not imposed, but is verified a posteriori. In my own presentation it is imposed a priori.

occupied, but representative points occur within arbitrarily small distance of them. The important results for my present purpose are that the total number of members of the world system is not finite, and the most distant are receding with all but the velocity of light, i.e., we can find members moving with speeds arbitrarily close to that of light.

Let us now put together the four considerations: (1) the relativity of time; (2) the running down of any finite portion of the universe according to the second law of thermodynamics; (3) the expansion of the universe, with members moving at all speeds up to (but just not including) that of light; (4) the infinitude of particles in the universe.

Consideration (4), which is implied by the analysis of world structure just discussed, seems to me to be necessary if we are to avoid the philosophical difficulties which would crop up if the number of particles in the universe were finite. For they could always be mapped in a flat constructed space, and if this space were finite the particles would possess a center of position, and so absolute location in this space would have a meaning. We should want to ask, but be unable to answer the question, why the universe came to be associated with this particular standard of absolute position and absolute rest. We should in fact have found a frame of reference that was specific, yet we could not mention anything to distinguish this frame from any number of physically equivalent ones, except that the universe happened to select it for occupation. In crude language, how could the universe possibly know what frame it was adopting—how could it identify it in the desert of featurelessness. A universe possessing an infinite number of particles does not necessarily possess a mass center, and in the case of the model I am discussing definitely does not possess one. Each particle is equally a center of symmetry. But if the universe were supposed mapped in a finite curved space, and consisted of a finite number of particles, it would still determine an absolute standard of rest in this completely featureless medium, and no one could say how it does it! In the model I am considering, relative position and velocity alone have a meaning.

Now let us compare our own experiences with the experiences of an observer situated on a very distant nebula moving with nearly the speed of light. The clock of the moving distant observer will be, to us, almost standing still, and the epoch at which it stands will be little removed from the epoch at which synchronization occurred, that is, the epoch of separation. Thus whilst our own clock records 2,000,000,000 years as the time that has elapsed since all the nebulae were close together, for a nebula moving at 9/10 of the velocity of light, the time *now* read by the moving clock (our *now*) will be $2{,}000{,}000{,}000\times\sqrt{1-81/100}=870{,}000{,}000$ years; for a nebula moving at 99/100 of the velocity of light, 280,000,000 years; for a nebula moving at 999/1,000 of the velocity of light, 90,000,000 years; for a nebula moving at 9,999/10,000 of the velocity of light, 28,000,000 years. These figures have a perfectly concrete meaning. If we detect an event taking place, as we say, *now* on a nebula moving with 9,999/10,000 of the velocity of light away from us, then the age of the universe reckoned by the moving observer on this nebula, at that event is only 28,000,000 years—comparable with the age formerly assigned by Kelvin to the universe in our own time scale. We see that the phrase " the age of the universe " has no objective content. Given an event, we have to mention an observer in whose " now " it occurs, and the ages are different according to the observer chosen.

It then follows that the universe for the distant observer has only been running down for 28,000,000 years. For us it has been running down for 2,000,000,000 years. And these two estimates relate to the same event, observed by two different observers. Thus for the fast-moving observer the universe has run down less than for us, at the two " nows " corresponding to the same event. Since, with an infinite number of nebulae in the world running away from us with all speed up to that of light, we can always find an example of a nebula with a velocity which is arbitrarily close to that of light, we can therefore specify a nebula for which, at the event on it in our " present ", the running-down of the universe is as little as we please (reckoned from its zero).

It follows that though the universe is running down for each separate observer, no absolute measure of the amount it has run down at any definite instant of our time can be given. For us, it has run down a definite amount. But for other observers, whom *we* regard as contemporaneous observers, it has run down less, and we can always in principle mention observers for whom it has run down as little as we please. Here there is no sense in which it can be said that the universe is running down independent of an observer. In the ordinary sense of *always*, it always contains observers or states which are practically at the outset of their world careers, ready " wound up." The world system, though decaying and dying at each separate place and for each separate observer, always comprises other observers, at great distances, for whom this process of decay has hardly gone on at all. It is not a question of cycles of rejuvenation, or of a process of revivification. The fresh start is always present, but it is not really a fresh start, it is the one start that every portion had, but differently reckoned. The world system is like a tree which decays at its center, but lives on just under the bark. Thus no absolute sense can be attached to saying that the world *has* run down, though everywhere it *is* running down. It always contains experiences for which the process of running down has hardly progressed at all. The world therefore lives forever. Near its apparent boundary, the world in Keats' words is:

> For ever piping songs for ever new . . .
> For ever panting and for ever young.

If we call "creation" the indescribable and unobservable state out of which the systems were born (for us, 2,000,000,000 years ago) then we may say that there are always events in the world for which antecedent creation is only just a thing of the past. We cannot observe the event of creation itself, even in the limit, for it is only an occurrence in our present for nebulae moving with the speed of light, and these if they existed would be invisible, unobservable.

The event of creation itself is discreetly mantled in invisibility. Not only can we not go behind creation, we cannot go right up to it; but we can get within an arbitrarily short experience of it, by observations that are in principle capable of being carried out. There is no reenactment of creation. Creation—one event; I have missed out the copula. You can say "was" or "is" at your choice. There is no difference in the two propositions, until an observer is mentioned. In any one observer's world-wide present, for whom creation "was" so many years ago, we can always specify events the observers at which reckon creation as arbitrarily close to "is."

This situation may be very difficult to imagine. The difficulty is just that of imagining an infinity of objects in a finite space. (It must be remembered that the dimensions in the direction of motion are reduced by the motion, in accordance with the law of the Lorentz contraction.) But there is no difficulty in describing what we may expect to observe, and this is all that can be demanded. The usual theories put the burden of the trouble on the difficulty of imagining a conceptual curved space. I transfer the difficulty to that of imagining an open set of points. This is not really difficult, and in any case it has the advantage of being describable in terms of experience.

The application of the second law of thermodynamics, invoked in the ordinary proof that the universe is running down, involves the axiom that in any process which occurs in the world it is possible to find another portion of the world unaffected by the process. For to estimate the increase of entropy consequent on the change—to estimate the degree of "running down" involved in the process—it is necessary to compensate the process by reversible changes carried out between the affected part of the universe and the unaffected part. A process must be imagined in which the affected part is restored to its initial state, and the entropy changes thereby occasioned in the orginally unaffected part estimated. It follows that if a process goes on which affects the whole of the universe simultaneously it is impossible to estimate the change of entropy. In such case the proof of the entropy-increase breaks down. Now, the expansion of the universe, with bodies separating at different speeds, is a phenomenon which goes on of itself and affects the relations of all the separate parts continuously; it may be described as a nonuniform radial dilatation, resulting in increasingly perfect velocity segregation of the separate parts. But the universe is not an enclosed system. Unlike the systems considered in thermodynamics, it has no confining boundary, though as we have seen it has an apparent though unattained boundary. Whether it is surrounded by "empty space" or not is a meaningless question, since it can be shown that there is no possible causal connection between the objects (if any) outside the sphere of observation and those inside it.

The expanding universe may be described as creating space as it expands, or alternatively as expanding into empty space. This external unobservable space need not be actually empty; its contents can be readily described mathematically, but they automatically make room for the observable part to expand into, so that the space behaves in effect as empty. The external occupants are genuine wills-o'-the-wisp. In either case the system is totally different from an enclosed system, and it acts as its own Maxwell's sorting demon. Maxwell pictured a demon capable of opening and closing a door in a partition in a gas-filled vessel in such a way as to segregate fast-moving molecules from slow ones. The natural expansion of a cloud of objects such as nebulae into "empty" space is precisely such a type of segregation. For it effects and then accentuates a complete sorting-out of velocities, more and more completely concentrating the faster objects at the greatest distances. Just as Maxwell's sorting demon could cause the gas on one side of a partition to become hot and the other cold without expanding mechanical work, and so could avoid the consequences of the second law of thermodynamics, so the universe as a whole avoids the heat death. It does this in virtue of the expansion and the infinity of particle number, taking into account the relativity of time.

To summarize, the passage of time is a definite part of the experience of each individual, and from it may be constructed both time measures and space measures without the introduction of the concept of the rigid body as a length-measuring tool. Different individuals assign different epochs and different distances to the same event, and the relation between the epochs they assign is perfectly definite for any two observers (in uniform relative motion) who stand in the same relation to the rest of the universe. This relation, predicted long ago by the special theory of relativity, is derived here from a different observational basis. It is applicable as it stands to the different bodies forming constituents of the expanding universe, which presumably contains, and on a reasonable basis for extrapolation certainly contains, particles moving with all speeds up to that of light, and, moreover, an infinite number with speeds lying within any arbitrarily small fraction of the velocity of light. Such particles, in the worldwide instant of an observer near ourselves, estimate the world far younger than we do. For them the world has scarcely begun to run down. Particles, nebulae, or observers can be specified arbitrarily near to the event of creation, in their own reckoning, at the worldwide instant corresponding to any specified event in the history of any other observer. The world is thus running down, ageing, and decaying for each separate observer, but contains an infinite sequence of observers for whom it is arbitrarily young. The world is thus a continuing system; each particle or nebula has an evolutionary experience behind it and in front of it, with ultimate decay as its goal, yet the world as a whole cannot be said to decay. It is not the same in an observer's today as in the observer's yesterday, but it is the same forever. Creation never recedes into the past; it is only just beyond the limit of observability in our own present. Time advances for each separate observer, but the universe as a whole knows no definite age at an assigned event; the worldwide instant of the observer to whom this event occurs contains experiences which assess the age of the world at all values from that assigned by the given observer down to zero. Each observer may legitimately count himself, and will in fact reckon himself, as the world's oldest inhabitant.

I believe that these various considerations go far toward removing the apparent contradictions between thermodynamics and relativity to which we earlier drew attention. Though I have been led to these conclusions by studying one particular possible model for the universe, the same conclusions, or substantially similar ones, probably follow on any model, in particular on those which make use of a conceptual curved, expanding map—so-called expanding space—to represent the world. The main points are the existence of nebulae moving with all speeds up to that of light, so that all possible smaller time reckonings are existent in the world-instant of a given observer at a given time reckoning; the inevitable running-down of the universe for each separate observer, with the existence of all lesser degrees of run-downness in the same world-wide instant; and the existence of a singular condition for nebulae at the maximum distance, such that the singularity in our past experience which we call creation reproduces itself at, and is all but observable near, the apparent boundary of the system. I commend to philosophers the idea that creation is ever present in the universe; not a new idea, but one to which, in my opinion, we are led by the strictest interpretation of modern physics and astronomy in the light of their philosophies.

STANDS SCIENCE WHERE SHE DID?[1]

By Ivor Thomas

The 1933 meetings of the British Association, held last month at Leicester, formed a convenient halting place for men of science to look back upon ground definitely won and to survey further territory upon which an attack may be expected imminently. Already they have struck their tents, and are again moving toward the enemy ranks. The attack is being made along the whole line, from the very small to the exceedingly great. But it is at the extremities that the big battalions are concentrated, and reconnoitering parties are daily bringing more and more information both of the structure of the atom and of the nature of the universe as a whole.

Science thus offers us a kind of Platonic Dyad of the Great and Small, but it is not wholly undetermined. Taking the smaller end first, we may now be fairly confident that there exist four fundamental particles out of which the whole material universe is compacted. There may be others as yet undiscovered, but of these four we may now be quite certain. There is the negative electron, discovered in 1897 by Sir J. J. Thomson, which bears, or rather is, a negative charge of electricity. Secondly, there is the proton, discovered in 1911 by Lord Rutherford, which is positively charged and has a mass about 1,840 times that of the negative electron. It was thought for a long time that these were the only building bricks in nature, that out of them in suitable numbers and combinations the atoms of all the 92 elements could be formed. The model atom was a miniature solar system with a central nucleus consisting of protons and embedded electrons with a number of electrons circulating in the manner of planets. The number of orbital electrons was such that their electric charge would just cancel out the resultant positive charge on the nucleus, the whole atom being in a state of electrical equilibrium. This theory was worked out for every element, including 2 that had not then been discovered, from hydrogen with 1 circulating electron to uranium with 92. It was proved that the orbital electrons were arranged in groups, and the theory beautifully explained many spectroscopic phenomena and such properties as the conductivity of metals.

[1] Reprinted by permission from the Nineteenth Century and After, October 1933.

The theory appeared to be so perfect that the goal of physical research seemed in sight. But theoretical minds were not content to accept the proton and negative electron simply as brute facts. They asked: Why not an elementary particle without any charge at all? Why not an electron with a positive charge? Why not a proton with a negative charge? Moreover, a theory elaborated by Professor Dirac, which had won the admiration of the whole scientific world by the ease with which it accounted for several "brute facts", seemed to demand the existence of positive electrons.

What the theoretical mind demanded has at last been found by the empiricist. No negative proton has yet been discovered, but the existence of an uncharged elementary particle, or neutron, and of a positively charged electron, or positron, has now been placed beyond question. The isolation of the former was the work of Bothe in Germany, Curie and Joliot in Paris, and Dr. Chadwick at Cambridge; that of the latter was achieved by Anderson in the United States and Mr. P. M. S. Blackett and Dr. Occhialini at Cambridge, and in the last few weeks M. Jean Thibaud, of Paris, has confirmed their work by a new method. It was suggested that the neutron was composed of a proton and negative electron, but the view now generally held is that the neutron is sui generis. The mass of the neutron is certainly not far removed from that of the proton. It is believed that the neutron plays no small part in the constitution of atomic nuclei. The positive electron, on the other hand, does not appear to form part of the nuclear structure. Positive electrons seem to be generated as twins with negative electrons near, but not in, the nucleus during atomic collisions. A reason has to be given why neutrons and positive electrons are so rare in nature. In the case of positive electrons, the answer was given by Professor Dirac when as yet they were undiscovered; he showed that almost as soon as they are formed they must be destroyed. But they live long enough for their tracks to be photographed by Mr. Blackett.

Now that so much is known about the ultimate structure of matter, the dream of the transmutation of the elements has been realized. The history of alchemy affords not a little justification to the Hegelian belief that history is a process of affirmation, denial, and synthesis. Many of the best minds of the Middle Ages favored the idea that other metals could be transmuted into gold, an idea most elaborately presented in the Summa Perfectionis of Geber. St. Albertus Magnus did not disbelieve it, though he characteristically thought that gold so produced was different from gold won from the earth. The "experimentis of alconomye" of which Piers Plowman spoke in the next century were universally practiced, and faith in them survived even the upheaval of the Renaissance and Reformation. The immortal Sir Isaac Newton believed in transmutation, though there is no evidence that as master of the mint he produced gold by any means other than were customary. But the tide was turning. The Honorable Robert Boyle initiated an age of sceptical chemists, and Edward Gibbon could write with that superciliousness which no one else has ever approached:

> Philosophy, with the aid of experience, has at length banished the study of alchymy; and the present age, however desirous of riches, is content to seek them by the humbler means of commerce and industry.

That, however, was not the end of the story. Depth in philosophy, and greater experience, have brought back from exile the idea of transmutation banished by Gibbon. Toward the end of the nineteenth century it was found that certain elements were actually being transformed into other elements without man's aid; in fact, man could do nothing to accelerate or even hinder the process. They were the radioactive elements, whose atoms were very heavy and complicated, and therefore unstable, with a tendency to break up into simpler atoms. In this way lead was left behind when uranium disintegrated. Man could only watch the process, but it furnished him with the means by which he himself could transmute one element into another. For radioactive substances emitted alpha-particles, or helium nuclei, at enormous velocities, and these could be used as projectiles to bombard matter in the hope of transmuting it. The hope was realized; thus when Lord Rutherford fired alpha-particles into nitrogen a form of oxygen was obtained. This was not a disintegration of matter, as in radioactivity, but a building up of atoms, the oxygen atom being heavier than the nitrogen.

But there was still a weakness in this process—man had no control over the source of his projectiles. Another step forward was taken last year by Dr. Cockcroft and Dr. Walton when protons obtained by the passage of electricity through hydrogen were fired at a lithium target. Sometimes, apparently, a lithium nucleus would capture a proton and would split up into two helium nuclei. The process, which was wholly under the control of man, has subsequently been extended to other elements, and alchemy may now be said to be a well-organized science. The newly discovered neutrons have also proved themselves excellent projectiles for transmuting matter by bombardment. (It should perhaps be pointed out, in view of popular beliefs to the contrary, that the "splitting of the atom" holds out no immediate hope of a new source of power. It is true that when a single atom is transformed more energy is obtained than is put into it; but only a small fraction of the projectiles fired into atoms are successful in making hits on nuclei, and on the whole far more energy is put into the process than is obtained out of it.)

A few more comparisons between the medieval alchemists and the modern physicists may be not inapposite. Medieval alchemy was guided by the principle that underlying all the different substances was a prima materia, the specific differences being due to the addition to this prima materia of different sets of qualities. The problem of transmutation was therefore a problem of removing one set of qualities and substituting another. At the beginning of the last century Prout suggested that hydrogen was the basis of all matter. That has been proved to be not precisely true, but all forms of matter are made up of protons and electrons, with a sprinkling of neutrons, and hydrogen is the simplest of those forms. Transmutation has therefore become a problem of rearranging protons and electrons. This is not fundamentally different from the medieval idea. Moreover, by a happy inspiration the medieval alchemists were obsessed with the idea that gold could be obtained by somehow treating mercury with sulphur—a happy inspiration, for we now know mercury to be next after gold in the periodic table of the elements—i.e., to have just one more orbital electron. Finally, it is worth noting the part that England has played both in alchemy and in the modern way of transmutation. Robert of Chester, Roger of Hereford, and Richard of Wendover have their successors in Lord Rutherford, Dr. Cockcroft, and Dr. Walton.

So much for the present state of microscopic physics. A convenient bridge to the macroscopic world is provided by the cosmic rays; they were the means by which the positive electron was discovered, and on one theory they are the cause of the expansion of the universe. They were called cosmic rays because they appeared to come from all directions in outer space; but men of science now confess they know far less about cosmic rays than they formerly thought they did, and in view of doubts about their cosmic nature some workers prefer to talk about "the penetrating radiation." Of its penetrating nature there can be no two opinions. The rays were first discovered about 30 years ago when a physicist found that an electroscope round which he had piled lead sufficiently thick to shield it from all known forms of radiation was nevertheless discharged. Since then a vigorous attack on the problem of their nature has been made, an attack which has increased in intensity of recent years and is now one of the most fascinating of scientific pursuits.

It is no armchair or laboratory task. The first essential is a knowledge of the intensity of cosmic rays at as many times and places as possible. Accordingly a great variety of observations has been made. Professor Regener, of Switzerland, clearly sharing Gray's faith that—

> Full many a gem of purest ray serene
> The dark unfathom'd caves of ocean bear,

has measured the intensity of cosmic radiation 750 feet below the surface of Lake Constance; and he has sent up balloons with self-recording instruments to a height of 17½ miles. Professor Piccard, of Belgium, has himself made two personal ascents into the stratosphere at great risk to his life. Professor Compton, of the United States, has organized expeditions to 81 stations all over the world at heights from sea level to 20,000 feet. Professor Kolhörster has gone down into a Prussian salt mine and brought back evidence of cosmic rays, four times as hard as the most penetrating discovered by Professor Regener, which are capable of maintaining the electric charge of the earth.

But the mystery of the cosmic rays is still unsolved. A few years ago it was confidently thought that cosmic rays were of the same nature as light, only with very much shorter wave length. They were placed at the lower end of the gamut of radiation which was thought to run: wireless waves, heat waves, infrared rays, light, ultraviolet rays, X-rays, gamma rays, and cosmic rays. On this basis several novel theories to account for their origin were proposed. Sir James Jeans thought they were the product of the complete transformation of matter into energy "annihilation." Professor Millikan thought they were liberated when helium was formed out of hydrogen somewhere in space. The Bishop of Birmingham thought it "not wholly improbable" that mixed up with the cosmic rays were messages from beings on other planets in a more advanced state of development than ourselves.

Since then physicists have become less confident of the nature of cosmic rays. Most investigators now think they are not of a wave nature, but consist of electrified particles, possibly electrons. That takes away the ground from under those who would see in cosmic radiation the birth-cry or death-rattle of an atom, or an interstellar broadcasting service. If cosmic radiation does consist of electrified particles, it will be attracted towards the earth's magnetic poles, and it becomes important to decide by experiment whether that is so. Professor Compton's expeditions do show that the intensity of cosmic radiation is greater in temperate than in tropical latitudes. The result is not wholly decisive, but what we know as cosmic radiation is almost certainly a mixture. Apart from the primary cosmic rays there are the secondary rays formed when the primary rays strike the earth's atmosphere. Cosmic radiation may consist not only of many rays of different intensity, but may include corpuscular and wave parts. The radiation, it may be added, appears to be nearly constant in time at any one place; as it is the same by night as by day, the sun can hardly be its origin.

Another reason for the indecisiveness of the theory of cosmic rays is the comparative rarity of the rays on the earth's surface. But when

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they are detected they make their presence felt by their extraordinary penetrating power. On account of this power they make good projectiles for bombarding atomic nuclei. Mr. Blackett and Dr. Occhialini were using them to bombard copper when they obtained a shower of about 30 particles, among them several positive electrons. But though the rays are comparatively rare upon the earth, they are probably very important in the universe taken as a whole. That is because the matter in the universe is aggregated into lumps at great distances apart, but the cosmic rays appear to be spread out all over space. Hence, their total effect is likely to be very great.

This line of argument gives plausibility to the cosmological speculations of the Abbé Lemaître, a Belgian priest who has recently joined the staff of the Catholic University at Washington. The Abbé Lemaître believes that the whole universe began as a single atom a few astronomical units in diameter. That allows for all the nuclei of all the atoms in the universe to be packed closely together. This primeval atom possessed a tendency to disintegrate, and finally did burst with explosive violence, sending forth streams of cosmic rays and showers of particles. Their pressure has caused the universe to expand, and it is still expanding. Observational evidence of this expansion is thought to be provided by the spiral nebulæ. We live in an island universe or nebula called the Milky Way, and there are many similar nebulae, only smaller ones for the most part, scattered about in space. When the light from these distant nebulae is split up by a spectroscope into its component colors, the colors are shifted toward the red end of the spectrum compared with the standard position. The most natural interpretation of this shift is that the spiral nebulae are receding from us; it corresponds precisely with the fall in the note of an engine's whistle as it passes an observer. The velocity of recession can be measured by this means as well as detected, and appears to be proportional to the nebula's distance. A nebula whose light takes 3.26 million years to reach the earth gives a velocity of 344 miles a second; one whose light takes 150 million years on the journey gives a velocity of 15,000 miles a second. Of course, the shift to the red may be interpreted in other ways, but that is how it would be interpreted usually. Sir Arthur Eddington observed at Leicester that the Lick Observatory catalog spoke of "radial velocities" in general, but cautiously used the term "apparent radial velocities" for the spiral nebulae; that, he said, reminded him of the clergyman who said he would arrive (D.V.) on Friday, and on Saturday in any case. It should be noted, however, that loss of energy by light in its passage through space would account for the shift to the red, but such an explanation would be entirely ad hoc.

The Abbé Lemaître's is but one of several theories of the expanding universe. It may seem that there is an obvious self-contradiction in the notion of the universe expanding. If it expands, it must be into something, which ex hypothesi is in the universe. But when physicists talk of the expanding universe they mean the material universe consisting of the galaxies and the space in which they are contained, not strictly the sum of all things. In this sense an expansion of the universe is certainly possible. Such explanations will remove most of the paradoxes associated in the popular mind with astronomical theory. When in a recent paper Professor de Sitter, to give another example, spoke of the stars being older than the universe, he did not mean by the beginning of the universe what most people understand by that term, but the minimum of a certain quantity entering into his theory. At Leicester he explained this paradox by the analogy of the Californian trees, which are much older than California!

Having admitted the idea of a universe changing in size, many types of change are theoretically possible. The universe can expand continually, it can contract until it shrinks to a minimum size, or it can go through alternating periods of expansion and contraction. The different versions of the expanding universe theory can best be examined historically.

The roots of the theory go as far back as 1916, when Professor Einstein had just published his general theory of relativity. In that theory space and time were on an equal footing, and the space-time universe was supposed to be infinite in every direction. But Professor Einstein quickly became dissatisfied with the universe, chiefly, it would seem, because he did not understand what happened to his equations at infinity, and in 1917 he introduced the notion of a universe that was finite but unbounded—i.e., a universe with a finite volume that could be measured in cubic miles. This universe was supposed to be full of uniformly diffused matter. It had many peculiar properties. A ray of light, for instance, would return to the point from which it set out unless deviated by some means from its natural path. The reader of Emerson's Uriel may recall a prophetic anticipation of this Einstein universe:

> Line in nature is not found,
> Unit and universe are round;
> In vain produced all rays return.

Our actual universe, of course, is not like the Einstein universe because matter is aggregated into stars and nebulae and not spread homogeneously through space. Professor de Sitter capped Dr. Einstein's theory with a world empty of matter. The actual universe would, of course, be intermediate between the worlds of Einstein and de Sitter. The interest of Professor de Sitter's theory for us is that any particles introduced into it would tend to run away from an observer stationed at the origin; and the light from distant objects would give a spectrum shift toward the red. In a sense, therefore, the notion of an expanding universe is to be found in Professor de Sitter's theory.

But it was not until 1922 that the theory as strictly understood was founded. A. Friedmann then pointed out that the Einstein universe was unstable, so that if once disturbed it must go on expanding or contracting. Although he published his proof in one of the best-known German scientific periodicals, it fell completely unnoticed. Independently the Abbé Lemaître was developing a similar theory, and in 1927 he published his results, only to find that they also were unnoticed. But in 1930 the ground was better prepared, chiefly owing to the growing evidence for the recessive motions of the nebulae. Sir Arthur Eddington expressed the wish that a certain mathematical result had been worked out; Lemaître, who had previously been a pupil of his, wrote to say he had already obtained it. From that moment the theory of the expanding universe leaped into prominence. Sir Arthur Eddington has himself been no mean contributor to it. Although most men of science do not believe he has completely justified his particular form of the theory, all are forced to admire it by its extraordinary elegance and power. He obtains by pure theory a value for the expansion of the universe which does not differ so very much from the observed value of the recession of the nebulae. In the course of the working he obtains a quadratic equation whose roots are in the ratio 1,846 to 1, which is the ratio of the mass of the proton to that of the electron. And he is able to prove that on his theory the total number of particles in the universe is 10^{79} (10 followed by 79 noughts).

Dr. McVittie and Dr. McCrea have done some valuable investigation of the effect of condensation in the matter filling the Einstein universe. But the most original contribution to the theory recently has been that of Professor Milne, of Oxford. At first it seemed to knock the bottom out of theories of expanding space, because Professor Milne explained the recession of the nebulae by using ordinary kinematics and Euclidean space. Consider a number of billiard balls moving on an indefinitely large table. If any point be taken on the table, there comes a time when all the balls will seem to be moving away from it. Some will always have been moving away; others will first come near the point and then pass away; but given sufficient time all will appear to be moving outwards, and the fastest-moving will naturally be farthest away. Professor Milne seemed to have hit on an absurdly simple explanation of the recession of the nebulae, the only difficulty being that it presupposes the nebulae have had their great velocities from all time, whereas most of us like to think of all the stars being formed out of one primeval mass. But Professor Milne has elaborated his theory to a form in which very strange things happen. In his universe all observers in uniform relative motion observe identical world pictures. The observable volume of the universe is finite, but the system has no age and no radius—only an age and a radius when a particular observer is specified at a particular stage of his experiences. What we call " creation " in the past history of any one observer reappears on the confines of the observable system, where, however, the particles become invisible owing to recession with the speed of light. It is all passing strange.

Such in broad outline are some of the problems the physicists of today are trying to solve. They will be solved only by the closest cooperation of experimenter and mathematician, theoretician, and empiricist. The way in which fact and theory are intertwined was well shown by a paper read by Prof. Dayton Miller. Given on the last day, and unentered on the original program, it has not secured the attention it deserves. As is well known, the theory of relativity is based ultimately on the Michelson-Morley experiment of 1887. Professor Miller showed that even Michelson and Morley did not get the completely null result assumed by the theory of relativity, while he and Morley have repeated the experiment since and have always obtained a positive effect, which appears to vary with the time of day. Unless some explanation is forthcoming, the theory of relativity will need considerable modification in the light of these experiments. At Leicester, Lord Rutherford suggested that the facts are all-important, and theory must be kept in its place. Sir Arthur Eddington seemed to suggest that if the facts do not agree with the theory, tant pis pour les faits. Lord Rutherford is not so obviously right as appears at a first glance, for facts are generally discovered only under the guidance of some theory. But we may rest assured that if the difficult but entrancing problems of modern physics are to be solved, it will be by the perfect union of fact and theory, and that alone.

HIGH VOLTAGE [1]

By Karl T. Compton
President, Massachusetts Institute of Technology

[With 1 plate]

While there is much truth in the statement that necessity is the mother of invention, it has often been pointed out that it is far from true that necessity is the mother of discovery. Discoveries come often most unexpectedly, in the pursuit of knowledge by the curious and observant. The great background of natural phenomena which have thus been discovered form an immense reservoir from which may be drawn natural laws or combinations of phenomena which can be made to work for the solution of men's needs or desires when necessity arises.

One of the most excellent examples of the fact that necessity is the mother of invention is found in the great number of applications of science which were made during the past war to cope with situations which never before had challenged the ingenuity of man. Such situations were the detection and location of submarines or of airplanes flying by night. There were also the location of underground mining operations or of enemy artillery by sound, or the direction of counter-battery artillery fire, also by sound. Such examples could be multiplied almost indefinitely, but the interesting feature of them all is that every one was handled by the application of some scientific phenomenon which had been known in the laboratory for many years. The necessities of war brought forth the means of applying these phenomena for particular purposes.

It is to a very recent example of this natural sequence of events that I will call your attention in this paper, an example taken from the field of electricity, the chosen field of Joseph Henry in whose honor this lecture has been named. It is a modern application of one of the oldest branches of electricity, a branch so old that some ultramodern textbook writers have advocated omitting it entirely from textbooks on account of the academic and impractical character of its subject matter. But let me first lay the groundwork for this new development in the field of high-voltage electricity.

[1] The third Joseph Henry lecture delivered before the Philosophical Society of Washington on Mar. 11, 1933. Reprinted by permission from Journal of the Washington Academy of Sciences, vol. 23, no. 6, June 15, 1933.

While electricity can be produced in a variety of ways, and it was some time in the history of the subject before it was realized that the electricity was the same kind of thing in all of these cases, nevertheless there are but three principal means of generating electricity. The first is static electricity, first discovered by Thales of Miletus as early as 600 B.C. Thales found that amber, when rubbed against other substances, had the power of attracting fragments of straw or leaves or feathers. In fact, the word electricity is derived from the Greek word electrum, meaning amber, and was first so used by William Gilbert in about 1600.

The second great step in the production of electricity was the invention by Volta of the voltaic cell in 1799, and from that time until the time of Faraday in 1831, the great development of electricity was in the production of batteries of various kinds. Volta was able to generate several hundred volts by piling up alternate layers of copper and zinc, separated by paper which had been moistened with acid, thus creating, in effect, a battery with a large number of cells in series.

When in 1831 Faraday made the discovery of electromagnetic induction and about the same time Joseph Henry discovered self-induction and independently repeated a number of Faraday's discoveries in mutual induction, the modern science of electricity and art of electrical engineering were born.

It is a striking fact, which perhaps we do not stop to think about, that this so-called "electrical age" has grown up during a period of one working lifetime, since men like Elihu Thomson are still living and men like Edison have just died, who built upon these scientific discoveries of Faraday and of Henry the modern art of electrical engineering.

With the development of electromagnetic devices, dynamos, motors, and transformers, the use of batteries, except for very special purposes, has largely been discontinued. Static electricity, which had been developed from the study of frictional charges and charges of conductors by induction, was relegated almost to the field of scientific but useless curiosities. The efficiency of electromagnetic generating apparatus has been developed to a remarkable degree, so that for the practical purposes of our industrial needs and our home needs the modern science of electricity has appeared to be eminently satisfactory.

It is true that there have been some other new developments of first importance in the electrical field, notably electronic devices, such as radio-tube detectors, amplifiers, and transmitters or devices which operate with ionization of gases, such as the mercury-arc rectifier and the glow discharge tube. These things, however, are more in the nature of electrical instruments or electrical control devices, and it still remains true that the production and distribution of electricity are basically carried on by means of the electromagnetic induction devices developed from the work of Faraday and Henry.

Let us follow the development of high voltage by electromagnetic induction. In this, as in all other fields, the first developments were crude, as was necessarily the case because instruments and methods had not been developed and everything had to be taken up de novo. When Joseph Henry wished to build his great magnet with several coils of wire he had first to invent insulated wire, which he did by wrapping strips of his wife's dresses and petticoats covered with shellac around the wire. When Henry wished to measure the voltage of the current produced in a step-up transformer he had no ammeter or voltmeter capable of detecting the small current at high voltage and had to substitute for them the students in his class, judging the voltage by the number of students who could be shocked when connected hand to hand in series across the terminals of the secondary of his transformer. Thus a voltage that would shock 30 students he estimated to be twice as high as one which would shock 15 students, and in this way he was able to arrive at a very crude but correct idea of the relationship between the number of turns of wire in the secondary of a transformer and the voltage which was produced therein.

The story is told of a striking lecture demonstration given by Henry while at Princeton. He hung a secondary coil of a large number of turns of wire on the inside wall of his classroom and had the students of his class join hands in series across the terminal of the coil. The primary coil of this transformer was concealed from the students, being suspended on the outer wall of the building from wires passing out through an attic window and connected with a large voltaic battery in the attic. When Henry rapped against the wall his assistant in the attic plunged the copper and zinc battery plates into the acid, thus sending a current through the primary, which induced a high voltage in the secondary and shocked the students of his class.

It is probable that Henry, burdened as he was with administrative duties and the difficulties of finding the means wherewith to carry on his experiments, did not realize so clearly as did his contemporary, Faraday, the ultimate practical value of these things which he was doing. Faraday, when once asked by the King, "What is the use of these things?" replied, "Your Majesty, of what use is a baby?" And another time, when he was asked by the Prime Minister this same question, "Of what use are these things which you are doing?" he replied, "Your Excellency, some day you may be able to tax these things." Henry, however, was so wrapped up in his scientific pursuits that he gave little thought to the possible practical application of his work. It is said that when he was once urged to press his claim as inventor of the telegraph and other instruments, he replied that there were far too many interesting things to be done in the laboratory to permit him to take time with such matters.

There has been a practical urge for the development of high voltage power from three different points of view. The first and most important of these is for the transmission of electric power over large distances. It is much more economical to transmit power at high voltage and small current than at low voltage with large current, because the resistance losses depend upon the current and not the voltage. For this reason the voltage of high-power transmission lines has continually risen from first a few hundred volts, then a few thousand, not many years ago 60,000, and now upwards of 200,000 volts. The losses of power and the necessity of auxiliary equipment are such that, according to a practical rule, it is not economical to transmit electrical power farther than 1 mile for every 1,000 volts. From this we see that a modern 200,000-volt transmission line could be economically used to transfer power from the power-generating station to distances of about 200 miles, but beyond these distances such transmission of power is not economical. For that reason, in any area requiring the use of electricity, power-generating stations must be located at distances of not more than 200 miles from each other.

The question may be asked as to why the voltage is not raised still higher than 200,000 volts; and the answer to this is found in the fact that, with higher voltages, the electric field in the air surrounding the wire becomes so intense as to ionize the air, causing a leakage of electricity from the wire into the air in the form of an electric discharge known as a "corona." This phenomenon of corona is one of the facts which set the practical upper limit to the voltage which can be used for transmission.

It is not feasible to generate directly voltages in the range of several hundred thousand volts, because the difficulty of insulation becomes too great, and an electric dynamo with insulation adequate to withstand even several thousand volts would have to be so large, to include the necessary insulation, as to be unwieldy and inefficient. Consequently, the power is generated at relatively low voltage, usually a few hundred volts in alternating current, and this is sent through a step-up transformer insulated in oil, in which the secondary has a hundred or a thousand times more turns of wire than the primary. In this secondary coil the very high voltage is generated for transmission over the power lines. Then at the other end of the line the power is fed through a similar transformer in the reverse order and comes out of that secondary as a very large current at relatively small voltage.

There has been no really fundamental difficulty to be overcome in these power transmission lines, although there have been very many interesting problems of science and engineering to be solved. The proper design of a transformer to be efficient and to be sufficiently well insulated is one problem. Perhaps the most difficult problem has been that of proper switching devices so that these high-voltage currents can be started and stopped without excessive arcing at the switches. It is such developments as these which have made the great generating stations at Niagara Falls and the many other hydro-electric or steam-electric generating stations such an important feature in our present industrial life.

The second thing that has stimulated high-voltage developments of the electromagnetic type has been the X-ray. For ordinary purposes, from 30,000 to 100,000 volts are adequate for either diagnostic or therapeutic purposes. Of recent years, however, in the endeavor to find the most effective methods of treating internal cancerous growth there has been an increasing desire to go to much higher voltages, and consequently X-ray tubes operating on as much as a million volts have been developed at the General Electric Co., at the California Institute of Technology, and elsewhere.

To generate the high-voltage power for these X-ray tubes, recourse has been had to transformers connected in series, the primary of one transformer being connected with the secondary of the other, and all transformers after the first being insulated. By such means, large power can be delivered and high voltages obtained, although a million volts appears to be about the practical limit, because there are parasitic currents known as " charging currents " which drain a great deal of energy uselessly from the system when an alternating or " varying current " is used at such high voltages. Furthermore, the equipment becomes tremendously expensive on account of the requirements for insulation.

The third thing that has led to high-voltage developments of the electromagnetic induction type has been the study of the effect of lightning on transmission lines and the desire of electrical engineers to duplicate as nearly as possible the effect of lightning by means of high-voltage sources for laboratory study. For this purpose there has been developed the impulse generator, in which a series of condensers capable of storing electric charge at high voltage are charged in parallel from a high-voltage transformer and are then connected in series, so that the overall voltage delivered is the sum of the voltages across the separate condensers. By such means impulsive or momentary voltages of 10 or 15 million volts have been obtained.

These are exactly right for studying transient effects like those of lightning, but the impulse generator is inherently incapable of serving properly any purpose which requires a steady and reasonably constant source of high voltage. The discharge in this impulse generator lasts only a few hundred thousandths or millionths of a second.

This impulse generator represents the peak of high-voltage accomplishment by the electromagnetic method, and you will notice that this is accomplished by combining with the electromagnetic device, namely, the step-up transformer, a series of condensers which are essentially electrostatic instruments.

Let us return now from the high-voltage developments, based on principles of electromagnetism, to the historically earlier type of electric generation which falls within the general field known as electrostatics. The characteristic of these devices has been the relative ease of producing high voltages, but with an exceedingly minute quantity of electricity.

The first electrical machines of which we have any knowledge were frictional electrical machines constructed about 1663 by Otto von Guericke. They consisted of globes of sulphur made to rotate about an axis so as to rub against the hands if held against them. In this way the globe of sulphur became electrically charged, and the charge of the opposite sign appeared on the person who touched the globe. Isaac Newton appears to have been the first person to use a glass globe instead of sulphur, but it was Ramsden in 1768 who really constructed the first object that might really be called an electrical generating machine.

The Ramsden machine consists of a glass plate which can be rotated by a winch and which passes with rubbing contact between two leather pads. By friction the glass becomes positively charged and the pads are negatively charged. These positive charges are taken off the glass disk as it passes in rotation between combs of sharp points. Similarly the negative electricity from the pads is collected from them and delivered to another terminal. For a number of years the only development of the art of electrical generation consisted in finding various materials which might be put on the glass or on the leather pads to increase their effectiveness in separating frictional electricity.

A later development of a frictional machine is that invented by Lord Armstrong of Newcastle, England, in 1841. Lord Armstrong was experimenting with steam boilers. By accident one of his assistants received an electric shock when he touched a piece of metal against which a jet of steam from a leaky boiler was striking. This led Lord Armstrong to further experiments leading to the steam electrostatic generator. The action of this generator consisted in blowing drops of condensed steam, by the steam pressure, out through a series of nozzles against a neighboring metal plate. The droplets of water were charged by frictional contact against the walls of the nozzles. The electrical power was created by the work done in moving the charged droplets against the electric field which developed between the nozzle and the plate on which the droplets struck, and, of course, this power was in turn derived from the driving power of the steam, which carried the droplets out and away from the nozzle.

Another whole series of electrostatic generators was built upon the principle of electrostatic induction. Perhaps the simplest of these was the Belli doubler, which was devised in 1831 and operated on the same principle as a later device designed by Lord Kelvin and better known as the "Kelvin replenisher", described by him in 1872. This action is shown schematically in figure 1. When the rotating member with the insulated plates *E* and *F* is at the position shown, positive and negative charges are separated from the connecting wire, which brushes lightly against *E* and *F*, by means of the electrostatic forces arising from the charges on the neighboring metal armatures *C* and *D*. As the rotating arm turns and breaks contact with these brushes the charges are carried on *E* and *F* and, when they touch the springs *C* and *D*, respectively, these charges are communicated to the armatures, thus increasing the charge already existing on these armatures. Then at the next contact with the brushes at *E* and *F* the process is repeated. Consequently the charge on the armatures continually builds up until it reaches such magnitude, or rather until the voltage rises so high that the charge leaks away as fast as it is produced, leaking away either through the insulation or by a corona discharge produced by breakdown of the surrounding air.

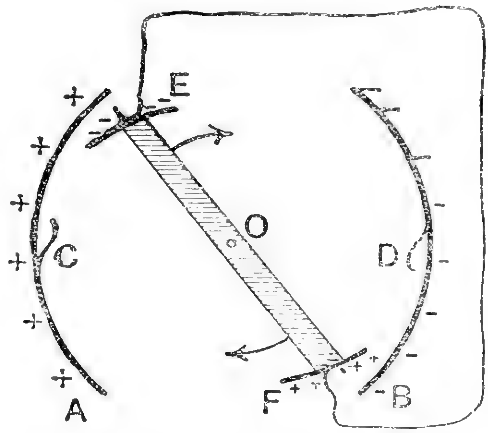

FIGURE 1.—Schematic diagram of Kelvin replenisher.

A large variety of instruments, some simple and some very complicated, have been developed to carry on the idea of the Belli doubler in a more efficient manner. Such instruments were devised by Varley in 1860, by Toepler in 1865, and by Holtz between 1864 and 1880, but by far the most successful of these devices is the well-known Wimshurst machine, which was first invented in about 1878. This machine is well known to everybody, I think, as the "influence machine", whose action may be described as follows:

Imagine that, in some way or other—for example, by friction—a small negative charge is located on the metal sector of the rotating disk opposite the point *C* of figure 2. This negative charge will

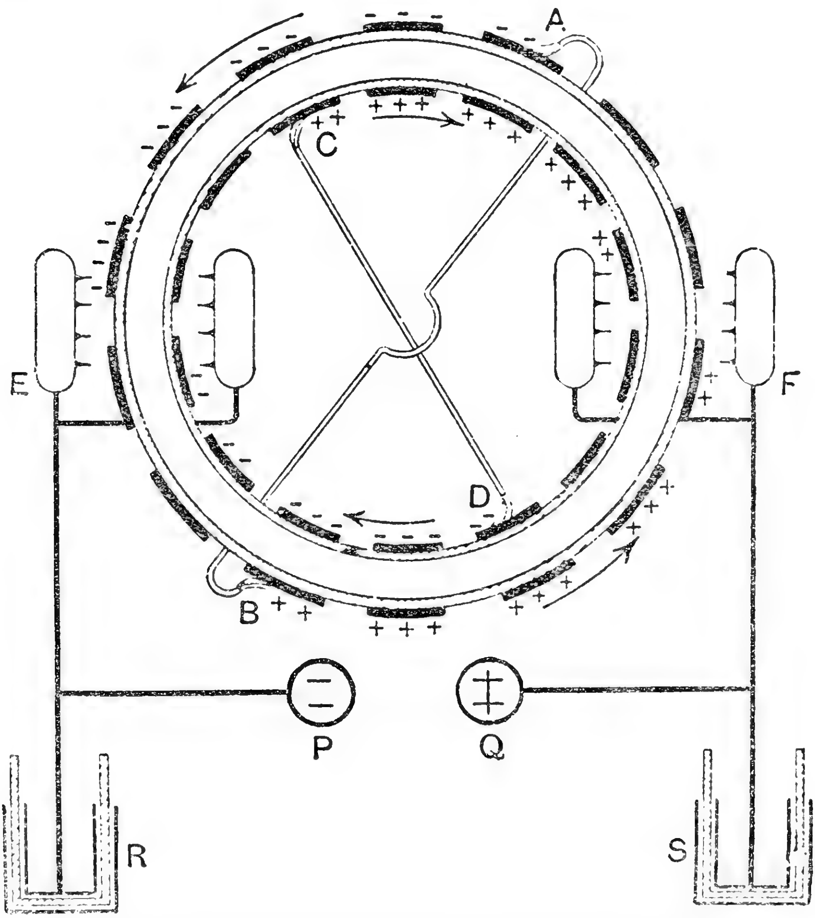

FIGURE 2.—Schematic diagram of Wimshurst influence machine.

induce the separation of positive and negative electricity in the metal rod *CD*, drawing positive charge to the point *C* and forcing negative charge to the point *D*. At these two points the charges are collected on the metal sectors of the second glass disk which is rotating in the opposite direction. Thus all the metal sectors to the right of *C* carry positive charge collected from *C* and they all deliver it to the sharp needle point at *F*.

At the same time these positive charges on the metal sectors to the right of C will similarly induce negative charges in the metal rod AB, which charges will be deposited on the metal sector to the left of A and will in their turn be collected by the sharp point at E. Thus the process is a continuous one, E and F collecting negative and positive electricity, respectively, from the metal sectors on both of the revolving disks. By having a multiplicity of revolving disks these Wimshurst machines may be made to deliver a considerable amount of power and were in fact at one time quite largely used in the X-ray art until they were supplanted by the more powerful and much more convenient electromagnetic induction devices described previously, including set-up transformers, induction coils, and the like.

One of the most ingenious types of electrostatic induction machines is the famous Kelvin water-dropper which is shown in figure 3. Here perhaps more easily than in any of the other induction machines can be seen the way in which a small charge once produced may result in the continual building up of an indefinitely large charge, if the arrangement of apparatus and connections are suitably arranged. Assume for a moment that for some cause, such as friction of the wind or anything else, there happens to be a small charge on the cylinder A. Every drop of water leaving the outlet in A will therefore carry a small induced negative charge which will be delivered to the cup below, thus raising the cylinder at B to a negative charge. All of the drops of water which come from the outlet inside of B will therefore carry the positive charges which will be collected in the trap below and serve still further to increase the positive charge on A. So the process goes on, the charges building up until through leakage or through a corona discharge to the air, they leak away as fast as produced.

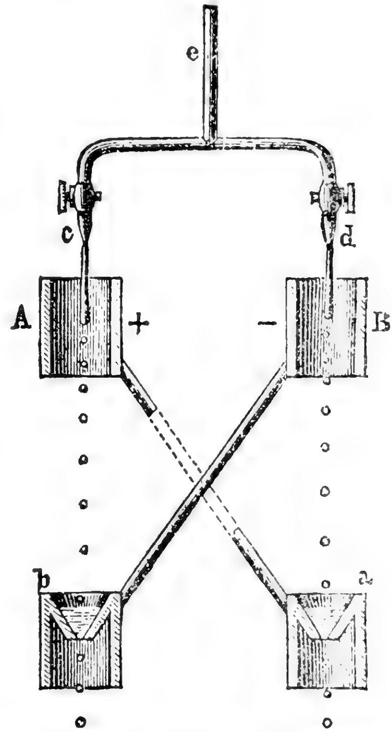

FIGURE 3.—The Kelvin water-dropper.

At this point I am minded to make a confession regarding my first experiment in physics. I conceived the idea of producing electrolysis by the use of gravitational energy alone, and set up a device somewhat similar to the Kelvin water-dropper. My device consisted of drops of copper sulphate coming from an outlet like that in the cylinder *A* and falling into a platinum funnel like that directly below *A*. I charged the cylinder *A* with a large negative charge from a static machine, and this charge remained on the cylinder, which was well insulated. Consequently, every drop of copper sulphate that dropped carried an induced positive charge and delivered it to the funnel *b*, which was earthed. This excess positive charge would of course be in the form of copper ions which would be deposited on the platinum in the process of neutralization of the drop. After running the apparatus for an hour or so, I looked at the platinum cylinder to see whether I could see any copper deposited on its inside, and finding none, I set the apparatus going in the late afternoon and let it run automatically until the following morning. Again examining the funnel, I found no deposit of copper and, somewhat surprised, I sat down to figure. I soon discovered that the copper would be present in far too small a quantity to detect. In fact, if every drop were charged with the largest amount of electricity which it could carry without losing it by corona to the surrounding air, and if the drops had fallen as fast as possible beginning with the time of Christ, I would by this time have collected barely enough copper to be shown by the most sensitive known chemical test. This little experience illustrates the vast difference in magnitude between the kind of currents that we are accustomed to deal with in electromagnetic induction devices, dynamos and motors, and these relatively very feeble currents of electrostatics. These drops were charged with high electrostatic voltage, and the device was a fairly efficient electrostatic generator, and yet 2,000 years would have been required to deposit an amount of copper such as would appear in a fraction of a second with only a moderate current of the type that we ordinarily use in electromagnetic instruments.

In recent years an interesting development of the Kelvin water-dropper has been proposed by Dr. Swann, of the Bartol Research Laboratory, in which the water drops are replaced by steel balls which fall under the action of gravity, and in order to make the process continuous, there is the suggestion that these balls may be carried back again to the upper container by means of magnetic control. In this way the succession of falling balls behaves somewhat like a continuous belt containing metal sections separated by insulated regions of air and driven by gravity. In the absence of leakage this kind of a generator should be capable of developing such a high voltage that the electrostatic attraction of the falling balls would just compensate gravity. This would be an extremely high voltage such as could be obtained only if the apparatus were operating in a vacuum, and, in fact, Dr. Swann suggests that it may be operated in this manner.

With this historic survey of electrostatic generators, let me now return to the text of my address, "Necessity is the mother of invention." Until very recently there was no compelling need to force physicists to seek ever higher and higher voltages in electrical generating devices. Their needs were met by existing devices of the electromagnetic type. Within the past dozen years, however, it has become evident that a whole new range of fundamental investigation into the properties of atoms will be opened up by a suitable source of high potentials.

This new inducement may be said to have arisen with Rutherford's discovery that it is possible to transmute one chemical element into another by bombarding it with the fast electrified particles known as alpha particles, which are spontaneously given off by radioactive materials in the process of their disintegration. These brilliant experiments opened up a whole range of new explorations into the structure of the atomic nucleus and stimulated the imagination of scientists in regard to what might be done if only they had available some more powerful and better controllable source of high-speed missiles to shoot at the atomic nuclei. The alpha particles from radium do have tremendous velocities, but they are relatively few in number, and all the radium that could conceivably be gathered together in the world would not produce a stream of electrified particles comparable to that which can be obtained in an ordinary discharge of electricity through a vacuum tube. If only the voltage as applied to a vacuum tube could be made high enough to give the ions in a vacuum tube speeds comparable with or even exceeding those of alpha particles from radium, what a powerful attack could be made upon the nucleus. Not only could particles in billionfold larger numbers be used, but different kinds of particles could be tried, such as hydrogen nuclei, helium nuclei, lithium nuclei, neon nuclei, and so forth, and these could be given any desired speed up to the maximum limit determined by the highest voltage available. So for the past dozen years, thoughts of scientists have again been turned to means for producing ever and ever higher voltages.

It was to this end that the million-volt installation at the California Institute of Technology was designed. It was also to this end that a system of high-potential transformers and condensers was built by Cockcroft and Walton in Cambridge, with which they were the first successfully to disintegrate atoms by means of electrified particles produced from an artificial source and speeded up

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by an applied voltage. However, the necessities of the case have led to other suggestions for securing high voltages, because the inherent limitations of electromagnetic induction devices lead to prohibitive expense and complexity if voltages much above a million volts are sought by such means.

There have thus been three very interesting new developments in the art of securing high voltages, or perhaps more generally, electrified particles with those speeds that would be acquired with tremendously high voltages. Of these, in order of apparent utility, are the devices of Brasch and Lange in Germany, of Lawrence at the University of California, and of Van de Graaff at the Masschusetts Institute of Technology.

The greatest natural source of high voltage of which we have any knowledge is the thunderstorm. It is estimated that the voltages in lightning flashes frequency exceed a billion volts; consequently it was natural for Brasch and Lange to look to the lightning flash as a source of high potential and to set up what may be considered as a glorified Franklin kite. Their apparatus consisted of a pair of long cables suspended between mountain peaks in that region of the Alps where thunderstorms are most frequent. These cables may be thought of as huge wireless antennae for receiving the electrical impulses of nearby lightning flashes. This was an installation of real engineering proportions, since the porcelain insulators alone at each end of the cable weighed upward of 2 tons. The terminals of the two conducting cables consisted of large spheres, whose distance apart could be varied by drawing in or letting out cable. The voltage obtained was estimated by the sparking distance between these spheres and voltages were obtained ranging between 8 and 15 million volts.

Although the voltage was tremendously high, its erratic occurrence and uncontrollable nature has led Brasch and Lange to give it up in favor of somewhat more conventional means of producing their high voltage, and at present they are working with an impulse generator.

An extremely clever device is that invented by Prof. Ernest Lawrence, of the University of California, by means of which electrified particles may be given energy characteristic of several millions of volts with the application of a much smaller voltage. The principle is that of repeated impulses, analagous to the way by which the amplitude of swing of a child in a swing may be made very great by a succession of small pushes, properly timed. In Lawrence's apparatus an oscillating voltage is applied to the ions, first in one direction and then in the other, while they are moving in approximately circular paths in a magnetic field and conditions are adjusted so that every time the voltage is applied the electrons are speeded up by just that amount. Thus, by applying only a few thousand volts, protons have been obtained with energy corresponding to nearly 2½ million volts.

Figure 4 shows a diagram of the apparatus. The protons or other ions are liberated, by a suitable device, near the center of a flat, hollow cylinder, which is divided into two parts separated from each

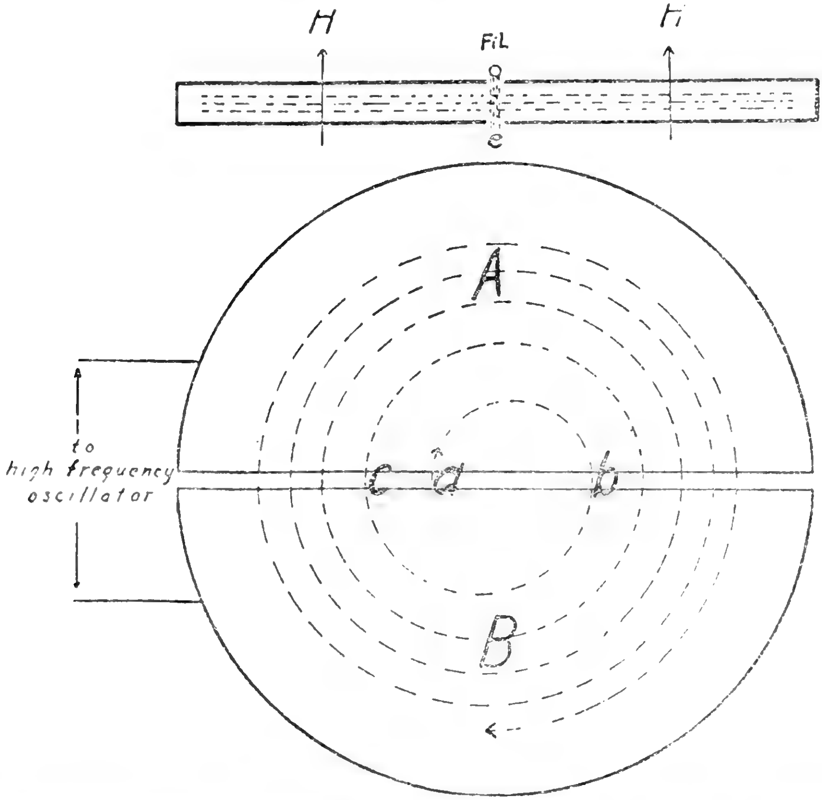


FIGURE 4.—Diagram of Professor Lawrence's apparatus for producing high speed electrified particles.

other. The oscillating high-frequency voltage is applied to these two parts, and at the same time the whole cylinder is placed between the poles of a powerful magnet. An ion starting at *a* is pulled by the momentary electric field across the gap and it takes, in the magnetic field, a circular path around to *b*. The frequency is adjusted so that by the time it reaches *b* the direction of the voltage has reversed so that the ion is again speeded up as it crosses *b* back into the half-cylinder from which it started. Then by the time it reaches *c* the voltage has again reversed to its original direction and it is given another push, and so on. The few-thousand-volts push is given to the ion every time it crosses the gap. It proceeds in ever-widening circles, attaining a speed limited only by the dimensions of the apparatus. With this device, Lawrence and his colleagues have reason for hoping that the speeds may ultimately be increased up to perhaps the equivalent of 10 million volts.

The currents are not very large, being reported of the order of a thousandth of a microampere. Nevertheless, these currents are tremendous in comparison with anything that can be obtained from radioactive material, and this source of high-speed, electrified particles will evidently be an important tool in nuclear investigation, as is in fact evident from very recent reports from Professor Lawrence's laboratory in which the experiments of Cockcroft and Walton in disintegrating lithium nuclei by means of high-speed protons have been confirmed and extended.

In the construction of this apparatus, the largest magnet ever built in this country has been put into use.

We come now to what I believe to be the most important development that has ever taken place in the field of extremely high voltages, namely, the Van de Graaff generator, invented by Dr. Van de Graaff as a result of considerations which were developed while he was a Rhodes scholar in England and which first took shape in the form of physical laboratory experiments at Princeton and which are now being developed and extended in the laboratories of the Massachusetts Institute of Technology.

From every point of view it is advantageous for very high voltages to have direct uniform currents. Van de Graaff was therefore led to develop an electrostatic generator, since electrostatic methods yield directly a steady unidirectional voltage such as is desired. Maximum simplicity was sought in the design. The simplest terminal assembly appeared to be a sphere mounted on an insulating column. Since the sphere must be charged and since the process should be continuous, the charge carrier should approach the sphere, enter it, and, after depositing its charge inside, should return parallel to its path of approach. This immediately suggested the action of a belt, a device long used for the transmission of mechanical power.

The logic of the situation therefore pointed directly to a generator consisting of a hollow spherical conducting terminal supported on an insulating column, a moving belt to carry electric charge to the sphere, a device for depositing the charge onto the belt in a region of low potential remote from the sphere, and a device for removing this charge from the belt inside the sphere and transferring it to the sphere. A refinement of these essentials was the addition of an induction device whereby charge of the opposite sign was carried by the belt on its return journey, thus doubling the current output. A second refinement consisted of a self-exciting charging device whereby the entire generator could be made to operate independently of any external source of electricity. Not only does this device attain the desired result in what appears to be the simplest possible manner, but it is also interesting to note that the energy transformations in its operations are exceedingly simple, consisting only in the transformation of the energy required to drive the belt into work done in separating and transferring electric charge from earth potential to sphere potential. Figure 5 shows, schematically, the operation of this generator.

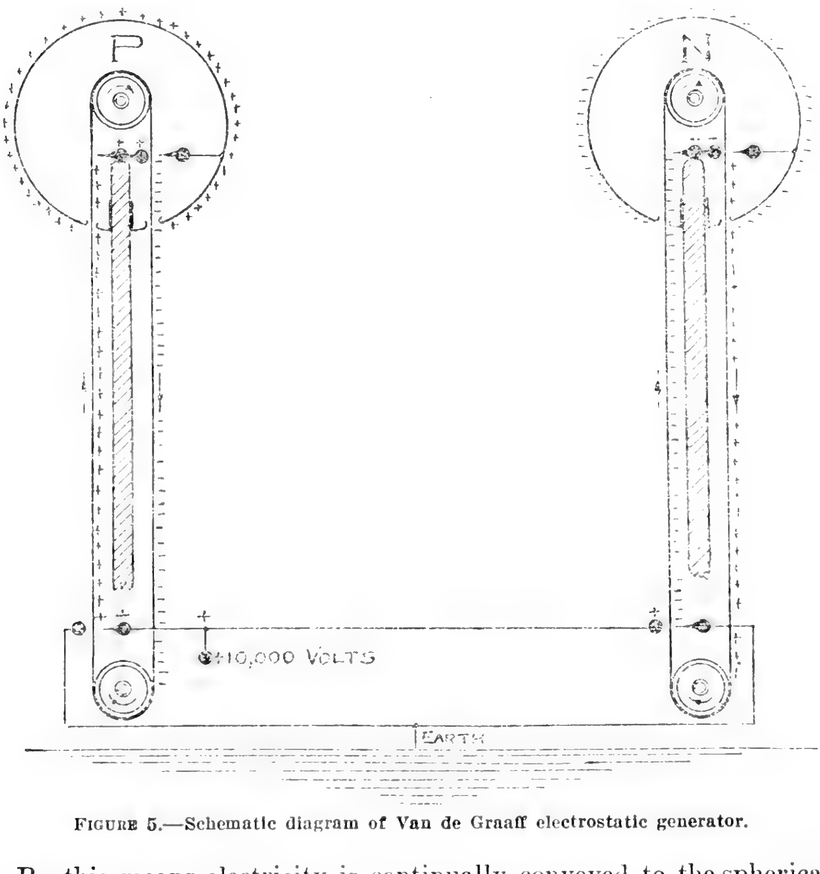


FIGURE 5.—Schematic diagram of Van de Graaff electrostatic generator.

By this means electricity is continually conveyed to the spherical terminal, whose potential consequently rises until limited by the breakdown of the insulation of the air in the form of a corona discharge at the surface of the spheres. This breakdown voltage depends on the size of the sphere, being approximately 750,000 volts for a 2-foot sphere and increasing to 5 million volts for a 15-foot sphere. Thus the attainable voltage depends upon the size of the spherical terminal.

The current, on the other hand, is simply equal to the rate at which electricity is carried to and from the sphere by means of the belts, and this in turn depends upon the size, speed, and number of belts and the quantity of electricity which can be placed on a unit area of the belt. This latter quantity is also limited by the breakdown voltage of the surrounding air, to an amount of about 5×10^{-9} coulombs per square centimeter of belt area. Under these conditions it is readily shown that a belt running at 6,000 feet per minute could theoretically carry a maximum current of 150 microamperes per inch width of belt. Actually, the best adjustments have given about half of this theoretical maximum, probably because the breakdown strength of the air is reduced by the mechanism whereby charge is sprayed onto the belts.

Theory and practice also show that these belts may be placed as close together as is geometrically possible, in fact, practically in contact, without interfering with their capacity to carry charge. By packing many belts together it is therefore possible to produce very sizeable currents. For example, a small laboratory model for demonstration purposes, constructed this year in the laboratories at the Massachusetts Institute of Technology, develops 1½ million volts between a pair of 2-foot spherical terminals and delivers a current of 600 microamperes carried on two 8-inch belts in each sphere.

Even in this small model the currents are approximately a million times greater than those which have been obtained in the high-speed ion source designed by Lawrence.

The first model of such a generator that was actually constructed was built in Princeton in the fall of 1929, being built out of a tin can, a silk ribbon, and a small motor, at no expense. This model developed 80,000 volts, being limited by the corona discharge from the edges of the can.

The next model was designed and built for operation in a vacuum tank for reasons to be outlined later.

The third model was built to give a quick and easy demonstration of the possibilities of the machine, using 2-foot spherical terminals supported on pyrex rods, and supplied by current carried on silk belts 2¼ inches wide, driven by small motors. This apparatus was demonstrated successively in Princeton, New York, Washington, Boston, and elsewhere. Although built at a total cost of less than $100, it developed more than twice as high a voltage as any direct current generator of which we have knowledge.

Encouraged by the success of this model, plans were immediately made for the construction of as large a generator as seemed practical for operation in air, the limitation being placed by the size of the house in which it must operate. The largest place available was a dock built for a Goodyear dirigible on the estate of Col. E. H. R. Green at South Dartmouth, Mass, and which Colonel Green kindly put at the disposal of the Institute. Ten million volts was selected as the highest voltage that could be used in a building of this size without excessive loss of current through the air to the roof and walls. For this voltage, therefore, there has been built a generator with 15-foot spherical terminals made of welded aluminum, mounted on 24-foot textolite insulating columns in the form of 6-foot cylinders, and carried on large fabricated steel trucks, running on a 14-foot gage railway track in order to vary the position of the terminals when desired.

In this construction the Research Corporation gave invaluable aid through assistance in the engineering drawings and through a grant of $10,000, which defrayed approximately half the cost of the generator.

Plate 1 is a photograph of this generator, taken on the day before Christmas. In using this generator for experimental purposes it is planned to use the inside of the spheres as laboratory rooms, and to mount the discharge tube, suitably designed for producing high speed ions, between two spheres.

Every feature in the construction and operation of this large generator has gone as expected, and a few days ago the first belt was put into operation and voltage generated as expected. This belt is made of paper 3 feet wide and running at about 5,000 feet per minute. The initial trials gave an output of 600 microamperes, and previous experience indicates that with the proper adjustments this output may be increased to a milliampere. The design of the apparatus is such that a large number of belts may be made to operate in parallel, so that there will be no difficulty whatsoever in securing an output of between a tenth and a hundredth of an ampere if such large currents become desirable. It will be noted, however, that if currents as large as a tenth of an ampere are used at 10 million volts, the generator will be delivering 1,000 kilowatts.

The enormous possibilities of this machine become evident when we compare a possible input of 1,000 kilowatts in the form of 10-million-volt electrified particles, with the sources which up to the present have been available for experiments on atomic disintegration and which have been principally small amounts of radioactive material.

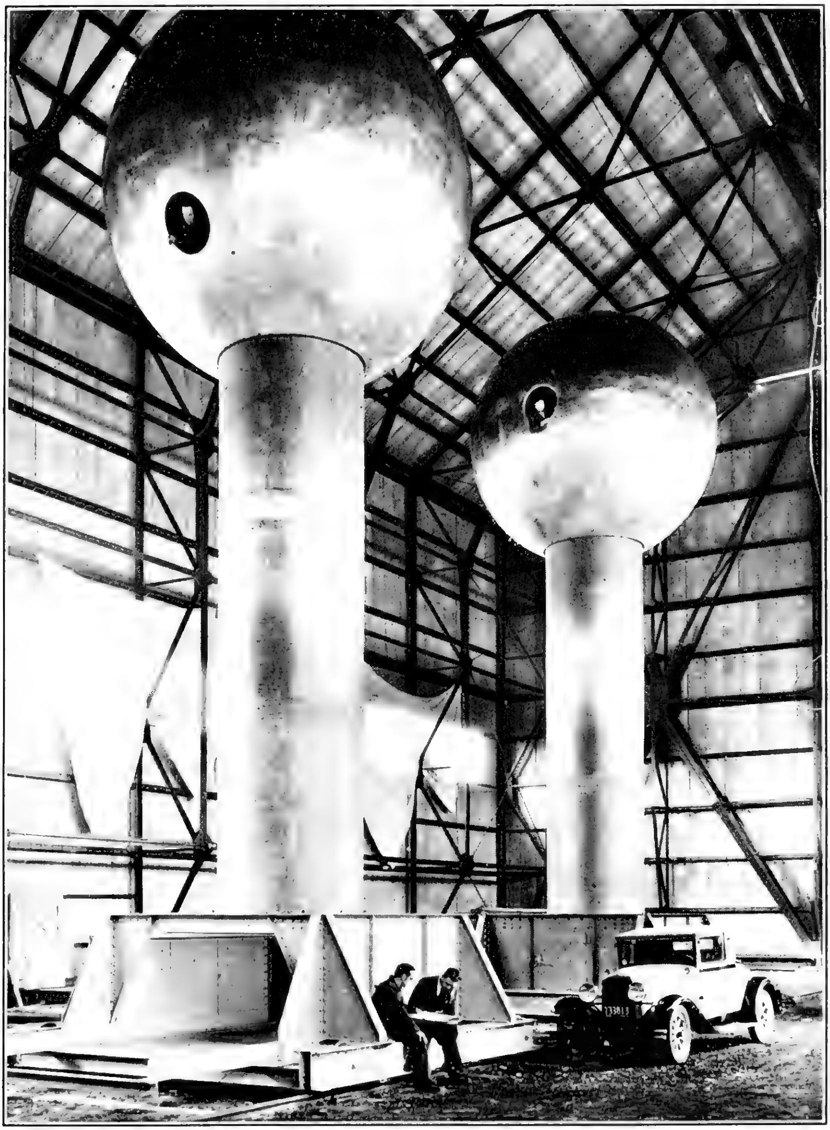
We come now to a very interesting aspect of this type of generator, namely, the influence of the surrounding insulating medium. If the generator is placed in some medium whose electrical break-down strength is greater than that of air, then the voltage and the current both increase proportionately and the power output increases as the square of the break-down strength. The two media most convenient are either some gas such as air at high pressure, or a vacuum. With gas at high pressure, the break-down strength is approximately proportional to the pressure, so that the operation of a generator in a tank of gas at 30 atmospheres pressure should give 30 times the voltage, 30 times the current, and 900 times the power of the same device mounted in the open air. It is relatively easy to build a container for compressed gases and to mount a generator in it, and this, in fact, has been done by Dr. Barton at Princeton, originally with the collaboration of Dr. Van de Graaff.

By far the most intriguing possibilities of this generator are found in its vacuum embodiment, because a high vacuum is the best of all insulators since it offers no "windage" resistance to the motion of the belt, and because many of the applications of the high voltage will themselves be in vacuum discharge tubes which can be built right into the generating system.

Such a generator has been designed and built. It is still in the experimental stage, but various complicating factors have one by one been overcome. Experience to date indicates that there is in sight no insurmountable obstacle to the construction of generators which may even reach considerably higher voltages than the generator at Round Hill.

In conclusion, it is interesting to know that two Van de Graaff generators have been built and operated in Washington under the direction of Dr. Merle A. Tuve, of the Department of Terrestrial Magnetism of the Carnegie Institution. One of these has been actually used for experiments on atomic disintegration and the other instrument, a larger one developing upward of 2 million volts, is awaiting a suitable housing, now under construction, for its satisfactory operation. Dr. Tuve in Washington, Dr. Coolidge, of the General Electric Co., and Dr. Slack, of the Westinghouse Co., all of whom have built and experimented with Van de Graaff generators subsequent to the demonstration of Van de Graaff's first air-operated instrument in the summer of 1931, have been very helpful in reporting their experiences with the generators.

In conclusion, it may fairly be said that this new type of generator as an electrical instrument has already been highly successful and shows promise of very considerable further development. It remains to be seen whether the necessity which was the mother of this invention—namely, the desire for high-speed particles for the study of atomic nuclei—will lead to important new knowledge of atomic structure with the aid of this device. Several good men are begin-



Courtesy The Technology Review.

THE LARGE VAN DE GRAAFF GENERATOR OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

ning work on the application of these voltages to nuclear disintegration, and it will not be long before some indications, at any rate, may be obtained as to the significance of the new developments in high-voltage technique.

Whether or not the apparatus will be successful in opening up new fields of atomic investigation, it has already opened up the possibility for electrical investigations and possible practical applications of electricity in a new voltage range, and it will be surprising indeed if there are not some developments of scientific and practical significance that will eventually emerge from this new field of activity.

THE BATTLE OF THE ALCHEMISTS[1]

By Karl T. Compton
President, Massachusetts Institute of Technology

[With 3 plates]

Long, long ago, when gods mingled among men, the god Hermes established the first laboratory on this earth and discovered many new and interesting substances by subjecting various kinds and mixtures of earth and rocks to the influence of fire or water. Not being blessed with the protection of the United States Patent Office, he kept his discoveries secret by putting his products into jars, which were carefully closed and sealed. Hence arose the term "hermetically sealed", and the chemistry and metallurgy which thus sprang from the god Hermes was long known as the "hermetic art."

According to another legend, a group of wicked angels were expelled from heaven and settled on the earth, taking unto themselves human wives. To these wives the fallen angels disclosed the magic secrets of science, and the wives recorded these secrets in a book which was called "Chema"—the first handbook of chemistry. Thereafter those who practiced this art were called "alchemists." The ancient historian Tertullian tells of these fallen angels who thus revealed to mankind the knowledge of gold and silver, precious stones, and medicines.

However these things may be, there is ample documentary evidence from Egypt that alchemy was a flourishing science and art in Alexandria before the third century, and it is probable that a famous book whose destruction was ordered by Diocletian in about A.D. 290 was one containing receipts and formulas for producing alloys to simulate gold and silver and for manufacturing artificial jewels.

These early alchemists, like modern chemists, were guided by a theory. Like our modern theories, theirs was imperfect, and like ours it was an attempt to interpret and predict on the basis of a generalization of experience. They started with Aristotle's conception of four fundamental elements—earth, water, air, fire. (These

[1] The Seventh Steinmetz lecture, delivered before the Schenectady section of the American Institute of Electrical Engineers, Nov. 18, 1932. Reprinted by permission from the Technology Review, vol. 35, no. 5, February 1933.

are not so different from, for example, the notion of the four states of matter proposed by Sir William Crookes, the solid state, the liquid state, the gaseous state, and the ionized state.) The alchemists also believed that there was one basic entity—prima materia—which was identical in all bodies but which took different forms according as it was brought into combination with one or more of the fundamental elements—earth, water, air, and fire. (In our time, we recognize this prima materia to be electricity, existing in two forms as electrons and protons.) By action of earth, water, air, or fire on the various manifestations of the prima materia, these alchemists performed oxidation, reduction, solution, smelting, alloying, and it is not to be wondered that they interpreted their work as a "transmutation of matter." From their standpoint it was transmutation.

On account of the variety of colors which their compounds exhibit and their ease of chemical change, it is not surprising that mercury and sulphur were of particular interest to the alchemists, and were supposed to be quite close to this prima materia which they sought. It is not so easy, however, to understand their choice of some of the other substances. For example, Beauvais in 1250 classified matter as consisting of four spirits and six bodies: the four spirits were mercury, sulphur, arsenic, and sal ammoniac—and the six bodies were gold, silver, copper, tin, lead, and iron—of which gold and silver were pure and the rest impure.

In addition to this Greek background, which was gropingly scientific in its approach, the mystery and magic of the Orient were introduced from Arabia, Persia, and India as a result of the various wars and invasions. Thence came the notion of the "philosopher's stone", whose magic touch would transform common substances into gold. (I suppose that the philosopher's stone should be thought of as the first catalyst—only it was, like the fountain of youth or the end of the rainbow or Utopia, only a beautiful product of the imagination.)

We must not despise the efforts of these alchemists. Among them were numbered such great minds as Newton, Leibnitz, and Boyle, all of whom studied and practiced alchemy, though they were beginning to realize its defects. But from this mixed ancestry of legend, experiment, and magic was born the modern science of chemistry.

In the rapid rise of chemistry during the nineteenth century, a beautiful and nearly perfect scientific theory of atoms and molecules was developed as a far extension of the ancient philosophical ideas of atoms of Democratus. How sound was this theory was demonstrated by the fact that it was only extended, but not essentially changed, when physicists devised methods of counting and weighing molecules individually, measuring their separate velocities and the energy and force required individually to pull them apart into their constituent atoms. The puzzles of the old alchemists were solved by the recognition of two classes of substances, elements and compounds, of which the former retain their identity throughout all action of earth, water, air, fire—or any other physical or chemical agent. Thus alchemy, which sought to transmute the elements, became supplanted by chemistry, which occupied itself with the various combinations of these elements to form chemical compounds. "Alchemy was dead! Long live chemistry!" But is this the end of the story?

The textbook in which I first studied chemistry in 1904 defined an atom as "an indivisible, indestructible, and unchangeable unit of matter." Yet 5 years earlier J. J. Thomson and his colleagues had split up atoms into electrons and positive ions, and within 20 years it had come to be realized that the atom could be very changeable—could, in fact, exist in any one of an infinite variety of conditions commonly termed "excited states." Thus the atom is not indivisible and is not unchangeable. But these changes do not really affect the identity of the atom. The electrons which it loses come back to it or others take their places; it does not stay in its excited states very long, but reverts to its normal state, usually within a hundred millionth of a second. So, after all, the atom is still the same old atom, and its new attributes which have been discovered by the physicists, while they add to its versatility, do not undermine its fundamental character of good old-fashioned chemical respectability.

In its ionization and its excited states the identity of the atom is like that of a man. You may cut off his hair or his nails, but they come back. You may even amputate a finger or a leg, but he is still the same man. Or you may excite him to a fit of anger or activity, but he cools down again. Through it all he retains his identity through that mysterious something that we call his soul.

Now the soul of an atom is its nucleus. Through ionization and excited states this nucleus remains, so far as we know, unchanged. Until we know the nucleus of the atom we no more know the atom than do we know a man by his hair, nails, fingers, or legs. What do we know about the nucleus?

Beyond a doubt we know very exactly the mass of every kind of atomic nucleus and that it is composed of a definite number of protons and electrons, which we know, and that it has a positive electric charge, which we know accurately. Thus the hydrogen nucleus consists of a single proton; the helium nucleus consists of 4 protons and 2 electrons and has a mass which is 0.77 percent less than the sum of 4 hydrogen nuclei; the uranium nucleus consists of 238 protons and 146 electrons, etc. We also know that the nucleus is very small in comparison with the overall atomic dimensions, i.e., much smaller than 10^{-10} centimeters in diameter—probably less than 10^{-11} centimeters.

We have good reason for thinking that some atomic nuclei are magnets, with a magnetic moment equal to that of one electron, and that this is true if there is an odd number of electrons in the nucleus. But there are some phenomena that have not as yet been reconciled with this idea of the magnetic properties of the nucleus. Furthermore, there is reason to believe that the proton configurations in the nucleus may also contribute a magnetic moment far smaller than that due to the electrons.

We know that atomic nuclei are deformable under the action of intense forces, such as can only be exerted by electrified particles, like alpha particles from radium, which are shot toward the nuclei with such tremendous velocities that they may come very close before being deflected away by the repulsive force between nucleus and alpha particle. When their distances are greater than 10^{-10} centimeters, this force varies inversely as the square of the distance, as nearly as we can tell, which shows us that the nuclei are practically electrified points so far as distances greater than 10^{-10} centimeters are concerned. With closer approach, however, the force departs more and more from the inverse square law, showing that the nuclei have a structure or arrangement of electricity within their tiny domain, and that this structure may be deformed by strong electrical forces. All this information is inferred from studies of the angular distribution of scattering when alpha particles pass through thin films of matter.

We know that the nuclei are the seats of tremendous energies, as evidenced directly by phenomena of radioactivity and indirectly by certain aspects of the theory of relativity to which I will refer later. From radioactivity, also, we find that groups of 4 protons and 2 electrons (helium nuclei) appear to be particularly stable configurations within the larger structure of the nuclei of heavy atoms. We call these groups " alpha particles."

Having said these things, we have told almost everything that is known about atomic nuclei. Many other things we would tremendously like to know. How are the protons and electrons arranged in the nucleus? What is their state of motion? What forces hold them together? How is their energy stored away? Under what conditions can the nucleus be disrupted or this energy released, or the configuration changed? To all of these questions we must confess almost total ignorance.

Think for a moment what this ignorance implies. All of the positive electricity, most of the negative electricity, most of the mass, and by far the greater part of the energy of the world reside in atomic nuclei. We must therefore confess that we know as yet very little about most of the world of matter, electricity, and energy. This should make us rather careful about making such statements as one recently published by a leading exponent of the new school of theoretical physicists, who wrote: "The underlying physical laws necessary for the mathematical theory of a large part of physics and the whole of chemistry are thus completely known. * * *" It should also warn us against such rash statements as "the breakdown of the law of causality" and "the law of conservation of energy does not apply to individual processes but only statistically as an average." It would be far better simply to admit that, successful as we have been in describing by equations much of the behavior of those extranuclear electrons that move in orbits far outside the nuclei, we are still grossly ignorant of the most powerful elements of our material world.

A very crude analogy will illustrate the relative advancement of our present state of knowledge of atoms. Liken the nucleus to a building and the extranuclear electrons to a group of pebbles resting on the steps of a fire escape on the outside of the building. As we observe these pebbles, we notice that, from time to time, a pebble falls from one step to another. We do not understand why it falls, and make various attempts to hypothecate some model or mechanism which will explain the dropping of these pebbles. Bohr, Sommerfeld, Langmuir all take their turn, but none of them invents a mechanism that satisfies all of the observations. We become discouraged with model building. Finally a brilliant young man, Heisenberg, proposes that we do away with models entirely and concentrate entirely upon the observable quantities—the steps, the pebbles, and their falling. He finds a mathematical expression which accurately correlates the height of the steps (energy levels) with the probability that a pebble will fall (radiate) from one step to another. To the mathematician this accurate formulation of the mathematical relationship between the observable quantities is a complete and satisfactory explanation or theory. The physicist, however, guided perhaps by instinct (which is the accumulated wisdom of the ages) rather than by formal logic, is not satisfied. He feels impressed but a bit confused by the logic of the mathematician, and also a bit distrustful. Down in his heart he feels that there must be something more than a law of probability which makes those pebbles drop. He goes to investigate. He finds the door of the building locked. He pushes; he knocks; he gets help; he rigs up a machine to batter down the door; he makes a small hole through which he sees signs of activity within the building; he builds a bigger and better battering ram; he finally breaks down the door and goes in. Within the building he finds a huge factory; giant cranes carry around great masses of material; enormous machines press, hammer, and draw this material into various shapes. Stupendous forces are at work. The building shakes, and from time to time a little pebble on the fire escape is shaken down from one step to another.

So, I suspect, may sometime be resolved the peculiarities and puzzles of our present quantum theory—by small external manifestations of the enormous energy which we know to exist within the nucleus, but about which we now know too little even to make a guess as to how it may influence our present theories.

Be this as it may, where have we left the alchemist? We left him dead, killed by the chemist who had destroyed his hopes of effecting the transmutation of elements. But now the physicist has brought him to life again, with renewed vigor and enthusiasm. For if the atomic nucleus is a structure of electrons and protons, it should be possible to break up this structure or to add to it, and thus to change one chemical element into another. The agencies are no longer earth, water, air, and fire, but electricity and probably electrical particles shot with tremendous speeds into nuclei. The goal is not gold and silver but energy. And with the alchemist, who is a practical man trying to get something, is working the physicist, who is not an impractical man, trying to learn something. In fact, they are one and the same man.

A most significant event in this story was the discovery of radioactivity by Becquerel 36 years ago. Its significance became evident when Rutherford showed that the alpha and beta particles are, respectively, helium nuclei and electrons which are shot out of the nuclei of radioactive atoms with tremendous speeds, approaching that of light. Its significance became greater when Rutherford further showed that the parent atoms, in thus ejecting these particles, transform into atoms of different chemical elements. The law of this transmutation was thus stated by Fajans: Expulsion of a beta particle changes the atom into the next higher one in the periodic table, and the expulsion of an alpha particle changes the atom into one which is two steps lower in the table. Here, for the first time, were authenticated cases of transmutation of elements.

The energies liberated in radioactive transformation are prodigious, in comparison with the amount of material involved. For example, radium continually gives off about enough energy to raise its own weight of water from freezing to boiling temperature every hour. By the end of 2,000 years it will be only half used up. By the time it is completely transmuted into its final products, helium and lead, any given amount of radium will have generated an amount of heat equal to that from the combustion of 500,000 times its weight of coal. One pound of radium gives off enough energy to heat to boiling more than 13,000 tons of melted ice.

At first sight it appeared that here was at last in sight the goal of the alchemists. But alas there was one difficulty, the process is so slow. Suppose you have a gram of radium (which is a notable amount). You would have to wait 2,000 years to get half of its energy, another 2,000 years to get half of what is left, and so on. By that time you and your grandchildren will long have ceased to worry about a source of heat. Great as it is, the energy comes off so slowly that it leaks away and cannot be stored up for use when wanted. As a practical source of energy it is useless. Alchemists and others have tried every physical and chemical agency that they could devise in an effort artificially to speed up radioactive processes, but without avail. The process of radioactive transmutation proceeds in its own characteristic slow and sure manner most provokingly unaffected by man's best, but puny, efforts.

There are, however, some very decided rays of hope, for artificial transmutation has been produced in three distinct ways on a small scale. One of these dates back to about the time of the war, while the others have both been achieved within the past couple of years.

During the war I was charged with arranging for the demonstration of a French device for locating submarines for the benefit of British and American scientists who were engaged in the same problem. One of the British experts was Sir Ernest Rutherford. He sent word by the late Professor Bumstead, however, that he would be delayed through the necessity of completing certain laboratory experiments in which he thought that he had split hydrogen nuclei into two parts. " If this is true ", he said, " its ultimate importance is far greater than that of the war." With true scientific caution, however, he asked us to keep this matter confidential, since he was not yet sure of his interpretation. This caution was justified, for his subsequent work showed that he had not broken up hydrogen nuclei; but what he did find was equally significant—he had succeeded in knocking protons out of the nuclei of nitrogen, aluminum, and various other light atoms. This was the first success in man's long struggle by his own efforts to change one chemical element into another.

Rutherford's success came not by luck and persistence, but by trained physical insight and persistence. Realizing that the possi-

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bility of success lay in bringing the largest possible electrical forces to act on the nucleus, he first found that radioactive substance which shot out alpha particles with the highest speed, and then he let them shoot at the nuclei of light atoms, such as nitrogen and aluminum. He chose these because of the relatively small electric charges of their nuclei which repelled the oncoming alpha particles less strongly and therefore permitted them to come closer than the nuclei of heavy atoms would have done.

Under this vigorous electrical bombardment, some of the nuclei gave out protons. These were detected by the sparks of light which they produced on striking glass plates coated with special fluorescent materials. Their speed and their identification as protons were determined by measuring how far they would shoot through air and how much their paths were curved in a magnetic field. These protons may have been literally knocked out of the nuclei by the impinging alpha particles, but from some nuclei, as for example aluminum, the protons were shot out with much greater speeds than they could possibly have acquired from such impacts. It, therefore, appears that the bombarding alpha particle distorts the structure of the nucleus, which settles down into a new state of stability, shooting out the proton in the process. The alpha particle, therefore, serves as a sort of key to unlock the nucleus and release some of its energy. Ah, here we would seem to have achieved our goal, but no, the process is hopelessly inefficient as a practical source of energy. Only about 1 alpha particle in 600,000 happens to strike a nucleus in such a way as to produce a transmutation. The other 599,999 are simply scattered without apparently exerting any permanent effect on the nuclei with which they come in contact.

The second authentic type of transmutation is associated with the discovery of the neutron by Chadwick of Cambridge less than a year ago. For many years physicists have been led by logic to search for this neutron, and they have predicted some of its properties. For example, we have atoms of atomic numbers from 92 down to 6, 5, 4, 3, 2, 1—uranium to carbon, boron, beryllium, lithium, helium, hydrogen—whose nuclei have positive electric charges of 92 down to 6, 5, 4, 3, 2, and 1 units, respectively. Why should there not exist an atom of atomic number zero, with no charge on its nucleus? Such an atom would have no extranuclear electrons, and its nucleus would consist of equal numbers of protons and electrons (probably one of each) packed very closely together.

This atom would have no chemical properties and no physical properties of the usual type, which depend principally upon the electric field of the extranuclear electron. It would obviously be hard to detect, would penetrate easily through even the densest materials, might readily penetrate through even the nuclei of other atoms. The one thing it could do would be to "bump", for if it happened to strike head-on some other particle, such as a proton or an electron, it could deliver momentum to that particle by impact. If such a neutron particle should exist, it would not only be of the utmost interest as a new "building block" of atomic structure, but it would also be a most interesting tool, for it alone of all known particles could penetrate unopposed the sacred structure of nuclei and perhaps knock out a key stone or foundation stone of their structure, causing their collapse. But the neutron would be a most unmanageable tool, since, having no electric charge, we could not speed it up or control it by an electric field as we do electrons, protons, and other ions. We would have to take it as we get it and simply watch to see what it does.

Well, Chadwick discovered this neutron and found that it consisted of 1 electron and 1 proton. It is like a hydrogen atom whose orbital or valence electron has been completely captured by the proton nucleus—a hydrogen atom shrunk down to almost nothing. For the preceding 4 years Bothe and his German colleagues had been playing with neutrons but did not know it, considering them to be photons, i.e., radiations of wave length even shorter than the gamma rays of radium. Chadwick showed that, if the law of conservation of energy is true, they cannot be photons, and that their action on other atoms like nitrogen or argon is exactly what would be expected if they are neutral material particles of mass 1, i.e., neutrons. When these neutrons bump into nitrogen, argon, and other atoms, they knock them forward by just the amounts that would be calculated from the laws of impact of balls of mass 1 against balls of mass 14, 40, etc.

This is how the neutron was produced. The Kelly Hospital in Baltimore gave Chadwick a lot of old radium emanation tubes which had lost their activity for therapeutic purposes but which contained the radioactive residues. From these tubes Chadwick extracted polonium, an element which ejects alpha particles of extremely high speed. This polonium was spread over a small plate, which was placed about 2 centimeters away from a plate of beryllium, so that the beryllium was subjected to bombardment by the fast alpha particles from the polonium. It was then found that the beryllium emitted rays of a tremendously penetrating nature, which had the power of ionizing any gas through which they passed and of knocking forward those atomic nuclei which they happened to hit. All this was studied by means of ionization devices known as "Geiger ion counters", or by scintillations produced on fluorescent screens. These rays are the neutrons.

Written as a chemical equation, the process is

$$Be(9)+He(4)>C(12)+n(1) \qquad (1)$$

Similarly boron behaves like beryllium in giving off neutrons according to

$$B(11)+He(4)>N(14)+n(1) \qquad (2)$$

Here the alpha particle is, of course, a helium nucleus of mass 4, and the products of transmutation are carbon, nitrogen, and neutrons.

One striking feature of this transmutation is that the products are heavier atoms than the original atoms. This is a process of atom building and not atom disintegration as in the previously known cases of transmutation, radioactivity, and Rutherford's artificially produced nuclear disintegration. It is highly important to know that atoms may be built up as well as broken down.

The third and last success of the modern alchemists, to date, was the transmutation of lithium when bombarded by swift protons by Cockroft and Walton about 6 months ago. Here the reaction is

$$Li(7)+H(1)>2\ He(4) \qquad (3)$$

This is peculiarly interesting for several reasons. In the first place it is the first instance of transmutation produced by a particle whose speed had been produced by laboratory methods. In the previous cases the bombarding projectiles were alpha particles whose speeds were fixed beyond man's control by the inherent nature of the radioactive process—except that man could slow them down as desired by interposing absorbing screens in their path. In the present case, however, protons produced by ionization of hydrogen and speeded up by applied voltages up to 600,000 volts were used as the bombarding agents.

In the second place, such a source of bombarding particles may be made ever so much more powerful than the previous sources of alpha particles, for currents of microamperes or even milliamperes of protons may be used instead of the tiny natural currents of alpha particles which, from the high-speed sources like polonium, come out at the rates of only a few thousand or hundred thousand particles per second. Thus we may hope to carry on these transmutation processes on a chemical rather than an atomic scale.

In the third place, the proton has only half the charge of an alpha particle and therefore suffers only half the repulsive force as it approaches an atomic nucleus. For this reason we can hope to shoot protons much farther into nuclei than alpha particles can penetrate. Protons thus have in a certain measure the advantage of neutrons, which are not repelled at all, and the great advantage of their capability of use at controllable speeds and quantities.

The final interest to me, personally, in this type of transmutation, is the fact that it was the first of a group of transmutations predicted by Dr. Van de Graaff in a report which he made to me about 3 years ago, and on the basis of which he sought further facilities for developing the high-voltage generator on which he was then experimenting. He not only predicted the transmutation, but also the resultant energy liberation of 16 million volts. He did not predict, for there was no basis for calculating it, how speedy the protons would have to be to effect this transmutation, and I think everyone was surprised to learn that Cockroft and Walton detected it with proton energies as small as 125,000 volts. At 250,000 volts about 1 atomic transmutation was found for every thousand million protons which were shot into the lithium. At higher proton velocities the number of transmutations increased. In every case, however, the helium nuclei which were produced had about 8 million volts energy apiece, or 16 million for the pair. It was as if the proton, on entering the lithium nucleus, combined with it to produce 2 helium nuclei with repulsive forces between them so great that they flew apart with this tremendous 16-million-volt energy.

How was Van de Graaff able to predict this energy? How, in fact, can all the energies in atomic transformations be predicted—for they can be predicted in radioactive processes and in the other cases such as described in equations (1), (2), and (3)? The answer to this question lies in an equation, the product of Einstein's genius, perhaps the most important aspect of his whole theory of relativity. Contrary to the much publicized statement that only 12 people in the world could understand his theory of relativity, this part of the theory is very simple and I think that everyone in this audience can understand it—though perhaps not understanding the argument through which the conclusion was reached.

The equation is, simply,

$$E=M\ c_2 \tag{4}$$

or, Energy = Mass $\times$ (velocity of light)^2
or, ergs = grams $\times$ 9 $(10)^{20}$

Being interpreted, this simply means that mass and energy are interconvertible and that if mass disappears, energy takes its place in accordance with this equation. In more famaliar terms, 2.13 $(10)^{13}$ calories of energy are liberated for every gram of matter which vanishes. In still more common language, the annihilation of 1 pound of matter would create enough energy to heat 100 million tons of water from freezing to boiling temperatures. Such are the stores of atomic energy. Let us see how this works in reference to the preceding case of transmutation.

A certain isotope of lithium has atomic weight 7.008, and a proton has atomic weight 1.0072. Their sum is 8.0152. This splits up into 2 helium nuclei each of mass 4.00. Thus the product nuclei have mass 0.0152 less than the original combining nuclei. This lost mass is converted into energy according to equation (4). To calculate the energy, we first change 0.0152 from chemical units of atomic weight into grams, which gives a loss of 2.88 $(10)^{-26}$ g for every individual transmutation process. According to equation (4) this is equivalent to the liberation of 25.9 $(10)^{-6}$ ergs. This is the amount of energy which would be acquired by an electron in moving through a potential difference of 16,300,000 volts—which is what we mean by 16-million-volt energy.

Thus, by considering various atomic weights in connection with Einstein's equation, we gain a clue as to which atoms may be expected to be relatively easily transmuted, and what the resultant energy will be.

This brings me to the final stage of the discussion. With these promising beginnings, just recently achieved after centuries of effort, the alchemist takes renewed hope and enthusiasm in his quest. He now has some knowledge of how to plan his attack on the atom. He has at least two proven weapons, or rather missiles to hurl at atoms, viz, alpha particles from radioactive sources, and ions, such as protons, which are given tremendous speeds with high voltages. He will continue to batter away at the atoms with both of these. Of the two, the high-voltage ion source is the most intriguing on account of the almost unlimited possibilities of high speeds, through the development of high-voltage generators, and of high intensities through the development of potent sources of protons or other types of ions.

It is this feature which gives particular interest to the various new types of high-voltage generators which are now being developed in various laboratories. Most promising are those of Lawrence at the University of California and of Van de Graaff at Princeton and the Massachusetts Institute of Technology.

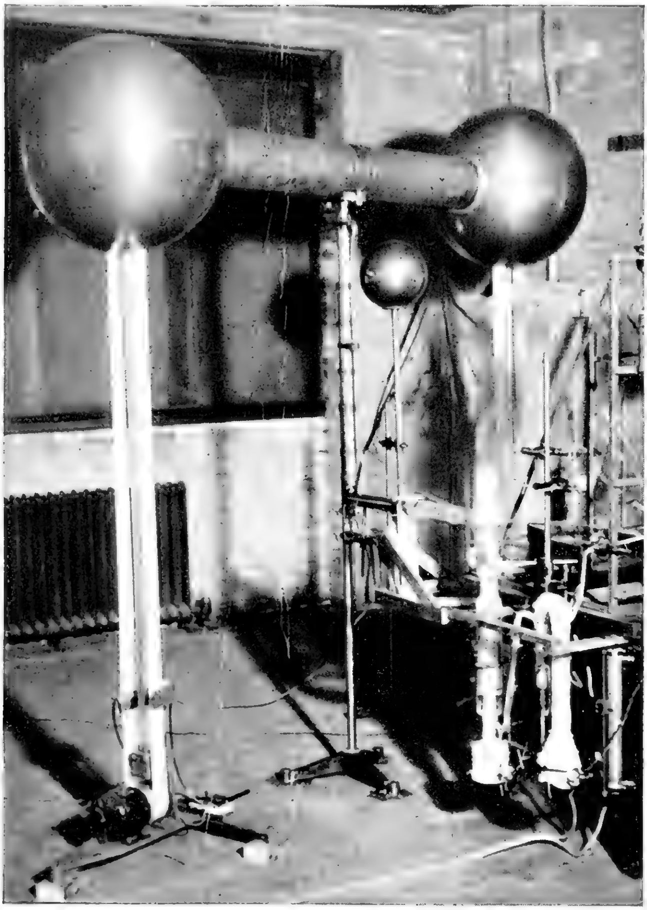
Lawrence does not actually use or develop a very high voltage, but he uses a moderate voltage to give a succession of pushes to the ions until they get to going with speeds which have considerably exceeded a million volts, and which may well reach 5 million volts with apparatus under construction. Without going into technical details, the idea may be conveyed by likening the operation to a child in a swing. By properly synchronizing the pushes, the child may be made to swing very high, even though each individual push would lift him only a short distance. Similarly, a voltage of 10,000 volts, applied 100 times in succession to an ion traveling around in a circle under the influence of a magnetic field, will give it the same final energy as if 1 million volts had been applied once.

Van de Graaff has gone back to electrostatic principles and developed a d.c. generator in which electricity at low voltage is sprayed onto a rapidly moving insulating belt, which carries it up into a spherical terminal on which it is deposited. The charge and potential of the terminal thus rise up to the point at which further increase is limited by the breakdown of the surrounding insulation. The voltage limitation is therefore that inherently determined by the geometry of the electrodes and the character of the surrounding insulating medium, while the current is limited to the rate at which electric charge is transported by the belts. After successful operation to 80,000 volts of a small generator made of tin cans, sealing wax, and a silk ribbon, a larger generator was built to deliver 30 microamperes at 1,500,000 volts. It was successful, as have also been similar and modified generators built during the past year in several laboratories.

The most ambitious of these generators is one designed to deliver 30 or 40 kilowatts at voltages calculated to be 15 million volts and expected to reach at least 10 million. This is nearing completion in the Massachusetts Institute of Technology experiment station on the estate of Col. E. H. R. Green at Round Hill, Mass. The terminals are 15-foot polished aluminum spheres, mounted on 30-foot textolite insulating cylinders, inside of which run the belts that convey the charge to the spheres. Each sphere is a laboratory room, within which the experimenter can assemble and operate the apparatus that bridges the gap between the positively and negatively charged spheres.

Although this Round Hill outfit is quite spectacular, it is probable that the most important developments of this apparatus will be not in the open air but in some container filled with a medium of superior electrical breakdown strength. The voltage increases directly and the power output directly as the square of this breakdown strength. Two such modifications have already been successfully operated in small models, one operating in the best attainable vacuum and the other in gas at about 30 atmospheres pressure.

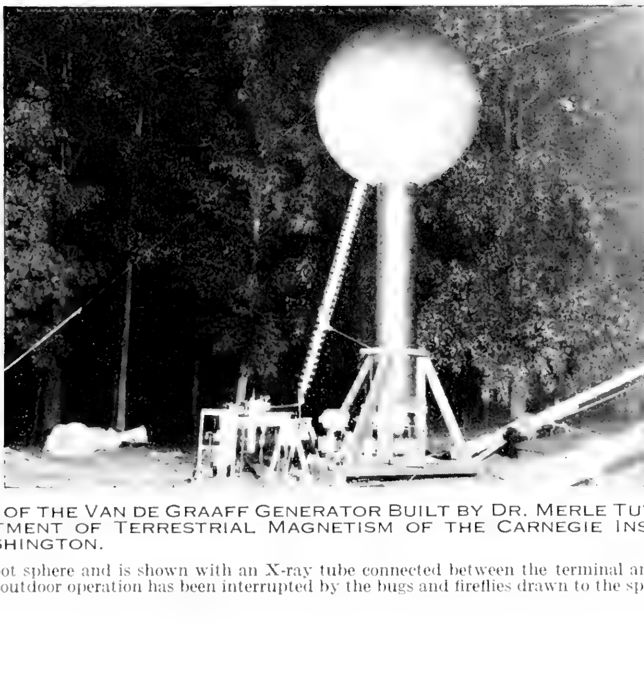
This is the story of the Battle of the Alchemists to date. They have matched their skill, strength, and all the resources of science against the dogged integrity of the atom for many centuries. Within the last 10 years, but mostly within the last 2 years, it begins to look as if the atom may succumb all along the battle front, even as it has already surrendered three strategic outposts. The field is open, and relatively so little explored that we cannot predict what will be discovered. But we should not be surprised if the next generation should uncover the most exciting and far-reaching developments in the whole history of science. Meanwhile Rutherford, Chadwick, Cockroft, and Walton, Lawrence, Van de Graaff, Bothe, and many others continue the work. They are the modern alchemists, direct descendants of the alchemists of the middle ages and tracing their ancestry back to Hermes and the fallen angels.



VAN DE GRAAFF'S FIRST MODEL 1,500,000-VOLT GENERATOR, WITH A DISCHARGE TUBE OF NEW DESIGN CONNECTED BETWEEN TERMINALS.

The spheres in this model were 2 feet in diameter as compared with the 15-foot diameter spheres in the new generator at Round Hill.

LOOKING UP ONE OF THE TWO GIANT SPHERICAL TERMINALS OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY'S ELECTROSTATIC GENERATOR.



A MODEL OF THE VAN DE GRAAFF GENERATOR BUILT BY DR. MERLE TUVE AT THE DEPARTMENT OF TERRESTRIAL MAGNETISM OF THE CARNEGIE INSTITUTION OF WASHINGTON.

It has a 6-foot sphere and is shown with an X-ray tube connected between the terminal and the earth. Its outdoor operation has been interrupted by the bugs and fireflies drawn to the sphere.

ROMANCE OR SCIENCE?[1]

By Paul R. Heyl
U. S. Bureau of Standards

The text for my discourse is taken from the editorial columns of the New York Times for September 18, 1932.

Your physicist is supposed to be a hard, matter-of-fact measurer who suppresses romantic speculation and talks only of energy, volts, ions, and electrons. Confront him with a mystery and he proves to be as human as the rest of us. Consider the cosmic rays. For years Milliken in this country and Kolhoerster, Hess, Regener, and others in Europe have been studying them only to their own mystification and ours. Measuring instruments are dropped into lakes a thousand feet or elevated 20 miles above sea level. Piccard imperils his life to determine the true nature of the rays. Professor Compton and a devoted band of physicists station themselves at the Equator, in the far north, on mountain tops, in deep mines to conduct their investigations. And the result? Romance—sheer romance.

Milliken spins a tale of electrons and protons combining in space, and of resultant cosmic rays that proclaim the continuous upbuilding of the universe, contrary to all the laws of thermodynamics. Jeans holds us spellbound with a poem about stars dying in a fierce radiance and bombarding us with cosmic rays in the process. Regener, as practical as the Irish foreman of a railway section gang when it comes to counting ions, looks at his equations as into a crystal and sees the beginning of things—sees primitive stars shedding cosmic rays and suffusing a relativistic universe from which they cannot escape because it is closed and finite. Stimulated by him, others imagine that, just as the bones of a dinosaur tell us something of the life that was on earth a few million years ago, so these fossil cosmic rays reveal the Almighty in the act of fashioning electrons and protons into nebulae, suns, planetary systems, and man himself.

For all the instruments and methods invented to test the cosmic rays, the physicist is still the medicine man from whom he is descended. Electroscopes and ionization chambers and other cosmic-ray measuring instruments seem strangely like wands and totem poles, and Einsteinian equations but incantations that make us believe we know more than we really do. That we are actually dealing with something like wishfulfillments in the cosmic rays is evidenced by the results obtained. Here is Milliken convincing himself that the cosmic rays prove that the universe is self-perpetuating. And Compton, adopting precisely the same methods, reaches the conclusion that the rays are only electrons swerving to the poles because the earth is a great spinning magnet.

[1] Address delivered before a joint meeting of the Washington Academy of Sciences and the Philosophical Society of Washington, Dec. 15, 1932. Reprinted by permission from Journal of The Washington Academy of Sciences, vol. 23, no. 2, Feb. 15, 1933.

What are the cosmic rays? There is no positive answer. We simply try to reconcile what the instruments indicate with our hopes and beliefs and imagine we understand the cosmos.

The same issue of the Times contains an editorial note entitled "It Is Done with Mathematics", which reads:

It is a relief to read that Professor Compton is back from studying cosmic rays in the Arctic region with the definite report that Professor Millikan is wrong. The cosmic ray, says Professor Compton, is not a wave, as Millikan thinks, but a particle.

It is a relief to find that when two men in the high realms of science hold opposite views one of them is right, and the other is wrong. Hitherto the public has had to get used to the idea that when two great physicists differ radically about something in the universe the answer is that both men are right.

What is the electron, a wave or a particle? It spreads after going through a hole, like a wave. It hits other electrons like a particle. An electron is both a wave and a particle. That would be nonsense by the rules of common sense, but it makes sense in the new sciences. There is a formula for it.

Some people think that the universe is expanding. Some people think that the universe is contracting. They are both right, says science. Professor Eddington can think of its being an expanding universe and a contracting universe simultaneously. Or, rather, he can find a mathematical formula that will describe that startling situation.

In the same manner space is finite, and space is infinite. There is a formula.

Obviously it is a delightful world in which you can have the coffee simultaneously hot and iced and out of the same cup, your egg simultaneously hard-boiled and scrambled, and the griddle cakes at the same time round and oblong.

But occasionally it is a relief to find black as the opposite of white and right as the counterpart of wrong.

Speaking to an audience of scientific men, we may pass with brief mention that portion of what I have read which deals with the disagreement of doctors. This is no new thing in science, and whenever it has occurred it has always been a passing phase characteristic of a stage at which our knowledge on a certain point was for the time too incomplete for unanimity of opinion. But beneath this good-humored banter there is to be discerned a serious undercurrent to which we may well direct our attention.

The unsettled condition of modern physical theory has become a commonplace among physicists. It now appears that it has sufficiently penetrated the nonscientific world to produce a state of mingled wonder and bewilderment, suggestive of those earlier days when men began to doubt the authority and infallibility of the Church. Moreover, it is noteworthy that this bewilderment of the editorial mind seems to be caused wholly by the doings and thinkings of physicists, if among these we may include astronomers, for what is astronomy but celestial physics? Chemists, engineers, geologists, and biologists seem to call for no special mention. They are taken for granted as steady-going fellows, cobblers with eyes not above their lasts, from whom society is in no danger. But physicists, it appears, are of different clay—iconoclasts, crack-brained theorists, ay, even writers of romance! And, if I guess rightly, this attitude of the editorial mind is not without a measure of instinctive sympathy on the part of many scientific men not of the physical persuasion.

Here is something for us physicists to think about. We are distinctly on the defensive on all sides. Why have we excited this suspicion? Why have we not been able to keep to the straight path with our fellows? If we are no longer regarded as safe and sane, is it our own fault, or that of the subject with which we have to deal?

It must be admitted that among the different conventional divisions of science physics occupies, indeed, a unique position. Ask the chemist the nature of the atoms and molecules with which he deals and of the forces which rule their reactions and he will refer you to the physicist for an answer. Ask the biologist concerning the processes of the living tissues which he studies, and he will be apt to tell you that they are but complicated chemical reactions; and the psychologist, if his opinion be asked, will likely say that the subject matter of his study is the most complicated kind of physiology. The psychologist leans upon the biologist, the biologist upon the chemist, and the chemist in turn upon the physicist; but between the physicist and nature there is no intermediary.

It is the task of the physicist to learn what he can about the fundamentals of nature, matter, and energy and their reactions, which as they rise in complexity form the subject for the study successively of the chemist, the physiologist, and the psychologist. Nor does the engineer, the geologist, or the astronomer make use of any principles which may be called distinctively his own; all these merely apply the fundamental principles of physics or chemistry on a large scale. The physicist is, in the best sense of the word, a scientific fundamentalist. If, therefore, there comes about any change in basic scientific concepts, it is the physicist in the front line who first feels the shock.

Now it happens that much of the new and strange in modern physical theory is bound up with two very fundamental concepts—matter and the atom. In particular, it is noteworthy that a large majority of the published physical work for the last 20 years has been directly or indirectly connected with atomic theory. In this connection there comes to mind the exhortation of President John Adams to the chemists of his day:

> Chymists! pursue your experiments with indefatigable ardour and perseverance. Give us the best possible Bread, Butter and Cheese, Wine, Beer and Cider, Houses, Ships and Steamboats, Gardens, Orchards, Fields, not to mention Clothiers or Cooks. If your investigations lead accidentally to any deep discovery, rejoice and cry "Eureka!" But never institute any experiment with a view or hope of discovering the smallest particles of Matters.

Is it the old story of Eden? Have we physicists eaten of the forbidden fruit of the tree of knowledge, and are we now suffering the consequences? However this may be, we will maintain, despite all accusations to the contrary, that our plight is not to be ascribed to original sin or to total depravity, but that the changes in fundamental concepts that are causing all the stir have been forced upon us as the logical result of approved methods of scientific study. And so compelling have been the reasons for these changes that there seems to be no more turning back possible for us than for our traditional first parents. We are thrust out of Paradise into contact with the bare world of Nature, and whether we like it or not we must somehow adjust ourselves to the new order of things. Concepts as old as human thinking are gone forever. Strange substitutes are replacing them, and until their novelty wears off it is inevitable that science should for the time appear as romance.

Would that it might ever remain so! But this is too much to expect. The thing that has been is that which shall be. Through familiarity we shall in time adjust ourselves to these new concepts as we have done to the telephone and more lately to the radio, once things of wonder, illumined by the halo of romance, but now mere commonplaces of our daily existence, matters of bargain and sale, at times even degenerating into nuisances and provocations to profanity.

The roots of the present revolution (or evolution) may be traced back for two centuries. The student of the history of science can discern during this period a certain trend of thought of which our present plight is but the logical outcome. This trend may be described as a steady drift away from materialism in our physical concepts.

The natural philosophers of the eighteenth century followed ancient tradition in explaining everything in terms of matter, which was regarded as a sine qua non, a basic concept without which physical thought would be impossible. Heat, in the eighteenth century, was a form of matter called caloric, which differed from ordinary matter in being unweighable and which could be soaked up by ordinary matter like water in a sponge. Light was another imponderable in the form of very minute corpuscles. Electricity and magnetism were held to be manifestations respectively of the electric and magnetic fluids. Added to these was another imponderable called "phlogiston", which was supposed to account for the phenomena of combustion. These five imponderables, together with ordinary matter, formed the stock in trade of eighteenth-century physics.

The physical science of that period was a rather loose and disjointed affair, consisting mainly of uncorrelated facts about these six supposed entities. But within this chaos there was working the leaven of a principle stated by Newton in his "Principia" as the first of four "Rules of Reasoning in Philosophy": "We are to admit no more causes of natural things, than such as are both true and sufficient to explain their appearances. To this purpose the philosophers say, that Nature does nothing in vain, and more is in vain, when less will serve; for Nature is pleas'd with simplicity, and affects not the pomp of superfluous causes."

In this Newton was but repeating a rule of philosophy laid down 3 centuries earlier by one of the medieval schoolmen, William of Occam: "Essentials are not to be multiplied beyond necessity." This in its Latin form was a famous saying in the Middle Ages, and was known as "Occam's razor." In modern parlance it would probably be called a pruning knife. In obedience to this principle the nineteenth century reduced these six essentials to three, and the twentieth century went still further.

It is to be noticed that all the fundamental concepts of eighteenth century physics were regarded as material, whether they were weighable or not. The nineteenth century retained the concept of ordinary ponderable matter but did away with the imponderables, replacing them by two new concepts, distinctly immaterial in their nature—energy and ether. Light now became a vibration of the ether; heat was regarded, according to circumstances, either as an ethereal vibration like light (radiant heat), or as a mode of motion of the molecules of matter; and according to a textbook of the period electrical phenomena were to be explained either as ether stress or ether flow, while magnetism was a matter of ether vortices. Thus at the end of the nineteenth century matter had been dethroned as sole monarch but had been given a place as a member of a triumvirate—matter, energy, and ether—to which were entrusted all the affairs of the universe.

It remained only to take the final step, which was done in the twentieth century. Up to this time the application of Occam's razor to scientific philosophy had been universally approved as conducive to economy of thought and general solidification of theory. But when Einstein pointed out that the concept of matter was not an independent necessity but could be merged with that of energy, the razor began to cut deep enough to hurt.

Einstein's argument was a strong one, for he showed clearly, and without any reference to relativity, that we must either regard matter as a form of energy or else disregard the experimental evidence for light pressure and also abandon Newton's laws of motion. As the latter alternative was more painful than the first, physical theory accepted the new cut of Occam's razor, eliminating the traditional concept of matter.

With the disappearance of matter as a basic entity the fundamentals of physics can best be described as disembodied ghosts masquerading under mathematical formulas.

"Hindsight is better than foresight." We could hardly expect this crash to have been foreseen, yet it is now clear that the concept of matter was doomed from the time that the trend set in against it. The progress of human thought is like that of some mighty glacier, slow but irresistible.

The atom has always been a subject of interest to physicists, and many speculations as to its nature have been advanced. When matter was an unquestioned axiom, the atom was explained on a material basis. Newton says in his "Opticks":

> All things considered, it seems probable to me that God in the beginning formed matter in solid, massy, hard, impenetrable, movable particles, of such sizes, figures, and with such other properties, and in such proportion in space as most conduced to the end for which He formed them, and that these primitive particles, being solids, are incomparably harder than any porous bodies compounded of them; even so very hard as never to wear or break to pieces; no ordinary power being able to divide what God himself made one in the first creation.

With the growth of the concept of the ether there was a parallel tendency to explain atoms as ethereal phenomena. Kelvin suggested that an atom might be a vortex ring in the ether, something like a smoke ring in air. With the merging of matter into energy the difficulty of explaining the nature of the atom increased greatly, yet the interest in the subject has shown no sign of diminution.

Twentieth-century experiment indicates that the atom is built up in some way of positive and negative charges of electricity. The present tendency is to regard the atom as electrical in its essence without committing ourselves to any definite hypothesis as to the nature of electricity. This electrical structure has taken several forms. Bohr's "solar system" model of the atom has "had its day and ceased to be." As far as our present ideas are capable of nonmathematical expression, the atom is to be considered as a collection of probabilities that an electric charge will be found here or there at points in a definite space pattern.

Nebulous and hazy as are our present ideas of the atom, it is evident that this condition is but a corollary to the parallel change that has taken place in our concept of matter, for if we have no clear idea of the whole, how can we know more about its parts? We have seen that this change has come as the consequence of an attempt to apply the principle of simplicity and economy in thought as laid down by Occam and Newton. We physicists submit therefore that as far as matter and the atom are concerned the present state of physical theory is not our fault, but is the result of attempting to apply to our subject the most approved rule of philosophy.

The second editorial which I have quoted raises a new question. The bewilderment of the editorial mind is caused here by the bizarre results obtained from mathematical formulas. Here again we may disregard the disagreement of doctors and focus attention on the point of basic importance.

We physicists have used mathematics freely since the time of Newton, and the results obtained have until lately always been regarded as regular and orthodox. It is only in the twentieth century that our mathematical conclusions have begun to appear fantastic.

The reason for this is not far to seek. There has been introduced into mathematical physics a body of doctrine which, while familiar to mathematicians for upwards of a century, had never been taken seriously by physicists prior to Einstein. I refer to the geometry of curved space and of space of more than three dimensions.

Perhaps nothing could be more transcendental and inconceivable than this hypergeometry, but mere inconceivability has never bothered mathematicians; nothing but inconsistency can do that. And it is a fact that once we admit the fundamental postulate of a fourth dimension it becomes possible to build up a hypergeometry as logical and consistent as that of Euclid.

The introduction of these novel concepts into physics has not taken place without a struggle. Much of the opposition disappears, however, when one realizes that Einstein did not propose these hypotheses as physical facts, but merely as a sufficient, though not necessary, mathematical description of certain phenomena. He himself regards this child of his brain quite sanely. "No amount of experimentation," he is reported to have said, "can ever prove me right. A single experiment may at any time prove me wrong." Yet the theory of relativity has gradually gained a hearing and a growing acceptance because of performance, by its ability to do things a little better than was possible before. Though its conclusions often appear strange, some of them have been experimentally verified, and as a result we have added to our stock two new phenomena—the deflection of light rays passing close to the sun and the shift of the Fraunhofer lines in an intense gravitational field. With these practical results to support us, I think we may maintain that hypergeometry and the theory of relativity have justified their provisional acceptance as working tools, no matter how romantic their conclusions. Even the concept of an expanding universe may yet be experimentally verified. Things equally strange have happened.

We may now consider another possible item in the indictment against us, one of which we shall have to accuse ourselves, as it apparently had not yet reached the editorial mind. Physicists themselves have been much concerned over an attack by certain of their own number upon nothing less than the law of cause and effect. It is truly remarkable that such an attack should have come not from the antiscientific but from the high priests of science themselves.

This latest skepticism concerns itself with the behavior of the electrons. The phenomena exhibited by these minute bodies have always been in some respects puzzling and incalculable, but scientific thought has been steadily optimistic, confidently awaiting the ultimate solution. The essence of the new view is that the behavior of an electron is incalculable, not because the problem is as yet too complicated for us, but because, to state it baldly, the actions of individual electrons are not governed by the ordinary law of cause and effect. The new philosophy recognizes that where an individual electron may be at this moment is a matter of observation, more or less imperfect; it admits that where the electron has been in the past is a matter of history; but it asserts that where it will be in the future is a matter not for definite prediction but only of statistical probability.

This doctrine appears to strike at the root of all law and order, and yet, curiously enough, its protagonists recognize the existence of a kind of law on the large scale, but deny that it extends to individual units. The new philosophy is not such a complete reversion to primitive type as might be hastily concluded.

Perhaps the best illustration that we can give of this new thought is one based upon the behavior of units large enough to be familiar if not altogether comprehensible—human individuals.

The behavior of any individual under given conditions is, rigidly speaking, unpredictable. For your belief that I will react in a certain way to my environment you have nothing but a probability, perhaps a very high one, amounting to what you may consider practical certainty, but never more than a probability. No one can say with absolute certainty that I will not, let us say, steal money during the coming year. It may be in the highest degree unlikely that I will, so unlikely that you may consider it insulting to harbor any suspicion of me, yet experience shows that occasionally an ordinarily well-behaved man may do a most unexpected thing. While no one can say definitely just what you or I or he or she will do, yet with several millions of such individuals to serve as a basis for prediction it is possible to estimate just how many of them will depart from rectitude during the next year and how much money will be involved in the total sum. Such is the accuracy of this prediction that bonding companies risk their capital on it year after year, and make money. Individually, man is more or less of an enigma; in the mass he is a mathematical problem.

Something very like this is the latest turn of scientific thinking. It asserts that the future behavior of a single electron is incalculable. We cannot tell whether it will turn to the left or to the right, whether its velocity will be accelerated or retarded. All that we can say is that there is a certain percentage probability of any particular behavior, and that such a prediction is always verified by the result when a sufficiently large number of electrons is taken into consideration. In the electronic realm there is no individual causal certainty. Instead there is something which is a conscious organism we would call caprice. Dirac even uses the term "the free will of Nature." Yet as we pass from the individual to the crowd, certain laws begin to appear, but they are no longer causal laws; they are only laws of probability.

There is a certain measure of experimental support for this position. The evidence is rather involved, and is circumstantial and cumulative rather than direct and specific, but this is not a fatal objection. And there is an imposing array of authority which has accepted this evidence—Bohr, Heisenberg, Dirac, Jordan, Born, Eddington, Bridgman, and others. The situation has been well summed up by De Broglie in one of his essays, from which I quote the following sentences:

> Causal laws replaced by laws of probability, physical individuals well localized and of well-defined movement replaced by physical individualities which refuse to let themselves be simply represented and can never be more than half described: such are the surprising consequences of the new theories. In digging under these laws of probability, shall we succeed in refinding causal laws as we have found recently behind the statistical laws of gases the causal laws of the movement of molecules? Certain arguments would lead to this belief, but it would be indeed imprudent to assert it.
>
> What we have said suffices, we think, to show the importance of the change in the point of view which has recently taken place in physics. Whatever may be the final fate reserved for these new doctrines it is of infinite interest to philosophers that physicists have been led, even though but for the moment, to doubt the determinism of physical phenomena and to question the possibility of describing them in a complete fashion within the frame of space and time.

Perhaps it would be well now to pause, to catch our breath and see where we stand, if indeed we have anything left to stand on. Well may we echo the dismayed queries of Macbeth and Banquo after the disappearance of the three weird sisters:

> The earth hath bubbles, as the water has,
> And these are of them. Whither are they vanish'd?
>
> Into the air; and what seem'd corporal melted
> As breath into the wind. Would they had stayed!
>
> Were such things here as we do speak about
> Or have we eaten of the insane root
> That takes the reason prisoner?

I think that we may feel safe as to the answer to the last question. The reassuring thing about all these new and strange theories is that they work. By means of them we are able to cut a little more closely to the line than was possible under the old regime. Practical physics was never more satisfactory; theoretical physics never less so.

This divergence between theory and practice is not to be understood as meaning that practice is being divorced from theory to its own advantage. On the contrary, there never was a time when practice was more closely dependent upon theory than today. New researches are almost invariably suggested by theory, and their results in a reasonable number of cases are confirmative of the theoretical prediction. Never was theory more fruitful. If we were totally on the wrong track, would Nature give us the abundant encouragement that she does? "By their fruits ye shall know them."

The difficulty with modern physical theory is not a lack of consistency; that mathematical requirement it possesses in abundance. It is the elusive and unreal nature of its fundamental concepts that gives us pause. But who are we that we should reproach Nature with being unreal? Perhaps the fault lies in our definition of reality, and of that Nature herself is the final and supreme judge. Guided by her answers to a century of experimental question, we have drifted steadily away from the material toward the immaterial in our fundamental concepts. If as a consequence science assumes an aspect of romance, perhaps this is because for the first time in the history of human thinking we have come close enough to reality to catch a glimpse of it. The picture is very different from that to which tradition has accustomed us, but so thought the contemporaries of Columbus and those of Galileo. And if the more closely we study Nature the more romantic she appears, perhaps we are but rediscovering something which the poets have always known and have not hesitated to utter.

> And like the baseless fabric of this vision,
> The cloud-capp'd towers, the gorgeous palaces,
> The solemn temples, the great globe itself,
> Yea, all which it inherit, shall dissolve
> And, like this insubstantial pageant faded,
> Leave not a rack behind. We are such stuff
> As dreams are made on, and our little life
> Is rounded with a sleep.

Romance or science—which shall we call it? It matters little, once we have been granted the vision to see that the two are not only consistent but inseparable.

ORIGIN OF FOLDED MOUNTAINS[1]

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I have chosen the origin of folded mountains as a subject for discussion for the reason that these great earth structures are of interest to all of us, and because the theories of their origin are many and widely divergent. For most of us the mountains are a great source of inspiration and pleasure. Whether we see them from afar or near at hand, there is always something about them that holds our attention. We see in them the ever active forces of nature; the rushing stream, the avalanche, the massive glacier, the jagged peak, the lightning flash, the ever-shifting clouds. From the earliest time man has opposed his strength to the mountain mass and frequently he has lost.

Much of the history of the earth is written in the mountain rocks and their structure. Man has learned much from this source but he has yet much more to learn. Leonardo da Vinci, the great artist, architect, and scientist, was convinced that the fossils in the rocks of the high Alps were once sea shells. We know now that he was right, that these shells were buried in the sands, clay, and ooze of the sea bottom and later were elevated to their present position. Not only were these sediments lifted, but they were folded, buckled, sliced, and mashed, and in places greatly altered and injected by igneous rock, so that the present mountain mass is a great structural complex. Some mountains are less intricate in their structure than the Alps, but others are even more complex.

From the study of mountains we get many facts. We find that there are many active, unbalanced forces in the earth. The elevation of the Colorado Plateau from below sea level to more than 8,000 feet above sea level shows a tremendous, persistent, and widespread vertical force. The rise and fall of many parts of the coast line of Italy in historic time is a good example of the less constant vertical forces. The folding, mashing, slicing, and shearing of the rocks in many of the mountains is ample proof of the lateral compressional forces in the earth's crust. Tensional forces, elsewhere,

[1] Presidential address delivered before the North Carolina Academy of Science, May 8, 1931. Reprinted by permission from the Journal of the Elisha Mitchell Scientific Society, vol. 47, no. 1, January 1932.

have pulled the rocks apart, allowing great wedge-shaped blocks to sink into troughlike areas, as that of the Great Basin, the Rhine Valley, and our own Triassic structural basin between Chapel Hill and Raleigh. By the use of the pendulum man is able to measure the relative mass of the various earth segments. It is found that the mountain masses are made of material lighter than the average of the earth's crust, and observations show that wherever the earth is receiving a load it tends to sink, as at present in the Mississippi Delta region, or in the northern United States during the ice invasion; also where load is being removed the earth's surface rises, as in many mountain areas losing weight by erosion, or as in the northern United States after the retreat of the great ice sheet. These compensating movements are very slow and have a considerable lag. Following the retreat of the ice sheet the Lake Champlain region, for example, was buried at first several hundred feet beneath sea water. Compensating forces (isostasy) have but recently finished returning this area to its normal elevation.

A study of the earth's mountains shows:

1. Mountains have generally been formed along the border of the land mass which furnished the sediments now found in them. (The sediments in the Appalachian Mountains came from a great land mass, Appalachia, now occupied by the combined Piedmont, Atlantic Coastal Plain, and the Continental Shelf.)

2. Young mountains are usually nearer the present border of the continent than the older mountains. (In western North America the Coast Ranges are younger than the Sierras or the Rockies.)

3. All older mountains, which have been deeply eroded, show a core of igneous or metamorphic rock.

4. Youthful, growing mountains are usually earthquake and volcanic zones, as witness the borderlands of the Pacific and Mediterranean areas.

5. Growing coastal mountains usually have great ocean deeps in front of them, the so-called "ocean foredeeps", as, for example, the six different foredeeps west of the Andes, the Supan foredeep of the Aleutian Islands, and the Tuscarora foredeep of the young mountain range of the Japanese Islands.

6. Mountain-making is going on seemingly with as great force as ever in the earth's history. All about the Pacific, lands are being elevated, and in many places the ocean foredeeps are sinking, frequently with sudden slips and violent earthquakes.

7. Mountain-making, accompanied by great continental emergence, has brought to a close each of the great geologic eras.

8. Many of the great mountains are curved or arcuate in character. All the present-day growing mountain-arcs, as the Aleutian Arc, the

Kurile Arc, and the Japanese Arc, have their convex side toward the ocean foredeep.

9. Most folded mountains have thrust faults and unsymmetrical folds.

10. All old mountains have been worn down, and most of them have been reelevated—some many times.

One of the questions most frequently asked is in regard to the origin of these earth highlands. Before we attempt to answer this question we must understand that mountains are of different origins. We have mountain peaks of the type of Vesuvius or Shasta, which have been built up from the earth's surface by volcanic ash and lava flow. Others like the Hawaiian Islands have been built up by a succession of lava flows from the ocean floor, in this case to a height of over 30,000 feet.

We have mountains made of great blocks of the earth's crust, faulted and tilted on edge and raised relatively above the blocks which have been down-faulted. The High Sierras, the Wasatch, and many of the mountains in the Great Basin area are examples of these so-called "block mountains."

We have the so-called "laccolithic mountains", which have been formed by the injection of great masses of igneous rock into the earth's crust and the arching of the earth's surface above such injected masses, as for example the Henry Mountains of Utah or the Crazy Mountains of Montana.

All elevated land masses are being constantly reduced by the agents of erosion, chiefly running water and glaciers. The least eroded portion of such elevated land masses, irrespective of cause of elevation, are left as so-called "erosional mountains", as Mount Mitchell, Monadnock, and the Matterhorn.

The most general type of mountain, however, is the one which is made up mostly of folded rock. All the great mountain ranges of the world belong to this type, though they may be locally modified by injection, faulting, or erosion into other types.

The origin of these great folded mountains has engaged the attention of many men of science. Strong differences of opinion have led to controversies, and these in turn have led to detailed studies of "Mother Earth." This study has been carried on by men of various sciences, but chiefly geology, physics, mathematics, and astronomy. The field is too broad to be mastered by any one group of scientists.

Before we undertake to discuss the origin of folded mountains, let us review briefly some of the known facts and current opinions concerning the nature of the earth's interior:

1. Under the influence of tidal forces the earth is at present as rigid as glass or as steel, and therefore largely a solid.

2. The density of the surface rock is about 2.7, while the density of the earth as a whole is about 5.52. This means that the density of the core is necessarily very high. Both the density and the character of the earth's interior have been computed from the behavior of the different earthquake waves in their passage through the earth and as recorded on seismographs in many parts of the world.

3. It is the general opinion of scientists that the outer crust of the earth is a highly siliceous material, largely granitic in character, extending to a depth of 35 to 40 miles in the continental areas. Under the shallow ocean basins it extends less deeply and is probably entirely absent in the deeper portion of the Pacific. Below the granitic layer and reaching to a depth of about 1,000 miles is basic igneous rock. This basic division increases in density with depth and reaches at base a density of about 4.5. The upper part of this division is basalt and the lower part is peridotite. The basalt portion has in general, at the present time, a crystalline upper layer, which is thicker under the ocean, where heat escapes more rapidly than under the continents. Beneath this crystalline layer the basalt is thought to be in a glassy, highly heated, solid-fluid condition.

From 1,000 miles to 1,800 miles there seems to be a gradual transition from peridotite to nickel-iron, with density increase from 4.5 to 9.

From 1,800 miles to the center of the earth, at 3,980 miles, the material is thought to be largely nickel-iron of a nonelastic character and possibly fluid, since transverse earth waves do not pass through it. At the center of the earth the density is estimated to be about 11.6. At the surface of the earth an equal mixture of iron and nickel would have a density of about 8.3.

4. The temperature in the crust of the earth, as recorded in deep borings, shafts, and tunnels, shows an increase with depth at the rate of about 1° Fahrenheit for each 60 to 70 feet. If this rate of increase continues with depth, which is improbable, the center of the earth would have a temperature of about 350,000° Fahrenheit.

5. The outer portion of the earth is a poor conductor of heat; thus the surface temperatures are mostly controlled by the sun's heat. The amount of heat radiated into space by the earth is greatly increased by the close approach of the molten rock to the earth's surface or during periods of vulcanism.

6. Radioactive materials in the earth occur in all types of rock but more largely in the acid or granitic types. It is thought by many that sufficient heat is derived from the slow decomposition of radioactive minerals to melt periodically a considerable portion of the basaltic layer, and locally the lower part of the siliceous crust.

7. At the earth's center there must be a pressure of about 45,000,000 pounds, or 22,000 tons, per square inch. Under this heavy

pressure all substances would be considerably reduced in volume, and it is not unlikely that there is in the earth a gradual molecular change of the lighter minerals into the heavier minerals, thus causing earth shrinkage. This molecular change is known to have occurred in the once more deeply buried portion of the visible crust. With release of pressure in surface layers of the earth, minerals tend to form with less density.

8. The amount of yielding of the earth in response to load is much too great to be explained by the elasticity of the rock. It can best be explained by the settling of the crystalline surface portion of the earth into the glassy, solid-fluid deeper portion, as a mass of soft, though elastic, beeswax will hold its shape and settle into a much harder, though solid-fluid pitch. We may think of this deep-lying, glassy, solid-fluid mass as the ocean on which ride the more rigid and elastic, crystalline rock-ships of the continents. When heavy loading occurs, a ship sinks deep in the water, and when unloaded, it displaces less water and rises. The geologist speaks of this compensation for load as isostatic adjustment. The glassy basaltic layer is highly sensitive to sudden transverse earthquake waves, thus appearing as an elastic body, but at the same time it yields readily to small, slowly applied forces.

In discussing the origin of folded mountains we must bear in mind that a number of the above conclusions concerning the earth's interior are relatively new and not fully proved.

Since most folded mountains are near the borders of continents and since most of them are made up in large part of great thicknesses of sedimentary rock, deposited in shallow water, it is apparent that the mountains have developed where once there was a slowly sinking basin of marine sediments (a geosyncline). In most theories of origin, therefore, the geosyncline is the controlling factor of location. Any theory to explain folded mountains must, of course, meet all the conditions of location, extent, characters of folding, amount of earth shortening, and sources of materials.

In considering present-day theories let us confine ourselves to those most generally accepted.

SINKING GEOSYNCLINES

One of the older theories is the so-called "geosynclinal theory", which holds that in regions of extensive sedimentation, usually along the border of continents, the slowly sinking geosynclines carry the unconsolidated and water-soaked sediments to great depths. These sediments become greatly heated by the ascending isogeotherms. With the increase in temperature and probable partial fusion in depth comes increase in volume, which finally more than offsets the slow sinking. This zone of highly heated and relatively weak sediments, having displaced the stronger rock by isostatic adjustment, is in condition to be readily folded by the lateral compression, exerted in the crustal portion of the earth, due to the shrinkage of the earth's interior through loss of heat or otherwise.

In the early days of this theory shrinking through loss of heat seemed ample to account for the known amount of lateral compression. Later, when larger horizontal movements were recognized, increasing earth density, through recrystallization, was added as another cause of radial earth shortening and compression. It has been apparent, also, that the wedge action of igneous masses, pushed up through the strata and forming great laccoliths in the strata, has been in some regions an added source of lateral compression. This theory is advanced by Arthur Keith, of the United States Geological Survey in accounting for the great amount of lateral compression in the Appalachian Mountains. We find that wherever in the Piedmont we have great masses of late Paleozoic igneous rock we have also to the northwest of these areas a marked bulge or salient in the Appalachian folds, as though the introduction of this igneous rock had pushed the folds to the northwest beyond their normal position. Such an igneous mass is to be found extending from Danville, Va., through Greensboro and Charlotte, and on into South Carolina.

According to this geosynclinal theory all continental borders should show parallel mountain growths. While this is generally true, there are glaring exceptions. For the most part the Arctic and Atlantic Ocean borders are relatively free from such parallel mountains. Along the border of these two ocean basins, mountains, where present, approach the shore at such angles as to suggest that they continue beyond the continental border. The Appalachians, for example, pass into the Atlantic from Newfoundland as though they are headed straight for Great Britain.

In brief, this geosynclinal theory explains the chief cause of zones of crustal weakness and supplies a few of the many possible reasons for crustal buckling. It leaves unexplained many facts connected with folded mountains.

CONTINENTAL-DRIFT THEORY

The second theory to be considered is the so-called "continental-drift" theory. It is one of the younger and more spectacular theories, which has a strong appeal to the imagination. If true, it would explain in a simple way many perplexing facts formerly explained in various ways. This fact alone has brought it many defendants.

According to this theory, in late Mesozoic time all the now separated continents formed one great continent, Pangaea, in the Greater

Pacific Ocean. Owing to unusual tidal and centrifugal forces, not successfully explained, this great unit mass broke up into the present continents, which drifted westward and Equatorward, Africa remaining relatively fixed in its present position. To account for the peculiarities of drift and the position of climatic zones, the position of the pole of the earth must be shifted through many degrees. According to this theory, the folded mountains were formed by the buckling of the sea sediments and subocean crust in front of the continental ship slowly plowing through the solid-fluid subcrust.

This theory is substantiated by the more or less perfect fit of the continents when restored to their theoretical former positions. The close fit of South America and Africa is obvious. The other continental masses do not fit so well. Greenland and North America were supposedly in contact with the west coast of Europe and the northwest coast of Africa. The west coast of India fitted along the east coast of Africa to the north of Madagascar. Antartica and Australia together overlapped the southeast coasts of South America, Africa, and India.

Professor Taylor,[2] of the United States, and Professor Wegener,[2] of Austria, are the principal advocates of the continental drift theory. Professor Taylor emphasizes the equatorward (centrifugal) forces, while Professor Wegener emphasizes the westward (tidal and precessional) forces.

The theory of continental drift explains the lack of coastal mountains on the Atlantic and Arctic borders and the apparent break of continuity of certain east-west mountains, as between North America and Europe, northern South America and the Mediterranean region, Argentina and South Africa. This theory might also, according to R. A. Daly, "make plausible Plato's account of the lost Atlantis, off the Pillars of Hercules." The mid-Atlantic ridge is thought to represent a parallel strip of land left behind in the continental migration and, later on, modified by vulcanism along the rift zone.

Against these major appearances and minor facts, in support of the theory, we find an equal or larger number of facts diametrically opposed to it. There is, for instance, insufficient space in the Arctic Ocean to account for the assumed southward migration of Asia and the westward migration of North America. The shifting of the poles could not have occurred as conjectured, because of the fact that large glacial areas are known to have existed in the postulated Tropics. Further, without polar shift, the theory does not account for the present position of Australia and Antarctica. When detailed structure and rock character of the corresponding coast lines of South America and Africa are examined they do not show the ex-

[2] See references at end of article.

pected relationship. It is further objected that we do not know of an adequate force for moving the continents over a solid-fluid subcrust.

While the theory accounts for the formation of the Tertiary mountains of the Pacific and the Mediterranean and also accounts for the lack of mountains bordering the Arctic and the Atlantic, it falls down in its explanation of so many other facts that we must reserve judgment as to its merits and accept it at present only as a brilliant attempt to give a general explanation for many scientific facts.

GRAVITATIONAL SLIDING OF CONTINENTS

Some years ago Eduard Suess put forward the idea in his epoch-making book, Das Antlitz der Erde, that the mountains of southern and eastern Asia have resulted from the slow creep or gravitational sliding of the great continental mass of Asia toward the bordering deep Pacific Basin. It was in part from this suggestion that F. B. Taylor, of the United States, and Alfred Wegener, of Austria, drew their elaborate continental-drift theories.

In recent years R. A. Daly, of Harvard, has elaborated on the probabilities of folded mountains resulting from the gravitational sliding of continents. He has cleared up a number of points of opposition and has added much new material. According to his theory the geosynclines bordering the continents cause the crystalline rock crust, composed of the granite shell and the upper frozen layer of basalt, to sink deep into the glassy basalt layer, which has less density than the crystalline rock above. Tension cracks allow the glassy basalt to work up through the crystalline belt and cause it to founder, thus removing the chief source of resistance to the gravitational sliding of the continent toward the ocean basin. The light, unconsolidated sediments, therefore, resting on the readily deformed basaltic glass, are easily folded and thickened by the advancing continental mass. The more rapid movement of the lands nearer the ocean than of the lands farther inland would cause tension cracks to develop some distance back from the continental border, with block faulting and depression, as, for example, the Great Basin in relation to the Sierras and the Coast Range, and the Triassic basins to the Appalachians. Also, the more rapid advance of the continental mass toward a great ocean deep than elsewhere explains the arcuate character of such island festoons as that of the Aleutian Arc and the Japanese Arc.

Further, according to this theory, as folding of the weak sediments continues, more and more of the underlying crystalline rock is foundered. As time goes on the lower portion of the zone of crumpled sediments is melted, and the great masses of foundered crystalline rock are either melted or turned to glassy material. Because of the advance of the continental border over the area of foundered rock, the increase in volume of the foundered rock through melting or vitrification would cause a gradual elevation of both the geosynclinal and the adjacent continental areas.

This theory, then, accounts for the formation of the arcuate mountain pattern, the folding, the tensional faulting farther inland, and the later uplift of the folded mountains and the bordering continental areas such, for instance, as the Colorado Plateau. This theory, along with that of Joly's, favors the possibility of a certain amount of continental drift.

The weakness of the theory lies in its assuming such great mobility for the glassy basalt and in the nonconformity of the theory with the structure of the tensional basins.

JOLY'S RADIOACTIVE THEORY

According to the Joly radioactive theory all known rocks have radioactive substances chiefly in the form of uranium or thorium. These two heavy atomic weight elements are slowly changing to substances of less atomic weight and finally to lead. In the change heat is given off. Man has been unable in any way to change the rate of decomposition by extreme temperature and pressure changes. At the known rate of decomposition one-half of the uranium will have disappeared in 5,000 million years and one-half the thorium in 13,000 million years. Granites and acid igneous rocks contain about twice as much radium as the basic igneous rocks and the sedimentary rocks. The loss of heat at the earth's surface is known to be about the same as the computed amount generated by radioactive substances in the 35-mile crust. In the thicker continental crusts more heat is generated than is lost, and everywhere in the earth beneath the crust, radioactive heat is constantly accumulating. The latent heat of fusion of basalt is 100 calories per gram. It would, therefore, take about 30,000,000 years for sufficient heat to accumulate to bring the subcrustal basalt to the melting point.

Radioactive substances have been undergoing decomposition and causing rise in temperature since the earliest geologic times as shown by radioactive haloes in Archean rocks, nearly two billion years old.

When fusion of the basaltic crust takes place, convection currents concentrate the heat on the crystalline rocks of the overlying crust. This crust is gradually thinned by melting from below, until the more rapid loss of heat, through the thinned shell, checks the process. If we assume with Professor Joly a 70-mile thickness of melting, the general 10 percent volume increase will lengthen the earth's radius by 6.5 miles. This elevation would cause general tension and cracking, especially of subocean crust and continental borders, with the outpouring of much lava.

Since the continents are in isostatic equilibrium (floating in a sea of lava), with decreased lava density they would stand relatively less high above the sea than formerly, provided the lava could escape, and we would have a period of ocean-basin spread and shallow sea transgression. With such expansion, the circumference would be, according to Joly, between 30 and 40 miles longer than normal.

When crystallization and shrinkage begin, as a result of cooling, the geosynclines are folded and pushed deeper into the earth. With continued crystallization and differential settling, the ocean basins are depressed more than the lands and are underthrust against the continental borders. With the return of the magma to a denser condition, the greatly thickened zone of relatively light sedimentary rock in the geosyncline is slowly elevated to a lofty mountain range, while the continents are considerably elevated. According to this theory the folding occurs during the late molten and early crystalline stages and most of the elevation comes later.

During the molten stage the tidal and precessional forces cause the crustal masses to have a slow migration westward, thus allowing the highly heated subcontinental magma to be carried into the ocean basin segment, and the continents to come to rest over the somewhat cooler subocean portions. It is thought that this relatively westward drift of the crust accounts for the great outpouring of basalts usually on the western side of the continental masses, as that of the Columbia River Plateau of western North America, the Deccan Plateau of western India, the Hebridean area west of Europe, and the Disco Flow west of the mountains of Greenland. By this same force, the continent with the deepest keel and the greatest frictional resistance to drift would have the least westward displacement. Asia, with the highest mountains, and therefore the deepest keel, should in the next molten period migrate less than the rest, as indeed it may have done in the former molten periods. The fact that South America has a deeper keel than North America would also explain its less westward migration.

According to the Joly theory the earth is now in the solid crustal stage, with continental growth not yet completed.

This theory has the advantage over all others of logically explaining the periodic flooding and elevation of the continents. It also successfully explains the folding of the mountains and the igneous activity associated with the early part of mountain building. It also supplies a logical explanation for the elevation of the mountains, long after their folding.

If the continents are shifted to the west during the hypothetical molten stage there should be an accumulation of acid rock material, originally molten, on the east side of the continents, and, through this action they should be building out a thinner crust toward the east.

Since the acid rocks of the continents contain about twice as much radioactive material as the basic rocks of the subcrust, the thicker continents should reach, in their basal portion, a condition of fusion before the basic rocks of the subcrust. This would bring about an elevation of the continent, followed by injection and ultimate spreading of the continent, with folding of the continental borders; all entirely independent of the general basaltic fusion. This source of folding has been emphasized by both G. R. MacCarthy and W. F. Prouty in recent articles.

ASTHENOLITHS

Bailey Willis in his recent articles on Continental Genesis and Metamorphic Orogeny, has laid stress on the importance of crystal growth in the metamorphic rocks as a source of lateral compression in mountain building. According to his theory, tidal and rotational forces have developed diagonally orientated strain zones in the earth outside the inelastic core. These strain zones in the deeper earth are favorable to rock fusion. The magma thus formed tends slowly to melt its way toward the surface along the zone of strain and to pond, along with other magma locally formed, beneath the poorly heat-conducting, crystalline outer crust. These local pockets of molten rock may reach dimensions of several hundred miles. The cumulative shearing stresses, associated with the growth of such an asthenolith, ultimately cause eruption around its border. This is followed, finally, by a central collapse. According to Bailey Willis, some of the extinct asthenoliths are marked by the larger depressions in the ocean basins, while the present active forms are marked by certain deeps " characterized by great seismic activity and beside which rise great mountain chains of volcanic or intrusive formations." During the life of this molten pocket, metamorphism of the surrounding rock is taking place with the formation of a flock of new minerals. The growth of these new minerals is largely in the horizontal plane, the direction of least resistance, and as the crystal growth exerts a pressure as great as the crushing strength of the crystal, and, therefore, the rock, we have here a tremendous lateral force in the areas of metamorphism. Such asthenoliths tend to form under both ocean and continent, but those which form under the continents have a stronger tendency to approach the surface along the continental borders than elsewhere.

The above theory of asthenoliths would explain both the igneous activity and the formation of the arcuate folds in the coastal island mountains of Asia. While the assumptions of the theory do not seem to be necessary to account for local pockets of molten rock beneath the earth's crust, the application of the force of growing crystals, in association with molten areas, explain certain facts in orogeny better perhaps than any of the other theories.

CONCLUSIONS

The foregoing brief discussion of some of the better-known theories of the origin of folded mountains shows that the question of origin is far from being settled. Some of the newer and more startling theories, such as the continental drift theory, have been carried to absurd extremes by some of the more enthusiastic and less well balanced advocates. On the other hand, a number of ultraconservative scientists, believing in absolutely fixed continents, can see no value in the drift theories. These reactions are according to the laws of human nature. I think it can be said in truth that none of the newer theories is completely in the right and that none is completely wrong. Here again we are traveling the same old scientific path.

No one, at the present, questions the truth of great horizontal and vertical movements in the earth's crust, in the formation of folded mountains, but only the causes back of such movements. Most geologists who believe in fixed continents and ocean basins think also of the horizontal movements largely as the result of differential settling of continental and subocean masses in a radially shrinking earth; or they think of them as due to actual enlargement of the crust by wedge action of igneous injections or by the pressure exerted by great numbers of crystals growing, in horizontal orientation, in the zone of metamorphism.

As a result of lateral compression from one or many causes, the rigid crust of the suboceanic section is gouged into the continental section, beneath its more rigid superstructure. This underthrusting by the ocean segments results in an overthrusting by the continents. Since the Pacific Basin is larger and deeper than the other ocean basins, it has a greater and more unbalanced underthrust than other ocean segments, and we have, therefore, the greatest foredeeps in the Pacific.

The geosynclines provide the location for the maximum buckling. Their elevation provides sediments for new geosynclines.

The theories of drifting and of sliding continents give us additional causes for horizontal compression. They also give reasons for directionally variable forces of tension and compression.

Arcuate mountains are best explained by either the gravitational sliding of continents or by Bailey Willis' theory of asthenoliths.

The Joly hypothesis of a periodically molten subcrust removes one of the chief objections to the theory of continental migration, namely, the nonmobility of the earth. It also makes possible the explanation of a number of facts previously unsatisfactorily explained.

The present-day theories taken as a whole account for all the observed facts in connection with mountain building, but it will be many years before there can be a general agreement as to the most important cause of either mountain folding or mountain uplift. Fortunately some of these theories can be tested. Exact longitudinal determinations, by use of radio, over a period of years, should give definite information concerning the drift of continents. Intensive geophysical tests should continue to yield facts about the earth's interior. Tidal and precessional forces are being checked by the mathematicians. Geologic materials and structures are being scrutinized, with the new theories in mind. In short the subject is undergoing a rigid quantitative analysis.

We shall probably find that in the great work of mountain building, not one or two causes, but many causes, are active, and that not all folded ranges are built in the same way.

LITERATURE

DALY, R. A.
1926. Our mobile earth. Charles Scribner and Sons, New York.

JOLY, J.
1925. Surface history of the earth. The Clarendon Press, Oxford.

KEITH, ARTHUR.
1923. Outlines of Appalachian structure. Bull. Geol. Soc. Amer., vol. 34, pp. 309–380.

MACCARTHY, G. R.
1928. The origin of folded mountains. Journ. Elisha Mitchell Sci. Soc., vol. 44, pp. 14, 15.

PROUTY, W. F.
1931. Triassic deposits of the Durham Basin and their relation to other Triassic areas of eastern United States. Amer. Journ. Sci., vol. 21, pp. 473–490.

TAYLOR, F. B.
1928. Sliding continents and tidal and rotational forces. [In] Theory of continental drift, pp. 158–178. Amer. Assoc. Petr. Geol., Tulsa, Okla.

WEGENER, ALFRED.
1928. Theory of continental drift. T. Murby and Sons, London.

WILLIS, BAILEY.
1929. Continental genesis. Bull. Geol. Soc. Amer., vol. 40, p. 281.
1929. Metamorphic orogeny. Bull. Geod. Soc. Amer., vol. 40, p. 557.

METEORITE CRATERS AS TOPOGRAPHICAL FEATURES ON THE EARTH'S SURFACE [1]

By Dr. L. J. Spencer, F.R.S.

[With 5 plates]

The problem of meteorite craters is quite a new one. Until 1927 the only known example was the "Meteor Crater" in Arizona, which since 1892 has been the subject of much discussion and controversy. Various theories have been put forward to explain its origin. The one most generally accepted at the present time is that the crater was formed by the impact of a gigantic meteorite on the earth's surface, but this view still finds some opponents. Strong support was given to this theory by the discovery made in 1931 of a group of craters near Henbury in Central Australia.[2] But definite proof was finally given by the remarkable discovery made by H. St.J. Philby during his crossing of the Arabian Desert early in 1932. The search for the legendary city of Wabar was graphically described by him at a meeting of the Royal Geographical Society on May 23, 1932. The "walls" of the city were found to be the rims of a series of craters, and the abundant "cinders" of the city "destroyed by fire from heaven" proved on examination to be a nearly pure silica glass. Nearby, rusted pieces of meteoric iron were also found, the largest remnant weighing 25 pounds.

The finding of the silica glass as cindery and slaggy masses and as complete "bombs" was in itself a remarkable discovery, for no similar material had ever been found before, and it was found in great abundance. Silica glass is, in fact, of rare occurrence in nature. It is best known in the form of fulgurites or lightning tubes, which are formed when sand dunes are struck by lightning.[3] Since a temperature of about 1,700° C. is required to melt quartz sand, the development of a large amount of heat is here indicated. Further,

[1] A paper read at the afternoon meeting of the Royal Geographical Society on Jan. 16, 1933. Reprinted by permission from the Geographical Journal, vol. 81, no. 3, March 1933.

[2] Alderman, A. R., The meteorite craters at Henbury, Central Australia. Mineralogical Magazine, vol. 23, pp. 19–32, 2 pls., 1932. Spencer, L. J., Meteorite craters. Nature, vol. 129, pp. 781–784, May 28, 1932.

[3] Mr. Philby's collection, from localities other than Wabar, includes a few small fragments of fulgurites, which were found in hollows between the sand dunes. An interesting fact is that the Arabs regard them as indications of the presence of water.

the smaller pieces of meteoric iron from Wabar when sectioned, polished, and etched show a partial destruction of the characteristic structure such as can be brought about artificially by heating the material to about 850° C.

Now the close association of silica glass and meteoric iron with a group of craters in a sandy desert can be accounted for in no other way but by the impact of a shower of large meteoric masses. We have, in fact, at Wabar a typical example of meteorite craters.

It is my present purpose to give some account of the few meteorite craters or supposed meteorite craters that have so far been discovered, in the hope that the scanty information at present available may be of some help to travelers in recognizing further examples. There are many craterlike depressions on the earth's surface, but it would be rash to assume that all have been formed by the fall of meteorites. Some other pieces of evidence must be sought for. Nothing is yet known of the mechanics of the formation of such craters. They are not merely dents or holes made just by the projectile force of the meteorite as hitherto supposed. They appear, rather, to be explosion craters due to the sudden vaporization of part of the material, both of the meteorite and of the earth, in the intense heat developed by the impact.

The meteorite craters so far described may be easily remembered by the following classification, with two examples in each class:

Single craters with associated meteoritic material (Arizona and Texas).

Groups of craters with associated meteoritic material (Central Australia and Arabia).

Groups of craters without associated meteoritic material (Estonia and Siberia).

Single craters without associated meteoritic material (Ashanti and Persia).

This makes a total of eight examples. It seems a pity to disturb this beautifully symmetrical arrangement, but farther on I shall add a third example to the second class, while the third and fourth classes are not proved, and the last example is more than doubtful. That leaves only five more or less certain examples of known meteorite craters.

The Arizona crater (pl. 1) was first brought to notice in 1891 by the discovery of many masses of meteoric iron scattered around the crater.[4] The finding of diamond in this iron aroused a considerable amount of interest and not much notice was at first taken of the

[4] Foote, A. E., A new locality for meteoric iron with a preliminary notice of the discovery of diamonds in the iron. Amer. Journ. Sci., ser. 3, vol. 42, pp. 413–417, 2 pls., 1891; and Proc. Amer. Assoc. Adv. Sci., vol. 40 (for 1891), pp. 279–283, 1892.

Accounts of the crater have been given by:

crater itself. It was known locally as " Crater Mountain " or " Coon Butte ", and was afterward called " Meteor Crater." The irons are known as the " Cañon Diablo meteorite " from the Cañon Diablo nearby. The locality is situated in Coconino County in the desert of north central Arizona and close to the Santa Fe railroad.

The crater is a basin-shaped depression approximately circular in outline with a maximum diameter of 3,950 feet and a minimum diameter of 3,850 feet, or three-quarters of a mile. Its depth is 570 feet. The outer slopes rise gently from the surrounding desert plain to a height of 130 to 160 feet at the rim, while the inner slopes are steep and precipitous, and partly covered with talus. The bottom is level (410 feet below the plain) with an area of over 300 acres, and was once occupied by a lake as shown by the presence of lacustrine deposits up to 88 feet in thickness. In the surrounding country the beds of sandstone and limestone (of Carboniferous age) are horizontal, but in the walls of the crater they dip radially outward at angles of 10° to 80°, and in one place are faulted. The outer slopes are covered pell-mell with fragmentary material ranging in size from blocks of rock estimated to weigh over 4,000 tons down to the finest " rock flour." Fragments are littered about for a distance of 6 miles from the center, and they were evidently ejected from the crater, the largest blocks being nearest the rim. Indiscriminately mixed with this material, and also buried in it, have been found thousands of pieces of meteoric iron ranging in weight up to 460 kilos (1,014 pounds) and also pieces of laminated iron shale resulting from the weathering of the iron. About 20 tons of the iron has been collected, but inside the crater only four small pieces have been found and relatively little of the iron shale. It is obvious that this meteoritic material must have been ejected from the crater at the same time as the blocks of sandstone and limestone.

Gilbert, G. K., The origin of hypotheses, illustrated by the discussion of a topographical problem. Science, vol. 3, pp. 1–13, 2 pls., 1896; and Presidential Addresses, Geol. Soc., pp. 2–24, 18 figs., Washington, 1896.

Barringer, D. M., Coon Mountain and its crater. Proc. Acad. Nat. Sci. Philadelphia, vol. 57 (for 1905), pp. 861–886, 1906.

Tilghman, B. C., Coon Butte, Arizona. Ibid, pp. 887–914.

Fletcher, L., A search for a buried meteorite. Nature, vol. 74, pp. 490–492, 1906.

Merrill, G. P., The Meteor Crater of Canyon Diablo, Arizona; its history, origin, and associated meteoric irons. Smithsonian Misc. Coll., vol. 50, pp. 461–498, 15 pls., 1908.

Barringer, D. M., Meteor Crater (formerly called Coon Mountain or Coon Butte) in northern central Arizona. Paper read before the National Academy of Sciences, Nov. 16, 1909; privately printed, 24 pp., 18 pls. [Philadelphia, 1910.] Further notes on Meteor Crater in northern central Arizona. Proc. Acad. Nat. Sci. Philadelphia, vol. 66 (for 1914), pp. 556–565, 3 pls., 1915; vol. 76 (for 1924), pp. 275–278, 1 pl., 1925.

For more recent short notes see Nat. Geogr. Mag., vol. 53, pp. 721–730, 1928. Science, vol. 69, pp. 485–487, 1929; vol. 72, pp. 463–467, 1930; vol. 73, pp. 38–39, 66–67, 1931. Scientific American, July, August, and September, 1927; June 1932, p. 363. Eng. and Min. Journ., vol. 133, p. 392, 1932.

Besides diamond, the Cañon Diablo meteoric iron contains 7.33 percent of nickel and small amounts of the precious metals platinum and iridium. One assay gave platinum 3.65 and iridium 14.95 grams per metric ton. It therefore seemed to offer a promising mining venture, the supposition being that the main mass of the large meteorite, perhaps 500 feet across[5] and weighing over 14 million tons, that formed the crater would be found buried inside. Mining claims were taken out by the Standard Iron Co. in 1903 and many trial shafts (6) and bore holes (23) were put down at considerable expense, but nothing of value was found. After passing through crushed and metamorphosed sandstone and abundant rock flour, undisturbed sandstone was met at a depth of 620 feet. The metamorphosed sandstone shows a partial fusion of the grains of quartz and grades into a friable and porous silica glass.[6]

Another company, the Meteor Crater Exploration & Mining Co., was formed in 1927, and a new drill hole was put down through the southern wall of the crater (under the supposition that the meteorite had entered at a slanting angle). After passing through 30 feet of iron shale cementing fragments of metamorphosed sandstone, the drill stuck at a depth of 1,376 feet, presumably against some hard object, which was believed to be the main mass of the meteorite. An attempt was then made to sink a shaft outside the crater to a depth of 1,500 feet from which the mass could be reached by a cross cut, but at a depth of 640 feet a heavy flow of water was encountered and the work had to be abandoned after the expenditure of $293,000. Attempts are now being made to raise funds for further exploration.

All this work, which has added much valuable detail to a knowledge of the crater, was carried out by the late Daniel Moreau Barringer, of Philadelphia, who was an enthusiastic supporter of the meteorite theory; and it is now being continued by his son, D. M. Barringer, Jr. Under the guidance of Mr. Barringer the crater was examined in detail by the late Dr. George P. Merrill, of the United States National Museum, and eventually he became an adherent of the meteorite theory. Previously this theory had been rejected by G. K. Gilbert, of the United States Geological Survey, in favor of the theory that the crater had been formed by a volcanic steam or gas explosion without the extrusion of any lava. Although there are no volcanic materials in the immediate neighborhood of the crater, yet there are extensive basaltic flows at a distance of 10 miles, and the extinct volcanoes of the San Francisco Mountains are only 30 miles

[5] A small asteroid of 1,500 feet diameter has also been suggested. This, composed of meteoric iron, would have a mass of 378 million tons.

[6] Rogers, A. F., A unique occurrence of lechatelierite or silica glass. Amer. Journ. Sci., ser. 5, vol. 19, 195–202, 9 figs., 1930. This silica glass is more like a sintered sandstone: it does not show the effects of complete fusion, as at Wabar.

away. There are still supporters of this theory; but it does not explain the intimate intermingling of shattered terrestrial rocks with meteoritic material, nor the presence of silica glass. It would be a strange coincidence for such a volcanic outbreak to take place just at the spot where masses of meteoric iron had previously fallen, and they certainly could not have fallen afterward.

Further, the temperature of a steam explosion would not be high enough for the production of silica glass. The same, and more, objections would apply to the theory that the crater has been formed by the solution of limestone, being of the nature of a sink hole.[7] The crater extends downwards into sandstone, far beneath the base of the bed of sandy limestone.

The Arizona crater, like the craters of Henbury and Wabar, shows an intimate association of meteoric iron and silica glass with fractured terrestrial rocks, and it was undoubtedly formed by the fall of a large meteorite. But whether the main mass of this meteorite still lies buried in the crater is extremely doubtful.[8] More probably such portions as were not vaporized by the intense heat developed by the impact were shot out by the gaseous explosion and scattered around the crater.

The Texas crater[9] is situated about 9 miles southwest of Odessa in Ector County. It is a shallow depression roughly circular in outline with an average diameter of 530 feet. The rim is about 18 feet above the bottom of the hole, but only 2 or 3 feet above the surrounding desert plain where horizontally bedded limestone is exposed. The steep inner slopes show the limestone dipping at 20° to 30° away from the center. A much-rusted fragment (1,120 grams) of meteoric iron was found here in 1922, and the crater was first mentioned in 1927. Amongst the fragments of limestone and sandstone forming the rim of the crater a few more small pieces of iron have been found together with numerous pieces of iron shale. The various suggestions made to account for the origin of this crater are discussed by E. H. Sellards, namely: (1) volcanic explosion; (2) salt dome; (3) expansion by hydration of anhydrite; (4) explosion of gas; (5) fall of a meteorite. The last is considered to be the most probable, and this view is supported by D. M. Barringer.

The Henbury craters (pl. 2) in Central Australia, known locally as the Double Punchbowl, are situated 7 miles west-southwest of Henbury cattle station on the Finke River, about 50 miles south of

[7] Dellenbaugh, F. S., Meteor Butte. Science, vol. 73, pp. 38–39, 1931.

[8] The only known case of a meteoric iron found inside a crater is mentioned below under Henbury.

[9] Sellards, E. H., Unusual structural feature in the Plains region of Texas. Bull. Geol. Soc. Amer., vol. 38, p. 149, 1927.

Barringer, D. M., Jr., A new meteor crater. Proc. Acad. Nat. Sci. Philadelphia, vol. 80 (for 1928), pp. 307–311, 1929. No pictures are available of this crater.

the MacDonnell Ranges. Pieces of meteoric iron having been sent from there to the University of Adelaide with the statement that they had been found around craterlike depressions, A. R. Alderman at once proceeded to the locality in May 1931, when he was quick to recognize the importance of the discovery.[10] Within an area of half a mile square he mapped 13 craters, and around them he collected more than 800 pieces of meteoric iron, together with much iron shale and some black glassy material. At one spot over an area of 6 by 6 feet more than a hundred small pieces of iron were picked up. The largest crater is oval in outline, 220 by 120 yards across, and 50 to 60 feet deep. The others are approximately circular with diameters ranging from 10 to 80 yards and depths from 3 to 25 feet.

With their gently sloping outer surfaces the craters are not very conspicuous until one stands on the rim, when the steep inner slopes come into view. The craters are, however, marked out by the growth of mulga trees, acacias, and coarse grass, since they act as collecting pans for rainwater in this arid region (average rainfall, 6 inches per annum). The steep inner walls consist of powdered rock and shattered blocks of sandstone, quartzite, and slate of Ordovician age. Only at one spot in the walls were the rocks seen to be apparently in situ and with the same dip as in the surrounding country. A feature that may perhaps be of some significance was noted by Mr. Alderman around two or three of the craters, but best seen around crater no. 3, which is 45 yards in diameter. Here, radiating from the rim, are five or six low ridges of sandstone, only a few inches in height and varying considerably in length, the average length being about 30 yards. It is suggested that these may have resulted by the percussion of the meteorite. Only two pieces of iron (one of 13 pounds) were found inside one of the craters, and these on the surface just inside the rim. A boring in the floor of crater no. 5 (25 yards diameter) passed through 8 feet of fine silt down to rock fragments, but no iron was found.

A large amount of material, together with much valuable information about the Henbury craters, has been sent to the British Museum by R. Bedford, of the Kyancutta Museum, in South Australia, who visited the locality in June 1931 and May 1932. This includes 642 pieces of the iron with a total weight of 891 pounds (405 kilos). The largest pieces weigh 292, 170½, and 120 pounds, but the majority are small and curiously twisted and curved. A selection of this material is on exhibition in the Natural History Museum at South Kensington. Most interesting is a group of four irons with a total

[10] A preliminary illustrated account was published in the Adelaide Chronicle of July 16, 1931, and a more detailed account in March 1932 (op. cit.). A few further details respecting the craters are given by A. R. Alderman, The Henbury (Central Australia) meteoric iron. Rec. South Australia Museum, vol. 4, pp. 555–563, 9 figs., 1932

weight of 440 pounds, excavated in 1932 from a depth of 7 feet inside the smallest crater. They were found in contact and with much flaky rust between and around them, and they are evidently the weathered remnants of a single mass. Immediately around and beneath the iron were broken blocks of rock, while the overlying material was fine grained and free from big stones. This crater (no. 13 on Alderman's map) is only 10 yards in diameter and 3 feet in depth; and in this case the explosion was evidently not sufficient to " backfire " the main mass out of the crater. Around the crater 60 small twisted pieces of iron were found, together with fragments of iron shale, but no silica glass. Excavation of the rather larger 15-yard crater (no. 11) gave a negative result.

The larger blocks of the Henbury iron when sectioned, polished, and etched show the normal lamellar octahedral structure (Widmanstätten figures) of a medium octahedrite. In the smaller twisted and curved pieces the lamellae are bent and twisted. Further, the kamacite is granulated, proving that here the temperature exceeded 850° C. Oxidation of the iron has proceeded along the curved cracks, along which the pieces eventually break up. These curiously twisted and curved pieces therefore seem to be weathered remnants of pieces of the iron which were torn, perhaps in a plastic condition, from the main masses by the force of the explosions. The corroded surfaces and the normal internal structure shown by the larger pieces of the iron indicate that these also are only weathered remnants of still larger masses, in fact merely the cores to which the intense heat had not time to penetrate by conduction. Pieces of iron shale are also found in abundance around the craters. These, especially when found buried, are sometimes clustered together in the form of " shale balls ", in which occasionally a core of unoxidized iron still remains.

Silica glass has so far been found only around the largest crater at Henbury, but not in the same perfection and abundance as at Wabar; and, being formed by the fusion of a ferruginous sandstone, it is less pure. It shows a curious distribution on the ground, for which no explanation can be offered. On the west side of the crater larger cindery and cellular masses and pieces of partly fused sandstone are found close to the rim; while on the east side small tear-shaped drops and threads with a smooth, glossy surface are found along a narrow strip of ground extending eastwards a mile from the crater.

At Henbury there must have been not a single mass but a shower of large masses of iron that formed the group of craters. The large oval crater, which shows a promontory on its longer side, was doubtless formed by two masses falling close together at the same time.

The Wabar Craters, discovered by Mr. Philby [11] in February 1932, are in the Rub' al Khali at 21°29½′ N., 50°40′ E. (pls. 3 and 4). Two distinct craters were mapped with indications of two others buried in the sand. Isolated patches of the slaggy material suggest that still more craters are buried. The larger crater is approximately circular in outline with a diameter of 100 meters and a depth of 40 feet (10½ meters). It shows a long gap in the rim on the northern side. The smaller crater, 200 meters distant from the first, is oval in outline with dimensions of 55 by 40 meters. The outer slopes are gentle and the inner slopes steeper, and the bottom is filled with drifted sand. For a distance of about 40 meters from the rim the outer slopes are thickly strewn with cindery masses of silica glass and smaller complete bombs of the same material, ranging in size down to small " black pearls ", which were picked up in large numbers.

The rims of the craters appear to be built up mainly of this silica glass. There are no rock fragments except as small angular pieces of a sintered sandstone enclosed in the larger masses of silica glass. Near the craters there is a small outcrop of a friable cream-colored sandstone composed of small shattered grains of quartz, and this presumably extends beneath the desert sand and the craters.

On the outer slopes of the craters there were also collected a few small pieces of meteoric iron and fragments of iron rust. A much rusted mass of meteoric iron weighing 25 pounds was found about 200 meters northwest of the smaller crater and nearer one of the buried craters. This must be only a weathered remnant of a much larger mass, as it shows the normal octahedral structure unaffected by heat. In the smaller pieces the kamacite is granulated. The group of craters indicate that here there must have been a shower of large masses of iron.

The reason for the unique development of silica glass at Wabar is no doubt that the large masses of iron fell on clean desert sand. A remarkable feature of the bombs and black pearls is their extreme lightness. Inside they consist of a very cellular white silica glass, and they are coated with a thin skin of black glass, usually with a highly glazed surface and often beset with minute pimples. The black glass is brown and transparent, with only a few minute bubbles, when examined in thin sections under the microscope. Chemical analysis shows it to contain some iron and a small amount of nickel in addition to silica. These structures suggest that there was a pool of molten and boiling silica (the silica vapor causing the highly cellular structure), and that a rain of molten silica was shot out from the craters through an atmosphere of silica, iron, and nickel

[11] Geogr. Journ., vol. 81, January 1933; and his book, The Empty Quarter, Constable & Co., London, 1933.

produced by the vaporization of the desert sand and part (perhaps a large portion) of the meteorite. The minute pimples on the surface were dewdrops from these vapors formed in the last stages.

The group of craters in Estonia are on the Baltic island of Oesel (=Saare Maa) at 20 kilometers northeast of Arensburg (=Kuresaare) on the farm Sall (=Kaali) (58°24′ N., 22°43′ E.). They have long been known and often described, first by J. von Luce in 1827. They have been thought to be earthworks made by man, and they have been compared with the crater lakes of the Eifel and the Campi Flegrei. Other modes of origin that have been suggested are that the craters were formed by (1) gas explosions, (2) oozing out of a bed of clay, (3) weathering of limestone, (4) solution of salt or expansion of anhydrite. In 1922 J. Kalkun compared them with the Arizona meteorite crater. Recently, in 1927 and again in 1929, a detailed survey with borings and trenches has been undertaken by J. A. Reinvaldt, Inspector of Mines in Estonia, and he comes to the conclusion that the craters were formed by the fall of a shower of iron meteorites. While his work was in progress a visit was made to the locality by E. Kraus and R. Meyer, of Riga, and Alfred Wegener, of Graz, and he freely supplied them with full details and drawings. As a result they published a long joint paper, which appeared only shortly after Reinvaldt's own paper.[12] Kraus inclines to the view that the craters were formed by the solution of the salt in saltdomes; but Meyer and Wegener, while considering this mode of origin to be possible, favor the meteorite theory as the more probable.

The main crater, which is occupied by a lake, is nearly circular in outline with a diameter of 92 to 110 meters. Its rim is 6 meters above the surrounding ground, while inside the depth is 15.5 meters. The steep inside walls show beds of dolomite (Silurian age) dipping away from the center at angles of 30° to 40°. Beneath this there is a zone of pulverized rock containing rock fragments; and the rocks at the bottom of the crater are shattered. Five other smaller craters, irregularly distributed over an area of three-fourths of a square kilometer, are described in detail. Four of these are circular in outline with diameters of 10 to 39 meters and depths of 1 to 4 meters. The fifth is oval, 53 by 36 meters, suggesting that two masses of iron fell together. In the bottom of one of these smaller craters the shattered bedrock shows an impression which is believed to rep-

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[12] Reinvaldt, I., with Luha, A., Bericht über geologische Untersuchungen am Kaalijärv (Krater von Sall) auf Ösel. Tartu Ülikooli juures oleva Loodusuurijate Seltsi Aruanded (Sitzungsber. Naturfors. Gesell. Univ. Tartu), vol. 35, pp. 30–70, 8 pls., 1928. Separate as Publ. Geol. Inst. Univ. Tartu, no. 11, pp. 1–42, 8 pls., 1928.

Kraus, E., Meyer, R., and Wegener, A., Untersuchungen über den Krater von Sall auf Ösel. Gerlands Beiträge zur Geophysik, vol. 20, pp. 312–378, 1 pl., 10 text-figs., 1928; Nachtrag, pp. 428–429.

resent the dent made by the meteorite. Reinvaldt supposes that the craters were formed by violent steam explosions, steam being suddenly generated from the ground water in the rocks by the heat of impact of the meteorites, and that the meteoric iron was shot out from the craters together with rock fragments. There are indications of other small craters that have been filled with stones collected from the land. A mantle of glacial deposits about a meter in thickness covers the ground. This in intermingled with the rock debris of the craters, proving that the craters are postglacial.

No meteoritic material has been found at this locality. The absence of masses of iron is explained by the fact that the ground has been tilled since time immemorial.[13] But pieces of iron shale should have been found in the excavations in the rims of the craters. Silica glass would, of course, not be found, as the surrounding rock is dolomite.

The Siberian craters (fig. 1, pls. 4 and 5) are rather disappointing, showing only as a series of small pools in a swamp. It is certain that some catastrophic event occurred there on June 30, 1908, but its exact nature still remains doubtful. Unfortunately no good and connected account has yet been given, but sensational reports appear periodically in the newspapers. The best account, collected from the available scraps of information, is that recently given by Dr. Whipple.[14] Only after a lapse of several years, in 1921, were inquiries made in the neighborhood of Kansk by Dr. Leonid A. Kulik, who is curator of the meteorite department in the Mineralogical Museum of the Academy of Sciences at Leningrad. A fireball had been seen and loud explosions heard over a wide area, blasts of hot air were felt, and an earthquake recorded at Kansk and Irkutsk, as well as at Tashkent, Tiflis, and Jena. Air waves had also been recorded on the microbarographs at Cambridge, London, Reading, and Petersfield in England, though they were not deciphered until 1930 by Dr. Whipple. Then it was remembered that remarkable midnight glows and twilight had been seen in Europe and Siberia on June 30, 1908, and the following nights. Mention of a " meteorite " [i.e., meteor, for no meteorite has even yet been found] was made by Dr. Kulik and others.[15]

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[13] A similar explanation is given for the absence of meteoric iron in India (as contrasted with the United States of America and Australia). Of the 106 recorded Indian meteorites only 1 is a found iron.

[14] Whipple, F. J. W., The great Siberian meteor and the waves, seismic and aerial, which it produced. Quart. Journ. Roy. Meteorol. Soc., vol. 56, pp. 287–304, 4 figs., 1930.

[15] Tschirwinsky, P., Meteorit vom 30. Juni 1908 im Ausflussgebiet der Flüsse Tunguska ni Sibirien. Centralblatt Min., p. 550, 1923.

Voznesensky, A. V., Fall of a meteorite on 30 June 1908 in the upper course of the Khatanga River [Russian]. Mirovédénié, Bull. Soc. Russ. des Amis de l'Étude de l'Univers, vol. 14, pp. 25–38, with small sketch map, 1925.

Obruchev, S. V., On the place of the fall of the great Khatanga meteorite in 1908 [Russian]. Ibid., pp. 38–40, with small sketch map.

In 1927 and 1928 Dr. Kulik [16] was able to locate the place of the fall, being led to the spot by the devastated forests. Pine trees are felled radially outwards for a distance of 60 kilometers (37 miles) from the center, the area of devastation covering several thousand square kilometers. A fourth expedition was made in 1929–30, when Dr. Kulik spent 20 months at the locality, but his new results are not yet published. He has, however, generously imparted some of the information,[17] and I have to thank him for a long letter of September 1932 and several photographs.

The spot is on the watershed between the streams Khushmo and Kimchu, which flow respectively into the Chambe and Chunya, both tributaries of the Podkamennaya (Stony) Tunguska, at 60°55′ N., 101°57′ E.[18] The nearest settlement is Vanovara, on the Stony Tunguska, 80 kilometers to the southeast. The center of the fallen forest is near the southern limit of permanently frozen ground, which is here at a depth of half a meter. In winter there is a half meter covering of snow, and the minimum temperature recorded in December 1929 was minus 56° C. In summer it is a region of peat bogs and mosquitoes. The rocks of the region are fine-grained and coarse basalts overlain by glacial deposits and peat. Only on the hills are rock exposures occasionally seen.

In the swamp are numerous round depressions—10 according to some accounts and 200 according to another—ranging in diameter from 10 to 50 meters and up to 4 meters in depth. Around the area of these "craters" the peat is thrown into concentric ridges. A trench cut through one of these ridges showed contorted folds of peat, clay, and ice. Three borings were made to a depth of 31.5 meters at the edge and in the center of one of the round depressions. Under the covering of peat there was permanently frozen clay down to 25 meters, and below that a sandy deposit which was not penetrated.

Kulik, L. A., On the connexion of meteorites and comets. Ibid., vol. 15, pp. 173–176 [Russian], pp. 177–178 [English], 1926. Les météorites du 30 juin 1908 et l'orbite de la comète Pons-Winneke [Russian]. C.R.Acad.Sci. U.R.S.S., ser. A, pp. 185–188, 1926. Here is also described the fall of a meteoric stone of 1.9 kg. at Kagarlyk, 60 km. from Kiev, Russia, at 7 a.m. on June 30, 1908. The Siberian fall was at 0h. 15m. (G.M.T.) on the same day.

[16] Kulik, L. A., Sur l'histoire du bolide du 30 juin 1908. C. R. Acad. Sci. U.R.S.S., ser. A, pp. 393–398, 1927. Sur la chute de la météorite "Podkamennaja Tunguska 1908." Ibid., pp. 399–402, with sketch map. Auffindung des tungusischen Riesenmeteors vom 30 Juni 1908. Petermanns Mitt., 1928, vol. 74, pp. 338–341, with sketch map, 1928. [Translation from Krasnoyarsk Workers' News of Aug. 9, 1927.] A notice of this appeared in the Geogr. Journ., vol. 73, p. 296, 1929. Abstracts of these papers and of all other recent literature on meteorite craters are given in Mineralogical Abstracts issued with the Mineralogical Magazine. Min. Abstr., vol. 5, p. 302, 1933.

An′, primary anus; *Bpr*, blastopore; *Mth′*, primary mouth.

[17] Crowther, J. G., More about the great Siberian meteorite. Scientific American, vol. 144, pp. 314–317, 9 figs., 1931. Osiris and the Atom, pp. 23–39, 4 figs., London, 1932. Olivier, C. P., Comets, pp. 198–205, 2 pls., London, 1930.

[18] These differ from the latitude and longitude previously stated. In his letter of September 9, 1932, Dr. Kulik gives the position of "Mount Farrington," determined by him astronomically in 1929, as ϕ 60°54′58.98″, λ 101°56′59.79″.

One view is that these depressions are formed by the freezing of water in cavities between the permanently frozen ground and that frozen only in winter, causing expansion and afterwards bursts. They are said to be of normal occurrence at the southern limit of permanently frozen ground. This view is opposed by Dr. Kulik. Another view is that they were formed by the solution of limestone, salt, or

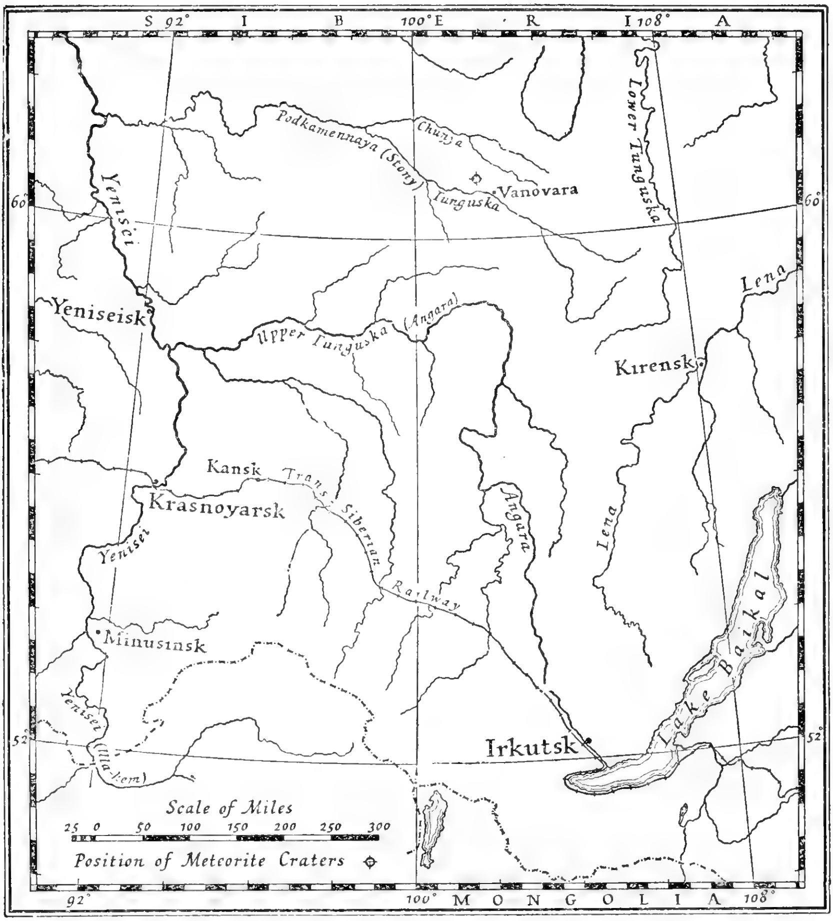


FIGURE 1.—Place of fall of the Siberian meteorite of June 30, 1908.

gypsum [19]; but this is at once ruled out by the bedrock being only basalt. Dr. Kulik believes them to be really meteorite craters, though he himself suggests some alternative explanations. They may have been formed by the folding of the surface layers by the blast of hot air, or by flooding following the melting of the frozen ground, or by

[19] Tschirwinsky, P., Ueber die Pseudometeorkrater in Arizona und auf der Insel Ösel. Mém. Soc. Russe Min., ser. 2, vol. 60, pp. 135–44, 4 figs. [Russian with German summary], 1931.

smaller still warm masses of meteoric iron lying on the frozen ground. None of these explanations, however, appears to be satisfactory, and it is indeed doubtful whether these small depressions are at all comparable with those of Henbury and Wabar. No trace of meteoric material has been collected by Dr. Kulik, but he was told by the natives that pieces of iron were formerly found in the central area of the fallen forest.

The Ashanti crater[20] occupied by the large circular lake of Bosumtwi lies on a watershed at 6°30′ N., 1°25′ W. It is roughly circular in outline with a diameter of about 6½ miles and a depth to the surface of the lake of 900 to 1,200 feet. The gentle outer slopes merge into the surrounding upland 300 to 600 feet below the rim, which is higher on the south side. The lake is nearly 5 miles across and 240 feet in depth, and its surface is 600 feet below the surrounding country. Pre-Cambrian phyllites exposed in places in the steep inner slopes show the same strike and dip as in the surrounding country. Granitic rocks, but no volcanic rocks, are present in the neighborhood. The view of the Gold Coast Geological Survey that the crater is due to faulting is not accepted. A gas explosion is not probable, and Dr. Maclaren suggests that the crater was formed by the fall of a large meteorite. But no meteoritic material has been found, and there is no shattering of the rock walls, and no fragmentary material in the rim.

The supposed crater in Persia was shown to General Dyer[21] in 1916 by his native guide Idu as a curious hole in a level plain near Gwarkuh (28°30′ N., 60°40′ E.) in the Sarhad district of Persian Baluchistan. The hole was then 150 feet long, 120 feet wide, and 50 feet deep with absolutely perpendicular sides. Idu said that it had been only half its present size, but twice as deep, and that his grandfather remembered how and when it was made. The old man told him that one night, when he was a youth, something exploded in the sky, and falling to the earth had punched a hole 100 feet deep in the plain. The spot was visited by C. P. Skrine[22] in 1921, who gives the dimensions as 95 by 70 feet, with a depth of 35 feet. At the time of a later visit in 1929 it had silted up by 3 feet. The picture given by Skrine shows a vertical hole through horizontal strata (apparently alluvial deposits), and it does not in the least suggest a meteorite crater.

The Campo del Cielo craters (fig. 2) in Argentina may now be added to the list of known meteorite craters. The locality is situated in the Gran Chaco on the border between the Province of

[20] Maclaren, Malcolm, Lake Bosumtwi, Ashanti. Geogr. Journ., vol. 78, pp. 270–276, 2 pls., 4 text-figs., 1931.

[21] Dyer, Brig.-Gen. R. E. H., The Raiders of the Sarhad, pp. 85, 86, London, 1921.

[22] Skrine, C. P., The Highlands of Persian Baluchistan. Geogr. Journ., vol. 78, p. 328, 1931.

Santiago del Estero and the Chaco Nacional, and around the railway station Gancedo (27°28′ S., 61°30′ W.). Native iron has been known from this district since 1576, when it was discovered by Hernán Mexía de Miraval. Rubín de Celis [23] in 1783 saw a mass which has been variously estimated to weigh 13½ to 45 metric tons, and a few large masses have since been collected. One weighing 1,400 pounds was presented to the British Museum by Sir Woodbine

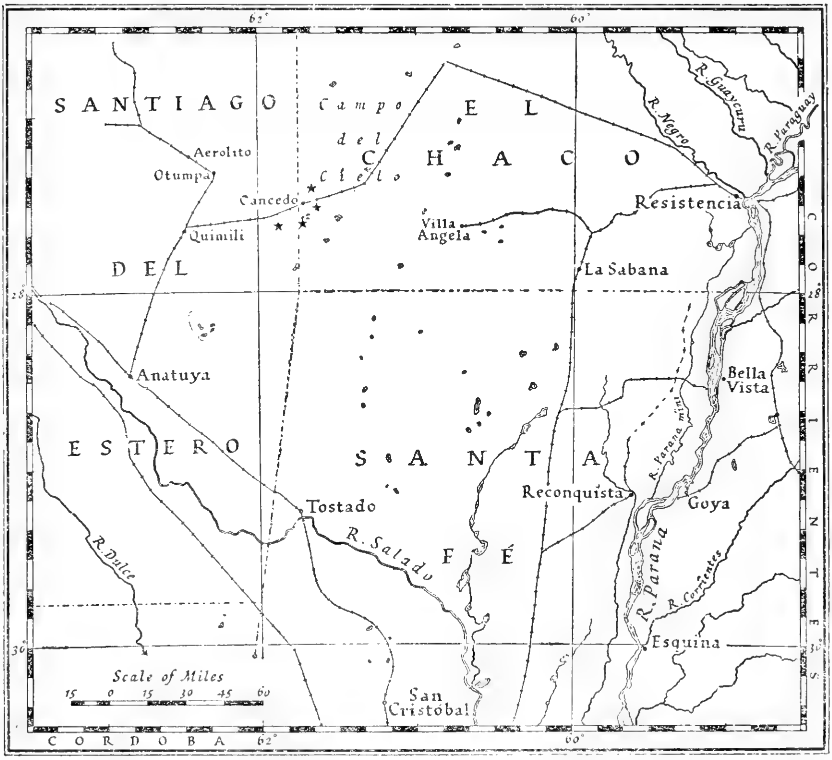


FIGURE 2.—Place of fall of the Campo del Cielo meteoric irons, showing numerous small lakes in the vicinity; stars indicate where masses of iron have been found.

Parish in 1826. At the place is a group of round and shallow depressions (hoyos or pozos), the largest, 78 by 65 meters, being occupied by a lake, the Laguna Negra, the rim of which rises only 4 feet above the surrounding level pampa. These have recently been examined by Dr. J. J. Nágera,[24] the chief geologist of the

[23] de Celis, Michael Rubín. An account of a mass of native iron, found in South America. Phil. Trans. Roy. Soc. London, vol. 78, pp. 37–42, 183–189, 1788.

[24] Nágera, J. J., Los hoyos del Campo del Cielo y el meteorito. Dirección General de Minas, Geología e Hidrología, Argentina, Buenos Aires, publ. no. 19, 9 pp., 19 pls., 1926. This report is reprinted with some of the plates by Antenor Alvarez, El meteorito del Chaco, 222 pp., 2 maps, 16 figs., Buenos Aires, 1926, where a detailed historical review is given.

Argentine Survey, and excavations were made in the hoyo called "Rubín de Celis" (also called "Pozo del Cielo").

This is circular with a diameter of 56 meters and a depth of 5 meters. Pits dug in the rim and in the center of the depression showed disturbed beds of sandy loess mixed with "white volcanic ashes" and "transparent glass in angular, curved, and striated pieces." There are no volcanic rocks in the surrounding pampa, and the Andean volcanoes are 500 miles away. This transparent glass, if examined, would most probably prove to be silica glass. Small fragments of rusted meteoric iron were found in one of the pits near the rim of the hoyo. A piece of typical iron shale (very similar to that from Henbury) from this excavation was presented to the British Museum by Dr. Antenor Alvarez in 1927, but unfortunately none of the glass was sent. Dr. Nágera concludes that the hoyas were not formed by the fall of the masses of meteoric iron, but that they were made by man. There seems, however, little doubt that they are really meteorite craters. They are easily accessible and close to the railway, and should certainly be further investigated. There are other suggestive features worthy of investigation in this district. Many small lakes and pozos are scattered around; and in particular a chain of small lakes extends southward from the spot where the large masses of meteoric iron have been found for a distance of nearly 100 miles into the province of Santa Fé.

SUMMARY OF CHARACTERS OF METEORITE CRATERS

The following tabulation of the dimensions of the described craters shows that there is a very wide variation in the ratio of width to depth. This ratio must be rapidly affected by denudation, and perhaps gives some indication of the relative age of the craters. This ratio will also depend on the type of rock, as shown in the two mine craters of La Boisselle and Hill 60.

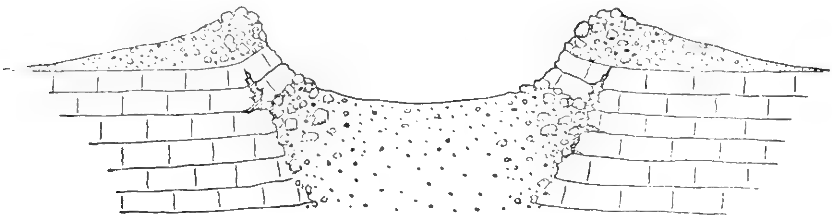
	Width, feet	Depth, feet	Ratio of width to depth
Texas	530	18	29.4
Ashanti	34,300	1,300	26.4
Siberia	164	13	12.5
Campo del Cielo	183	16	11.4
Estonia	33	3	11.0
Do	128	13	9.9
Do	300	50	6.0
Henbury	30	3	10.0
Do	240	25	9.6
Do	360	60	6.0
Wabar	328	40	8.0
Arizona	3,900	570	6.8
Hill 60, Ypres	340	67	5.1
La Boisselle, Somme	270	70	3.8

From the above accounts it will be seen that a certain amount of direct evidence is supplied only by the craters of Arizona, Henbury, and Wabar, and this has to be supplemented by a considerable amount of speculative deduction. Direct observation of how such craters are formed is, of course, quite out of the question. Meteorites of which the fall has been actually observed have always been of comparatively small size, and their velocity has been reduced by the resistance of the air to that of an ordinary falling body of about 70 meters per second. They make small holes, usually of not more than 1 or 2 feet in depth, in the ground. The largest meteorite of which the fall has been observed is a stone of 820 pounds, which fell at Paragould in Arkansas on February 17, 1930. This penetrated clayey soil to a depth of 8 feet, scattering clods to a distance of 50 feet in the pasture. On the other hand, the largest known meteorites, all of which are irons and none observed to fall, have been found by reason of their being partly exposed at the surface of the ground. The 60-ton Hoba meteorite discovered in South-West Africa in 1920 has its upper surface level with the surrounding ground, and around it there is no sign of a crater. The large masses of iron near Cape York in the north of Greenland were found loose on the rocky surface.

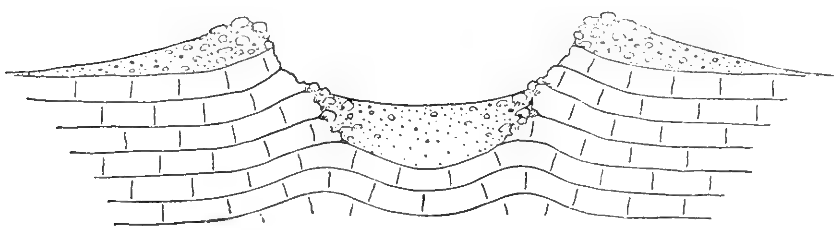
It seems therefore that meteorite craters are not merely dents in the ground made by the percussion of a meteorite; but that they are explosion craters due to the sudden vaporization of part of the material, both of the meteorite and of the earth, in the intense heat developed by the impact. When a large mass of iron traveling with planetary velocity is suddenly stopped, the kinetic energy ($\frac{1}{2}mv^2$) is transformed into heat at a localized spot with the development of a very high temperature. Simple calculations give very high figures.

The materials from the Henbury and Wabar craters give ample evidence of high temperatures. The transformation of kamacite from α-iron to γ-iron at 850° C. and the melting points of iron at 1,530° C. and silica at 1,700° C. are definite points on such a "geological thermometer." We may further add the boiling point of iron at 3,200° C. and that of nickel at 3,377° C. The boiling point of silica has been estimated at a minimum of 2,590° C., but this is probably too low. These are the boiling points calculated for the pressure of one atmosphere, but under the enormous pressures produced by the explosions at the meteorite craters they must have been considerably higher.

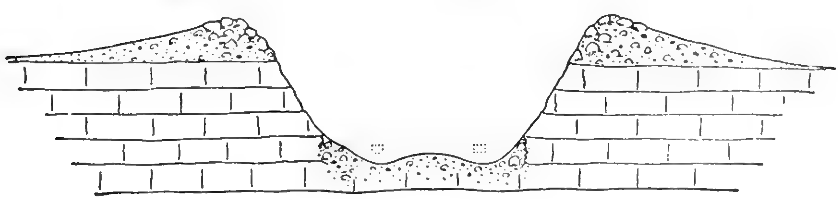
The upward force of the explosion must be very much greater than the downward force of percussion; and for this reason the beds exposed on the inside crater walls will dip radially outwards from the center (fig. 3*a*), instead of inward toward the center as might at first sight be expected. The outward dip could also perhaps be explained as in figure 3*b*, where a ring anticline has been formed by the percussion. The inner walls of the crater are always much steeper than the outer walls. The rim and outer slopes are formed of the fragmentary material shot out from the crater, and the amount of this material and the size of the blocks will show a gradual decrease with the distance from the center. Some of the fragmen-



a. Meteorite Crater: fracturing and tilting of strata by outward explosion



b. Meteorite Crater: ring anticline by percussion



c Mine Crater at La Boisselle, France, 1916

FIGURE 3.—Diagrammatic sections of craters.

tary material would also fall back into the crater and so cover up the shattered rock at the bottom. The known meteorite craters are all approximately circular in outline and their inner and outer slopes are symmetrical about the center; that is, the craters are figures of rotation about a vertical axis. This is as would be expected in the case of an explosion crater; but in the case of a percussion crater it would happen only when the projectile strikes the surface normally.

The most likely place to search for meteoric iron would be on the rim and outer slopes, where much will be buried, perhaps to be exposed later by weathering processes. Meteoric iron readily oxidizes and breaks up. Buried fragments will give rise to the formation of more or less compact iron shale and shale balls, and these may be expected to be more persistent than the iron itself. Silica glass can be formed only when the rocks surrounding the crater are highly siliceous, such as quartz sand or sandstone.

NATURAL AND ARTIFICIAL ANALOGIES

Basin-shaped depressions, often occupied by lakes, are common enough on the earth's surface, and they may be formed in several different ways. Volcanic craters and especially caldera (formed when the upper portion of a volcano is blown away by a violent explosion, or by subsidence of the cone) may be very similar in form to meteorite craters, but being composed of volcanic materials they are quite distinct. But in the case of explosion craters (or "embryonic volcanoes") an explosion of steam and volcanic gases may give rise to a crater consisting entirely of fragments of sedimentary rocks without the outpouring of any lava. Examples of these are the "maars" of the Eifel. The Pretoria salt-pan [25] (3,400 feet across and 400 feet deep), 25 miles north-northwest of Pretoria, and Lonar Lake on the basalt plateau of the Deccan, have been thought to be such explosion craters; but the former presents more points of resemblance to a meteorite crater than does, for example, Lake Bosumtwi. Explosions of gas may also take place in oil-bearing regions, sometimes with the formation of mud volcanoes.

The craters on the moon are usually thought to be of volcanic origin, but the suggestion has also been made that they were formed by the fall of meteorites. Their large size is perhaps related to the smaller force of gravitation. If the meteoritic theory is here true, we can only hope that the earth is not approaching the same stage.

Craters may also be formed on the earth's surface by the solution of beds of limestone, or of pockets of rock salt or gypsum.

As noted above, the craters of Estonia and of the Campo del Cielo have been considered by some authors to be earthworks made by man. This suggests that some other supposed earthworks may possibly be really meteorite craters. Many dew ponds are clearly artificial, but some supposed to be of Neolithic age may possibly have been formed by the fall of meteorites. As examples of large holes made artificially in the earth's surface mention may be made of the diamond mines

[25] Wagner, Percy A., The Pretoria salt-pan, a soda caldera. Mem. Geol. Survey South Africa, no. 20, 136 pp., 19 pls., 1922.

at Kimberley and the still larger Premier diamond mine near Pretoria.

A closer analogy is given by the craters formed by military mines[26] and high-explosive shells. The mine crater of La Boisselle, on the Somme (fig. 3c, pl. 2), exploded on July 1, 1916, was 270 feet in diameter from rim to rim and 70 feet deep. The rim consisted of debris piled up to a height of 15 feet above ground level and the outer slopes extended to 90 feet beyond, the total diameter being 450 feet. In this mine two charges of 36,000 and 24,000 pounds, laid at 60 feet apart and 52 feet deep, were fired together. The positions of the two charges are shown on figure 3c by the dotted squares. They formed a circular crater of greater depth than the charges. One of the craters on Hill 60, near Ypres, was 340 feet across the rim, and 67 feet deep; here there was one charge of 70,000 pounds of ammonal. These dimensions are comparable with those of the Henbury meteorite craters, but the craters here were in much softer rocks—chalk at La Boisselle and Eocene sand and clay at Hill 60. A photograph[27] of a devastated area on the Aisne in France, showing numerous water-logged shell holes and stripped trees, is extraordinarily similar to one of Dr. Kulik's photographs of the Siberian craters, only much more impressive (pl. 5).

As examples of much smaller craters produced by artificial means mention may be made of the splashes of drops[28] (also rain on mud flats), clay balls thrown on a slab of clay, and shots on armor plates.

Note added September 15, 1934.—Since the above paper was written, a more detailed investigation has been made of the materials from meteorite craters.[29] Further evidence is forthcoming that very high temperatures prevailed at the time the craters were formed. The meteoric iron was vaporized in large amount and condensed as minute spheres; those which fell into the boiling silica were preserved. Some of the vesicular silica glass from Wabar is estimated to contain as many as 2,000,000 of these minute polished spheres of nickel-iron per cubic centimeter.

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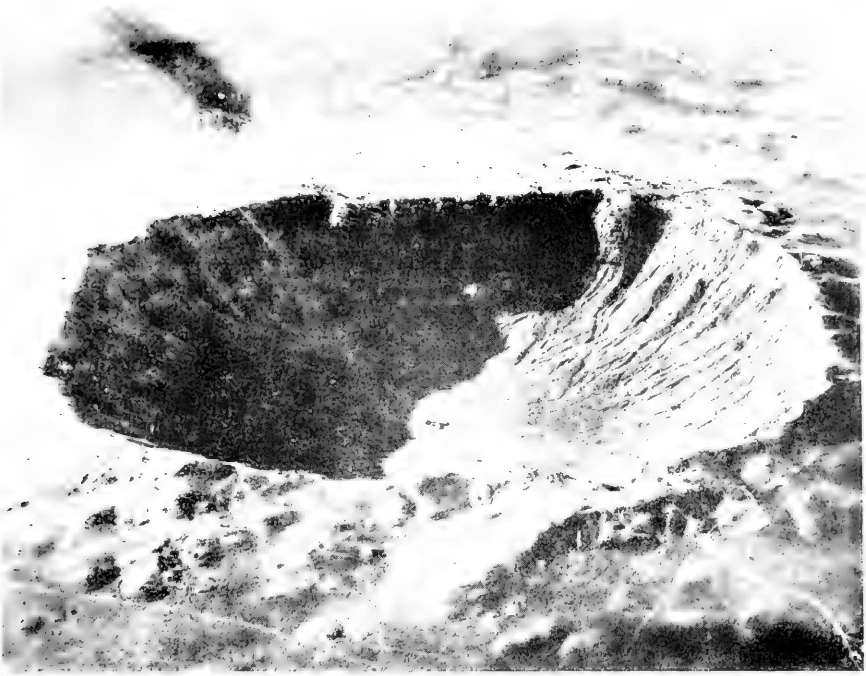
[26] Military mining, work of the Royal Engineers in the European War, 1914–19. Institution of Royal Engineers, Chatham, 1922.

[27] War Museum photograph no. Q37361.

[28] Worthington, H. M., The splash of a drop and allied phenomena. Proc. Roy. Inst. Great Britain, vol. 14 (for 1894), pp. 289–303, 15 pls., 1895. Cole, R. S., The photography of the splash of a drop. Nature, vol. 50, p. 222, 1894. Worthington, A. M., and Cole, R. S., Impact with a liquid surface studied by the aid of instantaneous photography. Phil. Trans. Roy. Soc., London, ser. A, vol. 189, pp. 137–148, 8 pls., 1897; vol. 194, pp. 175–199, 6 pls., 1900. Worthington, A. M., The splash of a drop. London, 1895; A study of splashes. London, 1908. Numerous interesting photographs are given in these books and papers, some of which bear a certain resemblance in form to meteorite craters.

[29] Spencer, L. J., Meteoric iron and silica-glass from the meteorite craters of Henbury (Central Australia) and Wabar (Arabia). Mineralogical Mag., vol. 23, pp. 387–404, 8 pls., 1933.



Carnegie Institution of Washington

1. AIR PHOTOGRAPH OF THE METEORITE CRATER IN ARIZONA.

D. M. Barringer.

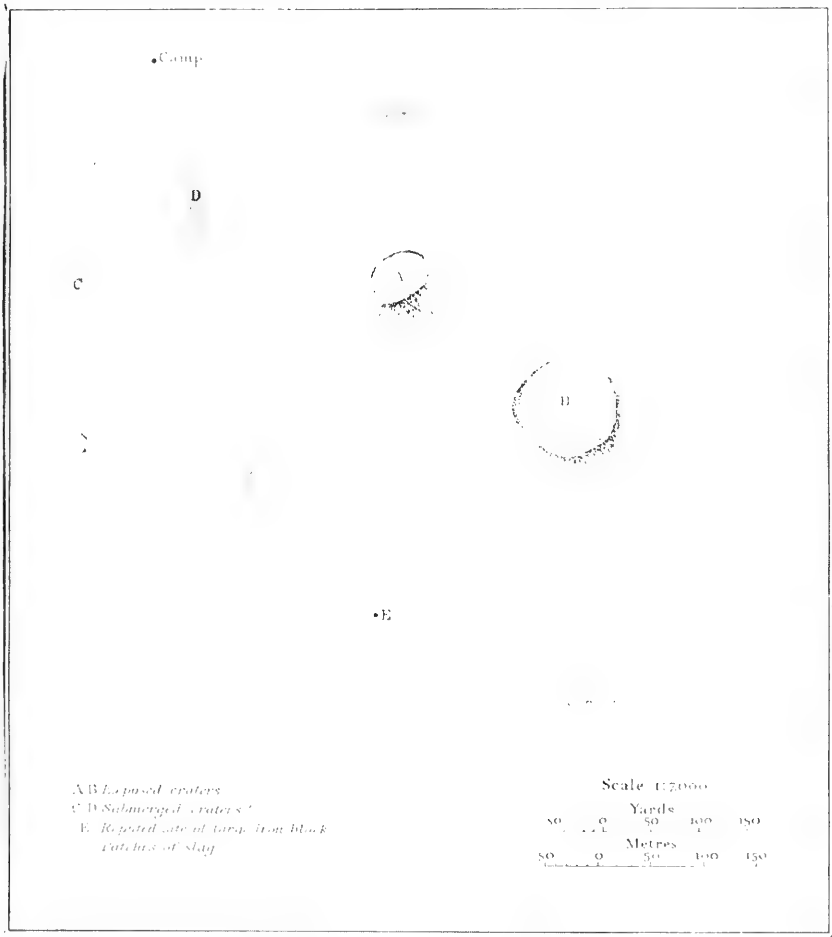
2. ARIZONA CRATER: EJECTED BLOCKS FORMING RIM.

Mineralogical Magazine 1932.

1. INSIDE THE MAIN METEORITE CRATER AT HENBURY, CENTRAL AUSTRALIA.

Imperial War Museum copyright.

2. MINE CRATER, LA BOISSELLE, SOMME, FRANCE, 1916.



H. St.J. Philby.

1. PLAN OF THE WABAR CRATERS, ARABIA.

H. St.J. Philby

1. METEORITE CRATER AT WABAR, ARABIA

Dr. L. Kulik.

2. FALLEN FOREST 10 MILES FROM CENTER OF EXPLOSION, SIBERIA.

Dr. L. Kulik.

1. SIBERIAN EXPLOSION, 1908: CRATERS IN SWAMP.

Imperial War Museum copyright

2. SHELL HOLES, AISNE, FRANCE, JUNE 1918.

A GEOLOGIST'S PARADISE

By R. S. Bassler
Head Curator, Department of Geology, United States National Museum

[With 4 plates]

Paradise to the geologist is not only the traditional far-away heaven with its gates of pearl and jasper and streets of gold, all precious minerals of interest to him, but it is also right here on earth where these minerals and many interesting earth problems are to be found. Ordinarily people think of Washington as a city of museums and libraries and governmental activities, but here in the Capital City we have one of the most favored areas of North America for the study of geology—a paradise for both teacher and student. Just what is geology, and why should a geologist find his paradise on earth? Geology, briefly, is the study or science of the earth and its inhabitants. The period covered by this study starts from the time our planet was a fiery mass revolving in its course through the heavens, subject only to physical laws, on down through eons of time to the present, when life has become such a predominant factor. Geology is all-inclusive, not only in the length of time it covers but also in the various sciences it comprises. For it embraces phases of the physical sciences, such as astronomy, physics, and chemistry, concerned mainly with early earth history, and the biological sciences, zoology and botany, studies dealing with the life of the earth.

Although a paradise for study may be found by the geologist in almost any place, naturally to the specialist one region may offer greater interest than another. The Bad Lands of the Dakotas—lands practically barren and deeply gullied by occasional heavy rains—reveal to the physiographic geologist, or student of land forms, a story, to express it scientifically, of the erosion of unequally resistant sedimentary rocks occurring in a semiarid region.

On the other hand, the sturdy granites of New England tell a far different story of earth history, for they were originally molten rocks formed deep in the earth's crust but now exposed at the surface by weathering. A striated or scratched boulder from New York State brings before the student of glacial geology a vivid picture of the ice age. And so on—each section of the country has its own geological formations, problems, and interest.

Like most other large cities on the Atlantic slope from New Jersey to Alabama, Washington is located at the fall-line, the name given to the junction of the flat-lying Coastal Plain to the east, composed of sands, clays, and gravels rather recently deposited, and the hilly Piedmont region to the west made up of granites and other ancient hard rocks. It was at the fall-line that the early settlers, pushing their way westward across the Coastal Plain by way of the Susquehanna, Potomac, and other waterways, found their progress impeded by rapids where the hard granites of the Piedmont were encountered. Since these places afforded many natural advantages such as water power, a purer water supply, higher and, therefore, healthier situation, and waterway transportation, they usually marked the beginning of settlements which have since grown into important cities. From north to south these cities—Trenton on the Delaware, Philadelphia on the Schuylkill, Baltimore on the Patapsco, Washington on the Potomac, Richmond on the James, and Augusta on the Savannah—clearly mark the line of contact of the plains and hilly regions.

Although from the original settlement at Georgetown, Washington might have grown into an industrial city, its selection for the location of the National Capital changed its reason for growth.

The Atlantic Coastal Plain, including the alluvial valley of the Anacostia River excavated in it, upon which the downtown business section and eastern half of Washington are built, really continues on east beyond the Atlantic seashore resorts and out into the ocean for a distance of 100 miles to the edge of the continental shelf. The sediments which make up the deposits of the entire coastal province have been so recently washed down from the higher lands to the west that the material has not yet had time to consolidate into rock. The process of building up the Coastal Plain still continues. During Revolutionary days the American Navy anchored at Bladensburg on the Anacostia River, a side estuary of the Potomac near Washington. Today, however, the water is here scarcely deep enough to reach the hubs of an automobile, and in a few years, unless man intervenes, the area will be dry land. The Coastal Plain has also alternately risen and fallen. Its northern portion has been submerged since its first general uplift, so that rivers such as the Potomac and Susquehanna, which cross it, were drowned and now occur as wide estuaries, in some instances extending back to the fall line.

This is the case of the drowned river valley of the Susquehanna known as Cheaspeake Bay, whose beaches offer the geology classes of the Washington schools many geologic phenomena for study. The classic Calvert cliffs, which outcrop for many miles along the picturesque bay shore, stand as an excellent example of the cutting and wearing away of the strata by wave action. Approach to the cliffs south of Chesapeake Beach can be had only by the water, and accordingly the student who wishes to search for fossils in the richly fossiliferous Miocene strata here exposed finds a bathing suit more appropriate than the characteristic hobnailed boots of the geologist. In the constant wearing away of the cliffs the waves also separate countless numbers of fossils from the sediments and strew them along the shore, where they are readily accessible to the collector. These fossils range from the microscopic foraminifera, shells of 1-celled animals, to the enormous vertebrae of extinct whales. Fossil sharks' teeth, some as much as 4 inches across, belonging to fish living some millions of years ago, are rather common, and it is no difficult task to secure a handful for stringing into a bizarre necklace. Searching for these teeth by digging along the strand line and allowing the next wave to spread out the material, thus exposing the specimens, is a rare form of fishing.

But one does not have to leave Washington to find fossilized marine animals. Sea shells and sharks' teeth found in the sedimentary sand and clay formations outcropping in the hills east of the Anacostia River prove that these deposits are likewise of marine origin. Good exposures of these strata, made up of Upper Cretaceous and Tertiary greensands capped by Miocene white clays formed of diatomaceous earth, may still be seen at various points along Good Hope Hill. The diatomaceous earth beds, composed almost entirely of microscopic siliceous plant remains, are of economic importance, particularly as a basic constituent of scouring powders. Above these two formations is the Pliocene formation of gravel and sand 20 to 30 feet thick containing pebbles of various rocks, minerals, and fossils which afford the student many opportunities to add to his collection. This formation is well shown in the earth mounds at Fort Totten, of Civil War fame, now overgrown by vines and trees, located at the northern end of the Soldiers' Home grounds. It is also to be seen in the gravel pits at Good Hope and at Tenleytown. The number of minerals to be found in these gravels and in the other rocks around Washington is astonishing, ranging from small gold nuggets, if you are lucky, to the fool's gold or iron pyrite which the earlier settlers shipped back to England by the shipload.

In the eastern part of Washington the Anacostia River, a transverse tributary of the Potomac, parallels the fall line and cuts through the oldest strata of the Coastal Plain where they overlap the granites of the Piedmont Plateau. The student who discovers the fossilized remains of land animals and plants, in the sands, red clays, and gravels of this formation, the early Cretaceous Potomac group, must conclude that these deposits were laid down on the ancient continent in river or swamp beds rather than in the sea. For here are found bones of dinosaurs, the giant land reptiles of the past; trunks of trees changed to flint and jet, and many leaf impressions between the clay layers.

The higher northwestern part of Washington is built upon the Piedmont plateau, which is the planed-off surface of former mountains whose rocks represent the oldest period of earth history. These rocks, well represented in Rock Creek and westward toward the Blue Ridge, have passed through so many changes of structure due to pressure and fracturing that their original aspect can only be surmised. They consist mainly of crystalline rocks, so-called because they were produced by the slow cooling and crystallization of ancient lavas or by the remelting and subsequent cooling of sedimentary strata, such as mudstones. Granites, the most common of the granular crystalline rocks, and schists, made up of thin layers of changed, compressed sedimentary strata, form here the predominating outcrops. Besides the characteristic granite-gneiss of the eastern Piedmont, which is well exposed throughout Rock Creek Park, other interesting rocks outcrop just west of the park, among them diorite, which weathers into green soapstone, and which has been used as a building stone for various houses in Washington.

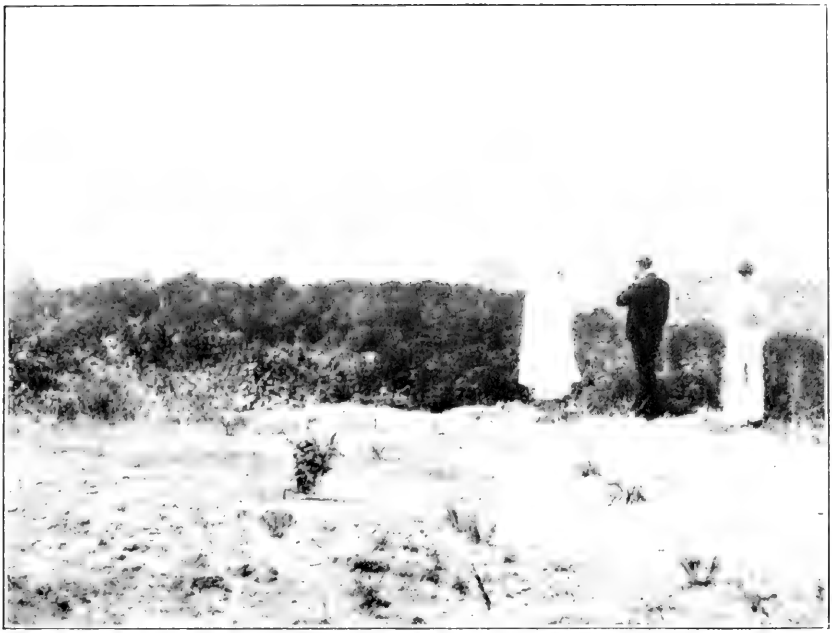
To study other rocks of the Piedmont, the geologist visits the Potomac gorge at Great Falls, where a banded granite, called the Carolina gneiss, outcrops extensively. The Potomac itself follows the so-called master joint planes of the great blocks into which the granite is divided, and within a short distance its course changes direction several times at almost right angles. Even these very hard rocks, because of their exposure to the weather for such countless ages, usually appear at the surface as crumbling masses of quartz grains, mica flakes, and clay, but along the walls of the stream gorge where weathering has not been at work so long, their real nature is perceptible. In the gorge of the Potomac another erosional feature is conspicuous, for here the polished rock ledges contain rows of pot holes, or circular excavations, sometimes as much as 7 feet wide and 10 feet deep, worn in the hard bedrock by the water whirling sand and boulders around in crevices until the cavities are produced. Dikes and quartz veins containing just enough gold to be annoying, intrusions of igneous rock from deep in the crust, faulting and the results of long weathering and erosion are other geologic phenomena plainly visible in the gorge.

Perhaps the most interesting field of geologic study close to Washington is the region of folded mountains, known as the Newer Appalachians, which rise west of the Piedmont plateau. These mountains, the Catoctin, the Blue Ridge, and ranges to the west, are composed of sedimentary rocks originally deposited in horizontal beds under the sea. During the many millions of years since their deposition, they have been forced by great pressure into a series of northeast-southwest folds, some extending a hundred miles in length, but not more than a few miles in width. It is to historic Harpers Ferry, located in the mountain region a short distance northwest of Washington, near the point where Maryland, Virginia, and West Virginia meet, that one may go to study the many phenomena of this region. So varied are these features that a list of them reads like the table of contents of a geologic textbook. Among the outstanding features here are two physiographic regions, the Blue Ridge Mountains and the Appalachian Valley; two base-leveled regions, or peneplains, now elevated, one to form the flat summit of the Blue Ridge, the other the floor of the valley proper; the greatly folded Appalachian structure; terrace formations demonstrating the former higher levels of the stream beds; and water gaps, features which give evidence that the rivers were able by their erosive power to hold their original courses while the slow process of mountain building was going on. Of historic, as well as geologic, interest is the series of chambers dissolved out of the Shenandoah limestone near Harpers Ferry forming John Brown's Cave, which remains as it was when used as a place of concealment for passing slaves to the North. Another point of historic interest is Jefferson Rock, a mass of lower Cambrian shale reposing on the high river bank overlooking the Shenandoah River and surrounding country. It has been named for Thomas Jefferson, our geologist-President, who frequented it for the inspiration he received from the magnificent view—an inspiration reflected in his various scientific papers.

But we return to Washington to study more recent geologic history. For here are deposits of the period known as the Quaternary, when the great ice sheet overspread the country to the north and reached as far south as the Missouri and Ohio Rivers. Although the glaciers did not extend to Washington, their effects are exhibited in the deposits brought down in the rivers swollen by the melting ice. These deposits are now in the form of flat plains or terraces along the river banks occurring on each side at definite altitudes, thus giving evidence of several previous higher elevations of the streams. The District of Columbia is the type locality for the study of these terraces, hence the name "Columbia" which has been given to the formation. An extensive development of one of these terraces exists in the Mount Pleasant plain at Meridian Park and adjoining upper parts of Washington, where the characteristic gravels can be seen. On the middle terrace, about 90 feet above sea level, is built a considerable part of Washington, including the Capitol. The most recent terrace, which is at very few places more than 40 feet above sea level, and the lowest, geologically speaking, contains the long line of public buildings from the National Museum to the Monument. In our own time a terrace is in process of formation at the present level of the Potomac by the gradual deposit of its mud and gravel.

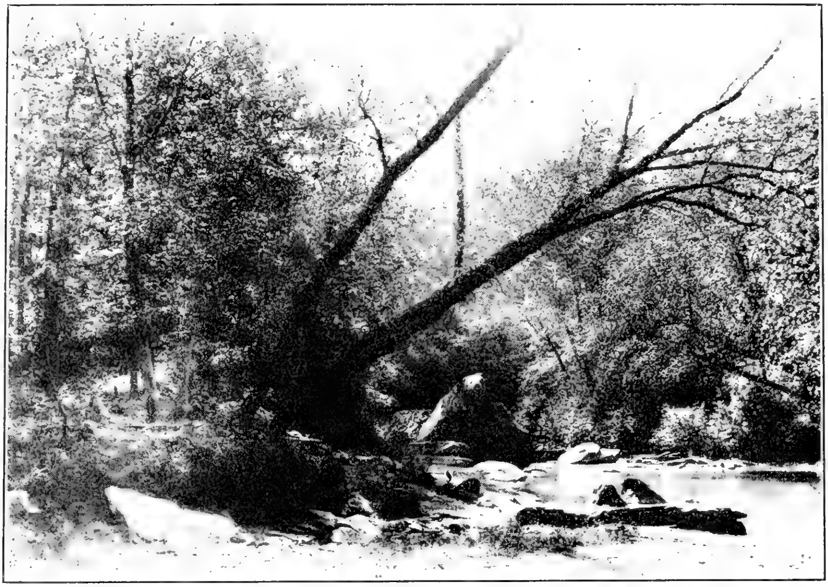
In addition to all these natural geologic phenomena exhibited in or near Washington, there are other circumstances which make the Capital City unique in the advantages afforded geology students and research workers. The various scientific bureaus of the Government: The United States Geological Survey, Smithsonian Institution, Geophysical Laboratory, Bureau of Standards, Carnegie Institution, and others afford most exceptional opportunities for the student of geology, as indeed for students of all sciences. And perhaps in no other place are there the library facilities which Washington offers. The Congressional Library with its many thousands of scientific volumes, so necessary to research workers, cannot be duplicated elsewhere. Finally there is the National Museum, whose scientists through many years of effort have collected and classified vast amounts of geologic material. Minerals and rocks of all kinds, and fossils from the oldest to the most recent, ranging in size from microscopic diatoms to huge reptiles 80 feet long, are on display and for study by those who seek a better understanding of earth history.

Is it, then, any wonder that here at Washington, where both nature and man have contributed to make conditions ideal for him, the geologist finds a paradise?

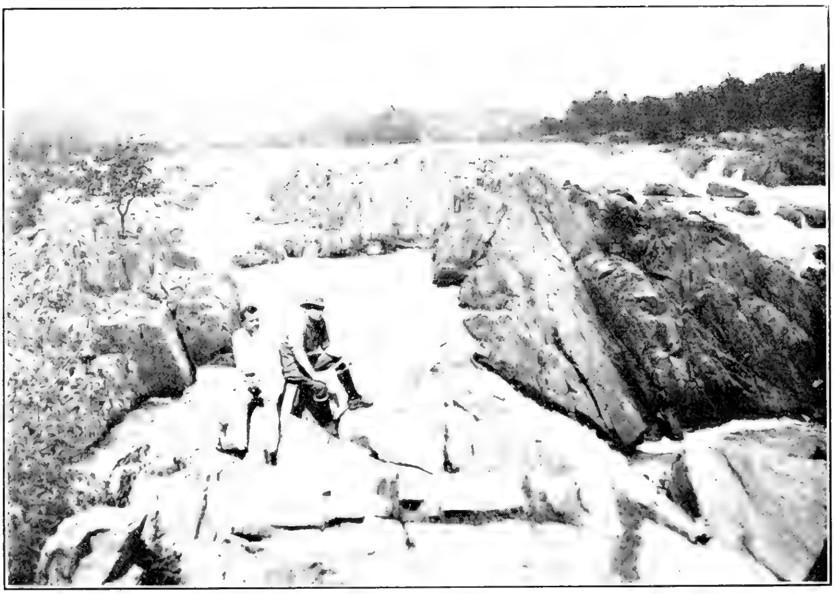


1. Washington, viewed from Good Hope hill with the recently elevated Atlantic Coast Plain capped by Pliocene gravels in the foreground, the Piedmont peneplain forming the skyline, and between them the alluvial plain of the Anacostia River with its terraces.

2. Calvert Cliffs along Chesapeake Bay, exposing richly fossiliferous marine Miocene strata.



1. Outcrop of weathered granite blocks along Rock Creek in the National Zoological Park.

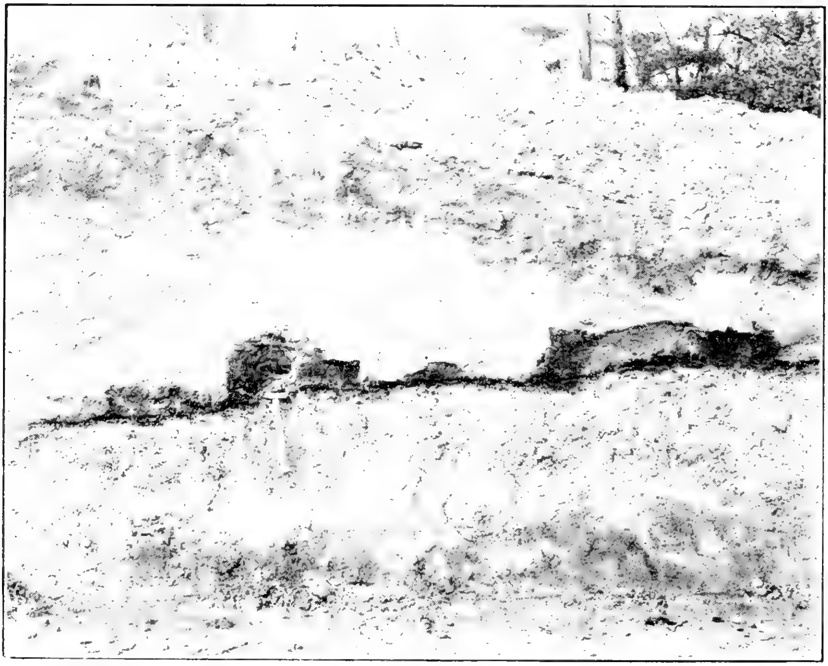


2. Great Falls of the Potomac on the Virginia side, showing the master and minor joint blocks in the granite gneiss, and in the distance an area honeycombed with potholes.

1. The Capitol on the middle Columbian terrace as seen in 1890 from the Bartholdi Fountain on the lower one.

2. The lowest Columbian terrace, upon which stand the National Museum, the Monument, and other buildings of downtown Washington.

1. Outcrop near the National Zoological Park, exhibiting an unconformity or gap in earth history, with the uptilted granite gneiss succeeded by horizontal beds of Upper Mesozoic sand and gravel.



2. Another unconformity near Washington. The hammer marks the boundary line between the Lower Cretaceous Potomac formation below containing land plants and dinosaur bones, and the marine Upper Cretaceous greensands with sharks' teeth and sea shells.

NATURE'S OWN SEAPLANES

By Carl L. Hubbs
Museum of Zoology, University of Michigan

I

Nearly all of the grand, fundamental discoveries and inventions by which man has lifted himself out of his dark animal past were but repetitions of discoveries and inventions which nature had made eras before our anthropoid ancestor first stood erect and looked up into the sky. The arrow by which primitive man gathered his raw meat was duplicated early in the course of animal evolution by the nematocyst—the poisoned arrow of the jellyfish. Fire by which the human progenitor cooked his food and warmed his body was paralleled by animal heat and matched more closely by the warmth produced by decaying matter with which certain reptiles and birds surround their eggs. High-power electricity, often considered the symbol of modern civilization, was long, long before utilized by nature in the electric eel, the electric catfish, the torpedo ray, and other fishes. Light, which opened up the night for man, was a frequent invention of nature—witness the firefly and many denizens of the inky depths of the sea.

Use of light for distant communication has, no doubt, been practiced for a time so long as to make the whole existence of man seem but a day. Communication by sound is similarly old. Music is one of the most primeval of human arts, but insects and birds made known their presence and desires by song at a far more ancient time. Even the modulation of the voice to produce language was incipiently developed in nature, as by certain birds. Modern communication systems in many ways fail to equal the marvelous functions of the nervous system of animals.

The cultivation of crops and the domestication of animals, which allowed man to settle down from a nomadic existence, merely repeated the evolution of analogous habits by certain ants. Slavery is also a fixed habit with some kinds of ants. Many of our social ways are but reflections of the habits of social insects.

Even organized warfare was an animal development. Some ways of modern war are old in nature: smoke screens are rivaled by the ink clouds by which squids escape their enemies; camouflage is all but universal in nature. Explosives as a weapon of combat seem to have been a human discovery not duplicated by nature—hardly a justification for man's feeling of supreme superiority over the natural world. The rocket plane, which some predict as an outstanding tool of war and peace in the future, will but repeat the mode of locomotion utilized by squids.

These inventions of nature are not the work of a demigod. They are the end products of evolution—the adjustment of animals to their environment. This evolution, it is now generally agreed, is accomplished by an orderly process: those individuals which are so constituted, so fitted to their environment, that they survive better in the intense struggle for existence, produce offspring like themselves, multiplying their own kind at a faster rate than do those individuals not so well endowed with characteristics favoring survival. Eventually those best fitted to survive breed out those less well fitted and thus populate their section of the world.

Man himself is a product of evolution. His ability to create ideas and things has been a leading characteristic fitting him to survive. The human "creations", which so clearly parallel the products of nonhuman nature, are therefore also the result of natural evolutionary processes. The distinction between natural and human inventions is consequently a rather arbitrary one, based on differences of time, of zoological position, and of degree, rather than on inherent differences in kind.

Probably the most outstanding among the basic human inventions which was not utilized by prehuman nature was the wheel. True, the wheel animalcules, or rotifers, produced circular water currents by movements of the double circle of cilia about the mouth, but this is not such a movement as would be produced by the spokes of a true wheel, each advancing independently, in rotation. The turning of a circular disk on or about an axle is a distinctively human invention only weakly anticipated (though perhaps suggested) by the motion of animal, including human, limbs around ball-and-socket joints. The wheel is not necessary to high human development, for the American Indians, including even the Mayas and the Incas, seem never to have known of this basic implement. In one form or another, however, the wheel enters into almost every phase of progressive human activity characteristic of the mechanical age in which we are living. All current means of transportation, of power development, and of machine production somewhere involve rotation on or about an axis. The release of man from day-long drudgery, the multiplication of power and wealth, the binding together of the world by instant means of communication, and rapid, facile means of transportation—all these factors basic to modern civilization are made possible by the turning of wheels.

II

The whirling motor and the whirling propeller, both involving the principle of the wheel, are the essential points by which the airplanes of man differ from flying fishes, nature's own seaplanes. With this exception, vital it is true, modern airplanes are marvelously close reproductions of flying fishes. To offset this defect in the natural product, the flying fishes are the masters of both water and air—submarines and seaplanes in one.

Pioneers in aeronautics and designers of early aircraft made the mistake of neglecting to study the most airplanelike of all animals, the flying fishes. The idea had become so firmly fixed in man's mind that birds are the preeminent animals of flight that they alone were looked to in the attempt to discover the principles of flight.

This firmly entrenched idea that bird flight is typical of all animal flight has since the time of early records prevented a large proportion of observers from appreciating the true method of fish flight. This erroneous preconception, like thousands of other fixed ideas, has blinded the eyes of man. It has put into his mental vision movements of the flying fish's "wings" which his eyes did not see and could not see, because they do not exist. Even some scientists, observing the fascinating flight of fishes, have thus duped themselves into thinking they saw that which they did not see, allowing their preconceived ideas of how fishes should fly to prevent them from seeing how fishes do fly, or rather from registering in their minds what their eyes must have seen. Most of the scientists who failed to fight off these blinding effects of preconceived ideas, however, were laboratory investigators, closet naturalists. Through the long period when men have allowed their minds to put movements into the flying fish's "wings", trained field naturalists have seen that these animals, while in the air, hold their supporting planes, the greatly expanded pectoral fins, as rigidly as though they were made of steel.

The question whether fishes flap their "wings" in flight constitutes one of the longest controversies in the history of natural science, and is still in dispute, despite the numerous essentially correct observations noted above. It has been a common tendency to deduce how fishes must fly, not only from preconceived ideas of the flight of birds but also from generally erroneous conceptions of the mechanics of flight. Had half the energy which has been devoted to these profit-less deductive studies been expended in inductive research—careful observations on the flight of fishes—the controversy would long ago have been settled, or at least would have been rendered very one-sided. In fact, a few hours of unprejudiced and close observation would usually have sufficed to prick the bubblelike theories born of deductions.

Now that the sight of airplanes, fulfilling the prophecies of Langley, is a commonplace experience of civilized races, the erroneous belief that flying fishes must flap their wings in order to fly is much less common than in previous years. False deductions that the weight of the fish's body can be sustained in the air only by a vibration of the wings, or that any body—even a moving plane—must continuously fall unless it continues to expend energy to counteract gravity, are not likely to be made by one who has watched airplanes with motors shut off, or, better, gliders, soar through the air and often rise as they proceed, with their planes clearly silhouetted against the sky.

III

For lack of space, no attempt is made to review here the very extensive, though mostly incidental and trivial, literature on the flight of fishes. This has been attempted by several writers referred to in the selected references given at the close of this article, notably by a German naturalist, Fr. Ahlborn (1895), by an American ichthyologist long associated with the Smithsonian Institution, Theodore Nicholas Gill (1905), and by an Englishman, E. H. Hankin (1914, 1920). As I wrote recently in presenting detailed field observations on the subject (Hubbs, 1933), "perhaps too much ink has already been used in discussing the flight of fishes."

Disregarding this voluminous literature, we may proceed at once to a discussion of just how the typical ("four-winged" or "biplane") flying fishes fly, according to the virtually unanimous views of recent, critical observers. A brief epitome is given in pictorial form. Figure 1, utilized for this purpose, was made by Grace Eager under my direction, as a substitute for photographs, preferably motion pictures, which still remain for some skilled wildlife photographer to contribute. This would be by no means an impossible task in certain tropic seas, where day after day hundreds of these fishes rise to soar away before a vessel.

UNDER-WATER MOVEMENTS

Under water, flying fishes swim with great speed, with both pairs of wings folded back against the body so that they resemble a trim submarine (fig. 1a). This may be seen especially well from a vessel

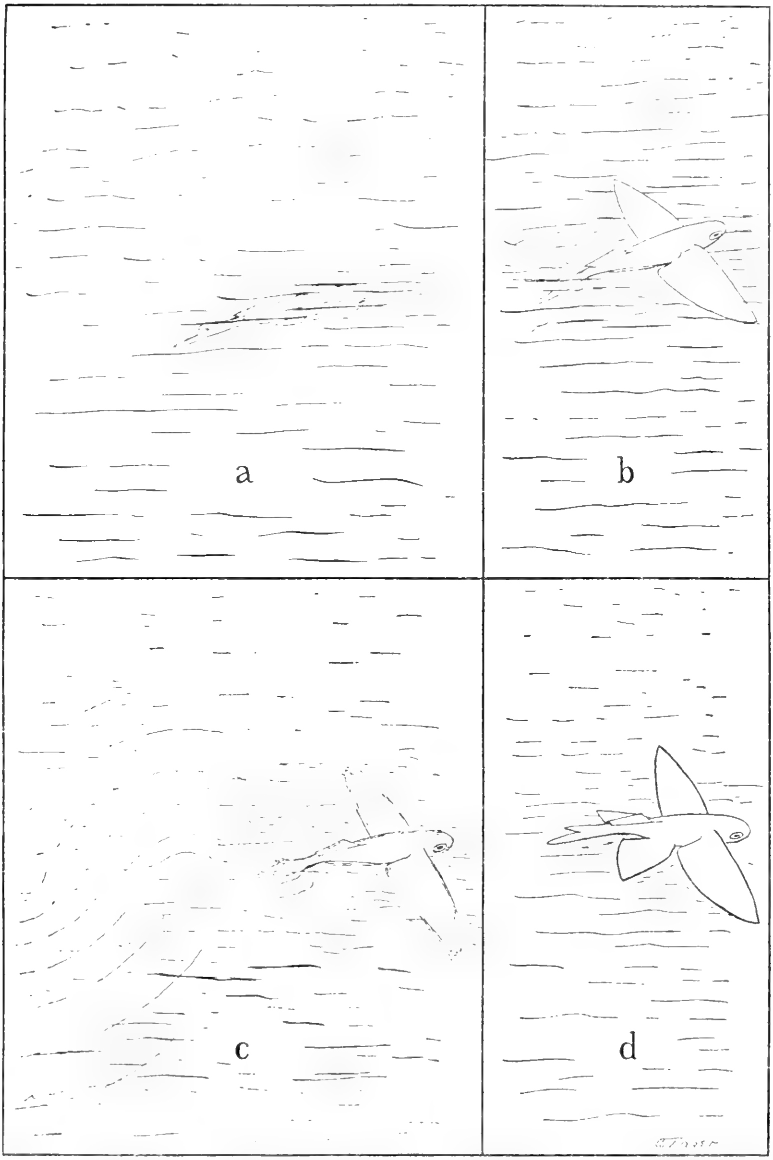


FIGURE 1.—Four stages in the flight of a cypselurine flying fish. Reproduced by permission from Papers of the Michigan Academy of Science, Arts, and Letters.

a, the fish approaches the surface, both pairs of fins folded; *b*, the fish breaks the surface and spreads the pectoral fins (upper or anterior planes) to support the anterior part of the body; *c*, the fish gains speed by the taxi or surface-skimming. The caudal beats the water; the body shakes; and the wing tips flutter in response, giving a false illusion of wing beating; *d*, the fish takes off by spreading the pelvic fins, thus lifting the tail out of the water. The planes are now held taut and rigid as the flying fish dashes through the air.

plying the clear sea off Santa Catalina Island, where lives in abundance one of the giants of the tribe, the California flying fish, which attains a length of about 18 inches.

THE SURFACE "TAXI"

On breaking the surface, the huge pectoral fins, the "wings" which function as the upper or anterior pair of planes, are spread wide and taut. This spreading action is apparently too sudden to be caught by the eye. Since these main supporting planes lie well in advance of the fish's center of gravity, the head of the flying fish is supported in the air at a slight angle with the surface of the sea, while the tail droops, because the lower planes (the enlarged pelvic fins), set behind the center of gravity, at first remain folded against the belly. For this reason the elongated and strengthened lower lobe or fork of the caudal fin remains submerged in the water (fig. 1b).

While a few of the flying fishes—such as the primitive, short-winged genus *Oxyporhamphus*, and the "two-winged" or "monoplane" type *Exocoetus* (or *Halocypselus*)—dart directly from the sea, the typical biplane species normally gain power for their longer flights by a surface "taxi" movement (fig. 1c), to borrow a term from aviation.

In obtaining the position just described at the surface of the water, the biplane flying fishes may suffer some slackening of their speed. They actually appear almost to balance themselves for a split second at the inception of their surface movements. At least we may be sure that at the start of the taxi sufficient velocity is not yet attained to carry the fish on a very long soar through the air. That this is true was evident from actual observations. When the taxi was misgoverned, much abbreviated, or even eliminated, on account of some condition of wind, wave, or obstacle, the fish was sustained in the air for only a few feet. And when a very short taxi was employed, the first flight was not much longer.

I believe that I have been able to observe the acceleration in speed which may be assumed to be produced by the taxi. In compound flights it is obvious that the slackened speed at the end of one flight is greatly accelerated by the taxi intervening directly between this soar and the following one. At the end of each taxi the fish appears to be catapulted into the air at a very high speed. What this actual speed is would be very interesting to know. I assume that it is not less than about 55 kilometers (35 miles) per hour, my very rough estimate of the average speed of the whole flights (drawn up from guesses of the distance traversed in timed flights). This estimate is in rough agreement with those of Hankin (1914, 1920), who computes the air speed of flying fishes to be 10 to 20 meters per second. That an acceleration takes place during the taxi may also be concluded from the fact that my estimate of the speed of the entire taxi is only 10 meters per second (about 35 kilometers per hour), which is less than my estimate for the whole flight and therefore almost certainly less than the speed attained at the end of the taxi and the beginning of the actual flight, which ends as the speed is gradually decreased. The taxi may, consequently, be assumed to accelerate the speed sufficiently to carry the fish for a considerable distance through the air.

The propulsive power by which this acceleration is accomplished is derived solely from a violent side-to-side vibration of the tail, as the fish skims along with only the strengthened lower caudal lobe in the water. The even, wave-ring disturbances thus produced on a quiet sea surface indicate that such a movement takes place, and the actual track which I once saw left on dust-covered water surface proves the point.

The retention of the propelling organ in the dense medium of water and the supporting of the moving body in the rare medium of air permit the attaining of a very high speed. This is the principle of the speed boat and the hydroplane.

The rapid shaking undergone by the stiff body clearly follows from the tail movement. The slight movement of the taut pectoral fins (fig. 1c) during the taxi has been mistaken by uncritical observers for an actual flapping of the wings, but this rapid vibration of the fins, like the less obvious but still observable shaking of the whole body, is solely a response to the violent tail movements. The vibration of the wing tips, having an amplitude of only a centimeter or two, and usually lasting a bare second, is certainly insufficient to give so heavy a body speed enough to carry it through the air. The hazy outline of the planes becomes transformed into knife-like rigidity, as I have observed hundreds of times for many species and as most other trained observers have indicated, at the very instant the tail movements cease when the fish rises into the air.

It is a curious fact that nearly all observers have failed to appreciate the simple reason why the wing tips flutter while the tail is vigorously beating the water surface. Even those who have taken the side that flying fishes do not fly by wing flapping explain this wing vibration as due to the action of the wind on the taut membrane. That this explanation is untrue follows from the fact that the vibration ceases the instant the tail fin leaves the water, although neither the wind pressure nor the wing tautness is then materially altered.

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The distance covered by the initial taxi is usually about 5 to 15 meters (or yards); some taxis are at least 20 meters long, but the average is nearly 50 times the length of an average flying fish, or about 9 meters (30 feet) long. Numerous timings made by me in Asia indicate that the average time involved in covering this distance is about 0.9 second. The average speed for the surface period of movement is therefore about 10 meters per second (36 kilometers per hour). This is the speed of an athlete on a short dash. But the speed of the fish, since it is accelerated during the taxi, is probably greater at the end of the taxi, when the fish hurls itself into the air. On the basis of some field observations (degree of detail not indicated) and of aerodynamic computations, Shoulejkin (1929) has concluded that a speed of 16 to 18 meters per second is attained at the end of the taxi. Like an airplane, the fish probably increases its power as it approaches the take-off.

To attain this speed the sculling action of the caudal fin must be very strong and rapid. My observations indicate an average of about 50 to 70 complete or double vibrations per second and 5 to 7 vibrations per meter.

The biplane flying fishes very often prolong their flight by taking a new start. Since they expend no energy to increase or maintain their speed in the air they gradually settle down to the water. They then either dive into the water or again start violently sculling to initiate another long leap through the air. The taxis of a compound flight subsequent to the initial taxi are typically short, seldom lasting a second and probably averaging half a second.

THE ACTUAL FLIGHT

During both the initial and intermediate taxiings the pelvic fins must remain folded tightly against the belly, for at these times they are always invisible. But at the instant the fish leaves the surface these fins flash into clear view and are very easily seen with binoculars or even with the unaided eye, especially when the pelvics are blackish. It is assuredly the upward force of air pressure on these posterior planes that lifts the drooping tail out of the water and thus actually initiates the air flight proper (fig. 1d). When the fish is thus forced into a horizontal position it lies at most only a few centimeters above the sea. This is probably a main reason why many flights are abortive, ending almost at once in a steep little wave.

The often repeated claims that a flying fish sustains itself in the air by flapping or rapidly vibrating the pectoral "wings" are apparently due, as already stated, to preconceived ideas that fishes must fly like birds, or to uncritical deductions that the mechanics of flight demand such movement, or to untrained or inattentive observation.

These claims have for the most part been made by others than trained naturalists or by laboratory zoologists equally untrained in field observation. Such accurate, trained observers as Moseley, Jordan, Gilbert, and many others have been unable to detect any movement of the fish's main planes while it flew through the air. Neither for the California flying fish nor for the several species I studied on the opposite side of the Pacific could I observe any wing movement which by any reasoning could be thought to sustain the fish in the air. The vibration of the pectoral tips through a small amplitude during the taxi, assuredly the mere consequence of the vigorous sweeping of the tail, as already stressed, ceases instantaneously as the caudal fin rises clear of the water. And these fins remain stretched taut and firm until the moment when the fish either dives into the sea or until its tail fin dips in the water and resumes the violent sculling, which immediately induces a renewal of the hazy appearance of the fin tips. The frequent naïve claims that this secondary vibration becomes apparent only when the fish is fatigued and that the wing vibration while the fish had been in the air was too rapid to be seen by the eye are at once refuted by the fact that the wing appears as a single blade, whereas if it had been moved too fast to follow, it would have appeared double like a humming bird's wing, with one image at each end of the stroke.

That there is absolutely no vibration of the outstretched pectoral fins while the fish is in the air is clearly observable, even without the aid of field glasses. Whenever a fish happens to fly directly away from the observer, a condition which would make easily evident any up-and-down movement, the edges of the planes always stand out clear like knife's edges, without a trace of doubling or of a blur, even when the fish flies into a high wind (which some have said causes a vibration of the fin). It has been with full certainty also that I have observed the rigidity of the planes hundreds of times as I have looked down through field glasses at flying fishes close to the boat. When the pectoral fins are blackish, and, better yet, when they are marked with an oblique yellow band or by black blotches, it is especially easy to appreciate that these fins remain motionless in relation to the fish.

The anatomical researches of Möbius (1878), Ahlborn (1895), Ridewood (1913), and others have disclosed no muscular or other modification sufficient to make one suspect that these fishes can flap their wings sufficiently to maintain their heavy bodies in the air.

The pelvic fins, the lower or posterior planes, likewise are never seen to vibrate. They remain folded as the caudal beats the surface and thus do not participate in the slight vibration of the fin tips induced by this tail movement. Especially when the pelvics are black or blackish it is possible to see through the binoculars that these fins do not vibrate while they are outstretched during the actual air flight.

The fact that the expanded paired fins do not vibrate after the fish leaves the water surface proves that the caudal fin does not beat in the air (another fantasy of some authors). Furthermore, the edge of this fin can be seen to be clear-cut while a fish volplanes away in line with one's vision.

THE CONTROL OF FLIGHT DIRECTION

I conclude from my observations, therefore, that a flying fish when in the air makes no effort by any flapping or vibration of the fins to add to the velocity it gained by the sculling of the tail during the swimming under water and during the taxi at the surface. That it does, however, use the fins in the air to control the direction of the flight is certain. This control is most often seen when a fish avoids the obstruction of the ship's bow by flying around it in a distinct curve, and even more spectacularly when one, headed directly for the ship's side, turns off at right angles in a curve of short radius. When a flying fish approaches even closer to the ship, it dives into the water, to take advantage of the greater resistance of that medium in making the shorter turn necessary to avoid a collision with the ship. The control is so nearly perfect that I have never seen one strike a vessel by day, though they do so when blinded by a light at night, and I have found one published record of a flying fish striking the side of a ship. Occasionally I have seen them collide, not with a ship but with one another (as though to heighten the analogy of their flight to that of airplanes). Flying fishes, therefore, seem to be lacking either in perfect flight control or in perfect air vision.

The flying fishes of the *Cypselurus* type, like airplanes again, show a vertical as well as a horizontal control of flight direction. This is beautifully evident as they maintain a course nearly parallel with a choppy water surface, just skimming over sharp-peaked crests and dropping to a lower level over the intervening troughs. As already noted, the diving to avoid collision with a ship likewise indicates a vertical control.

The claim has been made that flying fishes invariably take off into the wind, but I have seen them scoot away toward all points of the compass, while a strong wind remained in one quarter. The power and speed of the taxi seem sufficient to hurl them into the air, when the pelvic planes are expanded, no matter what may be the angle of the taxi to that of the wind. But after the fishes start their flight, especially as they begin to lose momentum, their direction is much modified by a strong wind. They tilt their plane surface more or less upward toward the wind and are thus carried off their original courses in a wide curve. To what degree the wind is so utilized to prolong or definitely alter the direction of the air journey is a point worthy of detailed inquiry.

THE DURATION OF THE FLIGHTS

A person's offhand estimate of the time a flying fish remains in the air is usually several times too high. During my observations on the species of biplane flying fishes in Asiatic waters I timed 424 flights or parts of flights. The two longest single flights, during which the fish remained completely out of the water, lasted only 12 and 13 seconds, respectively. Some flights which I observed among the Philippines, before I started to use the watch, seemed to be somewhat longer than any of those actually timed. Of 42 compound flights that were timed the longest lasted slightly less than 30 seconds. It is doubtful whether any flights cover a whole minute. The record flight actually timed is perhaps one of 42 seconds, recorded by Breder (1929) on the authority of a sea captain.

Most flights are short, lasting only 1 or 2 seconds, whether the sea be glassy smooth or decidedly rough. The average time for the first flight was 2.7 seconds for the smooth Bohol Strait, and 2.9 seconds for the rough weather on the open ocean. The average time for compound flights was only 2.6 seconds.

THE NUMBER OF SUCCESSIVE LEAPS

In order to obtain some definite data on the frequency and extent of these compound flights which characterize the air movements of the biplane flying fishes, I made numerous counts of the number of successive flights. Slightly more than half of the flights counted (164 out of 299, or 55 percent) were not continued at all. About three-fourths (76 percent) ended with either 1 or 2 leaps. Nearly nine-tenths (86 percent) of the total ended with 1 to 3 leaps, and more than nine-tenths (94 percent) ended with 4 or fewer stages. Only 1 flight in 16, on the average, was made up of 5 or more elements. The greatest number of successive flights observed was 12. It is doubtful whether a greater number is often undertaken. The numbers of successive flights under the different conditions of sea, weather, size, and species of fish was found to be independent of these conditions.

THE LENGTH OF THE FLIGHT

How far flying fishes fly apparently remains to be measured. Simultaneous use of two sectants, or the combined use of a geologist's compass and a distance finder, would seem to be a feasible way to make approximate determinations from a ship plying through quiet seas abounding in these fishes. The estimates of observers have been very indefinite: "A surprising distance"; "200 to 400 meters"; "distances of about a quarter mile are occasionally made." Accurate estimates of the speed of flight must await determination of the distance traversed.

IV

Studying the flying fishes from an aerodynamic standpoint justifies the title here given them, "Nature's Own Seaplanes." After describing the mode of flight in the biplane flying fishes in terms similar to those here used, Breder (1930) has written:

As soon as the tail leaves the water it immediately stops oscillating, and the fish becomes a glider. Up to that time they may be considered as a pusher type of plane.

The lift, of course, as in the plane, is chiefly obtained by means of an anteriorly placed pair of wings. These are cambered very much as in the modern plane and the support is consequently chiefly from above. According to Dowd,[1] the flying fish wing is so constructed that the upper surface is smooth and flush while the necessary thickness of the supporting rays is all below, which causes the lower surface to be ribbed. This is good construction, the sacrificing of the least efficient surface in the interest of mechanical strength. In the four-winged flyers considerable added lift is given by the ventral fins. In these advanced types the section of the body is squarish, the lower surface acting to increase the lift very much as in a plane built for large lift in which the fuselage takes part. The *Cypselurus* type with four wings and a flattened body seems to have gone in for large lift, whereas the *Halocypselus* type with but two wings and a more stream-lined body has apparently gone in for speed. These may be directly compared with corresponding fuselage types of modern planes (fig. 2, D).

Resistance in the air is considerably less in the flying fish than in the plane. The fish requires no landing gear whatsoever and there is a complete absence of external braces and little to produce parasitic resistance. The vertical fins are necessary as stabilizers. The skin friction must be slight on account of the wet and mucous-covered surface.

The inherent stability of flying fishes varies with the type considered. Generally the most advanced flyers show indications of greater stability than the more primitive ones.

Considering longitudinal stability; that is, in regard to a fore and aft pitching, without going into the details of the principles involved, the four-winged types should be much more stable, the ventral fins acting as combination lower planes and stabilizers (fig. 2, E). They may be considered as stabilizers placed rather far forward and large in proportion to their decreased leverage incident upon such a position or as the lower planes of a biplane type with an unusual amount of stagger. They are set at such a position as to give the proper longitudinal dihedral. Lateral stability is gained as in a plane by some sacrifice of lift by means of a lateral dihedral; that is, a slight tipping of the wings upward (fig. 3, A).

The horizontal stability is controlled by the lateral keelage, the total surface viewed when examined from the side. Most of this is effective posterior to the

[1] Dowd, R. E., Aerial Age Weekly, pp. 464, 465, Jan. 10, 1921.

insertion of the dorsal fin partly because of position and partly because of its larger area as compared with the remaining anterior part (fig. 2, F). A fish may be divided into four parts by erecting a vertical at the origin of the dorsal[2] intersecting its longitudinal axis (fig. 2, A). Designating these "anterior dorsal", "posterior dorsal", "anterior ventral", and "posterior ventral", it is at once evident that "anterior dorsal" and "anterior ventral" are practically identical, whereas "posterior dorsal" and "posterior ventral" are not.

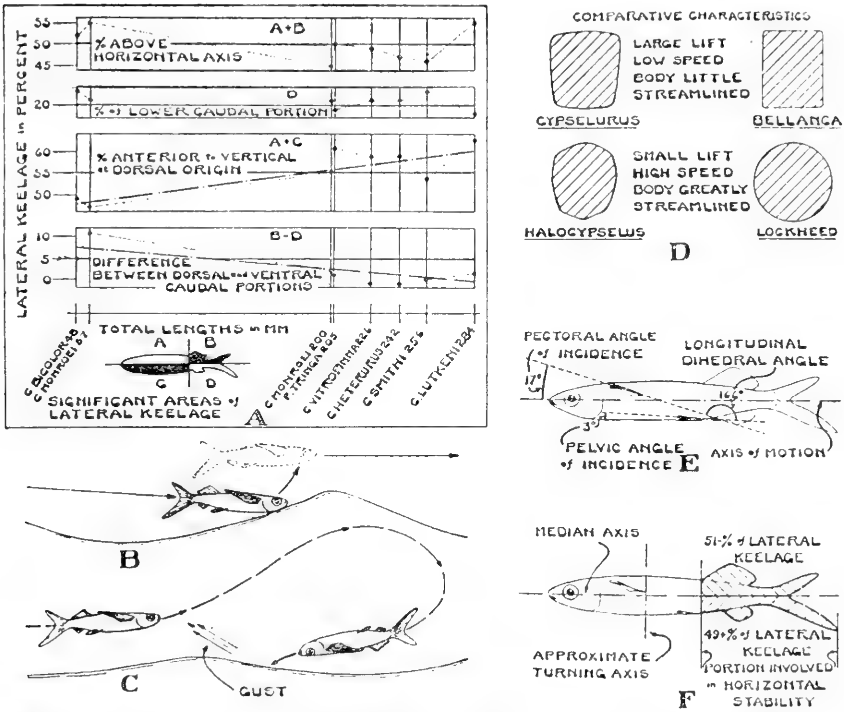

FIGURE 2.—The aerodynamics of flying fishes. Reproduced by permission from paper by C. M. Breder, Jr., published in Copeia.

A, graphic comparison of the significant lateral keelage areas in eight species of flying fishes of various sizes; *B*, flying fish richocheting from surface; *C*, flying fish making a poor "landing"; *D*, comparisons of greatest mid-sections of flying fishes and standard airplane types; *E*, diagram of elements involved in longitudinal stability as expressed in a flying fish. Angular figures illustrative only; *F*, diagram of elements involved in horizontal stability as expressed in a flying fish.

The percentage above the horizontal axis, "posterior and anterior dorsal", as compared with that below, "posterior and anterior ventral", is about equal in area, with a slight tendency for that portion below the line to be slightly greater. The average of eight fishes of various kinds shows 52.25 percent to be below the axis. Comparative measurements with four modern planes[3] in com-

[2] More properly such a vertical should pass through the center of gravity, but owing to the difficulty in determining this in preserved material and the fact that the body outlines are practically parallel between such a vertical and the dorsal intersection, for the present purposes the latter point will suffice.

[3] Based on area measurements of lateral keelage, including both sides of landing gear of Pitcairn PA-7, Uppercu-Burnelli, Belanca 1930 Pacemaker and Lockheed Sirius.

mon use show that they average 51 percent in this respect, a difference of 1¾ percent, which is not as great as the error involved in the methods employed in making these measurements. Neither the percentage above and below the hori-

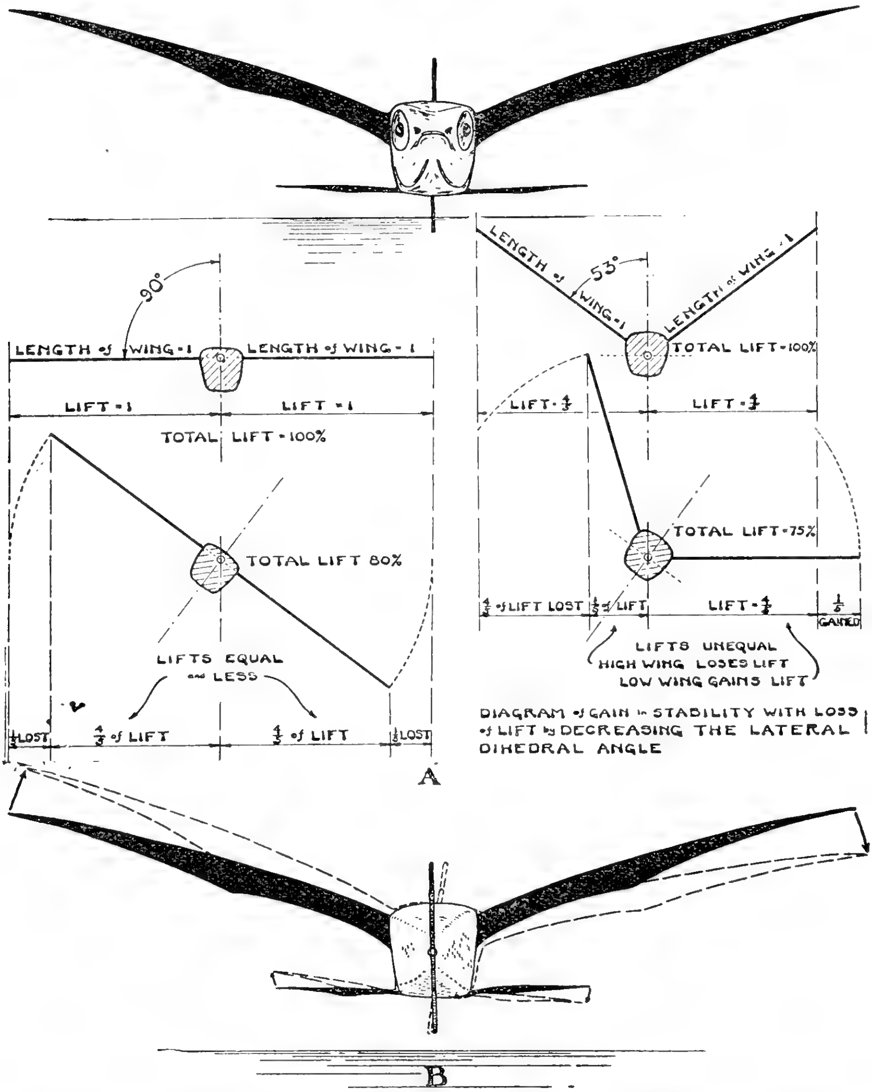

FIGURE 3.—The aerodynamics of flying fishes. Reproduced by permission from paper by C. M. Breder, Jr., published in Copeia.

A. Diagram of elements involved in lateral stability as expressed in a flying fish, including front view in flight.

B. Diagram of elements involved which give false impression of wing flapping, including rear view in flight.

zontal axis nor the lower caudal portion shows a moving trend with size. The later region bears little relation to the corresponding part of the plane, as it involves the fish's power plant, whereas in a plane there is only the tiny landing skid. However, if we consider the relation of the part anterior to the vertical to that posterior to it we find that the percent anterior rapidly rises from being equal to considerably exceeding the posterior portion in area. In the much larger planes a similar measurement is still greater, an average of the four planes measured being 80 percent. The excess of the "posterior ventral" over the "posterior dorsal" appears to increase with size, which is to say that the lower caudal lobe (the power plant) becomes relatively larger with an increase in absolute size. Here again we would expect to find no correlation with an airplane, and there is none.

Horizontal directional stability is attained by vertical vanes as in a plane and should be much greater in forms with high vertical fins such as *Parexocoetus* than those with low.

After a fish once leaves the water it is able to rise higher, holding its level with a decreasing speed by altering its camber and lateral dihedral, or in taking advantage of air currents. There is, of course, a point of maximum efficiency which could be worked on mathematically and would doubtless be close to that actually observed. In this respect fish flight is clearly very close to that of sail-planes. Dowd (1921) has examined exocoetids in great detail and finds them to be constructed close to the lines used in the best aeronautical engineering.

"Nature's Own Seaplanes" the flying fishes may surely be called. Flying fishes are indeed an outstanding example of the fidelity with which nature long ages ago anticipated, in the evolution of animals, both ancient and modern inventions of man.

SELECTED REFERENCES

Ahlborn, Fr.

1895. Der Flug der Fische. Real Gymnasium des Johanneums, zum 70. Geburtstage Prof. Dr. Karl Möbius, pp. 1–56, 3 figs., 1 pl. Hamburg.

Breder, C. M. Jr.

1929. Field observations on flying fishes; a suggestion of methods. Zoologica, vol. 9, pp. 295–312, figs. 301–305.

1930. On the structural specialization of flying fishes from the standpoint of aerodynamics. Copeia, 1930, no. 4, 114–121, figs. 1–3.

Derjugin, K.

1908. Die Entwicklung der Brustflossen und des Schultergürtels bei *Exocoetus volitans*. Zeitschr. Wiss. Zool., vol. 91, pp. 559–598, pls. 23–26.

Gill, Theodore.

1905. Flying fishes and their habits. Ann. Rep. Smithsonian Inst., 1904, pp. 495–515.

Hankin, E. H.

1914. Animal flight: a record of observation. Iliffe and Sons, London.

1920. Observations on the flight of flying fishes. Proc. Zool. Soc. London, no. 2, pp. 467–474, figs. 1–2.

Hubbs, Carl L.

1918. The flight of the California flying fish. Copeia, 1918, no. 62, pp. 85–88.

1932. Observations on the flight of fishes, with a statistical study of the flight of the Cypselurinae and remarks on the evolution of the flight of fishes. Pap. Michigan Acad. Sci., Arts and Letters, vol. 17, pp. 575–611, figs. 66–68.

Lull, R. S.

1906. Volant adaptation in vertebrates. Amer. Nat., vol. 40, pp. 537–564.

Möbius, Karl.

1878. Die Bewegungen der fliegenden Fische durch die Luft. Zeitschr. Wiss. Zool., vol. 30 (suppl.), pp. 343–382.

Nichols, J. T., and Breder, C. M., Jr.

1928. About flying fishes. Nat. Hist., vol. 28, pp. 64–77, 9 figs., 3 colored pls.

Shoulejkin, Was.

1929. Airdynamics of the flying fish. Int. Rev. ges. Hydrobiol. und Hydrogr., vol. 22, pp. 102–110, figs. 1–5.

THE MICROSCOPIC PLANT AND ANIMAL WORLD IN ULTRAVIOLET LIGHT

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[With 1 plate]

The spectrum, seven beautiful colors—red, orange, yellow, green, blue, indigo, and violet—has always been familiar to mankind as a rainbow in the cloud or in the dew upon the grass, but it was not until the seventeenth century that the analysis and synthesis was made of these colors. In the early part of that century, Father Grimaldi, an Italian Jesuit physicist, discovered the foundation of one of the methods of producing the spectrum. Purely by chance he placed a hair in front of a tiny hole through which a sunbeam penetrated his dark cell. He was astonished to see that the hair projected a shadow much larger than his own. He measured both shadows before he would believe his eyes were observing an actual fact. Then he made repeated trials in various ways, with always the same result. Finally, convinced of the truth of his accidental observation, he gave the name of diffraction to the deviation of rays of light from a straight source when they graze the surface of an obstacle. This property is used in the diffraction grating for the spectrum.

Father Grimaldi also observed with admiration the splendor of colors resulting from the passage of light through a prism, but he did not make any scientific study of them.

It was after Father Grimaldi's death in the same century that Sir Isaac Newton, then a keen young scholar at Cambridge, with the attention to details that leads to great discoveries, mused over the same live, brilliant colors cast on a screen in a dark room by a ray of sunlight passing through a prism. Each ray, distinct in its color, is also distinct in its refrangibility or bending. Newton saw that it was not the glass prism that communicated splendor to the ray of sunlight. The seven colors were invisibly united in white light; the prism separating them one from the other made them visible. By placing screens conveniently, Newton could study each ray separately and determine the different refraction for each one. He could reunite the seven rays by a new refraction, thus reconstituting one ray of white light.

These seven rays of light made visible to us when separated by a prism from the white light of a sunbeam are not the only rays that come from the sun; there are other rays that are completely invisible to our eyes. Beyond the red rays, making no impression on our eyes, are the so-called " heat waves " which have longer wave lengths than the red waves, and therefore are known as infrared. When the sun is at an angle of 45°, or midway to the zenith, 60 percent of the rays that may reach the earth at sea level in the direct beam are heat waves, and under 40 percent may be light rays.

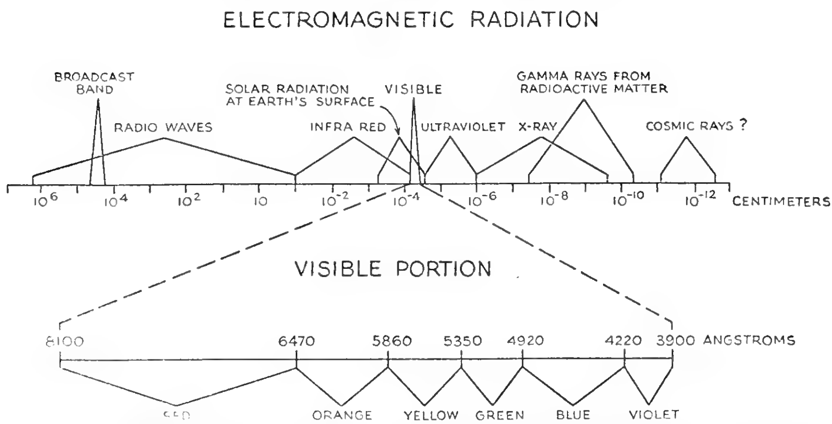

Figure 1.—Diagram showing the position of the ultraviolet region in the great electromagnetic spectrum. Data from W. Edwards Deming and F. G. Cottrell. Arranged by Earl S. Johnston.

At the other end of the spectrum, beyond the violet rays in sunlight, there is still another set of rays, invisible to our eyes but of vital importance to life on the earth. These rays are shorter in wave length than the violet, so they are called the ultraviolet rays. (See fig. 1.) Only a very small quantity of them—less than 1 percent—may be present in the sunlight that reaches the surface of the earth. Outside the earth's atmosphere there is a much larger percentage of them, but the ozone formed from oxygen in the upper layers of the atmosphere by the action of these ultraviolet rays serves as a ray filter that protects the life on the surface of the earth from these shorter rays which have been proved to be very destructive to tender tissues.

Evidence of the lethal action of these ultraviolet rays was revealed for the first time to the scientific world when Downes and Blunt (1877) reported that the short-wave-length ultraviolet rays in sunlight would kill the bacteria present in decaying organic matter. They erroneously believed that free oxygen was necessary to accomplish the bactericidal effect, just as Duclaux (1885), Roux (1887), Ward (1893), and Wesbrook (1895) concluded when they exposed cultures of disease bacteria to sunlight.

One of the early investigators who attempted an exact quantitative analysis of the biological properties of light was Hertel (1905). His monochromator with its quartz prism and lenses was similar to those now used in ultraviolet microscopy. By means of a thermopile he determined the relative intensities of four lines of the ultraviolet part of the spectrum, using the dispersed energy emitted from various metals under the influence of the electric arc, and he varied the intensity by regulating the amperage of the metallic arc. He found that the shorter the wave length, the greater the biological effect of the light on microorganisms. Hertel found that in the region of wave lengths around 2800 A, or about the shortest wave lengths of the sun's spectrum that can penetrate the ozone of the atmosphere, and at still shorter wave lengths, there was a very destructive action on bacteria and paramoecia (single-celled microscopic animals).

Since the pioneer work of Hertel, the lethal action of the invisible ultraviolet rays on those micro-organisms so small that their outlines are made visible to the naked eye only with the aid of a microscope has grown to be a subject of increasing interest to research workers all over the world. The names of these scientists are too numerous for individual mention. They have recognized in these short rays an invisible battalion of death and destruction to microscopic plant and animal life. With scientific foresight and patience, they are utilizing the lethal power concentrated in such rays to destroy the pernicious disease bearers, an invisible but deadly host.

Cernovodeanu and Henri (1910), working with bacteria that cause typhus, dysentery, cholera, and tetanus, found that the bactericidal rays were those in the ultraviolet below 2900 A, which are absorbed by the protoplasm of the cell. These ultraviolet rays produce on the protoplasm certain chemical and physical transformations that completely modify all the reactions of coloration. This action of the rays is quite different from that of heat or oxygenated water, or the ordinary fixators. Newcomer (1917), and Browning and Russ (1917) also irradiated plates of typhoid bacteria in a quartz spectrograph and found that the micro-organisms were killed by the invisible lethal rays ranging from 2100 A to 2900 A.

F. L. Gates (1929, 1930, 1933) one of the most accurate of modern workers, has emphasized quantitative physical methods in his studies of the bactericidal action of ultraviolet rays. He showed that the course of the reaction of an 18-hour culture of a bacterium, *Staphylococcus aureus*, to the short rays of ultraviolet was the same at each wave length studied. The reaction followed similar curves at all the different wave lengths, but occurred at a different energy level at each wave length. In other words, very different total incident energies were required at different wave lengths to produce similar effects. It is true that with young active bacteria, wide differences in the intensity of the incident ultraviolet energy could not be accurately compensated for by corresponding changes in the exposure times to the irradiation.

Gates also has observed a wide reaction zone covering the behavior of cells which are not visibly affected and those which seem to be killed outright by the exposure. Single organisms, apparently unaffected by the irradiation, grow and divide regularly on the surface of the nutrient agar, forming typical colonies of seemingly normal bacteria. Other organisms exposed to quickly lethal doses degenerate into ghosts or shadows that are undoubtedly dead. Between these two extremes are the organisms that after irradiation increase in size, especially in length, but do not divide when they reach the normal adult stage, so that long filaments of clear, highly refractile protoplasm are formed that look like spaghetti and may measure 50 to 150 microns. After 2 or 4 hours of motion these cells may (1) begin to degenerate and form ghosts, or (2) divide by cross fission into a number of large or small units which then degenerate, or (3) pinch off one or more apparently normal daughter cells at one end, which multiply rapidly to form colonies, while the original filament degenerates. Gates thus demonstrates that ultraviolet rays modify two coordinate functions essential to life, namely, cell division, and growth. By appropriate exposures the one can be temporarily or permanently suppressed, while the other may proceed for hours without hindrance until a limit is reached, and unless the division mechanism is restored, the cell degenerates.

Ehrismann and Noethling (1932), two German workers, irradiated several different species of bacteria under precise experimental conditions and determined a curve of the lethal threshold in the ultraviolet. They found that the sensitivity of the different species of bacteria to the radiation varies; also that there is a variation in the lethal effectiveness of different wave lengths. They also have determined that the sensitivity of the single species to the radiation is less as the bacteria are larger.

Two mysteries of modern bacteriology that the ultraviolet rays bid fair to elucidate are those of the virus and the so-called "bacteriophage." The viruses that cause diseases in plants and animals have long caused heated debate among bacteriologists, as there is general question as to whether they are enzymatic or chemical in nature, or whether they are entirely bacterial. The bacteriophage is maintained by one school of workers to be a living ultramicroscopic virus. Another school considers it to be an inanimate agent developed by the microbe as a result of the reaction between the invading organism and the tissue of the host, and that by the hereditary vitiation of the organism a lytic or cell-destructive principle is developed.

An example of the bacteriophage is the filterable substance obtained from patients recovering from bacillary dysentery which will dissolve cultures of the Shiga bacillus. A few drops of the dissolved culture reproduces the same phenomenon on addition to another culture, etc., indefinitely. The lytic property increases by dilution and retains its activity for several years.

With ultraviolet rays, Zoeller (1923) accomplished the inactivation of the bacteriophage. Mizuno (1929), a Japanese worker, has also reported the absolute destruction of the bacteriophage in the ultraviolet. McKinley, Fisher, and Holden (1926) determined the lethal effect of ultraviolet light on the bacteriophage and on two filterable viruses: herpes and Levadti's so-called "encephalitis virus".

Numerous workers have made experiments in which the inactivation of filterable virus diseases is accomplished by ultraviolet irradiation. Oblitsky and Gates (1927) studied vesicular stomatitis of horses and found that the similarity with the response of this virus to that of a common bacterium to ultraviolet suggests that the substance of the virus is similar in character and chemical constitution to bacterial protoplasm.

Rivers, Stevens, and Gates (1928), working with the inactivation of vaccine virus by ultraviolet rays, found also that rabbit skin treated for a few minutes with ultraviolet light and then inoculated at once with vaccine virus is less susceptible to the action of the virus than is untreated skin.

Since bacteria retain their power to produce diseases and to agglutinate blood even after they have been killed by ultraviolet rays, an improved method for the sero-diagnosis of typhoid and paratyphoid fever has been proposed by Lematte. Emulsions of these disease-producing bacteria that have been killed by the ultraviolet rays are added to test tubes containing the diluted blood of the patient to see if agglutination will occur (Laurens, 1933).

A potential side reaction of the ultraviolet effect on bacteria has been reported by Eberson (1920). He exposed types of meningococci to ultraviolet irradiation and studied the power of stimulating in animals the formation of defensive antibodies. He found that the treatment with ultraviolet rays diminished the virulence of the organism but increased the antigenic power. This work suggests a method for building up an immunity by successive injections of organisms irradiated for regularly diminishing periods of time. Evidence has been found that a few strains, or perhaps a single strain of bacteria may be sufficient for immunization against a heterogeneous group of types.

Bacteria and their products when sensitized previously are more easily affected by irradiation. Passow found that the staphylococcus bacteria were more quickly killed by the yellow-green rays, and in a longer time by the blue and violet rays if they were sensitized with rose bengal before irradiation. In general, the dyes with sensitizing properties stained the bacteria better than those which did not possess these properties, and with the exception of toluene red and indigo carmine, all the dyes which stained the staphylococci well and were not toxic were sensitizers. In the treatment of bacterial eye diseases, Passow recommends rose bengal as an aid to phototherapy, since it helps render the long rays with deep action bactericidal as well as the short rays which in themselves possess bactericidal qualities (Laurens, 1933).

Bovie and Dalland (1923) found that ultraviolet made specimens of *Paramoecium caudatum* extremely sensitive to heat, so that sublethal temperatures killed them. Heat following irradiation caused a greater degree of injury than heat preceding irradiation. If the temperature remained constant, the degree of sensitization varied directly with the temperature.

Diseases of plants that affect agricultural economics can also be treated with ultraviolet irradiation. Mulvania (1926), Newell and Arthur (1929), and Duggar and Hollaender (1934) have inactivated the virus of typical tobacco mosaic by ultraviolet irradiation, thereby gleaning information of value to farmers and horticulturists. The spores of grain smuts can be killed by the short rays, as shown by the work of Pilcher and Wöber (1922). The fungicidal action of the short wave lengths has also been proved by Fulton (1929) with a number of fungi, many of which cause harmful diseases of plants.

A contribution that promises to be of great value to humanity is now in progress at the Cancer Research Laboratory at the University of Pennsylvania. By means of microphotography and micromoving pictures, Allen, Franklin, and McDonald (1933) show the effect of ultraviolet rays on living organisms, such as Protozoa and the correlation of the effects with the absorption. The microscope used has an all-quartz optical system originally designed to make use of the higher resolving power obtained by using short ultraviolet wave lengths to which the glass systems are opaque. The microphotographs of cancer tissue taken 5 minutes after the death of an animal, and those of the same tissue taken 3 hours later show a marked change in the microabsorption spectra of the cells.

By irradiating and photographing with ultroviolet light in regular sequence, Dr. Francis F. Lucas of the Bell Telephone Laboratories has made series of photographs that show the cumulative effects of irradiation on the cells of blue-green algae. He has also made photomicrographs of living cells from malignant growths.

Paramoecia, 1-celled microscopic animals, have proved a favorite subject for experimentation in the ultraviolet. The lethal effect of the rays is preceded by a stimulating effect, according to Weinstein (1930). Rentschler (1931) describes the destruction of paramoecia in great detail, beginning with a shortening of the cell, the separation of the two cell walls to form a blister, the coagulation of the proteins of the cytoplasm, and finally the breaking of the cell wall, which allows the coagulated cytoplasm to flow into the surrounding liquid, where it disintegrates. The moving pictures made by the Cancer Research Laboratory show these changes in both paramoecia and *Euglena*.

Ultraviolet light has also been used by Köhler (1904) for making microphotographs of living *Nostoc*, an alga, and bacteria at 2800 A and 2750 A, respectively. Wyckoff and Arian (1931) have made ultraviolet microphotographs of bacteria also.

The destruction in the ultraviolet of yeasts, tiny colorless microscopic cells, so valuable because of their ability to make ferments, is not effected as quickly as that of bacteria, probably owing to the larger size of the yeast cells. De Fazi (1921) reports that the Peroni Brewery in Rome has an ultraviolet plant for the sole purpose of freeing the yeast from bacteria. Two yeasts that were producing spoilage in a carbonated beverage were destroyed in a short time by ultraviolet light, according to Feuer and Tanner (1921).

Lindner (1923), using a bottom-fermentation brewery yeast, greatly increased the velocity of the fermentation of dextrose by exposure to ultraviolet rays. Thus fermentation of 30 grams of dextrose yielded 199 cubic centimeters of carbon dioxide in 24 hours, and under irradiation by ultraviolet the yield was 2,743 cubic centimeters of carbon dioxide. The exposure of the yeast cells under fermentation conditions favored the activity of the yeast, but the exposure of the cells in a shallow layer of liquid was fatal.

Because of the bactericidal action of these ultraviolet rays, it is possible to make use of them in the sterilization of large quantities of water. During this process a complete destruction of animal

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and plant life is accomplished, but the gases and salts are not destroyed, reports Nogier (1910) among other authors.

In recent years the method of sterilization of water by ultraviolet irradiation has not been very widely used, owing to the competition of cheaper and somewhat simpler chemical processes such as chlorination for drinking water and coppering for swimming pools. There are, however, fields of usefulness in smaller-scale operations where the chemical processes are objectionable, especially where injury might be caused by an overdose, and in these the ultraviolet method is preferable. Some of these smaller-scale operations are the preparation of water for surgical purposes; sterilization of water for bottling, or for the supply of small consumers, such as individual homes; sterilization of water for washing butter, for the margarine industry, and wherever the water is to be incorporated in food; and the sterilization of water on shipboard, especially on ships navigating inland waters (Ellis and Wells, 1925).

Wine and cider can also be quickly sterilized by ultraviolet irradiation and, according to Maurain and Warcollier (1910), the wine has the greater transparency for the ultraviolet rays. Before the war, according to Henri, Helbronner, and von Recklinghausen (1915), the method of "ageing" wine by means of ultraviolet irradiation was utilized to a great extent in France. The ultraviolet changed the taste and color of the wine, and in a few minutes the new wine had assumed the characteristics of old wine.

The sterilization of milk is difficult because its flavor and food value must not be injured in any way during the process. These properties have always been injured in a small way no matter what means of sterilization is employed, and ultraviolet has not proved to be an exception. Ultraviolet rays are desirable for milk sterilization because when the milk is incompletely sterilized by irradiation, the noxious bacteria are more affected than the relatively desirable members of the lactic acid group. Helbronner and von Recklinghausen (1915) have found that complete sterilization by ultraviolet alone is difficult and that the necessary prolonged treatment has deleterious effects upon the flavor and digestive qualities of the liquid. For this reason, they have proposed the use of a combination of heat sterilization together with ultraviolet rays. When milk is given a short heat treatment at a temperature of about 60° C. the bacteria in it become so weakened that ultraviolet rays destroy them very readily. It is claimed that by this combination treatment the milk is not heated sufficiently to alter the flavor and that a very short irradiation time completely sterilizes the milk.

Monvoisin, Barret, and Robin (1914) have a patent on the use of ultraviolet irradiation for the process of sterilizing the surface of freshly killed meat and hardening it before dessication. This seems to be the only commercial use of the coagulating power of ultraviolet exposure found by Dreyer and Hansen (1907). They found that the ultraviolet coagulates the "coagulable" proteins, some in neutral or even in alkaline solution while others require acidification; and in all cases the reaction is accelerated by acidification.

Experiments with microscopic green plants have also been made in the ultraviolet. Gibbs (1926) studied filamentous green algae in the short wave lengths. He noted that a latent period occurred before death in his irradiated filaments of *Spirogyra nitida affinis*. The limits of the toxic action were the wave lengths 3126 A and 2378 A. The chloroplasts (green pigments in the plant) were observed to clump characteristically, owing to the great difference in intensity of radiation reaching the "near" and "far" sides of the filament. The behavior of the filaments was variable. Some died while apparently perfectly normal in appearance, while in the others there was coagulation of the protoplasm and a brown pigment that exhibited Brownian movement was formed.

Here at the Smithsonian Institution we have irradiated algae, unicellular green plants, with ultraviolet rays, and found that in the regions where the ultraviolet waves shorter than 3022 A (the approximate limit of ultraviolet irradiation in nature) were directed on the culture, the green algal cells were killed. The certainty of the lethal action as well as the quickness of the attack of the rays has also been studied (Meier, 1934). Plate 1 shows a photograph of a typical agar plate that had been covered with green algae and then exposed in the spectrograph for 74 minutes. The radiotoxic regions are indicated by the decolorized sections where the algae were killed at 2652, 2699, 2753, 2804, 2894, 2925, 2967, and 3022 A. This photograph is superimposed on a diagram of the intensities of the wave lengths. It should be remarked that a greater intensity of radiation, according to thermocouple measurements, was directed on the cultures at 3130 A, even though it did not prove lethal. Throughout the ages the plants that have survived on the earth have become attuned to solar radiation as it is received on the earth's surface and very possibly with the same spectrum limit as at the present time due to ozone. It is, therefore, not astonishing that the radiations shorter than the solar limit produce unusual effects.

In figure 2 are shown curves of reactions of different biological materials to ultraviolet compiled by Duggar and Hollaender (1934). In comparison with their own curves for the lethal effect of the short wave lengths on viruses and bacteria are the curves of protein coagulation from Sonne (1928); lethal effect on paramoecium, Weinstein

(1930); erythema production, Hausser (1928), and Coblentz, Stair, and Hogue (1931); and hemolysis, Sonne (1928). The curves representing bacterial action, virus inactivation, lethal effect on paramoecium, and protein coagulation are of the same general type. The curve in figure 3, showing the radiotoxic spectral sensitivity of a green alga, *Chlorella vulgaris*, for which the data were collected here at the Smithsonian Institution (Meier, 1934), resembles the other lethal curves.

Arnold (1933) reports that the photosynthetic mechanism of a unicellular green alga was destroyed when irradiated at 2537 A.

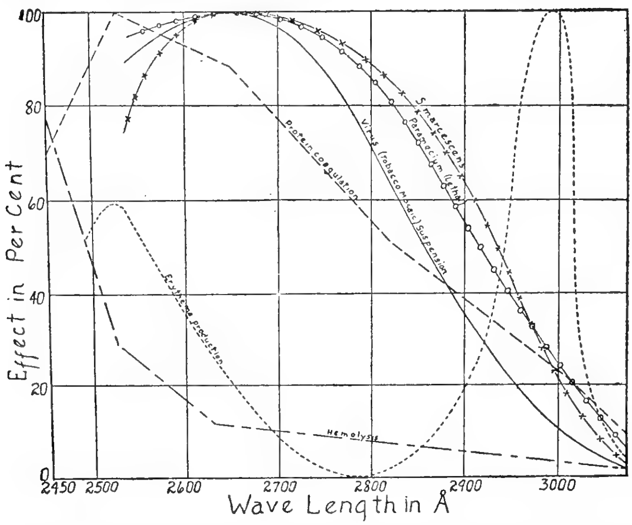


FIGURE 2.—Relative biological effects with respect to wave lengths, in the ultraviolet below 3100 A. Selected from various authors by B. M. Duggar and Alexander Hollaender.

The chlorophyll either remained unchanged chemically or there was a change so subtle as to escape detection or possibly the ultraviolet rays destroyed a substance other than the chlorophyll.

The Henris (1912) found that if the action of ultraviolet is not lethal, it may cause profound alteration in the constitution of the organism. They report observations on two new stable forms of *Bacillus anthracis*, the carrier of anthrax, that were produced by ultraviolet irradiation. One of these two new forms sets up an infection that is totally different from that of anthrax.

Several observers have reported changes in the morphology of bacteria due to ultraviolet irradiation. Generally there is an attenuation, or, in colored bacteria, a change in the pigment-forming function (Arloing, 1885).

The stimulative effect of ultraviolet on micro-organisms is more or less obscure at present. Petri (1929) reports that the development of two fungi was vigorously increased when they were grown on carrot medium that had been irradiated with ultraviolet light.

Bailey (1931) reported that the ultraviolet rays increase the formation of reproductive bodies in certain lower forms of plants. A bulb-rotting organism that never had been known to produce spores by which the proper classification of the organism might be made was induced to form these bodies after irradiation with ultraviolet light. Coblentz and Fulton (1924) found some indication of stimulation in their irradiation work at very low intensities. In this

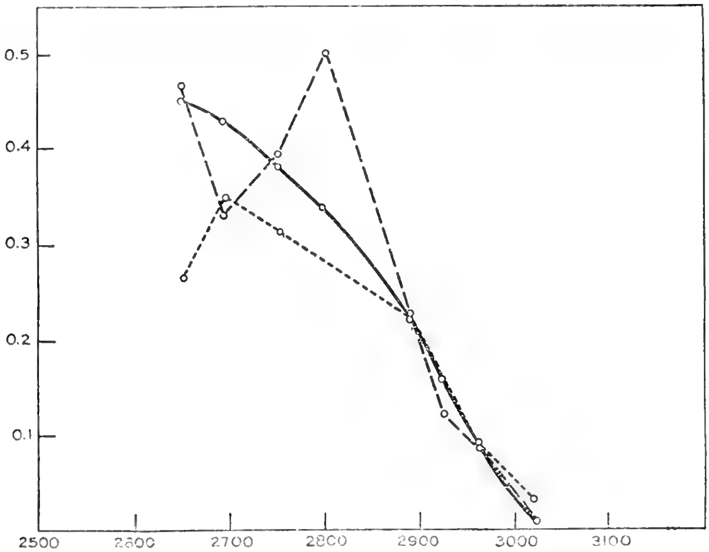


FIGURE 3.—Radiotoxic spectral sensitivity of the alga *Chlorella vulgaris* to ultraviolet rays. The abscissae are wave lengths in Angstroms. The ordinates are relative lethal effectiveness in arbitrary units. Black line, smooth curve; dash line, actual values; dot line, curve obtained by Meier (1932).

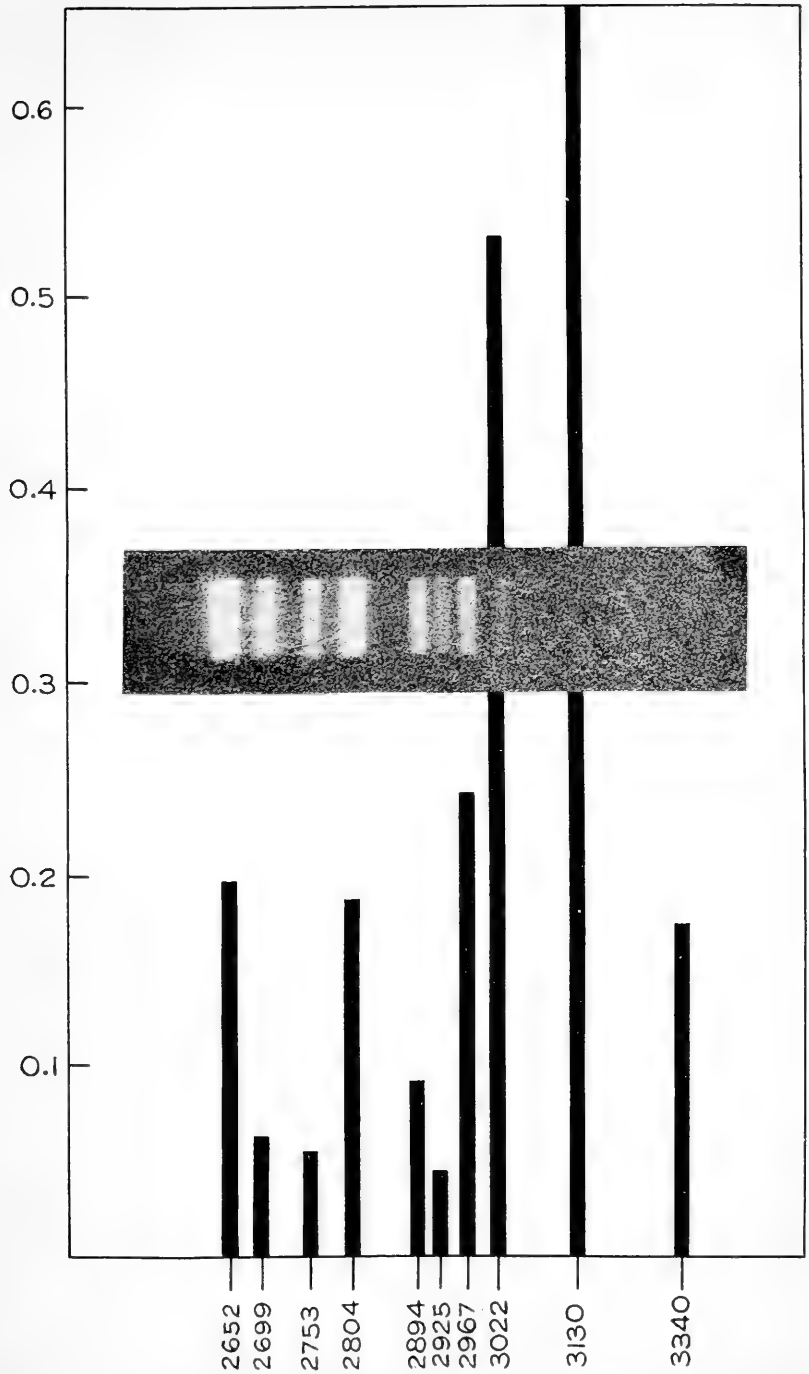
work they studied the effect of ultraviolet light when the exposure was applied continuously and intermittently with long or short intervals of rest. No differences in the density of the growth could be observed, whatever the method of exposure. This evidence seems to indicate that the intermittent exposure does not have a latent effect in stimulating growth or in continuing the lethal action during the intervals of rest, and that the lethal effect is cumulative. When the intensities were reduced the lethal action was greatly retarded; for example, using an intensity reduced to 1/50 it was necessary to expose the inoculated plate of bacteria for 75 to 80 seconds instead of 50 seconds in order to secure the same lethal effect. At still lower intensities there were some indications of stimulation instead of lethal action.

The real action of irradiation on the living cell is still unknown. The irradiation has two effects, stimulative and lethal. In general, the stimulative effect is caused by the wave lengths longer than 2900 A. The lethal effect is caused by shorter wave lengths, possibly because of the production of a toxic photoproduct which in a small quantity may act as a stimulant to cell division. Finsen (1900) at first thought that the irradiation with which he caused lupus acted as a bactericide. Later there was question as to whether the irradiation did not act as a stimulant to the tissues rather than as deadly to the bacilli. There are two elements in the action of the irradiation, a photochemical one and a biological one. The photochemical effect ends with the production of the dermatitis and the activation of substances in the skin and possibly in the blood, while the biological effect on metabolism, growth, and circulation lasts a longer period (Laurens, 1933).

An almost magical effect of these invisible rays is their ability to cause fluorescence in ordinarily pale, colorless microscopic organisms. Paramoecia and *Oxytrichia* (protozoans) fluoresce in all the ultraviolet lines of the quartz mercury arc. Giese and Leighton (1933) report that at 3660 A the fluorescence is of a pale greenish gray shade; at 3350, 3130, 3020, and 2537 A the animals are a pale greenish blue; at 2804 and 2654 A they have a more whitish light. Darting about in the ultraviolet rays, these habitually drab little creatures are transfigured with gorgeous, brilliant colors for their brief dance of death.

Bacterial colonies fluoresce according to their kind in different colors and different intensities of the ultraviolet, so that Stübel (1911) has thus proved that ultraviolet can be used as a means of identification of various colonies and races of bacteria. Under the microscope, as shown by the work of the Cancer Research Laboratory (1933) as well, larger micro-organisms are recognized more readily not only by their outlines, which by their own fluorescent light are made visible, but also by the details, such as the nourishment vacuoles of a paramoecium which can be perceived with perfect distinctness.

Thus, beyond the band of familiar visible colors that we see in the rainbow lies another band nearly five times as wide of invisible ultraviolet rays which have a profound and mysterious effect on microscopic plant and animal life and which therefore hold promise of great potential benefit to mankind. Physicists, biologists, bacteriologists, and medical men are uniting to expand our knowledge of these invisible rays, and as that knowledge increases, we shall doubtless be able to record many other beneficial uses of ultraviolet light.



AN ALGAL SPECTROGRAM, OBTAINED BY EXPOSING AN AGAR PLATE COVERED WITH GREEN CELLS OF THE ALGA "CHLORELLA VULGARIS" TO ULTRAVIOLET RAYS FOR 1 HOUR AND 14 MINUTES, SUPERIMPOSED ON A DIAGRAM OF THE INTENSITIES OF THE WAVE LENGTHS.

The abscissae are wave lengths in Angstroms. The ordinates are intensities in ergs/sec. cm.

LITERATURE CITED

(References to other work cited in this paper will be found in the various articles here listed.)

BAILEY, ALICE A.

1931. Ultra-violet light increases sporulation, says pathologist. U.S. Dep. Agr. Off. Rec., Feb. 26.

DEMING, W. EDWARDS, and COTTRELL, F. G.

1932. Chart of some electromagnetic relations. Rev. Sci. Instr., vol. 3, no. 6, pp. 296–297.

DUGGAR, B. M., and HOLLAENDER, ALEXANDER.

1934. Irradiation of plant viruses and of microorganisms with monochromatic light. I. The virus of typical tobacco mosaic and *Serratia marcescens* as influenced by ultraviolet and visible light. Journ. Bacteriol., vol. 27, pp. 219–256.

ELLIS, CARLETON, and WELLS, ALFRED A.

1925. The chemical action of ultraviolet rays. New York.

FEUER, BERTRAM, and TANNER, F. W.

1920. The action of ultra-violet light on the yeastlike fungi. I. Journ. Ind. and Eng. Chem., vol. 12, no. 8, pp. 740–741.

GATES, F. L.

1930. A study of the bactericidal action of ultra-violet light. III. The absorption of ultra-violet light by bacteria. Journ. Gen. Physiol., vol. 14, pp. 32–42.

1933. The reaction of individual bacteria to irradiation with ultra-violet light. Science, vol. 77, no. 1997, p. 350.

GIESE, A. C., and LEIGHTON, P. A.

1933. Fluorescence of cells in the ultraviolet. Science, vol. 77, no. 2004, pp. 509–510.

LAURENS, HENRY.

1933. The physiological effects of radiant energy. The Chemical Catalog Co., Inc.

LUCAS, FRANCIS F.

1934. Late developments in microscopy. Bell Telephone System Technical Publications, monograph B–792, pp. 1–47.

MEIER, FLORENCE E.

1934. Lethal response of the alga *Chlorella vulgaris* to ultraviolet rays. Smithsonian Misc. Coll., vol. 92 no. 3.

NEWELL, J. M., and ARTHUR, J. M.

1929. The killing of plant tissue and the inactivation of tobacco mosaic virus by ultra-violet radiation. Amer. Journ. Bot., vol. 16, pp. 338–354.

PETRI, L.

1929. Influenca di substrati nutritivi esposti ai raggi ultravioletti sopra le sviluppo dei funghi. (Influence of nutritive substrates exposed to ultraviolet rays on fungus development.) Boll. R. Staz. Patol. Veg., vol. 9, pp. 408–410.

PILCHER, F., and WÖBER, A.

1922. Experiments with ultra-violet light, Röntgen rays and radium for the control of plant diseases. Centralbl. Bakt., vol. 2, Abt. 57, pp. 319–327.

THE HISTORY OF AN INSECT'S STOMACH

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There is nothing that more strongly attests the kinship of all things living than the common function of feeding. The Brotherhood of the Animal Kingdom is established on the stomach. The history of the stomach is little less than coextensive with the history of animal evolution.

The fundamental nature of the act called "feeding", or, in other words, the physiological significance of the verb "to feed", is the supplying of material to living matter that can replace the material constantly being discarded as a result of the vital activity in living matter known as *metabolism*. The live substance of all plants and animals is contained in minute structural units called "cells." Physiological feeding, therefore, is a matter of attending to the nutritional needs of the body cells, and, on the part of an animal, is not merely the act of eating or filling a cavity popularly known as the "stomach" with a mass of potential food material. In the case of complex animals this procedure is only the beginning of a long series of physical and chemical processes that must take place before the cells are served. The function of filling the stomach, which in practice we so exalt as a social function while we attempt to hide its crudity with conventional methods of technique, is physiologically comparable with the delivery of raw foodstuffs to the kitchen.

The so-called "living" substance of the body is *protoplasm*, but it is doubtful if any matter itself is "alive" in the sense that we vaguely attribute to the word. The state of being alive, in its simplest phase, is the unique property of protoplasm by which it liberates energy and keeps on liberating energy, and includes also the power of protoplasm to grow by adding to its own substance. The energy of life is stored in complex molecules, which either are a part of protoplasm or are contained in protoplasm, and these molecules must be broken down in order to set free the stored energy; but immediately a new reserve of energy must be made available in new molecules built up in protoplasm to replace those destroyed. Hence, metabolism, which is the basis of life, is a continuous alternating series of making and unmaking of complex molecules in protoplasmic substance (fig. 1). Its constructive phase requires a constant supply of new building material (food) and new energy; its destructive phase is accompanied by a quick union of some of the protoplasmic substance with oxygen, and results in the liberation of energy and the production of waste materials. Animal cells require relatively complex, energy-containing food material, which normally is the source of most of their energy released. Some of the latter is consumed within the cells by the constructive processes of metabolism and growth, the remainder is available for the work of the animal. The green cells of plants take energy from the sun's radiation and build up energy-

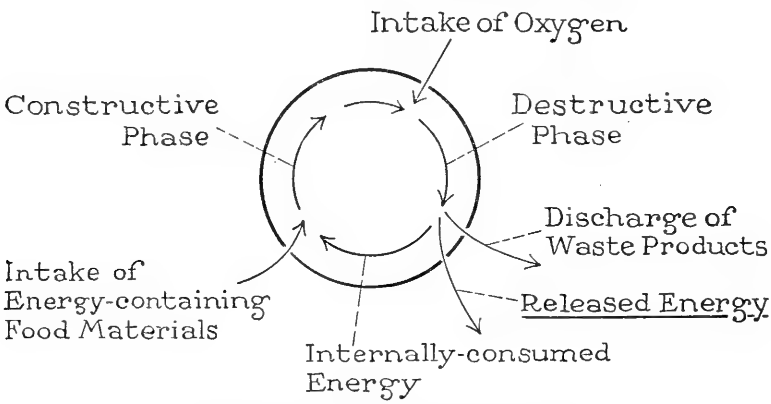

FIGURE 1.—Diagram of animal metabolism.

containing compounds from simpler substances. Life is the spark of surplus energy that escapes at each destructive phase of protoplasmic metabolism. The structural organizations of animals are mechanical devices for the utilization of their vital energies. The energy of life is not different from the forms of energy existing in inanimate nature; the feature that distinguishes living matter from nonliving matter is its chemical mechanism for furnishing a continual output of energy. A grain of powder once exploded is done for; the explosions of protoplasmic metabolism began with the origin of life and will not cease until life is extinct, because each is accompanied by a constructive process that builds up a new explosive. Life, in the physical sense should not be confused with consciousness, which may or may not be an adjunct of living organisms, but is not the cause of metabolism.

Protoplasm itself is a soft watery substance, not at all remarkable in appearance, and it is held in the form of cells only because each mass is covered by a thin outer layer of denser material having a structure such that the protoplasmic molecules cannot escape through it. The term "cell", therefore, might be supposed to mean one of the tiny capsules in which the substance of life is imprisoned, but in the biological sense it refers to the protoplasmic mass itself and its retaining wall. The mixture of things that constitutes protoplasm has a physical state in solution of the kind that chemists term *colloidal.* The component molecules are of relatively large size and have a complex structure. Diagrams of these molecules found in works on chemistry are often very intricate, but it is probable that the living molecules are still more intricate, because the diagrams are based necessarily on a study of dead protoplasm—the very methods of analysis being fatal to live matter, and it seems certain that live protoplasm must be different from dead protoplasm.

The cell wall, or cell membrane, as the cell covering is called, is a most important thing for the life of the cell, and it is in itself a highly remarkable tissue, though its structure is not yet fully known. Each cell must have a covering capable of retaining its own protoplasmic substance, but it must discharge its waste products and receive its food materials through this same wall. The cell wall, therefore, must be of such a nature that colloids will not pass through it, while at the same time it must be freely permeable in both directions to water and to solutions of chemical substances composed of relatively small or partially disintegrated molecules. A thin tissue having this property of being impervious to some things and freely penetrable by others is called a *semipermeable membrane.* The cell wall resembles a semipermeable membrane, but it has certain properties that no other natural or artificially prepared membrane possesses.

The food material that an animal takes into its stomach must contain substances from which cell food can be prepared. Most animals consume much material that is useless from a nutritional standpoint, but they have so adapted themselves to the form of foodstuffs in nature that their organization does not function properly without the nonnutrient parts of their ordinary diet. Hence, animals have instincts for eating certain things, and few of them can be made to eat things that their instincts refuse, even though the offering may contain all the nutritive elements needed to supply the wants of their cells. This generalization perhaps does not apply to the young of the human species, or if it does, dietitians do not believe in instinct, and parents have another word for it.

When it comes to feeding by the cells themselves, there is no question of instinct, taste, selectivity, perversity, or any other quality that might decide what an animal will or will not take voluntarily into its stomach. The only determining factor here is the physical permeability of the cell wall to the substances provided. If the latter are of a kind that can penetrate the retaining membrane, they will enter the cell substance, whether they be foods or poisons. It behooves an animal, therefore, to beware of what it puts into its stomach. One reason why substances in solution go through cell walls, or through any animal membranes, if they can, is the same as that which makes gas molecules in air, or "solid" molecules in water, spread all through the space available to them. You cannot put a gas in one corner of a room or salt in one side of a pan of water and make it stay there. The activities of the molecules make them go to the places where molecules of their own kind are scarce until there is an even distribution all through the medium. A permeable partition in the latter makes no difference in the final result. On this principle of *diffusion*, waste products, with which the cells become supercharged, pass out through the cell wall, and building

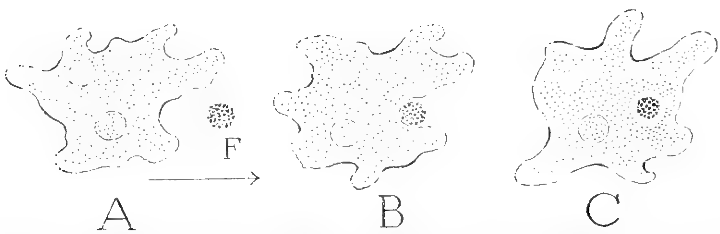

FIGURE 2.—Diagrams showing the method of feeding by direct ingestion of food material as practiced by an amoeba.

materials, of which there is a deficit in the cells, pass in if they are present in the cell environment. The laws of ordinary diffusion, however, do not account for all the phenomena of diffusion though cell walls. Some cells of the animal body have the power of converting food substances into a form that will pass the cell wall; others have not this power and must have their food prepared for them.

Materials containing the essentials of animal food are abundant almost everywhere in nature, but unfortunately most foodstuffs in their native state are not the kind of things that will dissolve in water and that will go through the semipermeable walls of animal cells. The first ancestors of all living cells, therefore, must have been confronted with the problem of devising a means to keep from starving in the midst of plenty.

Some of the one-celled animals, such as the amoeba, have solved this problem of feeding in a very simple manner, without reference to the permeability of the cell wall. The amoeba (fig. 2) being a soft and plastic creature, simply flows around any mass of food material in its course (B) until the food is pressed through its cell wall, which then closes over it (C). The food material is thus *ingested* in its natural state. Once inside the body of the cell it is there subjected to the processes of *digestion*. First the food mass is surrounded by a globule of water (fig. 3 A, *a*); then there are discharged upon it from the cell protoplasm substances called *enzymes* (*b*), which have the power of so altering the chemical composition of at least parts of the food material that the latter will be dissolved in the water globule; and finally the products of digestion are absorbed into the body of the cell (*c*) and thus become available as food to the cell tissue. Digestion of food material inside a cell is *intracellular digestion*. The amoeba eliminates the unused residue of its food by reversing the process of ingestion, that is, it just moves on and leaves the refuse behind.

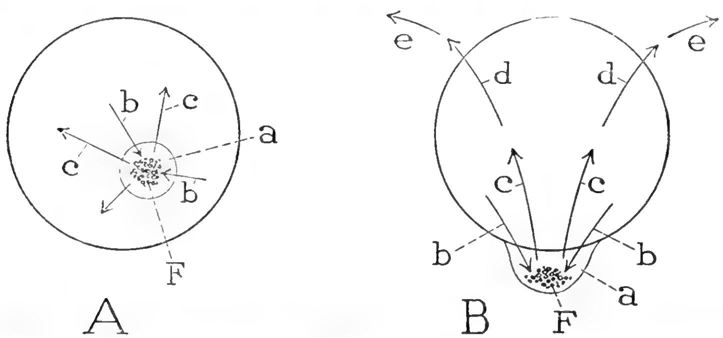

FIGURE 3.—Diagrams of intracellular digestion (A), and extracellular digestion (B).

It is evident, now, that the method of feeding practiced by the amoeba would have disadvantages for a many-celled animal composed of cells adherent in masses and having little or no power of individual activity. But, since intracellular digestion is possible, there can be also *extracellular digestion* (fig. 3 B), provided only that the cell wall is permeable to a water solution (*a*) of enzymes (*b*) formed within the cell. If digestion takes place outside the cell, however, the products of digestion must be ingested by the cell (*c*) through the cell wall, and this process demands that the cell wall be permeable also to the fairly complex molecules of the digested food substances, and still be impervious to the colloidal molecules of the cell protoplasm itself. The development of extracellular digestion with subsequent ingestion, therefore, has involved a high degree of perfection in semipermeable membranes. Extracellular digestion, it will be seen, includes three essentials: (1) It must change insoluble parts of the natural food material into a form that is soluble in water; (2) the substances rendered soluble must also be in a molecular form that will pass through the cell walls; (3) the digestion products must be substances of the kind that can be used in the constructive phase of protoplasmic metabolism. The ingestion of digested food material through the cell wall is generally designated *absorption.* In the case of the many-celled animals the absorbed food materials, furthermore, must pass clear through the stomach cells (fig. 3 B, *d*), or through other cells of the digestive tract, in order to be distributed (*e*) in the body liquid (blood) to the nondigestive cells of the body.

The method of feeding by absorption is practiced by most of the body cells of nearly all the many-celled animals, though, of course, all the cells do not do their own digesting—some live in a medium containing food already digested by some other set of cells or by some other organism. Certain animals harbor in their food tracts bacteria or protozoa having the power of digesting certain substances that they themselves cannot handle, and thus may thrive on a diet that would mean certain starvation to any ordinary creature.

A method of accomplishing some particular function in a certain way having once been adopted and handed down from generation to generation, an organ is almost sure to be evolved in which the function becomes localized. In the case of digestion the organ is the *stomach.* The stomach is a common inheritance of all the present-day many-celled animals, which is to say, it originated with the early ancestors of these animals and has been transmitted to all the descendants, with, of course, various modifications and improvements to suit individual needs. Hence, though our particular subject is the history of the insect stomach, the same history in a general way applies to all stomachs, including our own. Let us see, then, how stomachs began.

When an habitually scientific writer starts out to write a "popular" article, the first thing he thinks he must do is to adopt the first person plural; it makes him feel chummy with the reader, and he assumes that the reader will now easily understand all he is writing about. Then he plunges ahead in the most technical kind of language about things most people never saw or heard of. It is, therefore, somewhat disconcerting, now that after a long preliminary we have reached a point where the real subject of this story might be introduced, to realize that the history of stomachs is involved in zoological matter that a considerate writer should not assume to be perfectly well known to the reader. Hence, it will be appropriate to explain here a few important things about animals in general, and about certain groups of animals in particular, in order to define some technical words and in order to make certain ideas appear more reasonable than they might otherwise seem.

First, it must be understood that there is a pretty sharp division in the animal kingdom between the one-celled animals and the many-celled animals. The first are the Protozoa, the second the Metazoa. The Metazoa are the true stomach animals; they include everything from the sponges to us. Being confronted at the very outset of their career with the necessity of feeding a mass of cells that had lost their individualities, the Metazoa proceeded at once to the organization of a community dietary department.

There are three groups of metazoic animals that we shall mention particularly in connection with a study of the evolution of the insect stomach. The first group is the Coelenterata, which includes the hydras, the sea anemones, the coral polyps, and the jellyfish. These animals are principally double-walled stomachs. They seem to live very well without complicating themselves with other organs of any consequence; they have only the simplest kind of nervous system and a contractile tissue that passes for muscle, but they have no legs or other external appendages except a circle of soft tentacles around the mouth. The second group to be mentioned is the segmented worms, or Annelida, including the earthworms and many kinds of worms that live in the ocean. The ancestors of the worms apparently were too progressive to put up with the simple equipment of a coelenterate. They started new ways of doing things and equipped themselves inside and out with new apparatus that complicated their anatomy and raised their rating in the scheme of zoological classification, but it is not clear that they gained any material advantage over the coelenterates or added to their own happiness in any way. A curious land animal named *Peripatus* that looks like a worm with a long series of caterpillar legs is probably a relative of the annelids. The third principal group is the Arthropoda, the members of which we know more familiarly as the spiders, centipedes, shrimps, crayfish, lobsters, crabs, and insects. The arthropods adopted most of the ideas and organs of the annelids, but added to the worm equipment a double series of jointed legs. The arthropods have become so efficient in a mechanical way that some scientists think there is danger of their being eventually masters of the earth. Evidently they have at least found a modus of living with their own machinery, while ours, it is said, threatens to displace us. The secret of the arthropods is that each individual is his own machine.

Lest the reader begin to feel that this digression about jellyfish, worms, and arthropods has nothing to do with the subject of stomachs, it must be explained at once that all the important structural features of animals have been evolved around the stomach; that is, they have been developed as adaptations to feeding, or its accessory functions, such as the procuring of food, the distribution of food within the body, and the elimination of waste products of metabolism. The necessity of protection and the reproductive function have, it is true, had their influence on bodily form, but their effects are not so far-reaching or so deeply stamped in the body structure as are the characters that pertain directly or indirectly to the function of nutrition.

It is probable that in a very early stage in the evolution of the Metazoa the animal consisted of a mere sphere of cells, but that the cells later became arranged in a single layer on the outside, forming thus a cellular sac filled with liquid. The embryonic representative of this evolutionary stage is called a *blastula* (fig. 4 A). Its outer

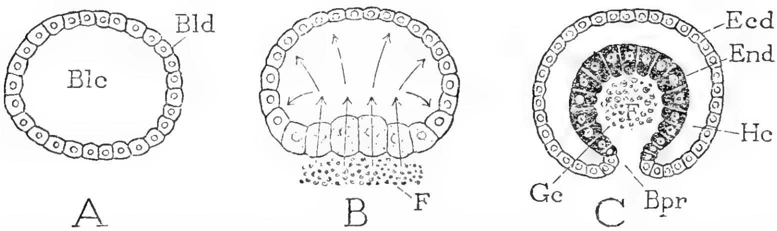

FIGURE 4.—Diagrams of early stages of general embryonic development, and the formation of the first stomach, or archenteron.

A, the blastula. B, differentiation of the digestive cells of the bastula. C, the gastrula, produced by invagination of the digestive cells to form an endodermal stomach (*End*). *Blc,* blastocoele; *Bld,* blastoderm; *Bpr,* blastopore; *F,* food material; *Gc,* gastrocoele; *Hc,* haemococle; *Ecd,* ectoderm; *End,* endoderm.

cell layer is the *blastoderm* (*Bld.*). In this stage the animal has no true stomach, and it cannot be said just how a free-living creature in the blastula condition obtained its food. Perhaps, however, all its cells were individually ingestive and digestive.

If embryonic development may be taken in a general way as a guide to the history of evolution, it becomes apparent that the blastula soon concentrated its digestive and absorptive functions in the cells of one particular area of its surface, probably the area most likely to come into contact with food material, for in the next stage of embryonic development it is usually found that the cells of one side of the blastula have become larger than the others (fig. 4 B), and subsequent history shows that these cells form the digestive surface of the animal. In the blastula this surface is often somewhat flattened or slightly concave. The ancestral representative of the blastula almost certainly inhabited water, and, if it lived mostly on submerged surfaces, it is much to be suspected that, when hungry, it simply sat down on any convenient mass of food material (*F*) and consumed it. Whether it practiced internal or external digestion we cannot pretend to decide, but in any case the digestion products were probably absorbed into the body cavity and there distributed to the other cells that had given up the power of individual digestion. Life must have been indeed sublime in those days before stomachs, when one could literally wallow in his food or even sleep in it—unless something disturbing happened in the environment. Unfortunately, however, something is always likely to happen to an animal in repose, and none of us likes to be disturbed during meals.

The ancestral blastula, pressed by the necessity of removing the hazards to its digestive composure, hit upon the simple expedient of withdrawing its digestive surface into the interior of the body. Here, in a sheltered food pocket (fig. 4 C, *Gc.*), digestion could leisurely go on, and there would be no danger of loss of food to a stronger competitor or by adverse currents of water, for the creature could simply swim away with its food inside it. By this evolutionary act, which was an anatomical involution but amounted almost to a physiological revolution, the blastula invented the *first stomach.* The organ was found to be so successful that it has come to be a standard part of the equipment of all the metazoic animals. Because of its great antiquity, and because of its historic importance, embryologists have commemorated this primitive stomach by giving it the fitting title of *archenteron* (*i.e.*, most ancient intestine). Furthermore, by this same act of establishing an internal stomach, the blastula, in terms of embryology, changed itself into a *gastrula*, and differentiated its single cell layer into an outer *ectoderm* (C, *Ecd.*), and an inner *endoderm* (*End.*). It now became necessary to take food into the stomach, and thus true *eating* began. The hole where the stomach was drawn in (C, *Bpr.*) became the first mouth, though it is called the *blastopore*, and served also for ejecting refuse. The stomach cavity is known as the *gastrocoele* (*Gc.*).

The establishment of the stomach was a great event in the history of us metazoans; nothing quite so important has happened since. Little thought was given then to the sufferings we should later endure in trying to keep the organ decently filled, or the evils that would come upon us from having it overfilled or improperly filled.

When it is understood now that the word "gastrula" is the diminutive of the Greek *gaster*, meaning "a stomach", it is evident that the word *gastrulation* may be applied to any process of stomach formation. The particular method above described is gastrulation by *invagination*, and most zoologists regard invagination as the probable historic way of stomach formation. Embryos and other young stages of animals, however, and we shall see more evidence of it, have a vexing habit of distorting history for their own convenience, when they are expected to repeat it. Embryologically, therefore, gastrulation may take place in other ways than by

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invagination. A common substitute is the multiplication of cells at some point on the inner surface of the blastoderm, followed by an inward migration of these cells to form a stomach that never was a part of the exterior animal. This plan of stomach building is distinguished as gastrulation by *proliferation.* But in general invagination and proliferation are interchangeable processes in embryonic development, so it is nothing to worry about if an animal in its growth adopts either one in place of the other. Where gastrulation takes place by proliferation there is, of course, no blastopore, though there is sometimes an external depression opposite the area of internal proliferation, suggesting that this is the site of a formerly open ancestral blastopore, which has simply been closed to accom-

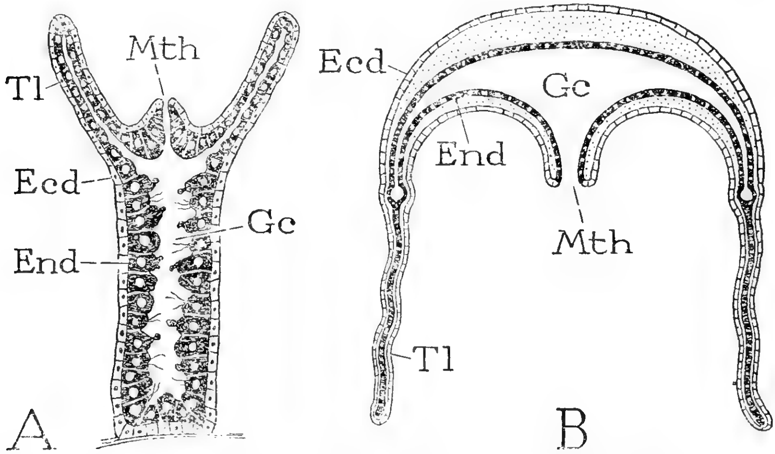

FIGURE 5.—The fundamental structure of coelenterates.

A, the polyp type. B, the jellyfish, or medusa, type.
Ecd, ectoderm; *End,* endoderm; *Gc,* gastrocoele; *Mth,* mouth; *Tl,* tentacle.

modate the conditions of development. An animal with a closed blastopore eventually acquires one or two secondary openings into the stomach.

At this point it is of interest to note that the Coelenterata have never evolved beyond the 2-layer stage of structure. They consist essentially of an outer ectodermal body wall, and an inner endodermal stomach wall (fig. 5 A), though there may be a few accessories such as nerves, motor tissue, and stinging organs, all developed from the ectoderm. The coelenterates are either cylindrical animals attached by one end to a support (A), or they are disk-shaped and float free in the water (B). Those of the first kind are known as polyps, the second are in general termed jellyfish, or medusae. In each form there is a mouth located axially; in the polyps it is at the free end of the body (A, *Mth*), in the jellyfish it is at the end of a short tube on the under surface of the body (B, *Mth*), and in both forms it is usually surrounded by a circle of tentacles (*Tl*). The entire inside of the body is occupied by a large stomach cavity, except that the jellyfish have a mass of transparent gelatinous material between the ectoderm and the endoderm. The stomach cells of the coelenterates are said to retain the primitive function of intracellular digestion; by extending protoplasmic arms they grasp and engulf food particles in the manner of the amoeba, and then eject the refuse back into the stomach.

The other metazoic animals are typically elongate in form but the elongation appears to be crosswise through the blastopore instead of through its axis. The lengthening of the animal, therefore, has drawn the blastopore out into a narow slit on the under side of the body. This conclusion, at least, appears to be warranted from a

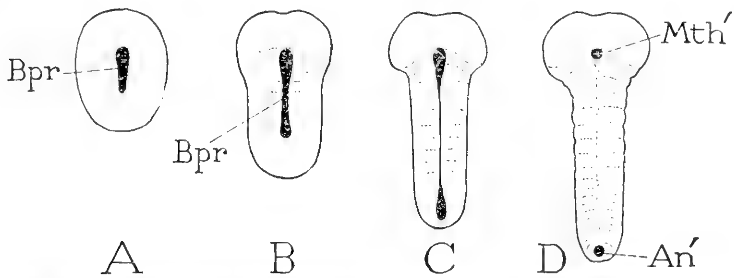

FIGURE 6.—Diagrams showing the probable evolution of the blastopore in the arthropods. *An′*, primary anus; *Bpr*, blastopore; *Mth′*, primary mouth.

comparative study of embryonic development, but, as in other things, the embryo is so prone to depart from its race history that its story may require a considerable amount of interpretation. Yet there are some forms that adhere very nearly to what we might expect to be a close approximation to historic truth. For example, the wormlike animal mentioned above, known as *Peripatus*, at an early stage of development has an open blastopore slit on the under side of its body, which gradually closes in the middle until only the two ends are left as openings into the stomach. The usual arthropod development, in which the blastopore is closed from the beginning, may, therefore, be interpreted in the light of *Peripatus* as shown diagrammatically in figure 6. The anterior remnant of the blastopore becomes the primary *mouth* (D. *Mth′*), the posterior remnant the primary *anus* (*Aǹ*). The gastrulation cavity, or archentron, is thus converted into an elongate stomach sac open to the exterior at each end (fig. 7 A).

The primitive mouth and the primitive anus (fig. 7, A, *Mth′*, *Añ*), however, do not remain at the surface of the body. Each is carried internally by an inward growth of the ectoderm (B), and the outer openings of these two ectodermal invaginations added to the food canal become the permanent mouth (*Mth*) and anus (*An*). The entire alimentary canal, it is to be seen, consists now of three parts, of which only the middle one (*Ment*) is derived from the primitive endodermal archenteron. The new anterior ectodermal part is called the *stomodaeum* (*Stom*), the posterior part the *proctodaeum* (*Proc*). The middle part, which is still the true stomach, is rechristened the *mesenteron* (*Ment*). It should be observed that, while the anal opening is terminal on the rear end of the body, the mouth aperture (*Mth*) is on the ventral surface a short distance behind the anterior pole of the animal. The part of the trunk before the mouth is termed the *prostomium* (*Prst*). This condition holds for all the Annelida and the Arthropoda. Some of the unsegmented worms have the mouth situated near the middle of the under surface of the body.

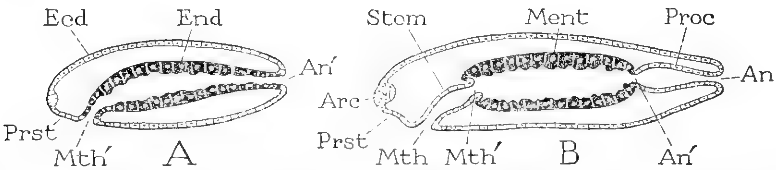

FIGURE 7.—Diagrams of the probable evolution of the alimentary canal in the ancestors of the arthropods.

An′, primary anus; *An*, definitive anus; *Arc*, primitive brain, or archicerebrum; *Ecd*, ectoderm *End*, endoderm; *Ment*, stomach, or mesenteron; *Mth′*, primary mouth; *Mth*, definitive mouth; *Proc.* proctodaeum; *Prst*, prostomium; *Stom*, stomodaeum.

The elongation of the body in the direction of movement has had a profound effect on the general organization of all animals that have evolved from this basic principle of structure. It has led particularly to many features characteristic of the annelid worms and the arthropods. The elongate form in itself is clearly an adaptation to greater efficiency of movement. Habitual movement in one direction has established one end of the trunk as the head end, and the other as the tail end. For this reason the nervous system originates at the same end as that containing the mouth, since the forward pole is the best place for the food intake orifice, and is also the end chiefly in need of sensory perceptive organs, from which the brain (fig. 7 B, *Arc*) has had its inception. This explains why with all us elongated animals, vertebrates and invertebrates, our eyes, organs of smell, and the brain are in our heads along with the intake aperture of our food canal. It explains also many of our habits and social customs. Of course, in our own particular case, since we as human beings have departed from the horizontal position, except for purposes of repose, it would be quite convenient for us now to have our mouth located somewhere nearer the stomach, say just above the level of the table; but, thanks to our horizontal animal ancestors, we are able to take our food without embarrassment in family groups and social gatherings. In short, it is much better that we have evolved from worms than from jellyfish. Such considerations may seem frivolous, but many ideas are funny to us simply because we take our accustomed facts too seriously. Historians are often given to speculating on what might be true today if something had not happened in the past that did happen. When we begin to inquire why we are not like what human beings might have been, we are likely to find that in most ways we are simply made-over animals, that we have very little in our organization that was designed in the first place for our particular use.

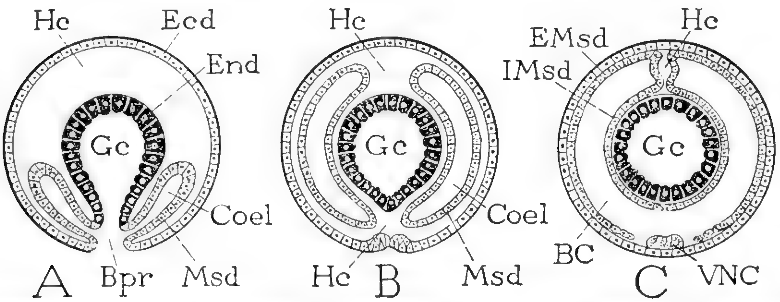

FIGURE 8.—Diagrams illustrating in cross-section the probable historic, or ancestral, method of formation and growth of the mesoderm in invertebrate animals.

A, the mesoderm being formed as hollow ingrowths along the lips of the blastopore. B, the blastopore closed and the mesoderm sacs extended upward around the alimentary canal. C, a later stage in which the walls of the mesoderm sacs form an inner lining (*EMsd*) of the body wall, and an outer covering (*IMsd*) of the alimentary canal, their cavities united ventrally with the blood cavity to form the definitive body cavity (*BC*) of the arthropods.

BC, definitive body cavity; *Bpr*, blastopore; *Coel*, mesoderm cavity; *Ecd*, ectoderm; *EMsd*, outer mesoderm layer; *End*, endoderm; *Gc*, stomach cavity, or gastrocoele; *HC*, blood cavity, or haemocoele; *Imsd*, inner mesoderm layer; *Msd*, mesoderm; *VNC*, ventral nerve cord.

Another feature common to all the metazoic animals other than the coelenterates is the possession of a third fundamental cell layer interposed between the ectoderm and the endoderm. This layer is the *mesoderm*. The mesoderm gives rise to the muscles, connective tissue, heart, blood vessels, fat, excretory organs, bones, and other internal parts that the coelenterates do not have. It originates as ingrowths of cells in each side of the body along the margins of the blastopore, or of the blastoporic area when the blastopore is closed. The history of the mesoderm is usually more or less obscured in embryonic development, but the probable primitive method of mesoderm formation in annelids and arthropods is well shown in *Peripatus*, and is here illustrated in a series of diagrams (fig. 8).

At A the mesoderm (*Msd*) is seen growing inward as a hollow fold on each side of the blastopore where the ectoderm was first continuous with the endoderm. Typically, the mesoderm forms a series of paired pouches, called *coelomic sacs* (*Coel*), corresponding with the segments of an annelid or an arthropod, for the body of these animals behind the mouth is always divided into consecutive parts, or segments (but segmentation is a topic we must omit from the present history). The mesodermal layers grow upward around the alimentary canal as the blastopore closes (B); their cavities (*Coel*) may remain distinct, but in the arthropods the coelomic walls partly break down and the contained spaces unite with the surrounding blood spaces (*Hc*) to form the definitive *body cavity* (C, *BC*). The outer and inner layers of the mesoderm, however, form respectively a lining to the body wall (*somatopleure*, *EMsd*), and a covering around the alimentary canal (*splanchnopleure*, *IMsd*).

The foregoing sketch gives probably an approximately true account of the historic method of mesoderm formation as it can be deciphered here and there from the incomplete and modified stories related in embryonic development. As we have seen, the embryo is always prone to get results by short cuts and adaptations to suit its own convenience, and therefore, while the embryo is commonly said in its development to repeat the history of its race, this statement is far from being literally true in most cases. The embryo, however, is not deficient in " biological memory "; it adheres closely to the general scheme and sequence of historical events, but we must consider the fact that it is usually shut up inside an egg, and is thus cut off from the outside world by an egg shell. Naturally, therefore, it cannot carry on its life functions in the way its free-living ancestors did, and as a consequence it has to adapt many events in its development to the way of living that is forced upon it. Then too, the embryo must complete its development in a very short time, often in a few weeks or a few days in the case of insects, while its ancestors took millions of years to cover the same ground. Hence, the embryo cannot be bothered with details, and it must attain its ends by expedient processes. Furthermore, the farther its immediate progenitors have departed from the structure of their early ancestors, the more difficult becomes the task of recapitulation, and the less likely is the embryo to follow the traditional path.

Let us now consider specifically the case of the insect embryo, some of its developmental problems, and particularly the way in which it builds up a conventional alimentary canal in spite of the roundabout methods it is forced to adopt. The egg of an insect is like that of any other animal in that it is a single cell, but the eggs of most insects are relatively very large because each contains an ample amount of food material for the future embryo (fig. 9 A). The food material is called *yolk* (*Y*). The first historic developmental stage that the egg must form is the blastula, but also the yolk must be available at once to the blastula cells, and later to the stomach cells. Hence, the first cells formed by the division of the egg nucleus (A, *Nu*) disperse to the surface of the yolk and there form a layer surrounding the latter (B). This cell layer is the blastoderm (*Bld*) and constitutes the blastula of insect development. The future insect, however, is not a product of the entire blastoderm, but of an elongate patch of thickened cells soon differentiated on the under surface of the blastoderm, known as the *germ band* (C, D, *GB*), which is the beginning of the true embryo.

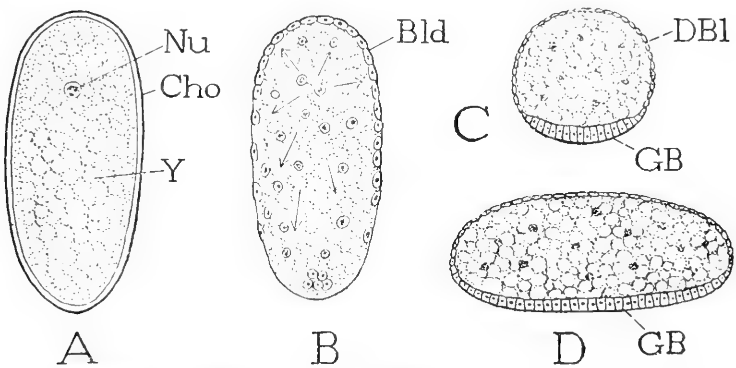

FIGURE 9.—Diagrams of early stages in insect development.

A, an egg of the usual type containing a large quantity of food material, or yolk (*Y*). B, the enclosure of the yolk in a layer of cells, the blastoderm (*Bld*), formed by division of the egg nucleus and migration of the resulting nuclei to the periphery of the egg. C, D, cross-section and lengthwise section of the egg at a later stage showing the thickened germ band (*GB*) on the under surface of the blastoderm.

Bld, blastoderm; *Cho*, the egg shell, or chorion; *DBl*, dorsal blastoderm; *GB*, germ band; *Nu*, egg nucleus; *Y*, yolk.

One of the first events, now, in the further development of the insect embryo is the formation of a groove along the under surface of the germ band (fig. 10 A), the walls of which either sink in bodily (B), or proliferate a mass of cells internally. In either case the germ band becomes two-layered (C). This developmental process looks like the formation of an endoderm from the ectoderm, but future events show that the inner layer thus formed is mostly mesoderm (C, *Msd*). However, it has been observed in some cases that from its median part certain cells (B, *Vph*) migrate into the yolk and appear to have a digestive action on the latter. These cells, therefore, are called " yolk-eaters ", or more technically are known as *vitellophags*. Moreover, there are also cells distributed along the inner surface of the mesoderm (A, *End*), or particularly aggregated in clumps at each end of it, that will later multiply and again enclose the yolk in an internal sac, which becomes the stomach of the mature insect. These dormant cells associated with the mesoderm, therefore, must be the endodermal cells of the embryo, and, if so, the vitellophags dispersed from them are also endodermal.

Here, then, clearly is a striking example of apparent utter disregard on the part of the embryo for the historic method of mesoderm and endoderm formation. Yet, we must admit that the insect embryo is true to its ancestral history insofar as it does develop each of these layers from what ought to be the blastopore area of its body, and in that it turns over the business of digesting the yolk to at least some of the endoderm cells, namely, the vitellophags. It is quite evident

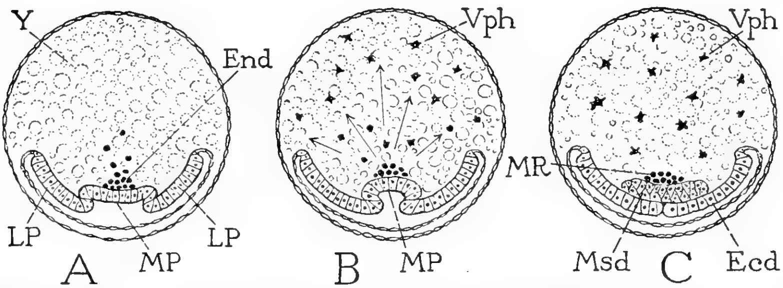

FIGURE 10.—Diagrammatic cross-sections of three early stages in the developing insect embryo showing one method of mesoderm formation, with accompanying endoderm cells.

A, the germ band divided into a middle plate (*MP*) and lateral plates (*LP*); gastrulation represented by internal proliferation of endoderm cells (*End*) from the middle plate. B, the middle plate becoming invaginated, most of the endoderm cells being dispersed in the yolk as vitellophags (*Vph*). C, the middle plate transformed into mesoderm (*Msd*) by the closure of the ectodermal lateral plates (*Ecd*); a remnant of the endoderm (*MR*) left on the inner surface of the mesoderm.

that if the embryo developed its endoderm by the traditional method of invagination, its stomach would become a sac *surrounded* by the food material. A stomach, however, is not designed to work from the outside, for in such a case it might digest the animal instead of the food. Stomach cells dispatched into the yolk, however, may digest the latter and render it available to the growing tissues of the embryo. Hence, while the insect embryo adheres to the fundamental principle of gastrulation, it discards of necessity the idea that stomach formation must proceed in one particular way.

Let us see now just how far the insect embryo has departed from the ancestral path in the matter of gastrulation. We first go back to the typical open gastrula (fig. 11 A) with the mesoderm forming along the sides of the elongate blastopore. If then we assume that the blastopore has closed, we arrive through B at the condition in C, which clearly suggests the developmental process that takes place in insects. With a closed blastopore the apparent gastrulation produces mesoderm (C, *Msd*) externally beneath the ectoderm, and endoderm (*End*) internally, but most of the endoderm is at once disintegrated to scatter its cells in the yolk as vitellophags (D, *Vph*), which lose no time in beginning their business of digestion. There is finally left only a remnant of the endoderm in the form of a layer of dormant cells resting on top of the mesoderm (D). Thus we see that the insect embryo has violated no fundamental law of development, and that its deviations from the conventions are necessary

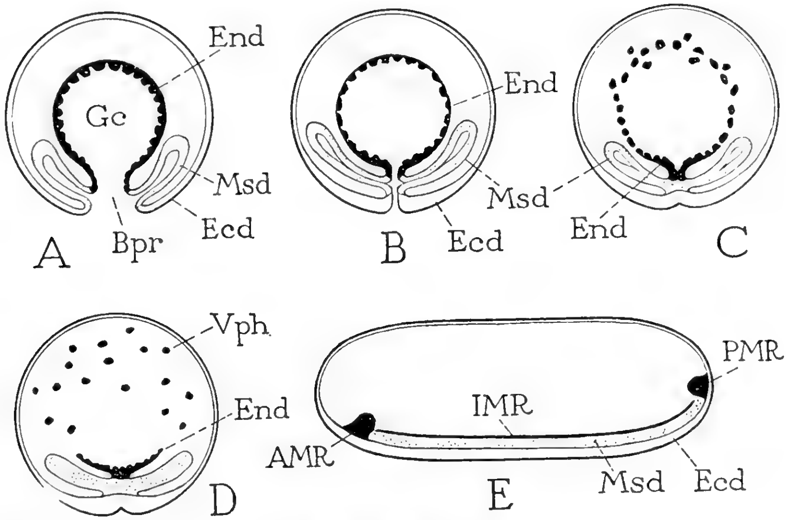

FIGURE 11.—Diagrams interpreting the formation of the inner germ layers in insects as modified gastrulation.

A, primitive gastrulation and mesoderm formation. B, the blastopore closing. C, the blastopore closed, the mesoderm covered by the ectoderm, the endodermal stomach (*End*) in process of disintegration. D, most of the endoderm cells scattered in the yoke as vitellophags (*Vph*), leaving a ventral remnant (*End*) resting on the mesoderm. E, lengthwise section of the embryo showing the three remnants of the endoderm (*AMR, IMR, PMR*) that will later regenerate the stomach.

adaptations to proper development within an egg filled with yolk.

The vitellophags are an emergency crew; they have only temporary employment, since a dispersed stomach could not function as a digestive organ for food coming in from the outside. The young insect is destined to live a free life; it must eventually, therefore, have a stomach of the usual kind provided at least with an intake orifice for receiving food material. Hence, it is quite necessary that the embryo should soon begin the building of a conventional gastric organ in order to meet its destiny of hatching and being left to its own resources in the outside world.

It is claimed by some investigators that in some of the arthropods, including certain insects, the wall of the definitive stomach is formed by a reassembling of the scattered vitellophags on the outside of the undigested remnant of the yolk. There is nothing improbable about this method of reestablishing a disintegrated stomach, but its actual occurrence is perhaps not fully substantiated, and some embryologists claim that if a stomach is thus formed it is a transient structure. There is, on the other hand, no doubt that the final stomach of most arthropods is a structure *regenerated* from the temporarily dormant remnant or remnants of the endoderm left at the two ends of the mesoderm, or forming a median strand of endodermal tissue along the length of the mesoderm (fig. 11 E). These regenerative endodermal remnants, since they form the definitive stomach, which is termed the mesenteron, are known as the *anterior mesenteron rudiment* (*AMR*), the *posterior mesenteron rudiment* (*PMR*), and the *intermediate mesenteron rudiment* (*IMR*).

The final process of the stomach regeneration is fairly simple and direct. The several mesenteron rudiments (fig. 12 A) begin a period of active growth. Their cells multiply and spread outward from their margins *around* the yolk. The anterior and posterior rudiments form cup-shaped extensions that approach each other from the opposite ends of the body (B, C), the intermediate rudiment, if present, contributes to the space between them, until finally the yolk is completely invested in a covering consisting of a single layer of endodermal cells (D). The embryo now has acquired its definitive stomach, or mesenteron, which proceeds to digest the yolk within it, and later takes care of the food that enters by way of the mouth. The vitellophags appear to be out of a job. Some investigators claim that they perish by degeneration, and are absorbed. The blood of adult insects, however, contains free cells that are suspiciously like the vitellophags; they devour and digest loose matter and possibly disease germs in the blood, and thus resemble the white blood corpuscles of vertebrate animals. These insect blood cells are known as phagocytes (i.e., eating cells). Perhaps they are descendants of the wandering vitellophags.

The mesenteron of the embryo is yet a closed sac. A stomach without an inlet or an outlet would be a useless luxury for a free-living animal, but it is entirely appropriate to an embryo confined within an egg shell. During the process of the stomach formation two pockets of the ectoderm grow inward at opposite ends of the body (fig. 12 B, C, D), the first carrying the anterior mesenteron rudiment, the second the posterior mesenteron rudiment. When the mesenteron is completely formed (D), therefore, it is suspended between two ectodermal tubes which are open to the exterior but closed at their stomach ends. Shortly before the insect hatches, however, the partitions between these tubes and the stomach sac are broken down, and now at last the creature has a continuous alimentary canal. Thus by a round-about path of embryonic development, this important organ has resumed the conventional form and structure that the alimentary canal must have acquired at an early

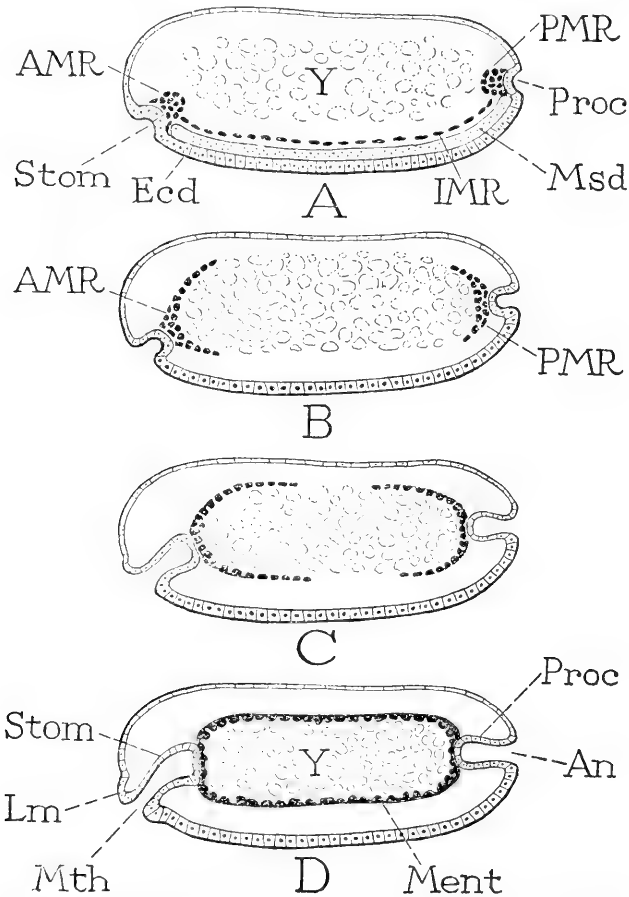

FIGURE 12.—Diagrams illustrating the regeneration of the stomach from the endoderm remnants, and the formation of the alimentary canal.

A, lengthwise section of the embryo, showing the endoderm remnants, known as the anterior, intermediate, and posterior mesenteron rudiments (*AMR, IMR, PMR*), and the beginning of the stomodaeal and proctodaeal ingrowths of the ectoderm (*Stom, Proc.*). B, the endoderm remnants beginning to grow around the yolk to form the stomach. C, a more advanced stage in the stomach formation. D, the endodermal stomach, or mesenteron (*Ment*), completed as the middle section of the alimentary canal, the ectodermal stomodaeum (*Stom*) and proctodaeum (*Proc*) forming its anterior and posterior parts.

period in the ancestral history of the free-living progenitors of the insects (fig. 7 B). Throughout the life of the insect the food tract preserves the evidence of its triple origin, since its three parts, the stomodaeum, the mesenteron, and the proctodaeum, are always distinct in their structure and function (fig. 13). The stomach of the adult insect is commonly called the *ventriculus*.

Before going on, it should be mentioned that the stomach in some insects does not open permanently into the proctodaeum until the end of the larval stage. The larvae of such insects are mostly parasites living in the bodies of other insects, or are the young of wasps and bees that live in cells containing their food supply. Here again is a case of adaptation to local conditions, for, just as the embryo has a closed stomach to retain its food, so the larvae of these insects, in order to avoid contamination of their food, have a closed intestine.

The ways in which young animals in their development depart from the ancestral structure, as represented in that of their parents, and then revert to the parental form is a most interesting field of

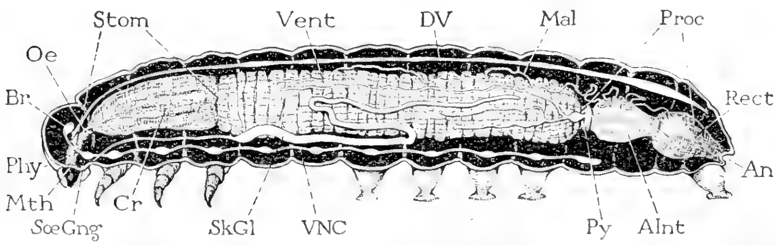

FIGURE 13.—Lengthwise section of a caterpillar showing the alimentary canal and other internal organs.

AInt, anterior intestine; *An*, anus; *Br*, brain; *Cr*, crop; *DV*, dosal blood vessel; *Mal*, Malpighian tubules; *Mth*, mouth; *Oe*, oesophagus; *Phy*, pharynx; *Proc*, proctodaeum; *Py*, pylorus; *Rect*, rectum; *SkGl*, silk gland; *SoeGny*, suboesophageal ganglion; *Stom*, stomodaeum; *Vent*, stomach, or ventriculus; *VNC*, ventral nerve cord.

study. In general, this temporary assertion of anatomical independence on the part of young animals, and the breaking away from ancestral conventions only to go back to them again, is termed *metamorphosis*. The phenomenon is particularly prevalent among the invertebrates, and, from what we have seen of the development of the insect stomach, it is clear that there may be embryonic metamorphosis as well as postembryonic metamorphosis. When metamorphosis is very pronounced it is usually found, as in the case of the insect stomach, that the primitive cells of an organ divide into an active erratic group that form the temporary structure, and an inactive conservative group that will later restore the organ in its adult form. Without this provision, an overambitious larva might get so far from the beaten path that it could not get back again. The reason for metamorphosis is usually to be found in a different way of living, a different habitat, or a division of labor between the young and the adult stages of the same animal.

Now that we have carried the young insect through its development to a point where it has acquired a complete digestive apparatus, it must not be supposed that the story is ended. The insect stomach keeps on having history to the end of its career. When the insect has once consumed the embryonic food supply that was enclosed in its stomach, it becomes from now on dependent upon food materials taken into the stomach by way of the mouth. During postembryonic life, therefore, the function of feeding becomes greatly augumented since it must include the acquisition of food, the reduction of the food mass, when necessary, to a form that may be taken into the mouth, and its passage from the mouth to the stomach. All these accessory functions involve the development of complicated mechanisms, a study of which would be pertinent and extremely interesting in connection with the stomach, but would lead us too far afield from our immediate subject.

The first use the young insect makes of its new feeding organs may occur while it is still in the egg, for many insects, when the time for emergence has arrived, swallow a liquid that fills the space between them and the egg shell. This swells out the body and gives the insect closer contact against the shell, so that by contortionistic movements, or by pressing a spine or a sharp ridge on the head against the shell, the latter is split and gives the confined creature a means of exit. The head protrudes first from the egg, and then a still further inflation of the body may be accomplished by swallowing air, giving an increased pressure that assists in the final escape. Young insects with well-developed jaws, however, may simply gnaw a hole in the egg shell, and leisurely crawl out. Such insects are very likely then to turn around and make their first meal on the rest of the shell.

In the matter of eating, insects are hard to understand. They have dietary laws that they follow scrupulously. While some of them will eat almost anything, the majority confine themselves to some particular kind of food, and plant-eating species often refuse almost everything but the leaves of a definite species of plant, though they will make a few concessions in cases of emergency. As an example of this trait we have only to recall the silkworm, which, as is well known, must be fed on mulberry leaves or it will not spin a cocoon, though when young it may be induced to nibble some lettuce or dandelion leaves to avoid starvation. This finickyness about food on the part of insects is not a matter of " taste ", for they will not even try the things they refuse. In this they resemble children, except that they never grow out of their perversity. The insect mothers in most cases know enough to lay the eggs where their brood will find on hatching the kind of food they will eat. Entomologists would like to know the reason for these dietary whims of the insects; they might turn a knowledge of it to advantage in the war against agricultural pests, but so far investigations have not revealed the secret.

Young insects are particularly constructed for the function of feeding. The period in an insect's growth from the embryo to the adult is above all else a digestive stage. The stomach is exalted over the other members, and all activities are devoted to keeping it full of food. The stomach itself at this period is a large, active, and energetic organ (fig. 13,*Vent*); its cells are constantly pouring out digestive juices, and absorbing the products of digestion. The latter are used partly by the growing insect, and partly are stored in the body as reserves for the use of the adult.

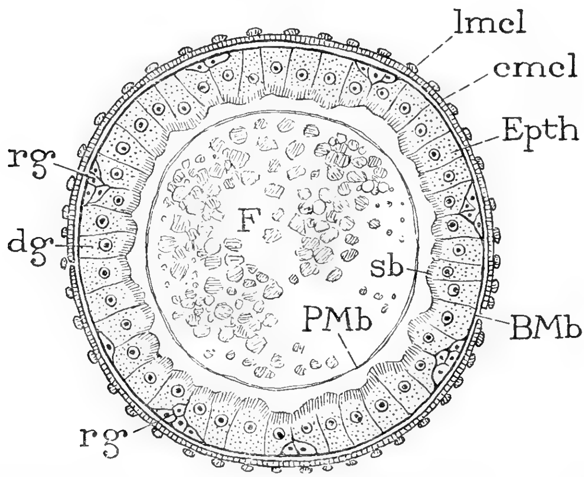

FIGURE 14.—Diagrammatic cross-section of the mature stomach, or ventriculus, of an insect.

BMb, basement membrane; *cmcl*, circular muscles; *dg*, digestive cells; *Epth*, endodermal epithelium; *F*, food material; *lmcl*, lengthwise muscles; *PMb*, peritrophic membrane; *rg*, regenerative cells; *sb*, striated border of epithelial cells.

The structure of the stomach is best seen in a cross-section (fig. 14). The principal part of its wall is a cellular layer, the epithelium (*Epth*), which is bounded externally by a thin *basement membrane* (*BMb*). On the outside is a muscular sheath composed of inner circular fibers (*cmcl*) and outer lengthwise fibers (*lmcl*). The inner margin of the epithelium has the appearance of being penetrated by numerous fine pores perpendicular to the surface, and for this reason it is called the *striated border* (*sb*). Within the cavity of the stomach is the mass of food material (*F*), but usually it is to be seen that the food is enclosed in a sack formed of a delicate film, the *peritrophic membrane* (*PMb*), which is given off from time to time from the cell surface, and probably serves to protect the latter from direct contact with the food. The peritrophic membrane, however, must be penetrated on the one hand by the digestive secretions from the stomach cells, and on the other by the digested products in solution which are to be absorbed by the cells.

The process of secretion in any gland cell is a chemical activity in the cell protoplasm by which certain substances are produced from the food materials brought to the cell by the blood. The nature of the secretion products differs according to the function of the gland; the principal products of stomach cells are digestive enzymes. The secretion materials accumulate in the cells until, at the proper time, the cell is flushed with water and the products are carried out in solution through the cell wall.

The digestive secretions formed by the epithelial cells of the insect's stomach are probably ordinarily discharged through the striated border. In many cases, however, it is to be seen that the inner

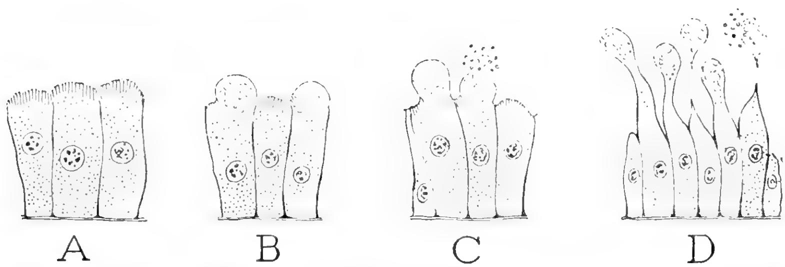

FIGURE 15.—Diagrams illustrating physical changes that take place in the digestive cells of the stomach wall.

A, cells in a "resting" condition. B, inner ends of cells protruding as swellings containing material supposed to include digestive enzymes. C, a swellng disrupted scattering its contents in the stomach cavity. D, globules separated from the cells, followed by disintegration.

ends of the cells have a spongy appearance, owing to the accumulation here of a clear liquid containing a coarse granular material, and that small swellings charged with this material push out from the cell surfaces (fig. 15 B). In other parts of the specimen these swellings may be globular outgrowths and some of them may be seen to be ruptured (C), scattering their contents in the stomach lumen. Or again, the globules may be drawn out on the ends of long necks, and then cut off as free bodies (D), which float off and distribute their contents by a final dissolution of their delicate wall. It has usually been supposed that these observed activities in the stomach cells constitute a drastic means for discharging quickly large quantities of digestive products; in other words, it would appear that the ordinary processes of diffusion are too slow, and that more effective results are obtained by an explosive disruption of the cells when once the latter are fully charged with digestive enzymes. Certain recent investigators, however, are inclined to think that these visible phenomena of cell disruption are dissolution processes of cells that have been exhausted by a period of intensive secretion, during which the secretion products were discharged through the cell walls in the ordinary manner. The question can be settled only by more extensive studies from a physiological standpoint.

Whatever may be the truth concerning the nature of the observed facts of disruption in the stomach cells, it is undoubtedly true that the process is a destructive matter to the cells themselves. Many of them eventually are entirely used up by these activities, and if there were no provision for their replacement by new cells the stomach itself would soon be exhausted. The digestive cells are too exclusively occupied with secretion duties to be able to reproduce themselves; a cell, once exhausted, has reached the end of its career. In examining the section of the stomach (fig. 14), one thing we did not observe is that in addition to the large cells (*dg*) forming the principal part of the stomach wall, there are other small and inconspicuous cells (*rg*) lying outside the others against the inner surface of the basement membrane. These small cells are *regenerative cells.* They have conserved their vitality by taking no part in the exhausting secretion business, and as a consequence their reproductive powers are unimpaired. When new digestive cells are needed to take the places of those worn out in the service, it is these regenerative cells that by division furnish the recruits. But the parent cell in each case remains behind always ready for further procreation. Thus there goes on throughout the digestive periods of the insect's life a continual process of destruction and regeneration of the cellular lining of the stomach. The regenerative cells may be scattered as shown in the diagram (fig. 14), but in many insects they are collected in groups, or nests (called nidi), or again they occur in small pockets of the epithelium (crypts), which may project in the form of slender processes on the outer surface of the stomach.

At the time that secretion is in progress, or following periods of intensive secretion, the same cells, in most cases, that furnish the secretion products must absorb the digested food materials and pass them through their inner surfaces into the blood of the body cavity. Fortunately, however, the stomach does not have to work all the time. Growing insects, as is well known, have periods when they cease from feeding activities and cast off the outer layer of their skin. This process is called *moulting*, or *ecdysis.* The time that intervenes between periods of feeding, when the outer skin is shed, is often spoken of as a "resting period." The appearance of resting, however, is quite superficial, except in the sense that the insect ceases to eat and to move about; physiologically this is a time of greatly increased activity when the processes of growth are particularly rapid. With many larvae, the cellular wall of the stomach is now cast off entire and a whole new cell layer is generated from the replacement cells. Thus the insect enters its next feeding stage with a fresh secreting layer in its stomach, which proceeds to digest and absorb the cells of the old discarded layer! Here is an example of economy characteristic of living things, but quite foreign to the physical world. At the final change of the larvae to the adult the stomach wall will be again renewed, after which it generally lasts until death, though certain beetles are said to continue periodically the shedding and renewal of the stomach epithelium as long as they live, regardless of the fact that they do not moult again.

In retrospect several points of interest may be emphasized. The first is that the vital processes of living things depend upon fundamental properties of inanimate matter. Second, the property of protoplasmic matter that we term life is a chemical mechanism, called metabolism, for the continual liberation of energy. Third, the structural organizations of animals are mechanical devices for giving the vital process optimum working conditions, and for utilizing the energy released by the body cells. Fourth, food is material that the body cells can use for energy production and for growth; digestion is the rendering of raw food stuffs of nature into a form soluble in water and suitable for cell food; the stomach is an outside part of the body turned in to make a pocket in which digestion takes place. Fifth, the general sequence of developmental processes by which an individual animal grows from the egg to the adult is determined by the course of the evolutionary history of the race. Sixth, the details or actual mode of development does not of necessity repeat literally the ancestral history of the species, since the young animal, whether the embryo in the egg or the free-living larva, must adapt its inheritance to its own way of living. The truth of this is particularly evident in the developmental history of the insect's stomach.

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TICKS AND THE ROLE THEY PLAY IN THE TRANSMISSION OF DISEASES

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[With 9 plates]

INTRODUCTION

Ticks rank among man's worst enemies. Some of the most deadly diseases of the human race and of domestic animals are borne by these creatures. Furthermore, all ticks are parasitic and weaken their hosts by sucking their blood and also irritate them by their bites.

While generally regarded as insects, ticks are not true insects, but are more closely akin to the mites and spiders. They constitute a separate superfamily, known as the Ixodoidea, almost world-wide in distribution. In this country there are about 40 species, nearly half of which are known to be of more or less economic importance. The diseases now known to be carried largely or wholly by ticks make a formidable array. Four different types of disease organisms are known to be conveyed by ticks, namely spirochaetes, piroplasms, rickettsias, and bacteria. They also carry certain parasitic worms and virus diseases such as heartwater of sheep, cattle, and goats and Nairobi sheep disease, and other maladies of man and animals the causative agencies of which are unknown, such as tick paralysis and certain tick fevers. Apparently ticks are of relatively little importance in the transmission of bacterial diseases, although in tularemia they appear to play a rather important part. The Protozoa of the family Babesiidae are ordinarily transmitted solely by ticks. Fortunately the diseases due to this group of organisms do not appear to attack man, though many species of mammals are affected by them. Among the rickettsia diseases Rocky Mountain spotted fever of man is carried exclusively by ticks, and apparently this is true of *Rickettsia ruminantium* of cattle in South Africa. A number of spirochaetoses of fowls, mammals, and men are tick-borne. Tick bites are annoying to most people, and certain individuals are especially sensitive to them. Furthermore, they often serve as points of ingress of secondary infection. Thus ticks are of distinct importance aside from the part which they play in transmitting specific diseases.

LIFE HISTORY AND HABITS

The life histories and peculiar adaptations of ticks to various conditions are interesting, and a knowledge of them is of much importance in studying their relations to disease transmission, and in devising methods of control.

In general ticks have four distinct developmental stages; the egg, the larva, or seed tick, the nymph, and the adult, male and female. All ticks require blood for their development and reproduction. The eggs are usually about one-fortieth inch long, oval and yellowish to dark brown in color. The eggs are laid in masses of a hundred or so up to 10,000 or 11,000. As the embryos develop, the eggs show a distinct whitish spot on one side. This becomes more pronounced as development progresses. The eggs hatch into six-legged seed ticks which are active in most species. After a meal of blood the seed ticks molt their skins and gain a fourth pair of legs. They are now known as nymphs. In some species there are two or three nymphal stages, the molts following blood meals. At the final nymphal molt the adult males and females are produced. In the family Argasidae, or soft-bodied ticks, the sexes are similar in size and general appearance, and both, with few exceptions, engorge with blood. In the other family, known as Ixodidae, or hard-back ticks, the males may or may not attach to animals. The females attach, and the rear portion of the body, being elastic, stretches so that when fully engorged the female is little more than a bag of blood, the head and legs appearing relatively small. Mating usually takes place on the host. When replete with blood the females let go their hold on the host and seek a protected place for laying their eggs. Attachment to a host and feeding are accomplished by inserting the beak or hypostome into the skin. The beak is provided beneath with rows of backward projecting spines which serve to attach the parasite firmly. Near the tip, on the upper side, are two cutting jaws or mandibles which work sideways. These are the principal cutting organs. The palpi, which are sensory organs forming a sort of sheath at the sides of the hypostome, are bent aside as the mouthparts are inserted.

There are many interesting modifications in the life cycles and habits of the different kinds of ticks by which they have adjusted themselves to the habits of birds or animals upon which they feed, and to the conditions under which they live and develop. One way in which the ticks vary greatly in habits is in connection with the number of times they leave the host to molt their skins. This has an important bearing on the disease-transmitting possibility of a given species, and on methods of control. For instance, some ticks find a new host each time they feed, after dropping off the previous host to molt their skins. This allows a given tick an opportunity to pick up an infection from one host and transmit it to another. Some adults also have the habit of engorging with blood several times at intervals of a few weeks to several months, using a different host for each engorgement.

The habit of engorging quickly and dropping for each molt makes control more difficult. Again, we find some ticks, such as the cattle fever tick, that have the habit of remaining on the host during molts. In the case of ticks with this habit such diseases as are carried must be transmitted hereditarily, i.e., from one generation of ticks to the next, through the egg. Some species of ticks will engorge on many different kinds of animals, while others are very restricted in this respect. This question of host preferences and host restriction is also an important one both from the standpoint of disease transmission and that of susceptibility to control. It is apparent that a species of tick which attacks only a few kinds of animals is likely to be more easily controlled or eradicated than a species which will feed upon any animals which come in contact with it. The cattle tick is a form which is restricted in the number of hosts upon which it will feed. This fact has made its eradication possible by regularly dipping its usual hosts, i.e., cattle, horses, and mules, or by keeping these animals out of pastures infested with the tick. These methods, put into effect by the Bureau of Animal Industry in cooperation with the various States, have resulted to date in the eradication of the tick from 651,311 square miles of territory in the United States, or about 89 percent of the area originally infested. (See fig. 1.) Many other kinds of ticks in this region which feed on a greater variety of animals and drop for their molts, were not materially affected or were only temporarily reduced in numbers by these eradication practices.

Some of the more interesting and economically significant of these habits will be brought out under the discussion of the different species.

FEEDING HABITS

Ticks will not develop without partaking of blood. Most ticks attach firmly to their host while feeding, and the blood is taken up slowly. The nymphs of the spinose ear tick, for example, may take as long as 7 months to become engorged. The time for engorgement of each of the different stages in most species, however, usually ranges from 3 to 12 days. Certain species engorge with extreme rapidity, and attachment in such cases is less firm, so that the ticks

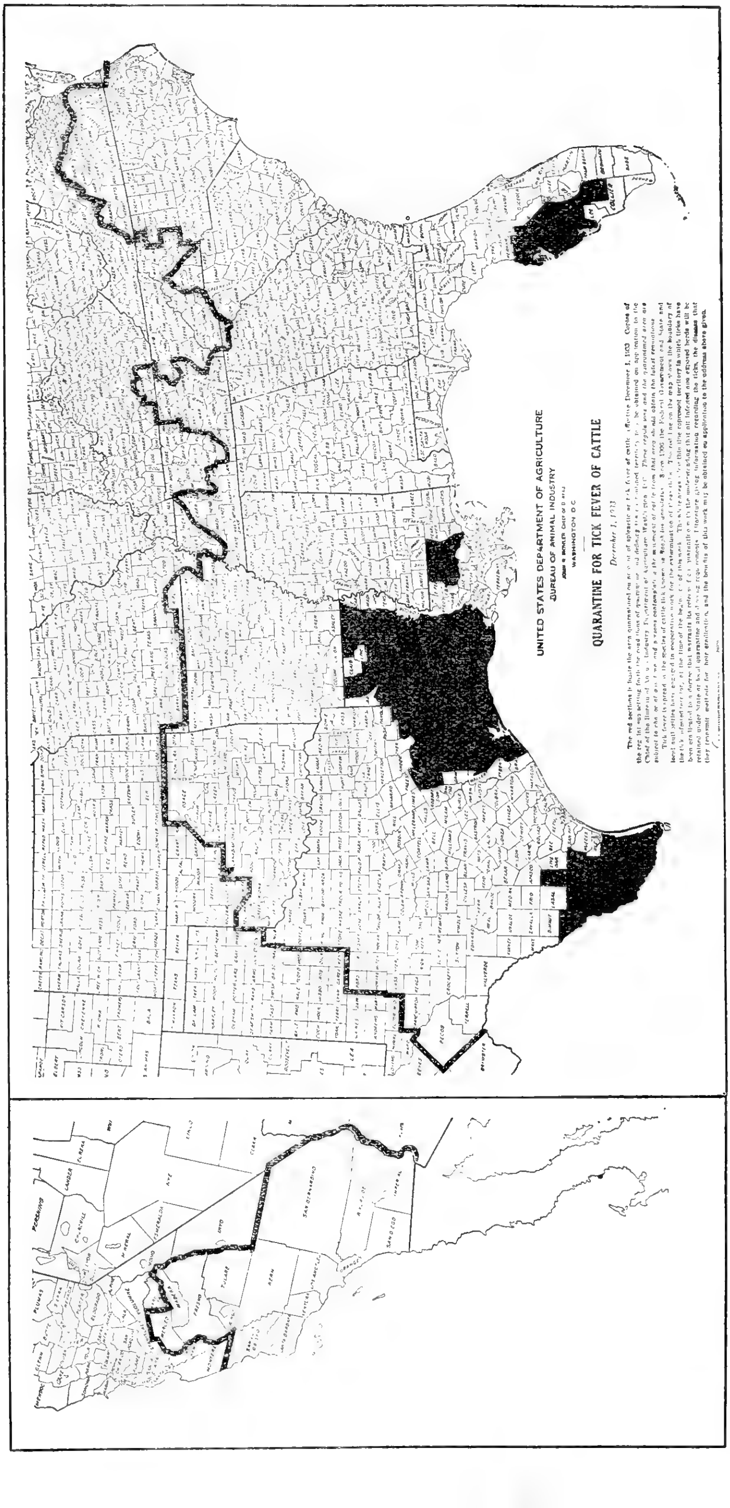


FIGURE 1.—Map showing original area in United States quarantined against the cattle tick and limited area remaining under quarantine in December 1933. (Courtesy Bureau of Animal Industry.)

may let go and crawl away to avoid danger. This habit is found among certain of the leathery-bodied ticks, such as the fowl tick and the relapsing fever tick. These ticks usually engorge at night and hence remain in close proximity to their hosts. In the case of the adults of the hard-backed ticks, such as the common wood ticks, little engorgement takes place during the first 2 or 3 days, but toward the end of the feeding period the bodies of the females distend with blood very rapidly. During feeding salivary secretions are injected into the host, and in some species these are very irritating. This secretion and the beak of the tick, which is sometimes broken off and left in the skin when a long-beaked species is removed, are responsible for the local lesions which may be inflamed and itch for weeks or even months after the tick is gone. As the ticks of species of Ornithodoros become distended with blood, a copious excretion of clear fluid is thrown out by glands near the base of the legs. In ticks infected with relapsing fever this excretion carries the disease organisms, and the fluid entering the wound made by the beak may be a medium of infection.

Some kinds of ticks attach to only certain parts of animals, while others are not particularly restricted in this respect. The spinose ear tick is a good example of the restricted attachment habit. This tick occurs deep in the external ear. The tropical horse tick, *Dermacentor nitens* Neum., has similar habits but does attach occasionally in the mane and elsewhere on horses. Most ticks attach to various parts of an animal but prefer the dewlap, shoulders and the region between the legs.

LENGTH OF LIFE

In general ticks are relatively very long lived. The length of life without food of the different stages of ticks is of considerable economic importance, as it must be taken into account in efforts to destroy these pests by starvation. Many species will live for upward of 8 months shut up in pill-boxes or tubes without food or water. This is true of the seed ticks, nympths, and adults. The greatest longevity recorded is in the case of the adult fowl tick which we have found to live for nearly 2½ years with no food whatever.

TICKS AND ROCKY MOUNTAIN SPOTTED FEVER

Rocky Mountain spotted fever is a very serious human disease which is carried to man exclusively by ticks. There are probably 700 to 800 cases a year in this country, and the mortality in parts of Montana is over 70 percent. (See pl. 1.) More cases occur in Idaho than any other State, but the virulence of the disease is much lower there, the mortality running from only 5 to 8 percent.

As is well known, the Rocky Mountain spotted fever tick, or wood tick of the Rocky Mountains (*Dermacentor andersoni* Stiles), conveys this disease to man in that region. For many years this disease appeared to be limited to the northern Rocky Mountain States, the intermountain region, and the eastern slope of the Cascades. This distribution of the disease was less extensive than that of the transmitting tick. In recent years, however, the disease has been recognized in many parts of the country far beyond the limits of distribution of the Rocky Mountain spotted fever tick. Obviously, other transmitting agencies are concerned in the region where *Dermacentor andersoni* does not occur. In the east the American dog tick, *Dermacentor variabilis* Say, carries the disease. This is the common wood tick of that region. The mortality in cases in Maryland, Virginia, and the District of Columbia exceeds 20 percent.

Dr. M. B. Maver, as early as 1911, showed that the western strain of Rocky Mountain spotted fever could be transmitted from diseased to healthy guinea pigs by ticks other than *D. andersoni*. Her tests were positive with nymphs of the western rabbit tick, *D. parumapertus marginatus* Banks, the lone star tick, *Amblyomma americanum* Linn., and the American dog tick, *D. variabilis*, and also with the adults of the latter. Dr. R. R. Parker has shown that the disease may be transmitted by the rabbit tick, *Haemaphysalis leporis-palustris* Pack. Positive transmission tests with species representing such a wide range in relationships and in habits strongly indicate that many other species may be capable vectors. Even though these are the only carriers, their distinction and host relations provide abundant opportunity for the transfer of the disease in every State in the country.

While no two of the species are exactly coextensive, there are many overlappings in distribution, and in most areas two or more suitable vectors are to be found. The relatively low percentage of individual ticks which become infective would indicate, however, that in many parts of the United States where ticks occur in relatively small numbers, the disease may not become established, even though introduced.

The bite of a single tick is sufficient to infect a person with the malady. Fortunately, however, the ticks must feed for some time to produce an infection. This time seems to vary from 2 to 8 hours or even longer as shown by experiments carried out by the United States Public Health Service.

The principal methods of preventing this disease are to avoid tick bites by wearing clothing calculated to exclude the pests, by frequent examination of the body for ticks, and by using prophylactic vaccine which has been developed by the Public Health Service. Naturally the reduction of the number of ticks will decrease the hazard of the disease. This matter is discussed in subsequent pages under ticks which serve as carriers.

TICKS AND SPLENETIC FEVER

One of the earliest demonstrations of the disease-transmitting role of insects and related forms was that of tick transmission of splenetic fever of cattle by Drs. Theobald Smith and F. L. Kilborne, of the Bureau of Animal Industry in 1893. This work has been of untold benefit to man because it pointed the way to the solution of other disease problems.

In the United States splenetic fever is carried solely by the common cattle tick known scientifically as *Boophilus annulatus* Say. The disease is caused by a microscopic single-celled organism known as *Piroplasma bigeminum*. This organism enters and destroys the red blood cells, and its multiplication is so rapid that it soon depletes the blood of red corpuscles, and often causes the death of the infected animal, particularly if the animal is mature. The organism is passed from one generation of the tick to another through the egg. This is necessary for the perpetuation of the disease because this species of tick remains on the same animal from the time of its attachment as a seed tick to its death as a male or its dropping as an engorged female.

Soon after the demonstration that this disease is carried by the cattle tick the life cycle and habits of the vector were studied intensively and much attention was given to ways of destroying it, both on account of its seriousness as a parasite and the role it played in the transmission of splenetic fever. As a result the possibility of eradicating the species from a given area was conceived, and finally the widespread eradication program was begun in 1906. That the tick will be entirely wiped out of the United States is now the belief of all progressive stockmen. With the elimination of the cattle tick splenetic fever vanishes, and improved livestock and better economic conditions follow almost immediately.

ANAPLASMOSIS OF CATTLE IN RELATION TO TICKS

For many years the disease of cattle known as anaplasmosis was confused with splenetic fever. The fact that it continued to occur in cattle in areas where there were no cattle ticks helped to direct attention to the fact that a malady distinct from splenetic fever was present. This disease occurs sporadically in many parts of the country and often takes a heavy toll among the infected herds. Its distribution does not appear to tally exactly with that of any one species of possible vector, but experimental work indicates that the disease is carried by several species of ticks and probably by other arthropods, notably flies. The investigations of Dr. Gerald Dikmans of the Bureau of Animal Industry showed that anaplasmosis can be carried by the cattle tick. In the case of this tick the malady is transmitted through the egg to the next generation. Dr. C. W. Rees, also of the Bureau of Animal Industry, has demonstrated the transmissibility of the disease by the brown dog tick, *Rhipicephalus sanguineus* Lat. While this is interesting scientifically, apparently it has little practical bearing, as this tick, especially in this country, is restricted very closely to the dog as a host, although it can be forced to attach to cattle. It is markedly domestic, being closely associated with the habitat of dogs. Rees' subsequent demonstration that anaplasmosis can be conveyed by the American dog tick is more significant, as that tick freely attacks cattle and has a rather wide distribution in nature. Rees has also shown that the disease may be conveyed by *B. annulatus australis* Fuller and by *Ixodes recinus scapularis* Say.

The results thus far obtained in transmission experiments strongly suggest that many species of ticks may be concerned in the transmission of this disease and that any of those commonly attacking cattle should be regarded with suspicion.

TICKS IN RELATION TO TULAREMIA

Tularemia or rabbit fever is widespread in this country, and it is regarded as a serious malady. While it is most commonly contracted by handling diseased rabbits, ticks are clearly of importance as carriers of it. Parker and Spencer, of the United States Public Health Service, have established the fact that the Rocky Mountain spotted fever tick and the common rabbit tick can transmit the disease, and that these ticks are the chief carriers of it among rodents in the Northwest. Parker and Green and Wade have also shown that the disease occurs in quail and other game birds, and it may well be the cause of the epizootics which devastate the wild bird and animal life from time to time. Since these ticks are biological hosts for the disease organism, *Pasteurella tularense*, that is, the infection acquired in one tick stage is passed on to the next, they constitute a sure means of perpetuating and spreading the disease among lower animals, thus increasing the danger to man. A number of instances where human cases have been contracted from the bite of the American dog tick and the Pacific Coast tick (*Dermacentor occidentalis* Neum.) have been found. Probably a number of other species of ticks play a part.

TICK PARALYSIS

In the Western States and in western Canada a number of children have died from a form of ascending paralysis induced by the Rocky Mountain spotted fever tick. This same species has been proved to be capable of causing paralysis in sheep and dogs. While this disease is not common, it is one which is worthy of consideration.

In Australia a distinct species of tick (*Ixodes holocyclus* Neum.) has been found to cause a similar malady in man and sheep. In South Africa still another tick, *Ixodes pilosus* Koch, causes a paralytic disease in sheep, and in Crete still other kinds of ticks appear to be involved in the same way.

The nature of the causative agent of tick paralysis is not known. Some think this disease is due to a specific organism, and others that a toxic material is introduced by the tick during its engorgement. The symptoms usually develop during the latter part of the period of engorgement, at the time blood is being taken in rapidly by the parasite. Apparently only the adult ticks cause the malady. In many cases the symptoms subside if the tick is removed before the paralysis has progressed too far.

OTHER TICK-BORNE DISEASES

Ticks have been convicted of carrying many other diseases of animals. Fortunately a number of these do not occur in this country. However, it is likely that some of them such as bilary fever of dogs and spirochaetosis of chickens are present in this country and have not been identified. It should be pointed out that we have well established in this country the fowl tick and the brown dog tick, which are carriers of these respective diseases. Through rigid quarantine some of the dangerous diseases have been prevented from gaining a foothold in the United States.

East Coast fever, one of the most formidable diseases of cattle in South Africa, is carried by several distinct species of ticks. The African disease known as heartwater of cattle, sheep, and goats is transmitted by the so-called bont tick, *Amblyomma hebraeum* Koch. Fortunately the virus of this disease is not retained in the blood of the animals after they recover.

Other diseases related to splenetic fever of cattle and spirochaetosis of fowls are transmitted among horses, sheep, and goats through the agency of ticks. In India a disease of dogs known as canine anemia has been shown by Dr. S. R. Christophers to be carried by the brown dog tick, in the body of which the causative organism goes through a portion of its life cycle.

No attempt is made herein to catalog all of the diseases in the transmission of which ticks play a part. It should be pointed out that in the case of most tick-borne diseases the disease organism passes a portion of its developmental stage in the body of the tick, and hence the tick is the usual, if not the only, means by which the disease is spread.

THE FOWL TICK

The fowl tick or blue bug, as it is popularly known, (*Argas miniatus* Koch) is one of the most persistent and serious pests of poultry in the Southwest. It is widely spread in Texas, New Mexico, Arizona, and California, and also occurs in destructive numbers in Florida. Although the spirochaete disease which this tick carries is not known to be present in the United States, the tick itself is so insidious in its attack that it is much dreaded by poultry owners. The facts that it can live more than 2 years without food and that it is very hard to destroy with ordinary insecticides adds to its seriousness as a poultry pest.

This tick always provides for its next meal, keeping in close association with its hosts. After the first or seed tick stage it attacks the poultry or birds at night and remains hidden in the cracks and holes near their roosting places during the day. It attacks chickens, turkeys, ducks, and other domestic fowls, and has been found on vultures, quail, and certain other wild birds. Occasionally man is bitten by it, especially when chickens are kept immediately adjacent to sleeping quarters.

The seed ticks immediately after hatching from the eggs are rather active and crawl about at night to seek a host. They attach on various parts of the body, and require from 4 to 8 days to become engorged. In 4 to 10 days they molt their skins and gain a fourth pair of legs. These nymphs, as they are called, feed but a few hours and hide in cracks or under bark, where they again molt. After a third or fourth engorgement they molt to adults. The adult ticks also feed for only short periods, after each of which the females lay from 100 to 250 eggs in the cracks in which they are hidden. (See pl. 2, fig. 1.) Females lay 4 to 7 successive batches of eggs, each preceded by a blood meal. The eggs hatch in 10 days during warm weather.

The methods of combatting the pest are based on its life history. They consist in making all fowls roost on perches which are so arranged as to be easily examined and treated (pl. 2, fig. 2). Nests are constructed which are readily accessible for treatment. The treatment consists of painting or spraying the roosts and nests or the entire inside of the chicken house, if it is generally infested, with the wood preserver known as anthracene oil or with crude petroleum. The introduction of the pests into uninfested houses can be avoided by proper quarantine methods.

THE SPINOSE EAR TICK

The spinose ear tick, known scientifically as *Ornithodoros megnini* Dugès, derives its common name from the spine-covered body of the nymphal stage (see pl. 3, fig. 1) and the fact that it attaches and develops deep in the external ear. This species is a serious pest of cattle and horses in the semiarid portions of the Southwest. It also freely attacks mules, goats, sheep, hogs, dogs, cats, and even man. A single tick attached deep in the ear will cause considerable irritation and pain, particularly in the case of man, and when the infestations in livestock become heavy they cause the ears to droop and a general unhealthy condition to become manifest.

The small six-legged seed ticks are found crawling rapidly about on fence posts, trees, and other objects, and when they are brushed off by a passing animal they soon find their way into the folds at the bottom of the external ear where they attach. The larvae become engorged in about a week. In this stage they are peculiar-looking pear-shaped objects, with legs scarcely visible. The molt takes place in the ear, and the spiny nymphal stage attaches in the same region and begins engorgement. They require from about 3 weeks to as long as 7 months to become fully engorged. They then detach, fall to the ground, and crawl upward on fence posts or trees where they find protected places, molt their skins, mate, and begin laying eggs. Unlike any other tick, this species does not feed in the adult stage, there being sufficient nourishment carried forward from the nymphal stage, to produce its quota of about 800 eggs. The egg-laying habit of this species is rather remarkable in that it is very intermittent. Oviposition usually begins within 8 to 15 days after the nymphs leave the ear of the host, and small batches of eggs may be deposited from time to time over a period of more than six months. This perhaps is an adaptation of the tick to the hot dry condition of the arid Southwest and doubtless helps to insure the perpetuation of the species.

The best method of destroying the ticks in the ears of livestock is by injecting into the outer ear a mixture of 2 parts of commercial pine-tar oil and 1 part of cotton-seed oil. Where the ticks are abundant in the posts of corrals and fences near the congregating places of livestock they may be destroyed by spraying such fences with creosote oil.

THE RELAPSING FEVER TICK

The leathery-bodied tick, known scientifically as *Ornithodoros turicata* Dugès, is related to the two preceding species. (See pl. 3, fig. 2.) It has been definitely connected with the transmission of relapsing fever of man, and very likely is the most important, if not the only species concerned in the transmission of this disease in the United States.

It is found in great numbers in caves in the Southwest from Texas to California and it often inhabits the holes of burrowing animals, and not infrequently invades the habitations of man, particularly in camps. It will undoubtedly feed upon any warm-blooded animal or bird which may come in contact with it, but it is likely that the ticks feed mainly upon rodents or bats.

The eggs are laid in the hiding places of the tick and hatch in about 13 days. The seed ticks, nymphs, and adults are all rather active, and in most cases only a short time is required for engorgement on blood. The females deposit several lots of eggs, each being preceded by one or two meals of blood.

It is obviously impossible to treat the breeding places of this tick with any degree of success, and since it is only occasionally found in the habitations of man about all that can be done is to destroy rodents near camps and other habitations. Occasionally dwellings become heavily infested with this tick on account of the proximity of suitable hosts, and in such cases spraying with tick-destroying materials, or fumigating with hydrocyanic-acid gas must be resorted to.

THE RABBIT TICK

The rabbit tick, known scientifically as *Haemaphysalis leporis-palustris*, is one of the most widely distributed species in this country. It is briefly referred to here because of its importance as a carrier of Rocky Mountain spotted fever and tularemia among rabbits and other animals to which it attaches. It does not attack man and therefore would not transfer a disease directly to him. It is not unusual to find upwards of 1,000 ticks attached to a single rabbit. Undoubtedly the blood loss and irritation due to these pests must have a distinctly adverse effect on the infested animals and birds. This tick also freely attacks quail, meadow larks, and certain other birds. In the case of birds it usually attaches on the head and neck. On rabbits it is found mainly on the ears and about the head. This tick drops from its host for each molt, and this gives ample opportunity for a specimen to pick up an infection in one animal and transfer it to another.

While the females do not lay many eggs, the maximum observed being only slightly over 2,000, all of the stages are relatively long-lived, and the fact that they will engorge upon so many different animals and birds maintains the species in goodly numbers.

Control of the rabbit tick appears impractical on account of its wide distribution and the fact that it feeds exclusively on wild birds and on rabbits.

THE LONE STAR TICK

The lone star tick, *Amblyomma americanum*, derives its common name from the single white spot which appears in the center of the back on the female (pl. 4, fig. 1). This tick is widely distributed in the United States and extends its range into South America. It freely attacks man and various wild and domestic animals. Although it has not been proved to carry any specific disease, its long mouthparts and the fact that it occurs in great numbers in certain areas make it a troublesome pest. Suppuration often follows the bite of this species and, in the case of man, it is not infrequent that the mouthparts are pulled off when an effort is made to remove the tick. This frequently leaves an inflamed and itching spot which may persist for weeks or even months. In Texas the species often becomes very troublesome on goats. Dairy cattle are also seriously affected and the milkers are constantly annoyed, particularly by the males, which crawl off the cattle and attack them. Reports have come to the Bureau of Entomology of serious losses among chickens and turkeys from the attack of the immature stages of this species.

The lone star tick drops from the host for each of its molts, and the seed ticks, nymphs, and adults are all long-lived. The seed ticks have been observed to live more than 9 months, the nymphs more than 16 months, and the adults 13 months. Females deposit from 5,000 to more than 8,000 eggs.

THE WINTER TICK

The species known as the winter tick, or elk tick, *Dermacentor albipictus* Pack., is an important pest of horses, cattle, elk, moose, and deer in many parts of the United States. Recently Drs. Cahn, Wallace, and Thomas carried on experiments which indicated that this tick is responsible for the death of moose in the North Central States, probably through its ability to transmit a specific disease of those animals. In recent years this tick seems to have become more abundant in the Southwest, and is now a troublesome pest of horses and cattle on the ranges in western Texas and New Mexico.

One of the peculiarities of the species is the fact that it is never found on animals during the summer months. The seed ticks attach to their hosts in the fall or in warm periods during the winter and spring. They remain on the animal for each of their molts. The seed ticks refuse to attach to an animal during warm weather but remain more or less dormant in dense clusters until the cool weather of fall when they will readily attach to passing animals.

The fact that this tick develops often in tremendous numbers on elk and moose, and the further fact that it feeds only during the winter time when dipping is difficult, makes control a real problem.

Undoubtedly the pest can be greatly reduced in numbers by dipping infested domestic animals during warm periods at intervals not to exceed one month. Proper pasture rotation will no doubt also tend to reduce its abundance.

THE AMERICAN DOG TICK OR EASTERN ROCKY MOUNTAIN SPOTTED FEVER TICK

In recent years the American dog tick, *Dermacentor variabilis*, has earned the sobriquet of the Eastern Rocky Mountain spotted fever tick. Until this tick was definitely connected with the transmission of this dread disease of man in the East the species was generally regarded as of little economic importance, although at times it becomes quite troublesome as a parasite of dogs, horses, and cattle.

It is widely distributed over the eastern two-thirds of the United States and also occurs in California. In distribution, therefore, it almost occupies the portions of the United States not covered by the Rocky Mountain spotted fever tick. It is especially abundant along the coast from Cape Cod to extreme southern Texas.

It has been found to pass the winter succesfully in the seed tick, nymph, and adult stages. It is very little affected by low temperatures and the immature stages may become attached to animals during mild periods in midwinter at the latitude of Washington. In the spring all the stages of the tick become active and the adults are prone to attack the larger domestic animals and man, although they clearly prefer the dog and its relatives as hosts. The various stages are shown in the accompanying plate (pl. 4, fig. 2, to pl. 7, fig. 1). The ticks drop off the host for each molt. The seed tick and nymphs are found on various small wild animals but appear to prefer meadow mice, pine mice, and white-footed mice. (See pl. 7, fig. 2.) These little animals are very abundant in the wooded country and doubtless the young ticks have little difficulty in finding a host upon which to engorge. It is not unusual for the females to lay from 5,000 to 7,000 eggs, and all of the stages are very tenacious of life. It has been found that the seed ticks, for instance, live at least as long as 12 months, the nymphs 12 months, and the adults 14 months.

The fact that the species feeds upon a number of different animals gives abundant opportunity for them to pick up the organism of Rocky Mountain spotted fever from any susceptible host. This generalized feeding habit also makes control very difficult. The number of the ticks can be distinctly reduced in a given area by dipping infested dogs and other livestock in a suitable tick-destroying material or, in the case of pet dogs, by systematically picking the ticks from the animals to prevent the dropping of any of the engorged females. In removing ticks from dogs it should be borne in mind that there is danger of becoming infected even through the unbroken skin by crushing the ticks in the process of removing them. Therefore, it is advised that the ticks be picked off with forceps and that the hands be thoroughly washed after the operation.

It is advised that tick bites be avoided as much as possible by wearing clothing calculated to keep the ticks off. High-topped shoes laced over army-type trousers help to exclude them. Too much dependence, however, should not be placed upon the exclusion of the ticks, and the body should be thoroughly examined at frequent intervals when a person is working or walking in tick-infested areas. Special attention should be given to the examination of the scalp as the ticks seem to prefer such a location for attachment.

This tick is especially abundant in wooded areas which are heavily grown up with vines and underbrush. This condition not only gives the ticks protection but it also protects the small wild rodents upon which the young ticks feed. This at once suggests the desirability of cleaning out undergrowth and destroying small wild rodents in the vicinity of habitations and camps. In areas where hawks, owls, and other predatory birds abound all that is necessary is to remove the brush cover and thus expose the mice and other rodents to the attack of these birds. Fortunately this disease carrier does not appear to feed to any great extent upon the game birds and animals.

THE ROCKY MOUNTAIN SPOTTED FEVER TICK

In the Rocky Mountains and the intermountain area wood ticks are very abundant. This species has been given the name Rocky Mountain spotted fever tick because it is the principal carrier of this terrible disease of man in that region. This species (*Dermacentor andersoni*) is related to the American dog tick. In general appearance it is not unlike the American dog tick, the body color being a rich reddish-brown and the back of the male tick being decorated with a network of lines. (See pl. 8, fig. 1.)

In addition to its importance as a carrier of Rocky Mountain spotted fever, this tick, as has been indicated, also produces tick paralysis in man and domestic animals and acts as a transmitting agent of tularemia. Furthermore, it is a serious pest of livestock. Its bites are a source of considerable annoyance to people and not infrequently produce rather serious local lesions.

The habits of this tick are very similar to those of the American dog tick. It has been found to feed in its various stages on a large variety of animals, the most important hosts of the immature stages being the mice, ground squirrels, and pine squirrels, while the adults feed mainly upon the larger wild and domestic animals.

Winter is spent in the nymphal or adult stages. The adults appear very early in the spring, often while snow is yet on the ground, and they decline very markedly in numbers during midsummer, relatively few of them being abroad after the 1st of August. The seed ticks usually do not live more than 2 months, but often nymphs survive for nearly a year and apparently the adults often live for more than a year and a half. The entire life cycle usually requires from 2 to 3 years.

The habits of the ticks make their control very difficult. A number of years ago the Bureau of Entomology and the Public Health Service in cooperation with the Montana Board of Entomology attempted to control this pest in the Bitter Root Valley of Montana where spotted fever was extremely virulent. The control efforts were directed against the ground squirrel and other small wild animal hosts, and special attention was given to the systematic dipping of the horses, cattle, and dogs during the spring months for the purpose of destroying the adult ticks. While the tick population was undoubtedly decreased by these procedures it did not eliminate the ticks from any given area. In addition to these control steps it is important to avoid being bitten by these ticks, and particularly not to allow ticks to remain attached more than a few hours at most. As has been pointed out short periods of feeding are not likely to induce the disease.

The Montana Board of Entomology, and subsequently the United States Public Health Service, have done considerable work with the propagation and liberation of a minute wasplike insect which attacks and destroys the nymphal stage of certain ticks. While the results thus far have not been especially encouraging, the importance of this tick as a transmitter of disease would seem to warrant the taking of any steps likely to reduce the number of ticks in a given locality.

THE BROWN DOG TICK

For a number of years many of the dogs in certain parts of Texas and Florida have been greatly annoyed by the attacks of the brown dog tick, *Rhipicephalus sanguineus.* More recently this tick has been spread, largely through the movement of dogs, from infested areas into many parts of the United States. While normally it thrives only in the tropics and sub-tropics, it has been found that where introduced into northern latitudes on dogs which are kept more or less constantly indoors the tick will live and multiply at least for a time in any part of the United States. The species is not only an annoying pest of dogs but is also a troublesome household pest. Where dogs are allowed indoors the ticks drop off and crawl upward, hiding in the curtains, around the window casings. and in protected places about the cornices, behind pictures, etc. It is seldom found attached to any other animal than the dog. It drops off the host for each of its molts. Eradication of the tick from a premises, particularly in the warmer parts of the country, is not an easy matter. It requires constant vigilance and persistent effort. The dogs must be treated systematically with derris powder or some other tick-destroying material at least every 5 or 6 days to prevent the ticks from becoming engorged and escaping. The free use of one of the standard fly sprays which consist largely of kerosene extract of pyrethrum will do much to reduce the number of ticks in living quarters. Infested out-buildings and kennels are best treated by spraying them with creosote oil.

THE CATTLE FEVER TICK

The losses in this country caused by the cattle fever tick have been variously estimated at from $40,000,000 to $100,000,000 annually. These losses come about in a number of different ways, the more important of which are the death loss and stunting effect of the disease itself, the reduction of milk flow, and general condition of cattle due to blood loss and irritation, the inability to bring in well-bred animals from areas where the disease does not occur, and the adverse effects of the disease on the industry due to the inability to move cattle to markets and to feeding areas outside the quarantine line.

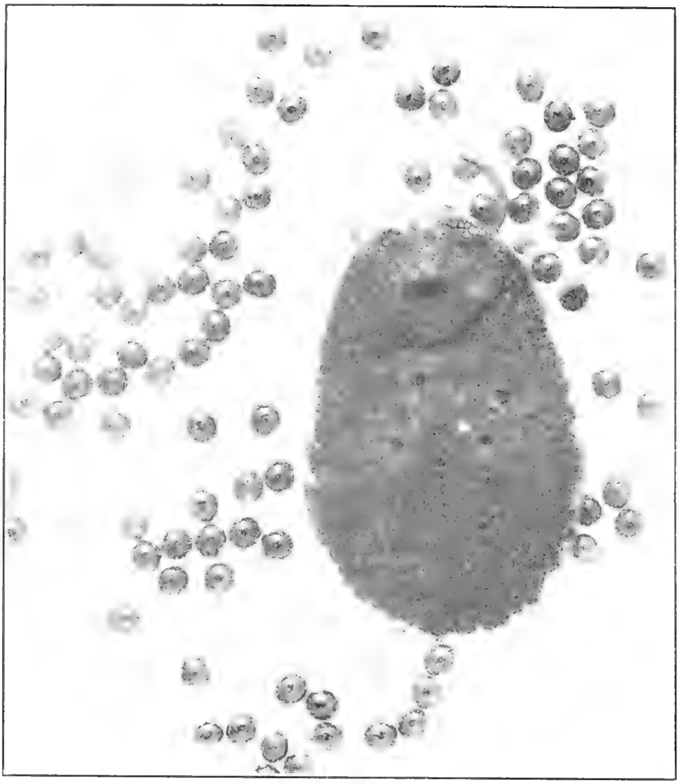
The original area normally infested by these cattle fever ticks covered practically the entire southern United States and a considerable portion of California. But as a result of eradication efforts this area has now been reduced to a relatively small number of counties in Florida and portions of Louisiana and Texas.

This species is primarily a pest of cattle but it also attacks horses and mules and is occasionally found on deer and a few other animals. It remains on a single host for each of its molts, the developmental period requiring from 20 to 60 days. (See pl. 8, fig. 2, and pl. 9, fig. 1.) The females usually begin laying eggs in 2 or 3 days after they drop off the host. These hatch in about 20 days into seed ticks, which crawl on the grass or shrubbery and await the passing of a suitable host.

In hot dry weather the seed ticks may perish in a month, but in cooler and more favorable weather they have been known to live as long as 246 days.

By studying the habits of this tick it has been found possible to destroy it either by systematic dipping of all infested animals at intervals of 2 to 3 weeks or by removing the normal hosts of the ticks from the pastures for a sufficient length of time for the seed ticks to hatch from the eggs and die of starvation. (See pl. 9, fig. 2.) The eradication of this tick from 650,000 square miles of the area originally infested is a monumental accomplishment. The success of this program carried out by the Bureau of Animal Industry, in cooperation with the various States concerned, has been dependant upon the rigid enforcement of quarantines, the education of the people to the benefits to be derived from the elimination of the pest, and a sustained drive from many quarters which has not abated since the eradication program was initiated in 1906.

TYPICAL VALLEY IN MONTANA WHERE ROCKY MOUNTAIN SPOTTED FEVER OCCURS AND THE TICK WHICH CARRIES IT ABOUNDS.

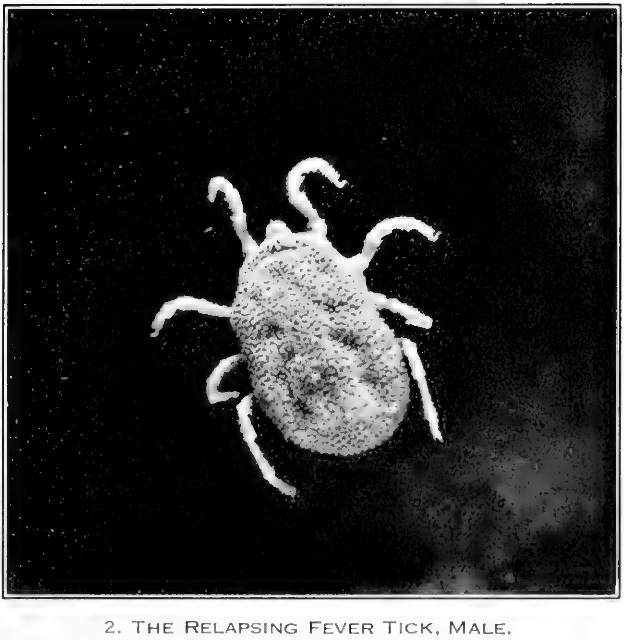


1. FOWL TICK AND EGGS.

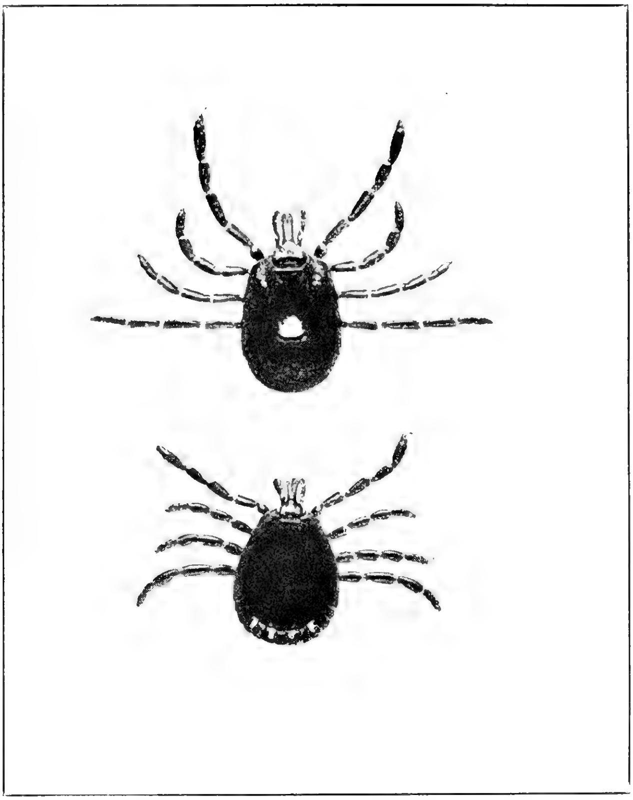
Note the flattened body which enables the tick to hide in cracks.

2. APPLYING ANTHRACENE OIL TO DEMOUNTABLE ROOST TO CONTROL THE FOWL TICK.

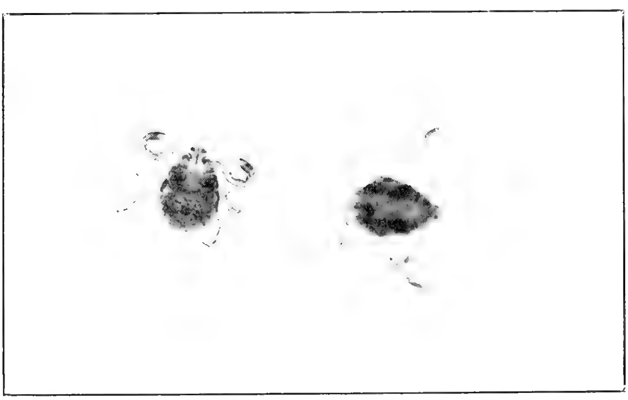
1. NYMPH OF THE SPINOSE EAR TICK.
Note the spines especially on the forward end.



2. THE RELAPSING FEVER TICK, MALE.

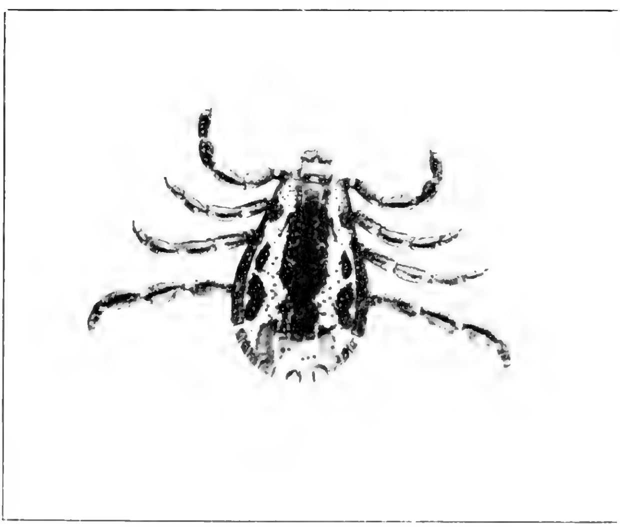


1. LONE STAR TICK, FEMALE ABOVE, MALE BELOW.
Note the white spot on the female which gives the tick its common name.

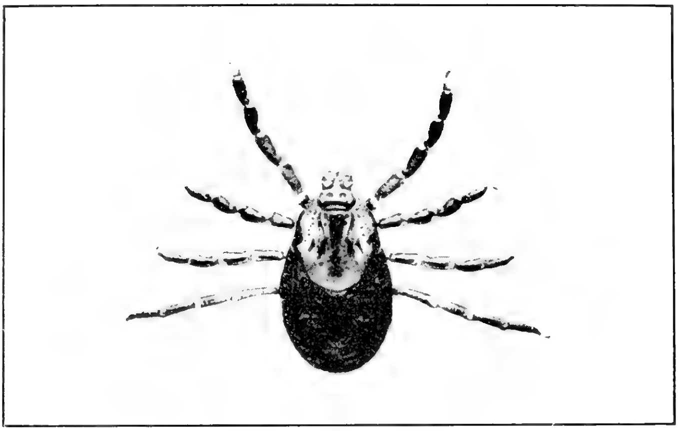


2. SEED TICKS OR LARVAE OF THE AMERICAN DOG TICK.
(Much enlarged.)

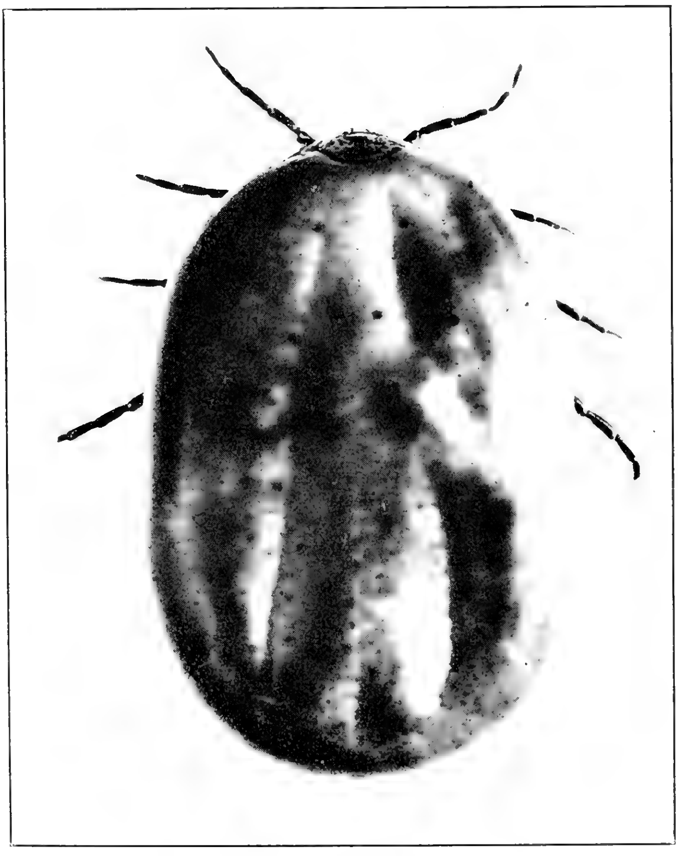
1. UNENGORGED NYMPH OF THE AMERICAN DOG TICK.
(Much enlarged.)



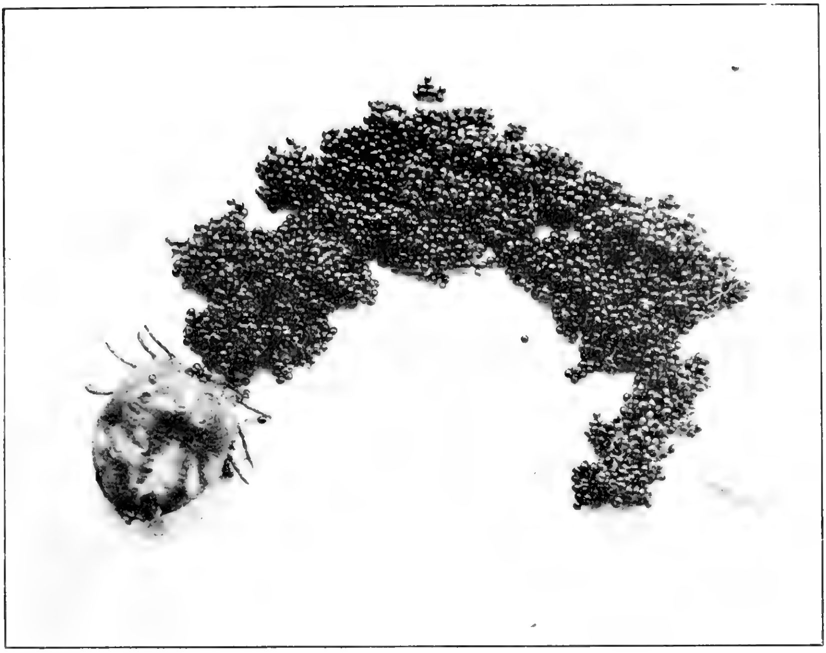
2. MALE OF THE AMERICAN DOG TICK.
(Much enlarged.)



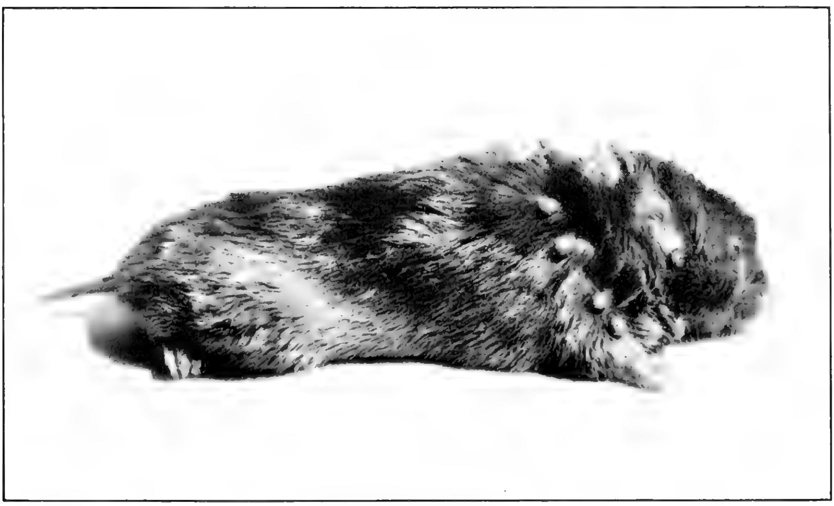
1. UNENGORGED FEMALE OF THE AMERICAN DOG TICK.
(Much enlarged.)



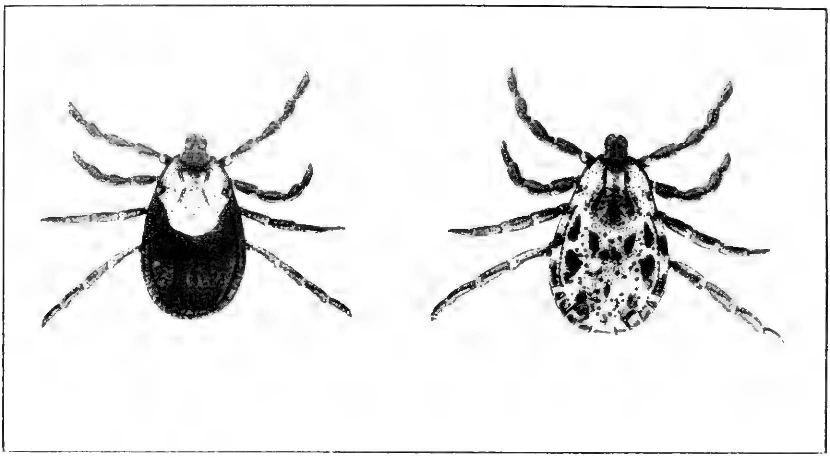
2. ENGORGED FEMALE OF THE AMERICAN DOG TICK.
(Much enlarged.)



1. FEMALE OF THE AMERICAN DOG TICK, WITH MASS OF EGGS.
The tick dies after depositing a single mass like this. (Much enlarged.)

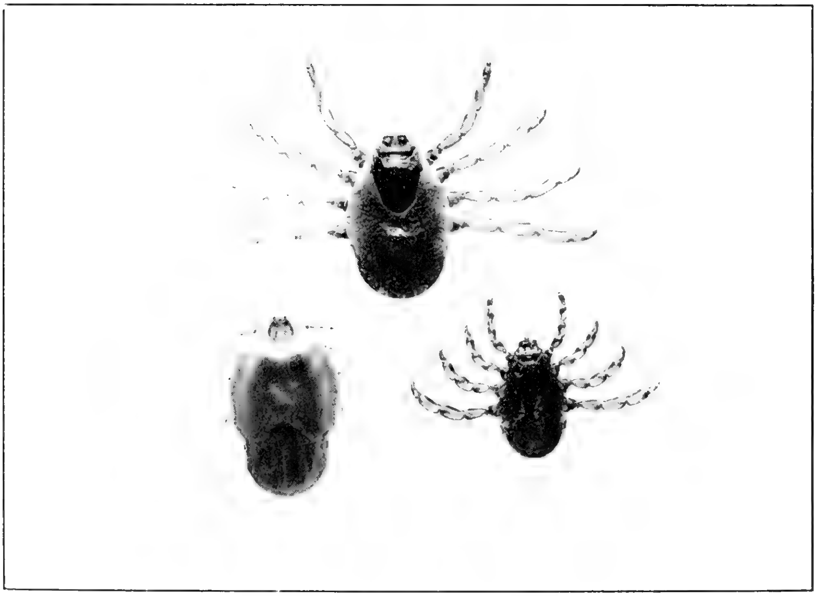


2. PINE MOUSE WITH A NUMBER OF ENGORGED NYMPHS OF THE AMERICAN DOG TICK ATTACHED.



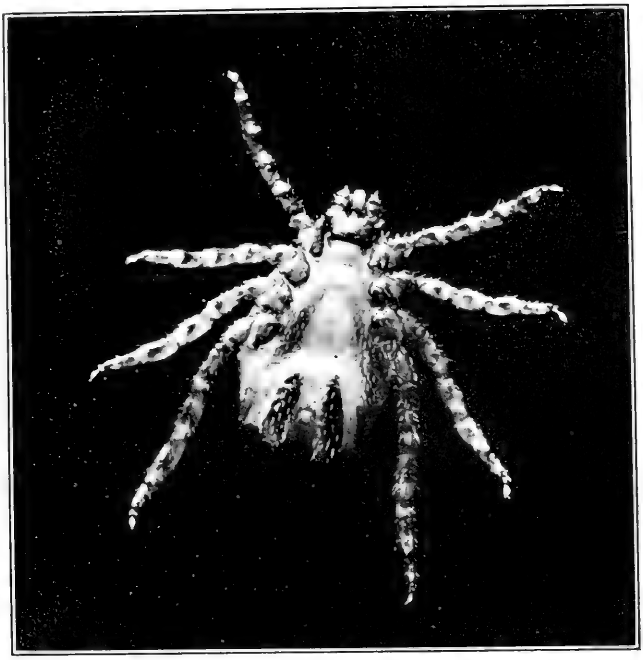
1. THE ROCKY MOUNTAIN SPOTTED FEVER TICK, UNFED FEMALE ON LEFT, MALE ON RIGHT.

(Much enlarged.)

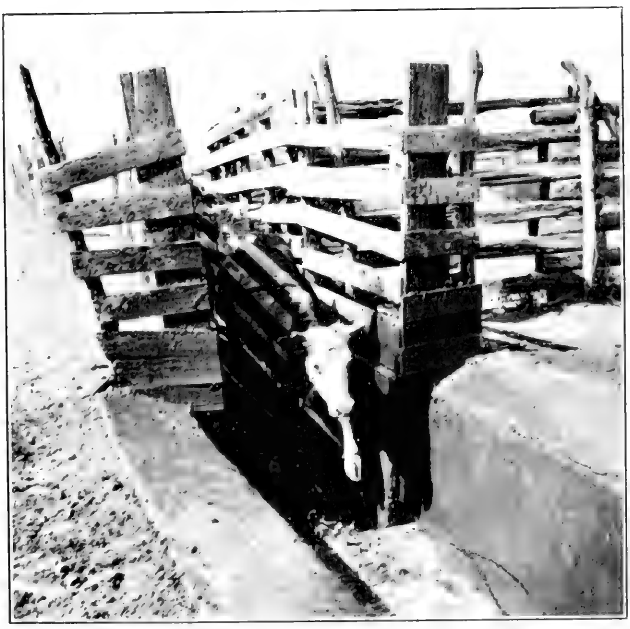


2. THE CATTLE FEVER TICK, UNENGORGED FEMALE ABOVE, ENGORGED NYMPH LOWER LEFT, AND MALE LOWER RIGHT.

(Magnified about 8 diameters.)



1. UNDERSIDE OF A MALE OF THE CATTLE FEVER TICK.
(Magnified about 16 diameters.)



2. COW ENTERING A DIPPING VAT CHARGED WITH ARSENICAL SOLUTION FOR THE PURPOSE OF DESTROYING THE CATTLE TICK.

THE FOREHEAD[1]

By Aleš Hrdlička
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One of the chief features of man in esthetics, in the popular mind and popular literature, in art, and in the mistaken old doctrines of the "phrenologists" and "physiognomists", the forehead has received unexplainably little attention in science, save as to an occasional descriptive characterization.

In anthropometry, outside of my own work, the only measurements taken on the forehead, and they but occasionally, were those of the minimum frontal diameter and those relating to frontal bulging or slope. The sloping forehead, regarded generally as a sign of inferiority, received especial attention, though mostly only descriptively. The most important dimension of the forehead, its height, was almost totally neglected. The only data on its measurement are those of the artists and are embodied in a few of the artists' "canons."

The oldest of these canons or artists' standards in which the height of the forehead is dealt with is that of Jean Cousin and dates from the latter half of the sixteenth century.[2] In this the height of the forehead, between the eyebrows and the hair line, is given as equal to the length of the nose, which equaled one thirty-second of the stature. This canon, modified somewhat by Blanc, became the lasting standard of French artists.[3] In this eventual form it stipulated that the forehead, from hair line to the root of the nose, was equal to one nose length, which in turn equaled one-thirtieth, or 3.33 percent, of the stature.

The reasons why workers in anthropology failed to measure the height of the forehead was the uncertainty of the landmarks. Whether one should choose the line of the eyebrows or the root of the nose for the lower limit, the point was more or less indefinite, and the same appeared to be true of the upper limit, which was considerably affected by the variation in hair insertion, and in whites by the early loss of hair in that region in many male individuals.

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[1] Reprinted by permission from Proceedings American Philosophical Society, vol. 72, no. 5, 1933.

[2] Livre de Pourctraiture, Paris, 1571.

[3] Topinard, P., Eléments d'Anthropologie gén., Paris, 1885.

My own interest in the measurement began almost with the commencement of my anthropometric work, in the middle nineties of the last century. Feeling the value of this determination I endeavored so to regulate the landmarks that they could always be followed with the least possible difficulty. The precision of the upper landmark was fairly easy. It was seen that in the majority of people the hair line over the forehead formed a fair arch on which it was easy to mark the point needed and which corresponded to the meeting of this arch and the central vertical line of the front. In numerous individuals, however, particularly males, the hair in the median line extends more or less downward in the form of an angle; where this exists it is disregarded, the hair arch being completed above it and the median point marked on it as usual. As to the lower landmark, I tried simultaneously both the interbrow point and nasion, which led to the final adoption of the nasion. Here a considerable uncertainty was met with and had to be overcome. There are many living of both sexes in whom the nasion can be detected certainly neither by sight nor by touch. The only way to determine its location with sufficient accuracy was found to be a thorough acquaintance with it in skulls, and through extended direct comparison of the skulls with the living. In that manner alone can proficiency be gained and a generally reliable measurement be assured. Even then there will doubtless be occasional errors, but these will not be large and will tend to compensate each other in the larger series.

It was on this basis that measurements of the height of the forehead have been carried on in all my anthropometric work since 1898. The procedure was and is to determine carefully and mark the hairline point as well as the nasion, and then to measure with the head calipers from the lowest point of the chin the two heights of the face (menton-nasion, menton-crinion); the difference between these gives the height of the forehead. When the observer is well experienced, after years of effort, he may do away with the marking, but this is safer and to those with less experience indispensable. Under such conditions the results of the measurements on adequate series of subjects are quite reliable.

My accumulated data on height of forehead extend now to many groups of the Indians, to some Egyptians,[4] to old American and a number of groups of the Old World whites,[5] some Negroes [6] and the Alaskan Eskimo.[7] The most recent series of whites is a highly interesting and representative group of prominent brain workers, mem-

[4] The natives of Kharga Oasis, Egypt. Smithsonian Misc. Coll., vol. 59, 1912.
[5] The Old Americans. Baltimore, 1925.
[6] The full-blood American Negro. Amer. Journ. Phys. Anthrop., vol. 12, pp. 15–33, 1928.
[7] Unpublished.

bers of the National Academy of Sciences. The subject is thus so advanced that it justifies a summing up and a presentation of the results.

The data at hand are to be considered in relation to three chief problems. The first of these is that of the correlation of the height of forehead with intellectuality; the second is that of racial differences; and the third that of differences in the two sexes.

FOREHEAD AND INTELLECTUALITY

Thanks to the measurements taken recently on the members of the National Academy, men who unquestionably represent the intellectual leaders in their lines, it is now possible to get some fairly definite light on the mooted question of the relation of the height of the forehead to brain superiority.

There are four excellent groups for comparison. The first is the standard group of old Americans,[8] comprising normal men in all walks of life. The second is that of the old American highlanders of northeastern Tennessee—one of the most belated groups educationally and otherwise in this country. The third group comprises old American members of the National Academy, and the fourth takes in members of the Academy regardless of derivation.[9]

The data on these four groups follow:

Height of forehead, males

		Centimeters
510	Old Americans at large	6.59
118	Old Americans: Tennessee Highlands	6.57
25	Old Americans, members of the National Academy	6.57
32	Members National Academy, irrespective of nationality	6.58

If the height of the forehead is any index whatever of brain activity and grade, some material difference should certainly appear in the dimension between the mountaineers and the members of the Academy; but there is no such difference. Instead, the two groups, so far apart in mental differentiation, have foreheads of the identical mean height. And this is true of all the four groups under consideration. The agreement is in fact most astonishing and beyond normal expectation with a measurement of such a nature. Yet it is no accident, for the proportions hold steady when tested on fair subdivisions of the groups.

There are few if any occasions when anthropology could dispose of data of such a very desirable nature. Groups were studied of

[8] At least 3 generations American-born on both sides of the family.

[9] As many of the members of the Academy are advanced in years, the numbers of those in whom no hair had been lost over the forehead is not large. There were 118, actually, in whom the height of the forehead could not be secured for this reason.

much the same derivation, much the same mean stature, but from the extremes of mental training, work, and achievement, and to a large extent also from the extremes of environment and habits. Yet no difference in the height of the forehead is found—nor, it may be said at once, in any of its other essential characters. This permits but one possible conclusion, which is that the lowness or height of the forehead, in normal human beings, does not express or have any relation to the kind of brain it helps to harbor. This will be further confirmed in what follows.

FOREHEAD AND RACE

Equally remarkable and unexpected conditions as those shown in the preceding section appear from the study of the forehead height in different races. The next table shows the dimensions in four important human groups.

Height of forehead, males

No.	Group	Centimeters	Relation to stature (S=1,000)
510	Old Americans at large	6. 59	37. 8
1, 239	American Indians	6. 62	39. 7
19	Fullblood young to middle-aged American Negroes	6. 98	41. 4
181	Alaskan Eskimos (Kuskokwim region)	7. 16	44. 2

All the measurements in the above series were made by myself, by the same method and with one and the same set of accurate instruments. Should there be any bias, it would affect similarly all the groups, for their measurements interdigitated in time; but the procedure is based too rationally to permit of much bias in any direction. If the facts are contrary to the anticipation, they are none the less realities. They do away completely with the idea that high forehead, in general, indicates a high intellectuality, or that it is a mark of racial superiority.

In both the absolute height of the forehead and its relative value to stature, the white old Americans at large—certainly one of the best of stocks in every way—stand not at or even near the head but at the foot of the four groups. They are surpassed in height of forehead by the Indian, still more so by the Negro, and most by the Eskimo. In the absolute measurements the differences in males in favor of the Indian are only one-half of 1 percent, but in favor of the Negro they amount to nearly 6, in favor of the Eskimo nearly 9 percent; and the last column of the table shows that these differences are even more marked in the relative height of the forehead to stature.

It is regrettable that there are no comparable data on the Asiatic yellow-browns, on the Negrillo and Negrito, and on the Australian.

HEIGHT OF FOREHEAD IN DIFFERENT BRANCHES OF THE WHITE PEOPLE

Thanks to the measurements taken since 1910 under my direction by medical members of the United States Health Service at Ellis Island, there are now available data on 14 nationalities of male white immigrants. These data include the height of the forehead, and the means of these, on the whole, are remarkably uniform, as well as closely related to those obtained by myself on the old Americans; yet there are also interesting differences. The absolute measurement, and its per mille relation to stature, follows:

Height of forehead in Old Americans and in immigrants

Absolute measurements	Centimeters	Height of forehead relatively to stature (S=1,000)	Centimeters
Armenians (25)	6.0	Armenians	35.9
Hungarians (50)	6.3	English	37.3
French (64)	6.35	Russians	37.4
Russians (50)	6.35	French	37.4
English (10)	6.35	Old Americans	37.8
Greeks (50)	6.4	Greeks	37.9
Rumanians (50)	6.5	Croatians	37.9
Croatians (50)	6.5	Hungarians	38.0
Poles (50)	6.5	Poles	38.2
Northern Italians (50)	6.5	Germans	38.3
Russian Jews (50)	6.55	Northern Italians	38.4
Southern Italians (50)	6.55	Rumanians	38.5
Germans (63)	6.55	Irish	39.3
Old Americans (510)	6.6	Russian Jews	39.7
Irish (32)	6.7	Southern Italians	40.1

The lowest forehead, and that both absolutely as well as relatively to stature, is shown by our group of Armenians, and the differences are large enough to be significant. The Armenian unit possesses also the smallest head of the 14 immigrant groups,[10] but their forehead is low even in relation to the smaller head. This may be an accidental showing. The Armenians are renowned as the shrewdest tradesmen of the Near East. If their forehead is low it must be, it would seem, of the nature of a localized racial character.

The next poorest showing is that of the Hungarians, but this is rather close to that of other white groups.

At the top of the series of forehead heights stand in absolute measurement the Irish and the Old Americans; relatively to stature, the short Russian Jews and the Southern Italians. There is a suggestion in this that the present lowered stature of these two groups is a secondary acquisition; the slight old Negro admixture in both the Southern Italians and the Jews could hardly alone account

[10] See my Old Americans, p. 235.

for the conditions. In the Old Americans, owing to their high stature, the height of forehead-stature relation is below the general medium. The position of the Irish, of whom only 32 had been measured, may be somewhat accidental.

While the data on these immigrant series cannot be regarded as perfectly representative of the different nationalities, owing to the limited numbers of subjects, with the wholly accidental selection of these and hence perhaps biased composition, nevertheless it is plain that barring one real and a few possible exceptions, the groups reflect a substantial racial similarity.

HEIGHT OF FOREHEAD IN THE TWO SEXES

The height of the forehead, it was seen above, presents unexpected and interesting similarities as well as differences both socially and racially; the data to follow demonstrate that it also shows interesting conditions in the two sexes:

Relation of absolute height of forehead of females to that of males (males = 100)

	Percent
Old Americans	97.9
American Indians	92.3
American Negroes	99.1

Height of forehead in the two sexes relative to stature

Group	Males (per mille)	Females (per mille)	Females: Males (males=100)
Old American	37.8	38.0	*100.5*
Indians	39.7	39.5	*99.5*
Negroes	41.4	43.8	*105.8*

The main result that appears from these figures is that the relation of the height of the forehead in the two sexes shows distinct differences in the three main American races. There are not many features of the human body that could show such irregularities.

The forehead of a white woman may be taken as a standard. Its absolute height is 2.1 percent lower than that of the male, but when compared to the stature (and also the size of the head—see my "Old Americans") it actually makes a better showing than that of the male.

The forehead of the Indian woman absolutely, as well as relatively to stature (and size of the head), is decidedly lower than that of the white woman. This lowness of the hair-free part of the front in the Indian female is in some instances very striking. It is not due generally, it may be said at once, to a low vault of the skull, but to a low extension of the hair.

In the American Negro the female forehead in absolute height is even nearer that of the male than in the whites, and exceeds considerably that of the male relatively to stature. The small number of available Negro subjects makes definite conclusions impossible, but the indications are very manifest.

INDIVIDUAL DIFFERENCES

The height of the forehead in each group examined was found to show extensive individual variation. The range of this is shown in the figures below. It exceeds considerably that of facial height [11] and all other facial and head measurements, except ear length. As with most other dimensions, it is appreciably greater in the male than in the female. Racially, though the figures are affected by the unequal and in one or perhaps two cases by inadequate numbers of subjects, it is evidently greatest in the American Indian.

CAUSES

The data given in this paper show definitely that, in general, the height of the forehead is unaffected by mental development, but is subject not only to large individual but also to substantial racial and sex differences.

Range of individual variation in height of forehead

Group	Range of variation	Difference (d)	Mean (m)	Extent of variation $\left(\frac{d\times 100}{m}\right)$
MALES				
Old Americans (510)	5.1 to 8.3	3.2	6.58	*48.6*
American Indians (1,091)	4.0 to 8.4	4.4	6.64	*52.4*
Eskimo (182)	5.3 to 8.6	3.3	7.16	*46.1*
American Negroes (20)	5.2 to 8.1	2.9	6.98	*41.5*
FEMALES				
Old Americans (207)	5.2 to 7.8	2.6	6.45	*40.3*
American Indians (453)	4.7 to 7.8	3.1	6.11	*50.7*
Eskimo				
American Negroes				

Both the race and the sex differences are of a peculiar nature. The race differences, except perhaps in the Negro, show but little taxonomic (classificatory) value. They are apparently largely incidental. The sex differences are not harmonious in the different groups, which is exceptional. In the white and the Negro they favor the females; in the American Indian [12] the condition is reversed.

[11] See my old Americans, pp. 393–394.

[12] As well as in the Eskimo, according to my impression.

All this naturally stimulates the inquiry into the causes of these phenomena. And the first direction of the inquiry turns to the skull. Is not a low or high forehead conditioned by low or high frontal part of the skull? Observation shows that exceptionally low or high front is to some extent attended by low or high forehead in the living; but if such extremes are eliminated it soon becomes manifest that there is but little correlation between the two. What differs is not so much the height of the bony front as the extension downward of the hairline. The variation in the height of the forehead in the living is essentially a variation in the height of the hairline, regardless largely of the underlying skull.

What causes the variation in the normal hairline can only be determined by further research. It is certain that low or again high foreheads "run in families." And it is plausible to accept that under the influences of segregation, isolation, and perhaps some form of conscious or unconscious selection, lower or again higher foreheads may become generalized in a locality or in a racial group. The case of the Indians suggests that an important part may have been played by sexual selection.

In addition, some causes of different lowness or height of hair insertion over the forehead may possibly lie in the hair system itself, with its blood supply and innervation; but it would be difficult to state precisely any definite factors in this connection.

THE HISTORICAL SIGNIFICANCE OF TEPE GAWRA

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[With 6 plates]

I

As recently as the year 1927 the name Tepe Gawra meant nothing at all to the archeological world. If it had appeared in print, Near Eastern specialists would promptly have recognized in it a designation of some ancient mound. To many of them the term *tepe*, instead of the Arabic *tell*[1], would have conveyed the indication that the mound in question must be sought in Turkish, Kurdish, or Persian territory. Not a few might have given *gawra* its correct equivalent of "great." But all this is purely hypothetical. The "Great Mound" had not been mentioned by name in the scientific literature devoted to ancient remains.[2] Though its location was occasionally noted, for an artificial hill rising to a height of more than 70 feet is not easily overlooked, the site remained anonymous even on the most elaborate survey maps. Only in a few neighboring villages, to the north of the Mesopotamian city of Mosul (fig. 1), did the name stand for a definite landmark. In the city itself, barely 15 miles away, the mound is still called after one Ali Beg, a former owner of the district. The nominal "greatness" of Tepe Gawra was thus a matter of strictly local terminology.

Now within the brief space of 7 years the situation has undergone a startling change. Today Gawra is one of the most frequently mentioned sites in Iraq. References to this place are to be found not only in the publications of Mesopotamian archeologists, but also in general works on the ancient civilizations of the Near East.[2a] Such a rapid rise to prominence from all but complete obscurity cannot

[1] In reality, the word *tell* occurs in the Old Testament, and it goes back to Akkadian (Assyrian) *tillu* "ruin."

[2] The irrepressible Layard opened some trenches at Gawra three-quarters of a century ago in search of Assyrian sculptures, which of course were not there. But he does not mention the mound by name. See his Discoveries in the Ruins of Nineveh and Babylon, p. 132, 1853.

[2a] See now Childe, New Light on the Most Ancient East, pp. 260–268, 1934.

have occurred without adequate reasons. It must be that the story buried in the long-forgotten mound has proved to be, upon being pieced together from the various remains recovered, of far more than local significance. To trace that story in terms of the successive civilizations preserved in the stratified deposits of Gawra is the purpose of the present paper. Only the principal features can be touched upon in a general account of this nature, the full details being re-

FIGURE 1.—Map of Mesopotamia.

served for a more technical study. But before we are ready for the presentation, it will be in order to explain how the mound came to be dug at all.

Various factors may lead to the excavation of a given site. In the early stages of Mesopotamian exploration attention centered on the largest ruins as the most likely sources of sculptural material. Nineveh, Dur-Sharrukin (Khorsabad), and Calah (Nimrud), all of them former seats of Assyrian royalty, have their size to blame for attracting the spade of the excavator; and the British Museum and the Louvre owe to the same circumstance some of their finest collections. Historical prominence has also been instrumental in equipping many an expedition. Once a site has been identified as that of Babylon or of Ur, there is no lack of bids for excavating permits; connection with the Bible is in such cases a very powerful incentive. Other centers come to be uncovered through sheer accident. The peasant's plough accidentally striking a buried vessel may lead to the most important discovery of a decade; the great finds at Ras Shamra, in northern Syria, which include epics in pre-biblical Canaanite written in a new form of alphabetic script, are due to precisely such a strike on the part of an unsuspecting peasant. In short, expeditions are attracted in the main to sites that have proved or promise to be productive of museum objects or of inscriptional material. The cost of a modern excavation is considerable, and reasonable assurance of material results is therefore a not unnatural prerequisite.

Gawra, however, could never have been started on that basis. Judging by the above standards, the first examination was discouraging. Intrinsically valuable finds were unlikely and only inveterate optimism could have encouraged an expectation of written records. But the mound proved fascinating, nevertheless, for a number of different reasons, and it may not be amiss to give these briefly. I shall lead up to the subject by stating the occasion which was to culminate in the excavation of the site.

In the year 1926 the American School of Oriental Research in Baghdad, cooperating with the Dropsie College of Philadelphia, undertook an archeological survey of northern Iraq. I had the privilege of being given the assignment. The task carried me from the Persian border in the east to the western slopes of the Sinjar hills which cross the Iraq-Syrian border. In the course of this surveying tour surface examinations were made of several hundred mounds, many of which turned out to belong to the prehistoric period. Conclusive evidence in each case was the presence of a characteristic type of painted pottery accompanied by implements and weapons of obsidian and flint. The discovery of a continuous belt of archaic sites (isolated mounds of that type had been found several years earlier) was particularly noteworthy in view of the fact that the relative antiquity of Mesopotamian civilizations was still very much a matter of dispute. It became thus manifest that the Chalcolithic age—i.e., the period of transition from Late Stone to Early Copper—was well represented on the eastern and northern fringes of Mesopotamia. But what was the length of that Chalcolithic period? The question could be answered only after a brief dig on some chosen site.

Gawra was visited during one of the concluding stages of the survey (pl. 1). The tall conical mound outlined against the foothills of southern Kurdistan was bound to impress at the end of a wearisome Iraqian afternoon. Yet the appeal was not purely esthetic. My somewhat perfunctory interest gave way to astonishment when it became apparent that here was beyond any doubt the oldest site that the country had yet presented. Tell-tale painted sherds and archaic implements covered the slopes of the lofty mound practically all the way to the top. If the upper strata contained Chalcolithic deposits, what date was to be assigned to the lowest layers?

One other factor helped to make fascinating the strictly archeological prospects of Tepe Gawra. A long series of prehistoric strata lay here above ground. Their excavation would entail therefore no serious technical difficulties, particularly since the hill was narrow and hence suitable for the removal of complete layers. A wide tell calls for digging in sections, with the inevitable result that the continuity of the given strata is disturbed to some extent. To obtain a cross-section of the accumulated deposits one must resort in such cases to trial "pits", digging underground and limiting the area of the sounding as one descends. This method is of course the only one that will yield the desired information within a comparatively brief period of time. But it is cumbersome and costly, imposing great hardships on the excavator and producing results that are necessarily tentative. It has been employed within the last few years in Ur, Warka (Erech), and Nineveh;[3] also in such Palestinian sites as Megiddo and Beisan. In 1927, however, the general interest in the prehistoric remains of the Near East had not been aroused to a point where it would warrant such experiments on a large scale. At Gawra, on the other hand, there was no need of elaborate subterranean operations, and that was one of the reasons why the mound seemed to be such a valuable find. It represented the contents of an ideal pit all exhumed, as it were, and arranged neatly in a definite order; with the added advantage that the oldest remains, preserved for once at the base of this uninverted cone, were bound to be more plentiful than the others. The analysis of the contents could be effected in this case with considerable economy of effort and expenditure.

And yet, in spite of all this good fortune which all but betokened the friendly intercession of some cosmic patron of archeology, the examination of the site had its discouraging aspects. Were the prospects of Gawra attractive enough from a practical standpoint

[3] Cf. Amer. Journ. Archaeol., vol. 36, pp. 465–471, 1932.

to induce a systematic excavation? To be sure, the mound bid fair to settle some difficult problems of relative chronology. But its very antiquity seemed to preclude the possibility of discovering written documents. By the same token, the chances of finding enough display objects to make the work worthwhile for a museum appeared hopelessly remote. Institutions which must depend for their funds on the enthusiasm of donors are naturally reluctant to undertake a task that promises no adequate return in tangible results. Museum directors get little praise for announcements that this or that expedition has met with pronounced "scientific success"; and they rarely control endowments ample enough to liberate them from a measure of sensitiveness to popular response. This happens to be the sad truth in the majority of instances.

Before sending my report to the sponsoring institutions at home I inquired about Gawra in the nearby village of Fadhiliyah. Had rains ever washed up anything besides sherds and flints? No; the mound was a total loss, containing no "treasures" of any sort and being much too steep for cultivation. This reply was of course incorporated in my recommendation to excavate Gawra for the sake of the information which it contained.

At that time the American Schools had not been favored as yet with a grant from the Rockefeller Foundation which was shortly to enlarge considerably the scope of their work in the East; nor was the Dropsie College in a position to undertake larger archeological tasks. When I was informed, therefore, a few weeks later that a small sum had been set aside for a trial dig at Tepe Gawra, I could appreciate the effort behind this minor financial operation. The rest was more or less a matter of routine. A permit to excavate was promptly granted by the Iraq Department of Antiquities. The owner of the land, a venerable scion of an old Arab family, generously ceded the mound to the expedition. Our staff included an architect, who worked for a practically nominal salary, and a volunteer recorder. A small gang of workmen was organized, and in October of the same year we were ready for the dig. The funds were of course exhausted before the end of the month, but by that time the future of the excavation had been assured. For our two trial trenches not only confirmed our original estimate that the mound would prove to be a mine of information, but they also uncovered important architectural remains which included a prehistoric shrine, and a fine collection of valuable and instructive objects. The results were published in the Annual of the American Schools of Oriental Research.[4]

[4] In vol. 9 (1929) under the title "Preliminary excavations at Tepe Gawra."

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Following a return to teaching duties at the University of Pennsylvania, I was delegated to lead another expedition to northern Iraq in the autumn of 1930, the University Museum and the American Schools cooperating in the undertaking. Our principal object was the excavation of Tell Billa, a large mound situated 8 miles east of Gawra. But the latter site had not been forgotten. Through the generosity of one of its governors the Dropsie College was enabled to participate with the two other institutions in further work at Tepe Gawra, to which we devoted 6 weeks in the spring of 1931 and 5 months in the season of 1931–32. The brief account which follows is based on the results of these three campaigns which required a total of 7 months of increasingly intensive work.

II

Owing to its conical shape, the upper stages of Tepe Gawra contained strata that were small in extent and easy to excavate. They were speedily studied and removed to make room for the layers below. Nor were the topmost layers notable for their depth. The later inhabitants of the site were compelled to remove the accumulated debris of the preceding occupations virtually down to their respective floor-levels, before new structures could be erected; otherwise the available area would have been too limited for practical purposes. With each lower level there is an increase in size and generally also in depth. Stratum VI was a crowded settlement compressed into a space of some 130 by 200 feet. Additional space was obtained by terracing the slopes of the mound. The buildings were preserved in several instances to a height of 6 feet, and they generally bore traces of repeated alterations. Stratum VIII was considerably larger. It proved to consist of three distinct sublayers, representing three phases of the same archaic civilization. The latest township of this stratum had survived to a height of 15 feet, imparting a remarkable depth to a layer that was to be followed by seven others, each superimposed on the preceding one.

By the end of our third campaign we had succeeded in removing eight main levels (not counting the substrata), the Gawra cone becoming truncated down to one-half of its original height. It is as yet impossible to estimate accurately the total number of layers that remain to be excavated. The lower and older half of the mound is known to us so far from the results of our trial soundings, hence the picture of the period can be given only in the broadest outlines. The upper half, however, is now exclusively a matter of record, for it exists no more in reality except in a series of secondary heaps of recently sifted debris. It is on this period that we shall naturally wish to concentrate.

EARLY GAWRA

The first settlers established themselves at Gawra at some early stage of the fifth millennium B.C. This general date is obtained by counting back from the established age of Gawra VI, which starts, as we shall see, at about 3000 B.C. The six strata from Gawra VI to Gawra I cover a span of 15 centuries. From Gawra VI down to the lowest layer the number of occupations is considerably larger. It is certainly not less than 10, probably more; a definite number cannot be given before virgin soil has been reached. At any rate, two millennia will be considered a conservative estimate for the duration of the settlements prior to Gawra VI. To come back to the earliest inhabitants, on present evidence they may be said to have made extensive use of painted pottery. There may exist still lower layers, not reached by our trial trenches, in which the pottery will prove to be undecorated. That reservation must be made. But the earliest settlers whose remains we have discovered specialized in painted wares. Their weapons and implements were made of flint, and of obsidian imported from the Armenian mountains. A certain amount of commercial travel is thus clearly established for this remote archaic period.

Who were these pioneer settlers, and from what district did they arrive to take up habitation in the Middle Tigris valley? The question is not merely one of local interest. The answer will apply to the first inhabitants of Mesopotamia as a whole, for related remains have been found recently in other sites of comparable antiquity, in Lower Mesopotamia as well as in the region of Nineveh. That is, when an answer is at length obtained. For the present it is a matter of much dispute.[5] The probability is that these visitors came in from, or by way of, the neighboring mountains of Kurdistan or Western Persia. Certain it is that the painted pottery technique maintained itself through many occupations. In the subsequent stages of Gawra we find parallels with the fabrics of Tell el-Obeid (near Ur) early Susa, Baluchistan, and even Neolithic China. By that time, however, many diverse influences were evidently at work. It is not necessary to assume that the racial stock remained the same merely because the people continued to decorate their pottery with painted designs, nor would such an assumption be plausible on the face of it. If we group together the makers of these early civilizations on the basis of the general resemblances of their wares, it is solely because criteria for a finer differentiation are not available just now. In course of time we shall be able to analyze this composite picture into its component elements. We shall then know more about the human characteristics behind these very ancient

[5] For literature on the subject see Amer. Journ. Archaeol., vol 37, pp. 455–466, 1933.

cultures. And no site is more likely to shed light on the subject than the mound whose biograph we are now engaged in following. The clear stratification of Gawra and the accessibility of its lower levels should help to settle the problem of the origin of the earliest Mesopotamians once and for all.

One cultural innovation of paramount significance helps to break up the early phase under consideration. In the lowest layers of Gawra there is no trace of the use of copper; the people were manifestly in the Neolithic stage. The metal makes its first appearance towards the end of the painted pottery occupation, thus ushering in the Chalcolithic era, during which stone was still the mainstay while copper, in its hammered form, was being gradually popularized. Many centuries were to pass before it ceased to be a luxury.

The stone work, whether in implements or in ornaments, is uniformly high in quality. The seal cutter and the maker of amulets have to satisfy steadily growing demands for their products. Only stamp seals are in use, pierced for suspension and adorned with incised animal designs. Terra cotta figurines of nude goddesses help to emphasize the cult of the powers of fertility. Beads are manufactured in great quantities.

MIDDLE GAWRA

This period is in some respects the finest that the site witnessed in more than three millennia of its history. The peak is reached with Gawra VIII, which may be dated safely to the middle of the fourth millennium B.C. We are now at the height of the Chalcolithic era, still some centuries removed from Early Bronze which is introduced in this instance by Gawra VI. Subsequent epochs may have commanded greater wealth as reflected in the abundance and variety of material objects. But Gawra VIII enjoyed something that was far more precious; its builders display faultless taste and an unerring sense of balance. The glory of this age is not its pottery, nor its jewelry or sculpture; it is in the consummate mastery of architectural design that these prehistoric artists really prove supreme.

Gawra VIII is properly an acropolis, the history of which can be traced through three structural stages. The successive alterations, extensive enough to alter the plan of each substratum, reflect accurately the changing social and economic conditions of the period. The fathers of this occupation built the township around four temples; each of them shows variations in design, but the whole is in harmony with a preconceived plan of the site. Spacious approaches enable the structures to stand out prominently as individual units, surrounded by gardens and courtyards.

The next generation fails to maintain the same high artistic standards. The fame of the shrines must have spread abroad and the site suffers from overcrowding. New buildings are added, detracting from the restful appeal of the acropolis; gone are the gardens and the spacious courtyards. In course of time, however, a healthy reaction sets in. The site is rebuilt, the temples alone being reverently preserved or restored. The whole is again pleasing to the eye, but the original spirit of measured restraint cannot be completely recaptured.

Many features combine to make this remote archaic stage of fundamental importance for the history of architecture. For the purposes of the present account a few details will have to suffice. As a typical example of contemporary design let us take the Western Temple (pl. 2, fig. 1) which was built at the very beginning of Gawra VIII. It is a rectangular structure with its entrance on the short side. The door is sheltered by an entrance porch or *liwan*, an entirely unexpected refinement in prehistoric building. From this liwan we pass to a central chamber, which communicates with four smaller rooms, two on each long side. The simplicity of this plan is a noteworthy achievement and symmetry is its principal characteristic. The deep porch emphasizes the entrance; the interior doors balance each other; on the exterior the long walls are decorated by three, and the short walls by two double-crenelated niches, all arranged in perfect symmetry. The front niches framed tall and narrow windows, the oldest improvement of this kind known to archeology.

Even more surprising is the fact that the builders of Gawra VIII made use of the true arch in the construction of vaulted halls (pl. 2, fig. 2). It has been known for some time that the Romans were not the inventors of the true arch. The Sumerians knew it as far back as the third millennium B.C. Now, however, the Gawrans turn out to have anticipated the Sumerians by at least five centuries.

We shall resist the temptation to dwell longer on architectural details. As it is, little space is available to sketch the material background of the period. Copper is still rare, and the more delicate tools as well as many of the ornaments are made of bone and ivory. Stamp seals have gained in popularity (pl. 3, fig. 1), but the best work of the glyptic artist is now seen on intricately carved ivory plaques (pl. 3, fig. 2). Beads are ubiquitous, the finest specimens being fashioned of a semitransparent obsidian. Painted pottery is no longer in vogue; the better wares, however, are given a high polish.

The racial identity of these Middle Gawrans is just as obscure as was that of the earlier inhabitants. Their undecorated pottery and distinctive architecture suggest the presence of a new ethnic element, come perhaps by the same route which the previous invaders had taken more than a millennium earlier. These gifted settlers must give way in turn to yet another group. The displacement is merely symptomatic of the general run of events at the end of the Chalcolithic era. For this is a period of migrations on a hitherto unprecedented scale, which reflect a spirit of all-pervading restlessness. Long-established civilizations are uprooted overnight, and a thick layer of ashes is all that has remained to mark the latest irruption. The upheaval is in a sense universal, and Gawra VIII is no exception. Paradoxically enough, the very swiftness with which the stratum was destroyed contributed to its ultimate preservation. As the buildings were swept by the conflagration the fallen bricks formed a protective layer of fused clay which subsequent builders found too troublesome to cut through.

When the smoke has blown away a new race is found intrenched on our site, now Gawra VII. This occupation is destined to be of comparatively brief duration. The destroyers of Gawra VIII were no more than pawns in the hands of greater powers; they attacked and destroyed because they had been attacked and rendered homeless by others. They had barely enough time to get settled in their new homes before the pursuers had caught up with them. Gawra VII is thus an ephemeral station, a period of transition between the old and the new. Archeologically the stratum is characterized by a new pottery which includes beautifully painted chalice types (pl. 4, fig. 1). But in terms of the cultural cycles of mankind the passage from Gawra VIII to VI signifies infinitely more than the crossing of a layer filled with frail ceramic fabrics. The few feet of interposed debris mark in this particular case the boundary between Chalcolithic and Early Bronze or, in other words, the transition from prehistory to history.

With this insight into the marginal character of Gawra VII we have obtained also a clue to the forces behind the contemporary migrations and upheavals. The underlying cause of all this restlessness was man's decisive conquest of copper. The discovery of certain fundamental principles of metallurgy had precipitated an industrial and social revolution of awesome proportions. Mere stone users were no match for the men who had stumbled somehow upon means of casting the metal and making it pliable. But the number of copper bearing ores being limited, access to such deposits became a matter of vital importance. Violent ethnic shifts and transpositions were thus the inevitable corollary of the new order of things.

In this manner was ushered in what we now call the historical age. "Not without heat and dust" we may repeat with the poet, nor, we may add, without sacrifice of much charm and beauty. Progress always seems to exact a heavy toll.

LATE GAWRA

In our gradual ascent of Gawra we have covered so far more than two-thirds of the way to the top. All that has remained is the rapidly narrowing cap of the old cone. Taking the mound as an archeological unit, we have made a hasty survey of Early and Middle Gawra and are now prepared to review the last stage, which is the least substantial of the three as regards respective occupational areas. In terms of ancient history, we have passed through the archaic, or prehistoric, occupations and have arrived in the Early Dynastic period. It is an indirect indication of the great antiquity of Gawra that its career is about to terminate at a time when history has barely begun.

By the Early Dynastic era is meant the period when the south of Mesopotamia was under the rule of the first authentic kings of Sumer. This is the time of the "Royal Tombs" and the First Dynasty of Ur, of the princes and priest-kings or patesis of Kish and Lagash, and of the dynasts recorded on inscriptions from a number of other places. It embraces several centuries prior to the advent of Sargon the Great. The commencement of this period has been placed at about 3000 B.C. on the basis of most recent archeological results.[6] The contemporaries of this age in the north are the people of Gawra VI. This synchronism is clinched by a long series of correspondences in weapons, cylinder seals, amulets, and pottery.

We have seen how the conquest of copper changed the political and ethnic map of the world. No less radical is the accompanying transformation in living conditions. In place of the leisurely ways of bygone days we sense now a feverish pace. A great industrial era has dawned and with it has come great wealth to the ruling classes of the population. The splendors of the tomb furnishings of Ur are by no means isolated instances of opulence and power, even though the most precious objects were safer with the dead than with the living. Luxuries seem no less abundant than every-day necessities. But in all this striving for comfort and pleasure the finest contribution of the previous centuries was ignored and forgotten. For this was not the time for architectural creations of beauty and precision.

The buildings of Gawra VI are solid but unattractive. The foundations are of rough stone and the walls are constructed of sunbaked brick. The houses are small and the streets narrow, for space is at a premium. The drainage system is altogether adequate.

Tools and implements, ornaments and weapons, and all manner of sundry articles, are now predominantly made of metal. Two

[6] See now the remarks of H. Frankfort in the Illustrated London News, no. 4961, p. 776, May 19, 1934.

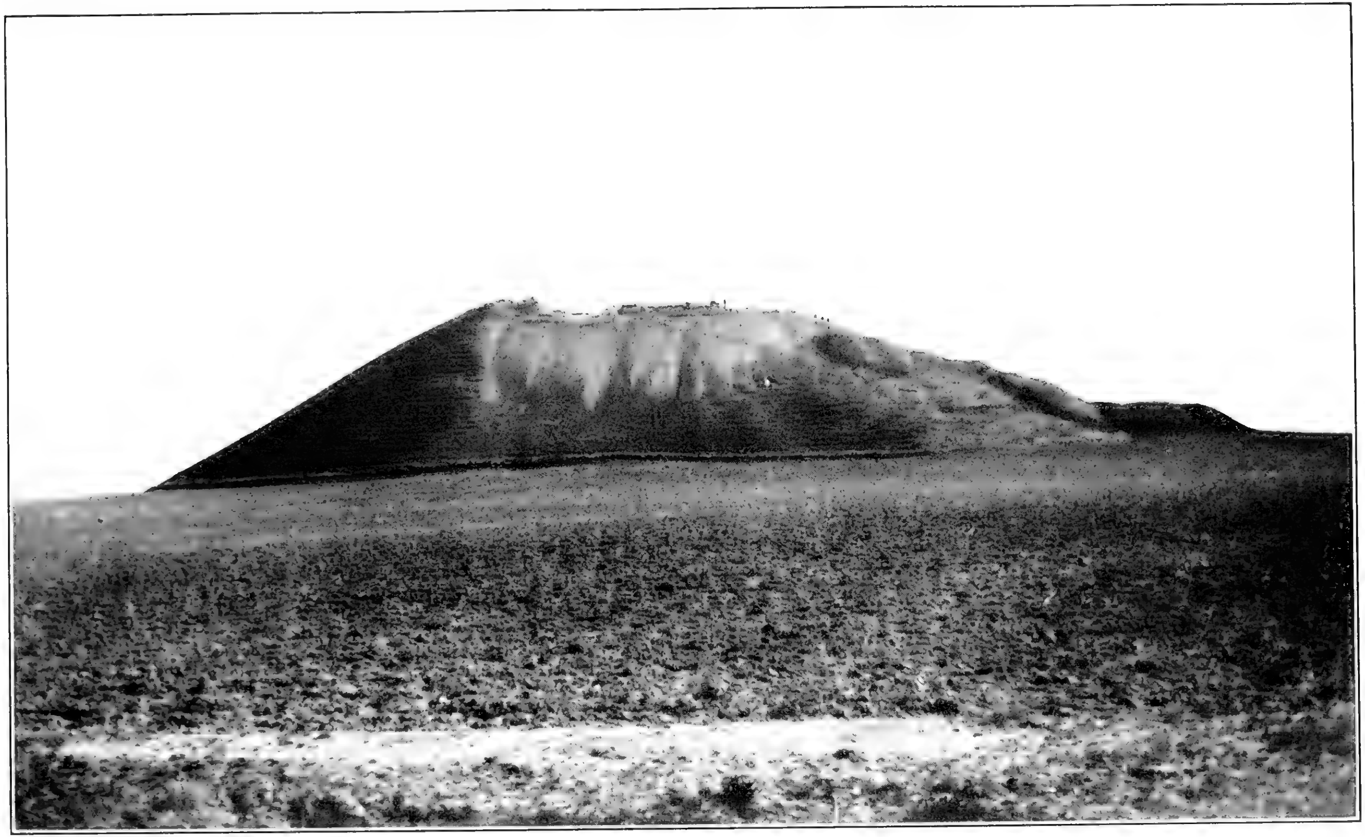
feet below there were hundreds of stone objects to one of copper, since in the Chalcolithic the emphasis was on the latter element of the compound. Now the floors are literally green with patina. We find knives and sickles, lance butts and spearheads, adzes and axes, bowls and frying pans (pl. 4, fig. 2; pl. 5, fig. 1). There are also delicate vanity sets, anklets, bracelets, hair ornaments, and a plentitude of pins and needles (pl. 5, fig. 2). The metal age is upon us in full force.

The high temperatures required in the casting of copper are applied also in the firing of pottery. The specimens are therefore excellent from a technical standpoint, having often the firmness and smoothness of polished stone. But painted decoration is not encouraged; very likely it would have been viewed as a waste of time. The potter furnished also objects required in the ritual of the day; fountainhead libation pots, too elaborate to be described here; terra-cotta figurines of various animals, votive couches and chariots. Among the latter the "covered wagon" (pl. 6, fig. 1) deserves special attention since it represents a type foreign to this region, but familiar in Trans-Caucasia. Obviously there was a good deal of intercourse with the north. The chariots proper may have been drawn by horses, for that animal is found represented among the figurines. At any rate, the oft-repeated assumption that the horse was brought to Mesopotamia about 2000 B.C. is no longer tenable. It may have been rare and expensive 10 centuries earlier, but it was not a complete stranger to the country.

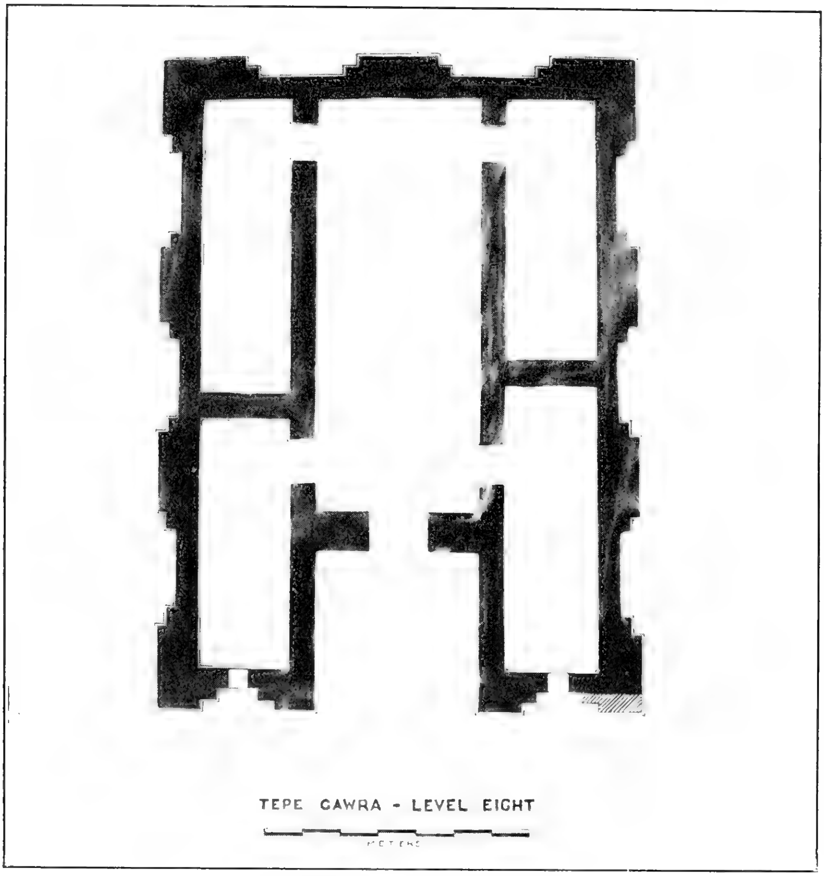
Among the most highly prized finds of Gawra VI are its cylinder seals, which have supplanted the older stamp seals. Some of them rival in workmanship the best specimens from Sumer. The decorative motives are many and varied. Some are typically Sumerian, while others disclose western and northern affiliations. Similarly diversified as to origin are the amulets and figurines of stone and alabaster (pl. 6, fig. 2), among which we discover good Aegean types. This eclecticism is characteristic of the period as a whole. The people of Gawra VI were a cosmopolitan community composed of many elements.

That they were an industrious group is seen, among other things, from the quantities of loom weights and spindle whorls found at this level. But life to them was not all work and fret. They had their presumably harmless pleasures, as may be gathered from their remarkably modern-looking game pieces (pl. 6, fig. 3). Was the throw of the dice accompanied by an invocation to the goddess of luck in the name of the infant that wanted a pair of sandals?

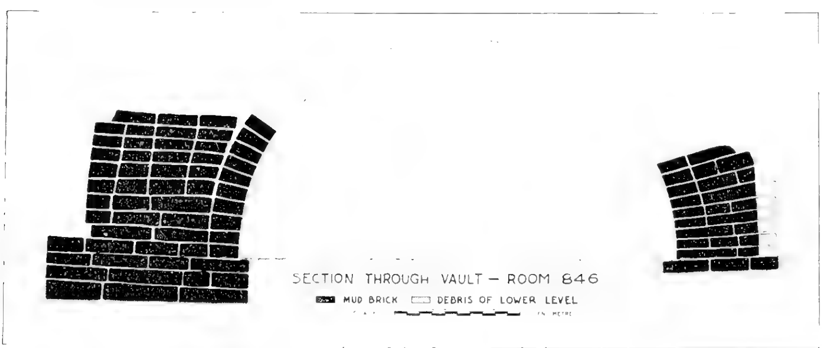
The latest history of the site need not detain us long. Gawra V is still able to support a massive shrine, but not much else. It takes us to the latter half of the third millennium. Gawra III is reduced to a small fort, and Gawra I to a minor observation post perched atop a steep-sloped mound. From this spot the watchman could see the Nineveh of 1500 B.C., a city as yet free from Assyrian domination. When a Tighlath-Pileser or an Ashurnasirpal dreamed the dream of a world empire, Gawra was already a lofty and mysterious tell. Sargon may have watched it daily from his palace at Dur-Sharrukin. If Gawra had then revealed to him its long history, would the King's plans have been modified? We wonder.



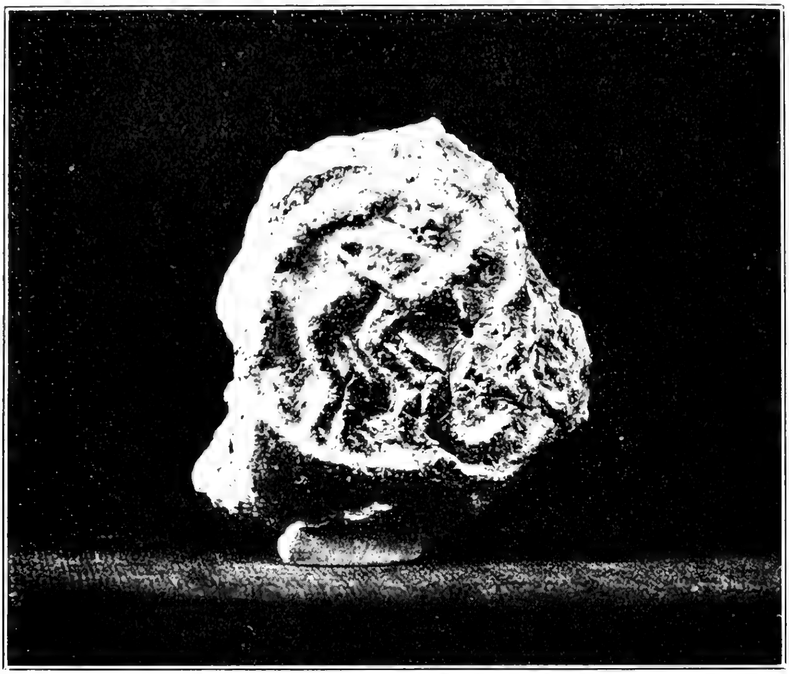
VIEW OF TEPE GAWRA, PARTIALLY EXCAVATED.



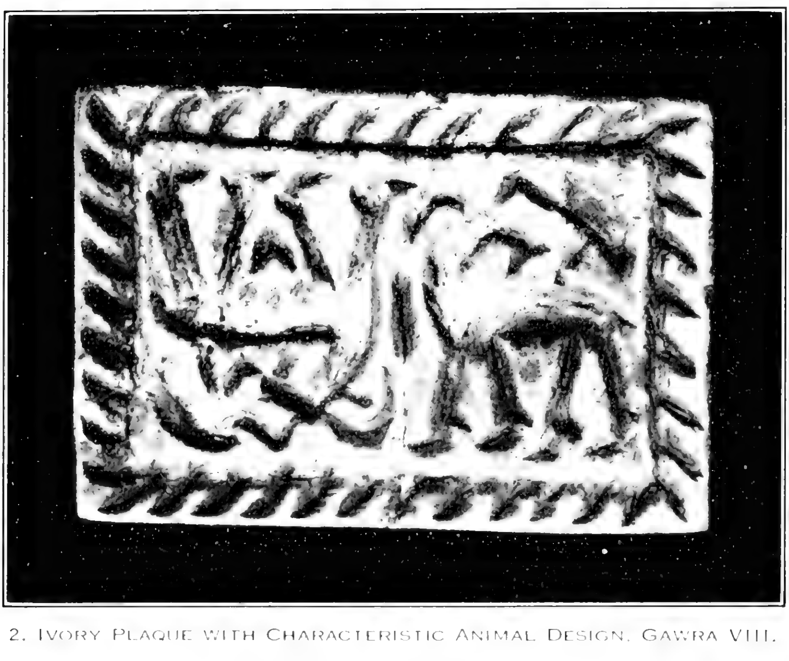
1. PLAN OF WESTERN TEMPLE, GAWRA VIII, C. 3500 B. C.



2. SECTION THROUGH VAULT, GAWRA VIII.

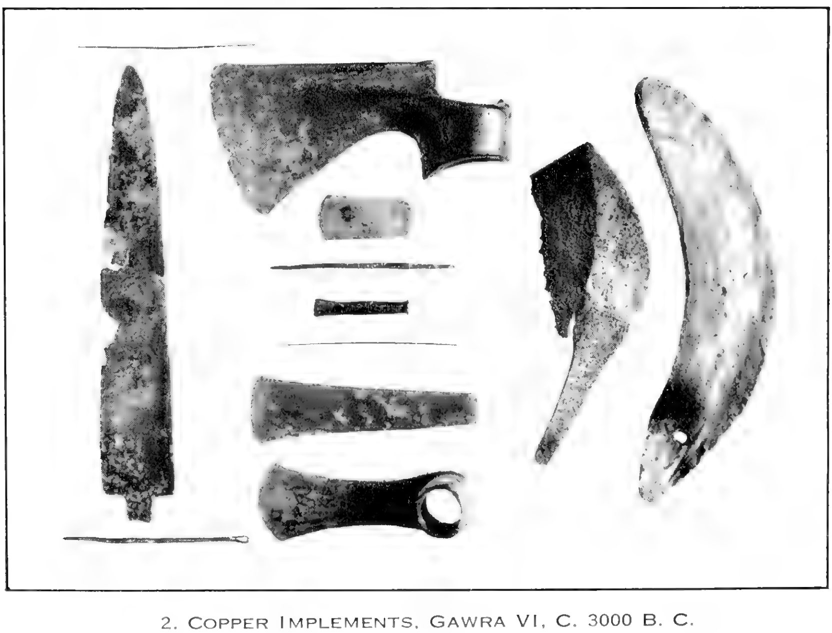


1. IMPRESSION OF A STAMP SEAL FROM GAWRA VIII, SHOWING A MAN, A WOMAN, AND A SERPENT.

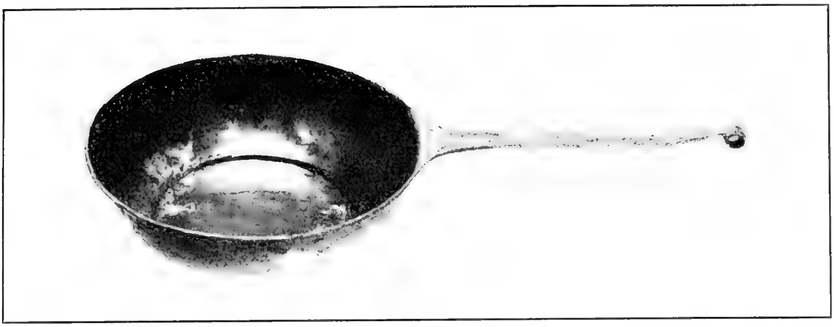


2. IVORY PLAQUE WITH CHARACTERISTIC ANIMAL DESIGN, GAWRA VIII.

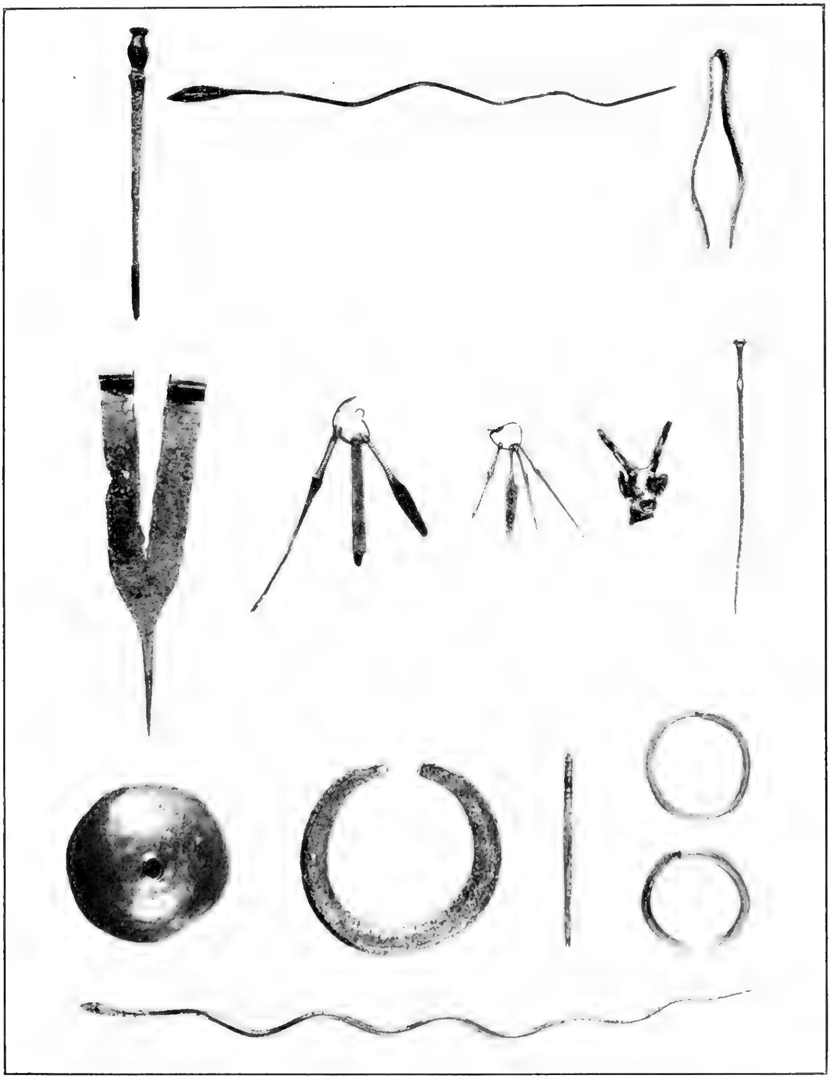
1. CHALICE, GAWRA VII.



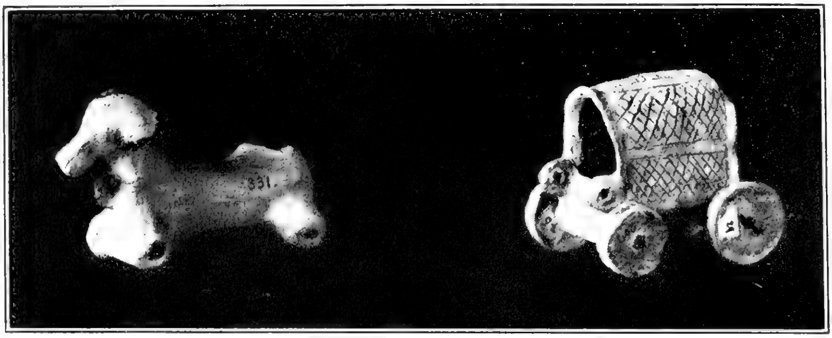
2. COPPER IMPLEMENTS, GAWRA VI, C. 3000 B. C.



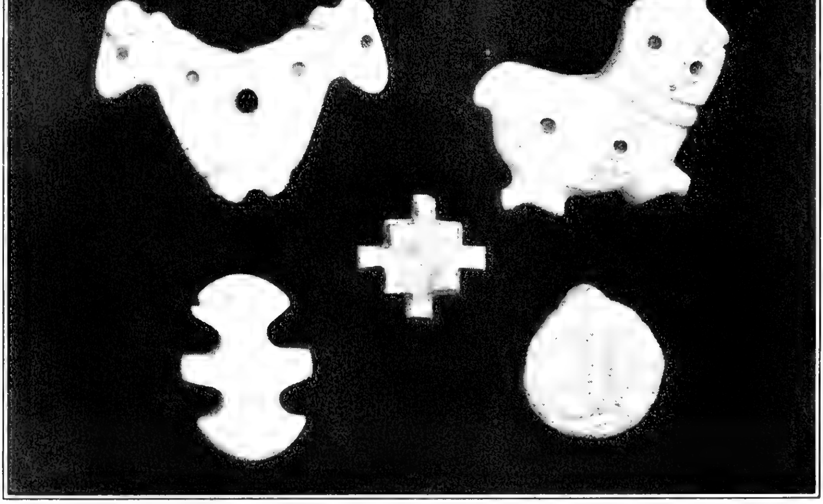
1. FRYING PAN, GAWRA VI.



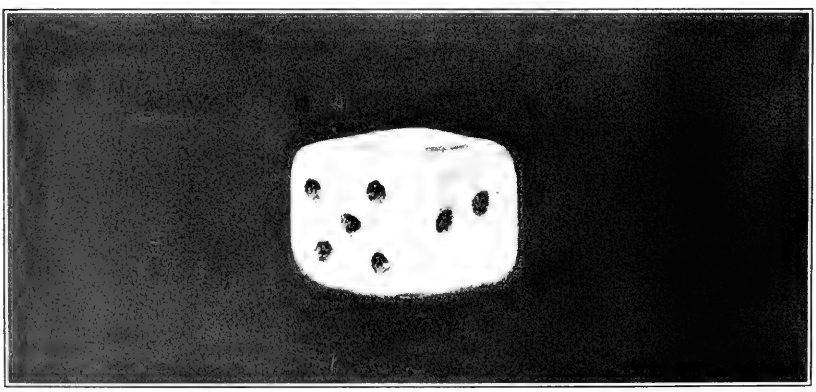
2. COPPER ORNAMENTS, GAWRA VI.



1. "COVERED WAGON." GAWRA VI.



2. AMULETS AND FIGURINES OF STONE AND ALABASTER, GAWRA VI.



3. GAME PIECE, GAWRA VI.

INDIAN MANUSCRIPTS OF SOUTHERN MEXICO

By Herbert J. Spinden
Brooklyn Museum, Brooklyn, N.Y.

[With 3 plates]

New light on the personalities who ruled in southern Mexico during the three centuries before the landing of Cortes and his Spanish adventurers in 1519 has been obtained from the study of several American Indian manuscripts in English libraries. Very few written documents made by the aborigines of Mexico and Central America in pre-Colombian times are known to have survived the vicissitudes of the Spanish Conquest and Inquisition, and of these the greater number are concerned with rituals and astrology rather than simple political history. But the illuminated books which I will now discuss are devoted primarily to genealogies, sequences in political events, and other truly historical matters, fixed in both time and place.

This history concerns a part of Mexico which is poorly represented in Spanish sources of the early colonial period, namely, the area in which the Olmecs, Mixtecs, and Zapotecs had developed important civilizations. In many respects these nations were more advanced than those of the Mexican highlands. It is believed that they temporarily became subject to the Toltecs in the twelfth century, when these conquerors were operating from Chichen Itza in Yucatan as well as from Tula, their capital city in the valley of Mexico now represented by the ruins of Teotihuacan. After recovering autonomy and flourishing independently for several centuries, these nations of southern Mexico were partly subdued for a second time by the Aztecs shortly before the coming of the Spaniards. While their arts and ceremonies are based largely on those of the ancient Mayas, their florescence came after the fall of the Toltecs, to whom also they were indebted.

BOOKS THAT FOLD LIKE SCREENS

In the Bodleian Library at Oxford University are found the Mexican codices of Laud, Bodley, and Selden, all of which reached this repository shortly after 1600 as items in great collections of manuscripts.[1] In the British Museum among other Mexican documents is the Zouche codex, the finest of all New World books excepting only the wonderful Dresden codex, Pot of Basil for the Maya civilization. Then there is the Fejervary-Mayer codex kept in the Free Public Museums of Liverpool, which, like the Laud, is thaumaturgic and need not be mentioned further.

For the ancient annals and biographies we must look to the Bodley, Selden, and Zouche codices of England and the Vienna codex of Austria (especially the reverse side, pages I to XIII). Some slight additional information can be gathered in two fragments of another codex, one part in Mexico being known as the

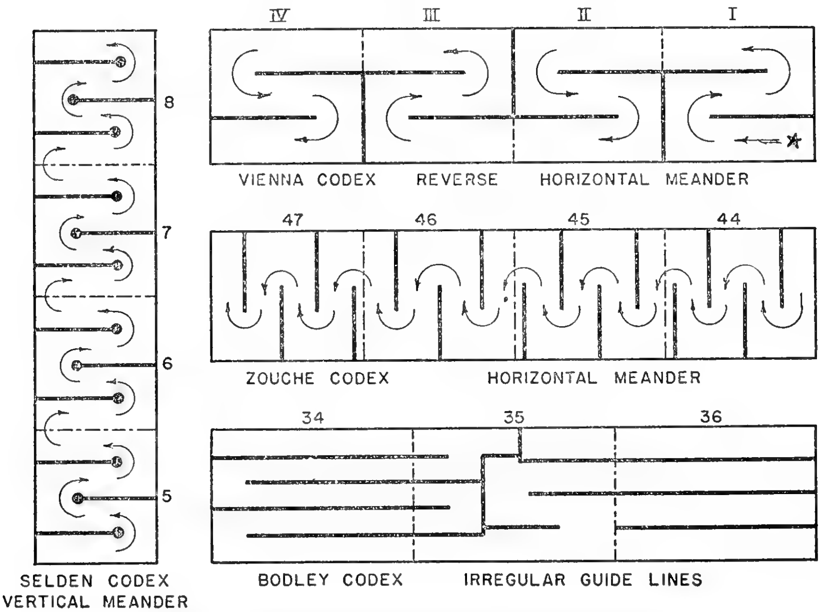


FIGURE 1.—Guide lines which control the stream of text.

Colombino, and another part in Austria being called the Becker. Perhaps some worthwhile data will also be found in a number of post-Spanish records kept on sheets of cotton which for the present we neglect.

All the books mentioned above are painted in colors on one or both sides of long strips of prepared deerskin, folded screenwise. The text, which consists of pictures and hieroglyphs, meanders between red guide lines, sometimes with complete regularity of pattern as in the historical section of the Vienna manuscript. At other times, as in the Bodley manuscript, the guide lines are arranged to

[1] Also this library possesses the Seldon roll and the famous compendium of Aztec history and social usages made by order of Mendoza, the First Viceroy of New Spain.

form a veritable labyrinth. (See fig. 1 for typical diagrams.) These meandering texts can be handled conveniently only in the screen form of the originals, which permits a sequence of pages to be spread out.

Unfortunately the Bodley and Selden codices are not available at the present time to the general student except in the century-old reproductions of Kingsborough, where each fold occupies a page.[2] His first publication in black and white omits the guide lines, but these are added in the colored reissue. There is an urgent need for facsimile editions of both Bodley and Selden codices for the freehand drawings of Kingsborough are often in error. It is even possible that dates and other important details now faint or invisible in the original manuscripts could be refreshed by special photography. The Zouche codex has been reproduced acceptably although some of the colors, especially the beautiful turquoise blue, are not correctly brought out. The Vienna codex has recently been published in irreproachable fashion.[3]

ARE THE PICTURES THOSE OF MEN OR GODS?

The contents of the Zouche codex were explained as history by Zelia Nuttall in her original brief commentary, although she thought the pictured text might be only a mnemonic aid to the recital of traditional epic chants. Her suggestions as regards the biography of the conqueror Eight Deer were amplified by J. Cooper Clark in his "The Story of Eight Deer in the Codex Colombino."[4] He covered the entries regarding this person in the several manuscripts now under consideration. More important still was the chronological arrangement of the various genealogies in the British Museum manuscript by Richard C. E. Long.[5]

In contrast to these writings Walter Lehmann in his recent commentary on the Vienna codex (p. 18) denies that an historical explanation of the matter in these ancient manuscripts is possible. Instead he believes that the intervals between dates have an astronomical import and that most if not all the named persons are gods rather than human beings or if some are human beings then these are concerned in religious or astronomical enterprises.

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[2] The writer expresses his gratitude to the officials of the Bodleian Library for permission to examine in detail the original Bodleian and Selden manuscripts and for photographs of certain pages; and to those of the British Museum for similar courtesy as regards the beautiful codex which was formerly the property of Lord Zouche.

[3] The reproduction of the Zouche codex was by the Peabody Museum of Harvard University (Codex Nuttall, 1902, with an introduction by Zelia Nuttall); that of the Vienna (Codex Vindabonensis, Mexic. I) by Max Jaffe, Vienna, 1929, with commentary by Walter Lehmann and Ottokar Smital; that of the Colombino (formerly the Dorenberg) in Antiguedades Mexicanas of the Junta Colombina in 1892 and that of the Becker under the title "Le Manuscrit du Cacique", by Henri de Saussure, Geneva, 1892.

[4] London, 1912.

[5] The Zouche Codex, Journ. Roy. Anthrop. Soc., vol. 56, pp. 239–258, 1926.

Clearly enough certain astronomical events are celebrated in some of the pictured events as in the indicated sacrifices to Venus, and it might be added that apotheosis of great men and women is an established thing in the religions of Central America. So the conflict in opinion is not so vital as it might seem.

Very early in my examination of the pieces in the Bodleian Library I came upon proof which fixes once and for all the fact that human beings and mundane affairs form the principle subject of these ancient records. In the Selden manuscript I noted that many persons were attached to year signs by a crinkly red line especially on the occasion of their first appearance in the narrative and that in later references to these persons the day sign which had accompanied the year sign was used as a personal name. Comparison with two very

FIGURE 2.—The umbilicus and the dates of birth.

naive representations of childbirth in the Zouche codex made it perfectly clear that the crinkly red line was the umbilical cord (see fig. 2), and it logically followed that the day sign which became a name was merely the person's natal day in the cycle of 260 differently named days which distinguishes the Central American calendar.

Although Brinton [6] declared that among the Cakchiquel tribes of Guatemala "the personal name was always that of the day of birth, this being adopted for astrological reasons", he gave no authority for this statement. Madame Nuttall in her commentary [7] took the position that among the Mexicans the calendarial names indicated membership in one of 20 social groups comparable to clans. This theory becomes manifestly absurd when observation is made of the variety of day names applied to the children of a single couple. Instances are found where a pair have the same day name, but occurring side by side, they must be regarded as twins.[8]

[6] Brinton, D. G., Annals of the Cakchiquels, p. 33. Philadelphia, 1885.
[7] Op. cit., p. 19.
[8] For example, a male and female among the offspring of Eight Wind and Ten Deer, Zouche codex, p. 5, are both labeled Three Lizard.

MAJOR EVENTS IN THE LIVES OF INDIVIDUALS

Given, then, the year and day of birth for many persons of historical importance in southern Mexico, we next find them making offerings at temples, getting married, fighting battles, and finally wrapped up for burial, all in connection with dates which enable us to construct the chronology of their lives. In figure 3, I combine references to One Monkey relating to his birth, his marriage to Lady Seven Water, an attack on his city made by Three Monkey, and finally to his death. The life of this One Monkey covered 65 years.

Important heirs make offerings at the temple at a tender age. On pages 4 and 5 of the Selden codex three persons destined to rule in succession at a certain city, which is indicated by a place-name hieroglyph attached to a temple, come in turn and burn incense before a sacred bundle on the temple platform on which rests a head of the Rain God.

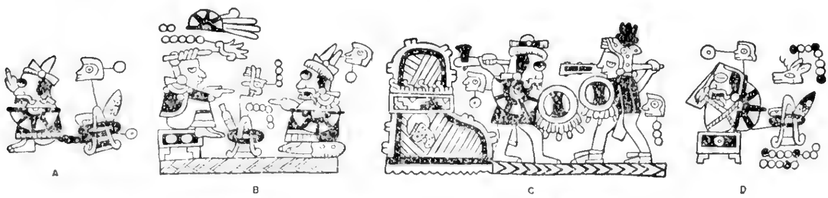

FIGURE 3.—Events in the life of One Monkey.

Marriage is represented in the Selden and Bodley codices by a man and women facing each other on a mat, while in the Zouche codex they usually face each other within a house. Sometimes the wedding ceremony is pictured including the carrying in of the bride, the bath which bride and groom take together, etc. A complete marriage ceremony is gorgeously portrayed on the double page 19 of the Zouche manuscript. Often a line of footprints leads from the parents to the bride or groom who has changed residence, as the case may be. When the text runs, as it usually does, in a narrow zone, children are commonly placed after the mother, with the years of birth recorded only for the older ones, except when the families are very prominent. It is a curious point that children at birth are rarely represented as actual children; instead they are pictured as of adult stature and wearing the dress and insignia of later life. I show in figure 4 the birth of Four Dog, also called Coyote, who was the eldest son of the famous Eight Deer, together with that of his sister Ten Flower.[9] The former was born on the day 4 Dog in the year 7 Rabbit, and the latter on the day 10 Flower in the next year 8 Reed. But although the date of Ten Flower's

[9] I follow the excellent suggestion of Long in spelling out numbers in calendarial names while leaving them as numerals in dates.

birth is given and she is joined to it like her brother by the conventional umbilicus, yet she is also represented as married to Four Wind and living with him at Knife Town.

An important event in the life of a leading hero comes when he has his nose pierced to receive the sacred jade button which will make him a knight or commander in the Order of the Eagles, or of the Jaguars, both being organizations of warriors. Sacred wars are indicated by carrying the staff of Venus, since at certain times it was necessary to find a royal victim to gratify the great planet. Eight Deer, the most thoroughly documented individual of southern Mexico, had his heart cut out as the victim of a sacred war, and at an earlier time he is shown assisting at the sacrifice of his own brother.

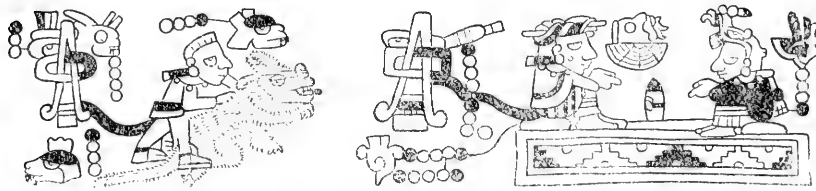

FIGURE 4.—Birth dates of the eldest children of Eight Deer, Bodley codex.

LADY SIX MONKEY IN THE SELDEN CODEX

Let us now examine an interesting passage which begins with the top section of page 5 of the Selden codex and runs up through pages 6, 7, and 8. In plates 1, 2, and 3 we have a photographic reproduction of this part of the original manuscript. The text meanders back and forth between horizontal guide lines which end in little loops where a turn is to be made. The lowermost section reads from right to left, the next one at the bottom of page 6 from left to right, etc. The dramatic history of a certain princess named Six Monkey, or Serpent Blouse, is here set forth.

First we see the mother and father of Lady Six Monkey, seated on a mat. The mother is Nine Wind, or Skull Jewel, and the father is Ten Eagle. He has come from Lord Ten Flower and Lady Two Snake, the day 10 Deer in the year 3 House, clearly referring to the marriage of the parents rather than to that of the son.[10] It seems that Lady Nine Wind bore three sons, namely One Reed, Twelve Water, and Three Water. All of these youths bear a flag and after them comes a date in the year 9 Calli, which is 30 years after the marriage of the grandparents. Next there is a shield and war standard before Skull Temple which may represent a place with

[10] In the Zouche codex, p. 23, the birth of the eldest son of Ten Flower and Two Snake is placed in the year 5 Reed, or only 2 years later than 3 House.

which war was waged. In all probability these youths died in battle before they could succeed to political positions.

With her back to Skull Temple we now see our heroine Six Monkey, who was probably the younger sister of these boys. Facing her is an old priest named Ten Lizard, who afterward appears as her protector. The third line of text begins with day 4 Wind in the year 4 House, approximately 8 years after the previous date. Next we see Ten Eagle defending his city against a certain Three Lizard, in a war which may have involved the inheritance of a tragic youth named Two Rain; his history is dealt with elsewhere. Above, in the fourth line of text, Six Monkey consults with two old priests, one being Ten Lizard and the other Six Vulture; and it may be that the latter foretells her death in the year 5 Reed, some 14 years hence. At any rate, we see footprints which take her head downward into the underworld on that future date. But the footprints continue, and we next see Six Monkey striding along.

In the top section of page 6 she is seated with a youth named Eleven Wind (wrongly recorded here as Ten Wind) in conversation with the ugly old Lady Nine Herb before Skull Temple. Behind the pair is an assortment of jewels, apparently brought as presents. The date is the day 10 Wind in the year 10 Reed, about 8 years before the prophesied death of Lady Six Monkey. Apparently the conversation concerns the marriage of Six Monkey and Eleven Wind. A round dance is also pictured in connection with this date and on the day 7 Flower of the year 12 House we see Eleven Wind and Six Monkey bathing together in accordance with the marriage rite (see pl. 2, lower right hand corner).

The next row has more presents and we see Ten Lizard at the same place which Ten Eagle had defended giving instructions to two men named Two Flower and Three Crocodile. The year is 13 Rabbit and the day 9 Snake. The two men set out on an embassy which concerns Six Monkey for the former carries her head and hieroglyph as his burden. Arriving before two towns these ambassadors are insulted by young chieftains named Six Lizard and Two Crocodile. I say "insulted", for the speech scrolls which come out of the mouths of the boys are tipped with flint knives, a logical ideograph for cutting words.

It is clear that our heroine Six Monkey did not brook such undiplomatic reception for her representatives. We see her in the top section of page 7 addressing the old lady Nine Herb about war. A shield-and-spear symbol of war lies on the ground between them and back of Skull Temple are two soldiers ready for the fray. Above, Six Monkey has one of the miscreant chieftains by the hair and the other is seated before the combined hieroglyph of the two towns in an attitude of surrender. This happens on the days 3 Herb and 4 Reed of the year 13 Rabbit (see pl. 3, bottom section).

No time is lost in cutting out the heart of Two Crocodile in the temple of Six Monkey's capital. Then the other culprit is turned over to the two ambassadors and their honor is appeased when he, in turn, is sacrificed before their own temple. In the next to the top line of our text Lady Six Monkey is annointed queen by Two Flower and in the same year 13 Rabbit she rules in peace with her chosen mate, Eleven Wind. Her first son, Four Wind, is born in the year 2 Knife, some 2 years later, and we see him tied to the date by the red umbilicus. The second son, One Crocodile, is born in the very year 5 Reed which had been set for the death of his mother. She appears no more in this narrative and the last entry shows the marriage of Four Wind and Ten Flower. (See fig. 4, above, for a parallel record of this event.)

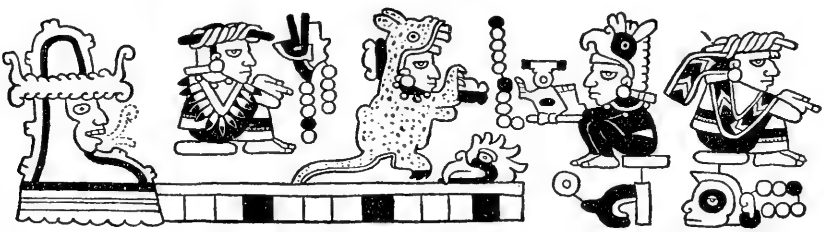

FIGURE 5.—A suitor, One House, brings presents to Nine Wind and Ten Eagle, the parents of Six Monkey living at Cloud-Belching Mountain, but Six Monkey turns her back on him.

OTHER REFERENCES TO LADY SIX MONKEY

The other codices add something to our knowledge of this Amazon queen. In the Bodley there is a shorter account of her rise to power, including her appeal to the gruesome old lady of Skull Temple, her leading in another prisoner, her marriage with Eleven Wind and the births of her two children. Both these sons marry daughters of Eight Deer and play a considerable role in the history of southern Mexico. Her husband either remarries or, perhaps, he already had another wife when he took Six Monkey. His daughter by the other wife was the official mate of Eight Deer, a situation leading to involved relationships. That is, Six Monkey's two boys both married daughters of their half sister.

There is only one reference to Six Monkey in the Zouche codex, and that is on page 4, where she resolutely turns her back on the young conqueror Eight Deer, whose face wears an expression of dismay. This was in the year 6 Reed when Eight Deer was 20 years of age and Six Monkey a mere child. Some idea of her popularity may be gathered from a repetition of this refusal motive in the case of a young suitor named One House. In figure 5 I show this rejection scene. Her mother and father are seated before the hieroglyph of their city (drawn in somewhat different fashion than before) and One House presents them with jewelry while Six Monkey gives him the cold shoulder.

WOMAN'S POSITION IN ANCIENT MEXICO

It is appropriate at this time to cast an eye at the social position which women occupied among the nations of southern Mexico. Even today Zapotecan and Mixtecan women have a name for self-reliance and personal independence, and it seems that in ancient times their social position was no less assured. We have already seen that Lady Six Monkey could handle both martial and marital situations. We need not understand that she captured men with her own

FIGURE 6.—How women went to war in southern Mexico (Bodley and Zouche codices).

hands on the field of battle, but at least she led her soldiers into action. The three pictures of militant feminism in figure 6 speak for themselves.

Also it is apparent that descent through the female line was recognized as legal, and that an eldest-born daughter sometimes succeeded to what we call the throne. In passages where the marriage of a woman of higher rank to an inferior male is pictured she may be seated on a stool or on the official mat, while he squats on the ground before her or uses a stone. (See One Monkey and his superior wife in fig. 3.) In cases where the male has the superior rank the wife may kneel before him.

Throughout all Central America and Mexico the mat rather than the throne was the ordinary symbol of administrative power, perhaps because it was used for conferences. That there were also ceremonial thrones among the early Mayas is clear enough from their sculptures and the right of the canopy is mentioned in Guatemalan histories among the prerogatives of royalty. The Aztec rulers are sometimes pictured as seated on chairs covered with matting. In the codices of southern Mexico the mat is frequently replaced by a rectangular block with geometric decoration. This recalls the architectural adornment of the stone structures at Mitla and in the abbreviated pictographs may imply " people of the palace " or, let us say, royalty.

Monogamy was certainly the rule in the royal marriages of southern Mexico, but there are instances where two women, probably sisters, marry one man and live with him under the same roof.[11] Also there are cases of great rulers who had one official wife and one or more other wives of lesser rank who dwelt apart, but whose children seem to have been recognized. Eight Deer was himself the offspring of a second marriage, although it is quite possible Nine Eagle, the first wife of his father, Five Crocodile, had died before the latter married Eleven Water, the mother of Eight Deer. But in the case of Eight Deer, himself, there can be no doubt that he had children by several women coming along at the same time. His official wife was the daughter of Eleven Wind, as we have seen, but by another woman than Six Monkey. Perhaps this second woman, Six Lizard, really married Eleven Wind after the death of Six Monkey. If so, the daughter could not have been more than 8 years of age when she married the already elderly Eight Deer and such an early marriage seems probable. Her first child came some 7 or 8 years after the celebration of the marriage. At any rate other evidence of child marriage is not far to seek.

The genealogical lay-outs often indicate marriages of nieces with uncles, etc. Thus Four Crocodile, the second son of Eight Deer by Twelve Snake, very clearly married Thirteen Flower, the daughter of his sister, Ten Flower, by Four Wind, the eldest son of Eleven Wind, and our heroine Six Monkey. Here is a close-knit marriage which may have been made for dynastic purposes.

One of the clearest cases of a dynastic mating goes back to an early stage of the recorded history. Two cities which I call Sun Mount and Riven Hill were joined by the marriage of Lady Twelve Vulture and Lord Twelve Lizard on a day 1 Rabbit in a year 1 Rabbit. The marriage is shown in the Vienna codex, page III, and in the Bodley codex, pages 3 and 4, with the place name hieroglyphs represented in connection with each individual. Their sons, Three Monkey and Four House, are later pictured in the Bodley codex on a rampage burning temples. They soon meet a fate which may have been deserved when we see them lying dead with their breasts open, indicating that their hearts had been cut out in sacrifice. In other

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[11] A good case of this is the marriage of a certain Twelve Lizard with two sisters named Four Crocodile and Four Knife; it is recorded in the Zouche, Vienna and Bodley manuscripts.

passages it becomes apparent that Twelve Vulture and Twelve Lizard lost their lives in a catastrophe which took a heavy toll. In figure 7, b–d, we see the royal couple wrapped up for burial.

The general event refers in some way to the woman with a skull for a head, living at Skull Temple and named Nine Herb, whom we have already met as the champion of Lady Six Monkey and to whom her son Four Wind in still later times is pictured as paying tribute. In one place (fig. 7, b) this old woman has the hieroglyph of a deer's foot. I think it probable that she represents Cholula, the city which inherited more than any other place the prestige of the Toltecs. First the deer's foot is the usual hieroglyph of Cholula. Secondly, the skull motive is particularly prominent in the art of that city, perhaps because it was the ceremonial center for the great warriors' societies. The purpose of these societies was to achieve immortality through apotheosis and in connection with the cult, skulls, cross

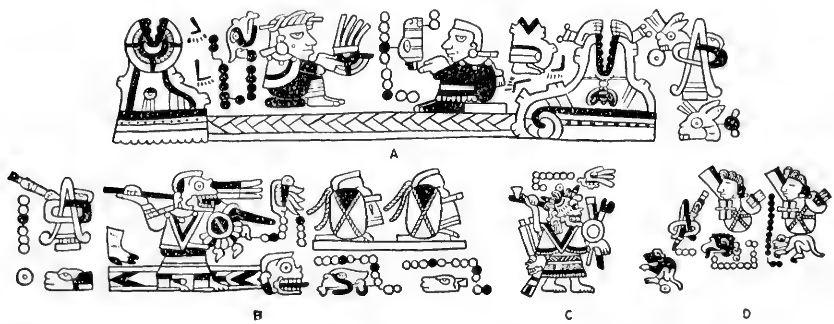


FIGURE 7.—A, the marriage of Twelve Vulture and Twelve Lizard unites two cities; B, a gruesome woman makes war on them with fatal results (Bodley codex); C and D, the same matter in the Zouche codex.

bones, shields, knives, severed hands, etc., are regularly shown. Thirdly, we see men with the peculiar knobby markings of mountains and stones taking part in the war against Twelve Vulture and Twelve Lizard. These may represent Toltecs, especially since the Mexican word for conqueror, applied par excellence to Toltecs, is *tepehuani*, which is allied to the linguistic root meaning stone and mountain. Lastly, Nine Herb as an individual could not have lived long enough to span the chronological interval between her first and last appearances in the narrative.

DESIGNATIONS OF OFFICE

Women are rarely pictured holding religious offices, whereas nearly all the historically important men are pictured in the habiliments of military and religious offices. Sometimes we are given the various stages whereby great leaders rise to the highest honors.

Time does not permit a detailed study of this aspect of ancient Mexican life but at least we may take note of certain classifications of the military and civil priesthood. The early Mayas were not given to human sacrifice, and while the eagle, and especially the jaguar, were prominent animals in their religion, there is little or no evidence of their importance in war. Among the Toltecs, however, these animals of prey became the patrons of warrior societies. These societies are much in evidence at Chichen Itza in Yucatan, thanks to the rich sculptural art which the Maya converts lent to the subject, and of course their importance was maintained among the Aztecs down to the termination of native culture.

In the codices of southern Mexico the Jaguar and Eagle warriors are very common, and much can be deduced concerning the nature of sacrificial ceremonies connected with the cults. In figure 8, I

FIGURE 8.—Military and religious offices; a Jaguar Man, an Eagle Man, and a Turtle Man.

picture a Jaguar Warrior, an Eagle Warrior, and a Turtle Man, the last being an order of the priesthood closely connected with human sacrifice. The Turtle Man is commonly shown as flying through the air bearing the heart of a sacrificed victim. The Turtle Man of our illustration is a certain Three Lizard, by other name Knife Necklace, who is pictured as having just died. Turtle Men with their bodies enclosed as here in a carapace are extremely common in the sculptures of Chichen Itza.

Many other priests wear the mask of the Rain God—equivalent to the Mexican Tlaloc—and there are others who wear the Sun disk as a priest of the Sun or combine this with the Rain God mask in an office which I designate as that of a Sun-Rain priest, or let us say weather prophet. In figure 9 the funeral of two warriors is pictured; one is an Eagle Warrior and a Sun priest and the other a Jaguar Warrior and likewise a Sun priest. It seems that their symbols of office were practically equivalent to name hieroglyphs.

IDEOGRAPHIC TRANSCRIPTION OF NAMES

We are now in a position to direct our attention a little more closely to the construction of personal hieroglyphs, other than those of calendarial origin. Among the easily transcribed women's names are Jewelled Eagle, Jewelled Parrot, Jewelled Skull, and Jewelled Water, in all of which the circular symbol of jade forms a part of the built-up sign. This symbol may also mean a bright orb, and in the case of Jewelled Incense the proper transcription may be Incense Star. Other names are Rainy Blouse, Serpent Blouse, Knife Blouse, Plumed Serpent, Flowered Serpent, Feathered Sun, Sun Fan, etc.

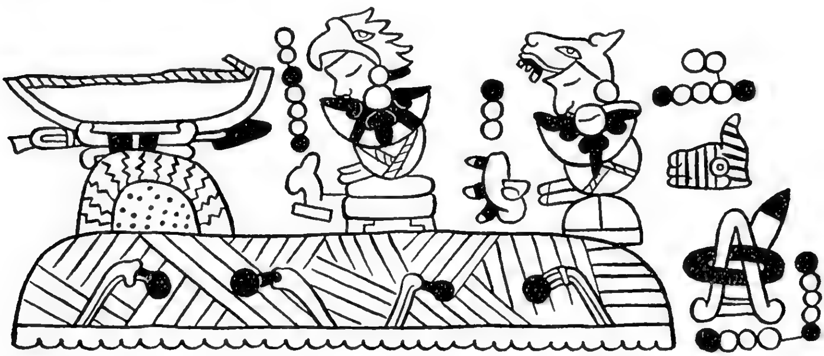
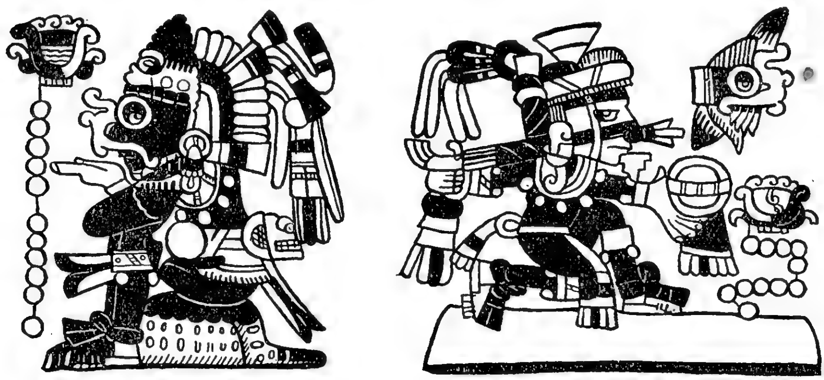


FIGURE 9.—Funeral of two warriors, note war clubs on the ground and bow and arrows on the mound. The detail across their breasts is half a Sun disk.

Men's names are made of sterner stuff, examples being: Stoned Jaguar, Blood-drinking Eagle, Bloody Face, Bloody Hand, Eagle, Coyote, Vulture, Eagle Star or Constellation, Snake Constellation, Flaming Arrow, Blue Dog, Yellow Dog, White Dog, Eagle Ball Court, Serpent Ball Court, Coyote Tail, Jaguar Claw, etc.

The acquired or descriptive names of men are frequently transformed into elements of dress and accoutrement. In figure 10 I illustrate this fact by two representations of an individual named Eleven Water. On page 34 of the Zouche manuscript he is shown as in *a*, being the eldest child of the bigamous marriage of Three Crocodile with Twelve Knife and Ten House. Note that his head has the form of a great flint knife with the points projecting above and below the distended jaws of a skull. The face of Eleven Water is enclosed in the jaws of this skull and is somewhat concealed behind the common Rain God mask, consisting of a ring-shaped eye and an irregular scroll which represents the nose and upper lip of Tlaloc. In the second representation of Eleven Water, on the following page of the manuscript, he is himself making a dual marriage with two richly costumed women. But in this picture he has a purely human appearance and the flint knife and mask of the Rain God are combined in his descriptive hieroglyph.

There are numerous analogous cases of individuals costumed to live up to their names and it may be that this was normal usage in those times. At any rate the common masquerades explain why human beings have been mistaken for gods.



A B

FIGURE 10.—Eleven Water masked and unmasked.

As regards place name hieroglyphs we limit ourselves to the examination of one example. In figure 11 I give a series of hieroglyphs for a place which may be called Cloud-belching Mountain.

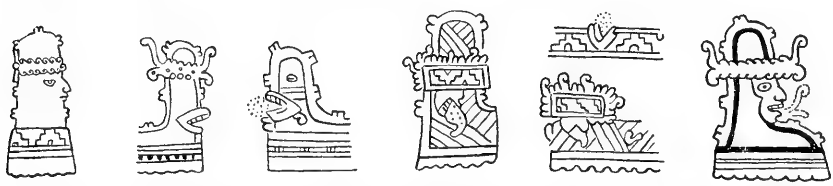


FIGURE 11.—A prominent place name, representing a mountain with a fillet of clouds and with a face, or at least a mouth, from which a cloud or smoke issues. It finally reduces to the belching mouth.

It is represented by a cloud-capped hill, bearing either a face or a mouth from which a dark smokelike substance issues. I suggest in passing that there may be some connection between Cloud-belching Hill and the tribal name Mixtec, which means Cloud People.

THE DESCENT OF KINGS

The tabulation of the numerous individuals recorded in the Zouche, Bodley, Selden, and Vienna codices would be enough to overwhelm a trained genealogist. But it is possible to pick out the more prominent families and arrange the persons composing them into as many as 10 generations. The problem is considerably aided by the dates, but numerous discrepancies must be admitted. The point is that in a great number of cases there is parallelism in the different codices and other supporting evidence.

The threshold is safely reached with Four Crocodile, also called Blood-drinking Eagle, and his wife, One Death or Sun Fan. Their establishment is at Sun Mount. The pictured name, Blood-drinking Eagle, is doubtless a reference to human sacrifice made to the eagle either as a messenger of the sun or as the patron of a war cult. Perhaps we may identify this Four Crocodile, Blood-drinking Eagle, with that Four Crocodile who is named as the first cacique of the Mixtec town of Tlilantongo.[12] Unfortunately space does not allow us to pursue such collateral identifications or even to discuss the problems of towns and tribes. We limit ourselves at this time to examining the pictographic and hieroglyphic record in the codices as self-sufficient.

Four Crocodile and One Death stand at the beginning of the record in both the Vienna and Bodley codices, and in the Zouche we see the two individuals at Sun Mount on page 21 in a preamble to an historical succession of rulers starting on page 23 with the marriage of their granddaughter Five Reed to an old warrior named Eight Wind. The eldest child of Four Crocodile and One Death is given in the Vienna manuscript as One Eagle and in the Bodley manuscript as One Vulture, but in both cases the given name is the same, namely, Jewelled Incense or Incense Star.

Probably these histories start with the resumption of autonomy by native aristocracies after the dissolution of the Toltec empire on or about A.D. 1220. Immediately we are in a welter of persons advancing the interests of this town or that, arranging dynastic marriages, engaging in holy or unholy wars, passing through the vicissitudes of chance and character. Several contemporaries of Four Crocodile and One Death occupy ruling positions of importance including a man named Four Rabbit, who marries the daughter of Four Crocodile. Their children are the daughters, Five Reed and Ten Crocodile and a son named Twelve Lizard. The seat of Four Rabbit was Riven Hill, and it seems that his two daughters made advantageous marriages and moved to the capitals of their husbands. The son married Twelve Vulture, a lady of Sun Mount, and we have already seen the fate which befell them (fig. 7, above).

Lady Five Reed marries Eight Wind, an old man previously married to a certain Lady Ten Deer. The eldest son of the second

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[12] See Caso, Alfonso, Las estelas Zapotecas, p. 72, Mexico, 1928.

marriage is Ten Flower who in turn is wedded to Lady Two Snake. Their eldest son is Twelve Lizard, 2d, and their next is Ten Eagle, whom we have already met as the father of Lady Six Monkey. The eldest son makes a double marriage, but the sole result seems to have been a youth named Five Earthquake or Heavenly Incense. He first marries Lady Two Herb and has by her a boy named Two

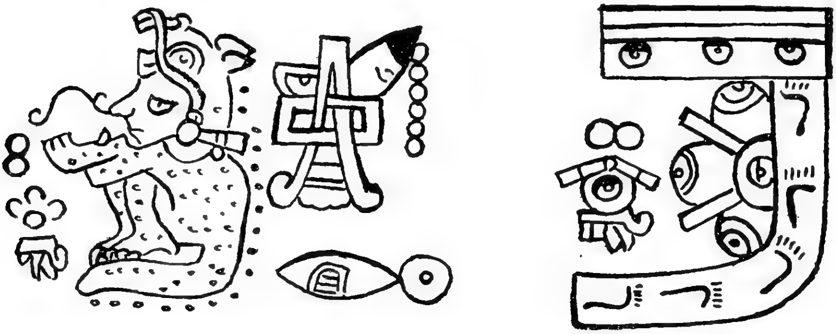
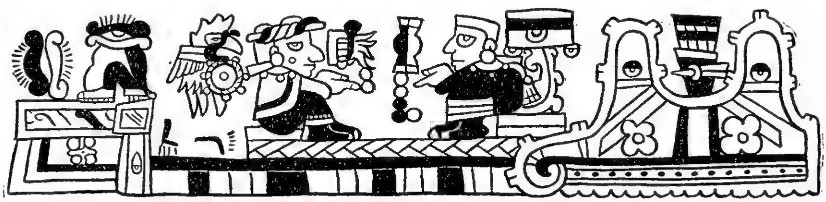


FIGURE 12.—Two Rain, end of a line, goes to the stars as a sacrifice: Bodley codex.



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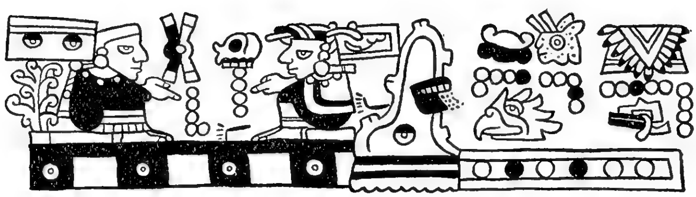


B

FIGURE 13.—The two marriages of Five Earthquake, first to Two Herb and secondly to Four Death, daughter of Ten Eagle and Nine Wind at Cloud-belching Mountain: Bodley codex.

Rain, who is sacrificed to the planet Venus at the age of 21. This event is dealt with in all four of our codices. (See fig. 12.) Five Earthquake also married Lady Four Death, a younger sister of Six Monkey, and it appears that this second alliance was the cause of war. In figure 13 the two marriages of Five Earthquake are pictured.

The line of Eight Deer departs from a Lady Ten Crocodile, who may have been the second daughter of Four Crocodile, but on this point the data are uncertain. Her son Thirteen Dog, Eagle Star, married a Lady One Vulture, whose hieroglyph is different from that of the One Vulture recorded as the eldest daughter of Four Crocodile. Their son Five Crocodile is the father of Eight Deer. Henceforward the documentation on relationships is fairly detailed. The epoch of Six Monkey and Eight Deer marks the culmination of these nations of southern Mexico. The real difficulty presents itself when we try to carry the record up to the Spanish Conquest. Here my arrangement differs considerably from the partial handling of the historical material by Long. For instance, I identify the Thirteen Dog, Eagle Star, of page 25 of the Zouche codex with the Thirteen Dog, Eagle Star, of page 28, where he makes a second marriage. This identification shortens Long's chronology by 104 years. Of course there is always the danger that a seemingly continuous picture series will hark back to a new departure in the past.

THE PROBLEM OF CHRONOLOGY

I have plotted the genealogies on coordinate paper allowing 10 years to the inch in vertical measurement and marking the known dates. On these diagrams I have shown the men in blue lines and the women in red, with the children ranged laterally in connection with each couple. The assured sequences and their dependable cross-references cover about three centuries. This circumstance and other considerations have convinced me that the entire recorded history of central and southern Mexico depends upon the innovations of Quetzalcoatl and that the chronology must be fitted into the Toltec year count which begins in 1168 with the year 1 Knife (table 1). Quetzalcoatl is given credit for inventing the Mexican calendar and for writing a sacred book taken as the standard for historical and religious uses. It appears that he passed his youth in Yucatan and acquired great efficiency in the ancient astronomical science of the Mayas and great liking for the ceremonial and ethical principles of their religion. Not only did he introduce among his people a cult of the reptilian Storm God of the ancient Mayas under guise of the Plumed Serpent—an innovation which caused a deep schism among the Toltecs, whose religion was largely devoted to human sacrifice—but he also evolved a means for objectively and ideographically recording the elements of time, person, place, etc., which must enter into any record of history.

TABLE 1.—*The cycles of Mexican chronology*

Year in cycle	Name of year	Cycle I	Cycle II	Cycle III	Cycle IV	Cycle V	Cycle VI	Cycle VII
1	1 Knife	1168	1220	1272	1324	1376	1428	1480
2	2 House	1169	1221	1273	1325	1377	1429	1481
3	3 Rabbit	1170	1222	1274	1326	1378	1430	1482
4	4 Reed	1171	1223	1275	1327	1379	1431	1483
5	5 Knife	1172	1224	1276	1328	1380	1432	1484
6	6 House	1173	1225	1277	1329	1381	1433	1485
7	7 Rabbit	1174	1226	1278	1330	1382	1434	1486
8	8 Reed	1175	1227	1279	1331	1383	1435	1487
9	9 Knife	1176	1228	1280	1332	1384	1436	1488
10	10 House	1177	1229	1281	1333	1385	1437	1489
11	11 Rabbit	1178	1230	1282	1334	1386	1438	1490
12	12 Reed	1179	1231	1283	1335	1387	1439	1491
13	13 Knife	1180	1232	1284	1336	1388	1440	1492
14	1 House	1181	1233	1285	1337	1389	1441	1493
15	2 Rabbit	1182	1234	1286	1338	1390	1442	1494
16	3 Reed	1183	1235	1287	1339	1391	1443	1495
17	4 Knife	1184	1236	1288	1340	1392	1444	1496
18	5 House	1185	1237	1289	1341	1393	1445	1497
19	6 Rabbit	1186	1238	1290	1342	1394	1446	1498
20	7 Reed	1187	1239	1291	1343	1395	1447	1499
21	8 Knife	1188	1240	1292	1344	1396	1448	1500
22	9 House	1189	1241	1293	1345	1397	1449	1501
23	10 Rabbit	1190	1242	1294	1346	1398	1450	1502
24	11 Reed	1191	1243	1295	1347	1399	1451	1503
25	12 Knife	1192	1244	1296	1348	1400	1452	1504
26	13 House	1193	1245	1297	1349	1401	1453	1505
27	1 Rabbit	1194	1246	1298	1350	1402	1454	1506
28	2 Reed	1195	1247	1299	1351	1403	1455	1507
29	3 Knife	1196	1248	1300	1352	1404	1456	1508
30	4 House	1197	1249	1301	1353	1405	1457	1509
31	5 Rabbit	1198	1250	1302	1354	1406	1458	1510
32	6 Reed	1199	1251	1303	1355	1407	1459	1511
33	7 Knife	1200	1252	1304	1356	1408	1460	1512
34	8 House	1201	1253	1305	1357	1409	1461	1513
35	9 Rabbit	1202	1254	1306	1358	1410	1462	1514
36	10 Reed	1203	1255	1307	1359	1411	1463	1515
37	11 Knife	1204	1256	1308	1360	1412	1464	1516
38	12 House	1205	1257	1309	1361	1413	1465	1517
39	13 Rabbit	1206	1258	1310	1362	1414	1466	1518
40	1 Reed	1207	1259	1311	1363	1415	1467	1519
41	2 Knife	1208	1260	1312	1364	1416	1468	1520
42	3 House	1209	1261	1313	1365	1417	1469	--------
43	4 Rabbit	1210	1262	1314	1366	1418	1470	--------
44	5 Reed	1211	1263	1315	1367	1419	1471	--------
45	6 Knife	1212	1264	1316	1368	1420	1472	--------
46	7 House	1213	1265	1317	1369	1421	1473	--------
47	8 Rabbit	1214	1266	1318	1370	1422	1474	--------
48	9 Reed	1215	1267	1319	1371	1423	1475	--------
49	10 Knife	1216	1268	1320	1372	1424	1476	--------
50	11 House	1217	1269	1321	1373	1425	1477	--------
51	12 Rabbit	1218	1270	1322	1374	1426	1478	--------
52	13 Reed	1219	1271	1323	1375	1427	1479	--------

The Mexican and Central American calendar in the simplified form used outside of Maya territory is clearly the adaptation of Quetzalcoatl. It follows the pattern of the Maya calendar proper, but omits the numerical count of days and the periods which are round numbers in the day count. That is, a permutation of 20 names and 13 numbers is used to produce the same short cycle of designations, while the 365-day year is constructed as before out of 18 months of 20 days each and 5 extra days. Taking these together, a larger cycle of 18,980 days is produced, essentially the calendar round of the Mayas. But Quetzalcoatl divided this for chronological purposes into a cycle of 52 years of 365 days each and let each year be known by its beginning day, namely, the day which ushered in his month, Toxcatl. Later it seems that the beginning of the civil year was pushed forward several months.

Unfortunately, no method was found to designate the different 52-year cycles, and when errors are made, generally by wrongly reading the numerical coefficients of the days Knife, House, Rabbit, and Reed (Tecpatl, Calli, Tochtli, and Acatl), which name the years, the effect is nearly always to produce the interpolation of entire cycles into the chronology. Fortunately, there are several unbroken year counts for Aztec history which depart from the year 1 Knife, 1168, and it is possible to demonstrate the errors in interpolations made by Ixtlilxochitl, Chimalpahin, and the anonymous author of the Annals of Cuauhtitlan. Actually, I do not think the custom of keeping annals prevailed among the tribes of the Mexican highlands until bookmaking was introduced by bands of Toltec warriors returning from Yucatan in the fourteenth century. An earlier use of writing in eastern and southern Mexico is indicated by the inscriptional record, but this also followed the model which Quetzalcoatl had perfected.

ASTRONOMICAL EVIDENCE IN CHRONOLOGY

Ludendorff in eight papers on Maya astronomy has demonstrated the correctness of the correlation of Maya and European dates which I had the honor to present and which for a time was subject to intense controversy. He has also demonstrated the marvelous accuracy of observations in connection with nearly all the planets. Part of this astronomy was carried over by Quetzalcoatl into the ceremonialism of non-Maya peoples. In the codices of southern Mexico there are numerous representations of the Venus staff and of human sacrifices connected with the time of the inferior conjunction of the planet Venus and the Sun. It is possible to convert a Mexican date into a Maya one or at least find the places at intervals of 52 years where such a date must fall in the precise Maya system.

The most conspicuous representations of Venus ceremonies are in connection with a day 1 Crocodile in a year 1 Reed. This date is recorded 21 times in the Vienna codex and it runs on the cover of the Codex Zouche as well as in the text in association with well-known objects of the Venus cult. Converting this recurrent Mexican date into Maya and then European equivalents, we find the most probable position in relation to Venus to be April 5, 1467, Gregorian Calendar. Here it coincides with the last visibility of the planet as evening star before an inferior conjunction with the sun on about April 9, while a first visibility of the planet as morning star falls on April 13. This agrees very closely (the discrepancy may amount to 2 days) with the Venus dates associated with the great Toltec ruler Quetzalcoatl, who died or was sacrificed on April 5, 1208, and who was converted in the God of Venus when the planet made her first appearance 8 days later. This earlier phenomenon was also in a year 1 Reed, but the day of the apotheosis was 1 Reed instead of 1 Crocodile.

Another astronomical date in connection with which Quetzalcoatl is pictured in the Vienna codex as coming down from heaven bearing the Venus staff is the day 5 Reed in the year 5 Rabbit. This date finds its sharpest correspondence on June 26, 1446, the inferior conjunction of Venus and the sun having fallen 4 days earlier on the summer solstice.

A third date at which coincidence is found is the day 7 Reed in the year 7 Reed, which is recorded 14 times in the Vienna codex and several additional times in the Zouche codex. This works out to the Maya date 11–13–19–11–13, 7 Ben 1 Yax, April 6, 1240, Gregorian calendar. The inferior conjunction of Venus comes 4 days earlier, so this date, like the preceding one, coincides with the heliacal rising of the planet.

More satisfactory for our purposes are the statements made in the Zouche codex in connection with the sacrifice of Nine Flower, Flaming Arrow, the brother of Eight Deer. The passage extends from page 52 to page 69 in the Zouche codex. First, on page 52, we see Nine Flower carrying the Venus staff, next Eight Deer and his companion at arms, Four Jaguar, make offerings at the altar on the day 13 Crocodile in the year 7 House. On the very next day Eight Deer has his nose pierced for the jade button of high office. Two men are pictured, then a second sacrificial scene of Eight Deer and his companion, next comes the capture of five towns indicated by a spear thrust into a place name. The days give the time of capture in the same year, the first two following close after the events already mentioned. At the left side of page 59 we see Eight Deer wearing the button in his nose and above him a Venus staff planted beside a temple: the days 1 Crocodile and 9 Wind are beneath the picture. As we shall see in table 2, when all the dates are arranged in order, the day 1 Crocodile coincides with the heliacal rising of Venus, while the day 9 Wind is perhaps intended for the autumnal equinox. Next follows a long succession of chieftains making obeisance to Eight Deer (pp. 54–68); at the end there are several who may be rather threatening. Finally, on page 68 there is another date, namely the day 4 Wind in the year 8 Rabbit. Again we see the planted Venus staff and Eight Deer in arms; four other men assist him, each a day ahead of the other.

As a terminal picture Nine Flower, the brother of Eight Deer, is sacrificed on the day 10 Rabbit in the year 8 Rabbit, while the Eagle and the Jaguar fight and the Turtle Man seizes a heart.

TABLE 2.—*Gregorian dates for the sacrifice of Nine Flower*

Year 7 House:		
Day 13 Crocodile	July 22, 1473	Preliminary ceremony.
Day 1 Wind	July 23, 1473	Eight Deer knighted.
Day 7 Rabbit	July 29, 1473	Additional ceremonies.
Day 8 Rain	July 30, 1473	Place captured.[13]
Day 1 Crocodile	Aug. 31, 1473	Heliacal Rising of Venus.
Day 9 Wind	Sept. 21, 1473	Autumnal Equinox.
Year 8 Rabbit:		
Day 4 Wind	Aug. 6, 1474	Venus ceremonies begin.
Day 5 House	Aug. 7, 1474	Eight Deer.
Day 6 Lizard	Aug. 8, 1474	Twelve Earthquake.
Day 7 Snake	Aug. 9, 1474	Two Monkey.
Day 8 Death	Aug. 10, 1474	Venus Priest.
———, ———		" "
Day 10 Rabbit	Aug. 12, 1474	Nine Flower sacrificed.

These datings indicate the possible accuracy of the entire historical record, although there are numerous problems yet to be adjudicated. It seems that Bodley and Selden records were continued for some time after the Spanish Conquest and I believe that this must also hold true of the Vienna codex, where page XIII, the last one of the genealogical record is clearly in a later hand than the rest. The obverse of this manuscript may deal with tributes and ceremonial obligations.

HOW IDEOGRAPHY DEVELOPS

In closing let me draw a few conclusions in regard to ideographic writing, especially since it seems the demonstration contained in the codices of southern Mexico may have a stimulating effect on the effort to solve the resistant hieroglyphic cartouches of the Mayas. It is not improbable that the phonetic hope has been overstimulated by the well-known data on the so-called ikonomatic system used in Aztec personal names and place names. This approaches a syllabary if not an alphabet, but of course it does not tell you the whole story of Mexican writing. There are numerous cases of pure ideographic writing; take, for example, the sign *youalli*, meaning night, which involves the symbolism of blood sacrifice at midnight.

It seems that sets of pictures and easily remembered symbols were devised by Quetzalcoatl to express the whole ideas rather than elemental sounds out of which words might be constructed. He ruled an empire in which many diverse languages were spoken and he required a graphic system independent of speech but easily explained in whatever speech was at hand. Of course, there were cultural con-

[13] One place captured on previous day, the others some time later.

formities within the wide circle of Toltec jurisdiction which made the interpretation of these symbols much easier than otherwise it might have been.

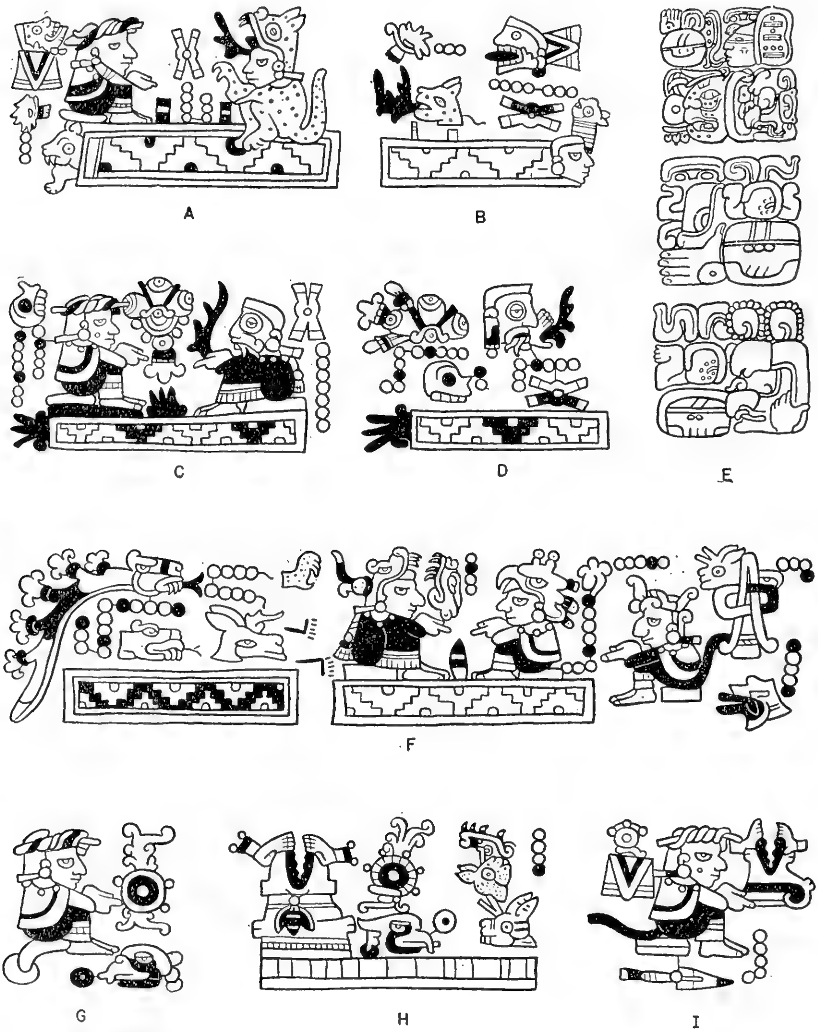
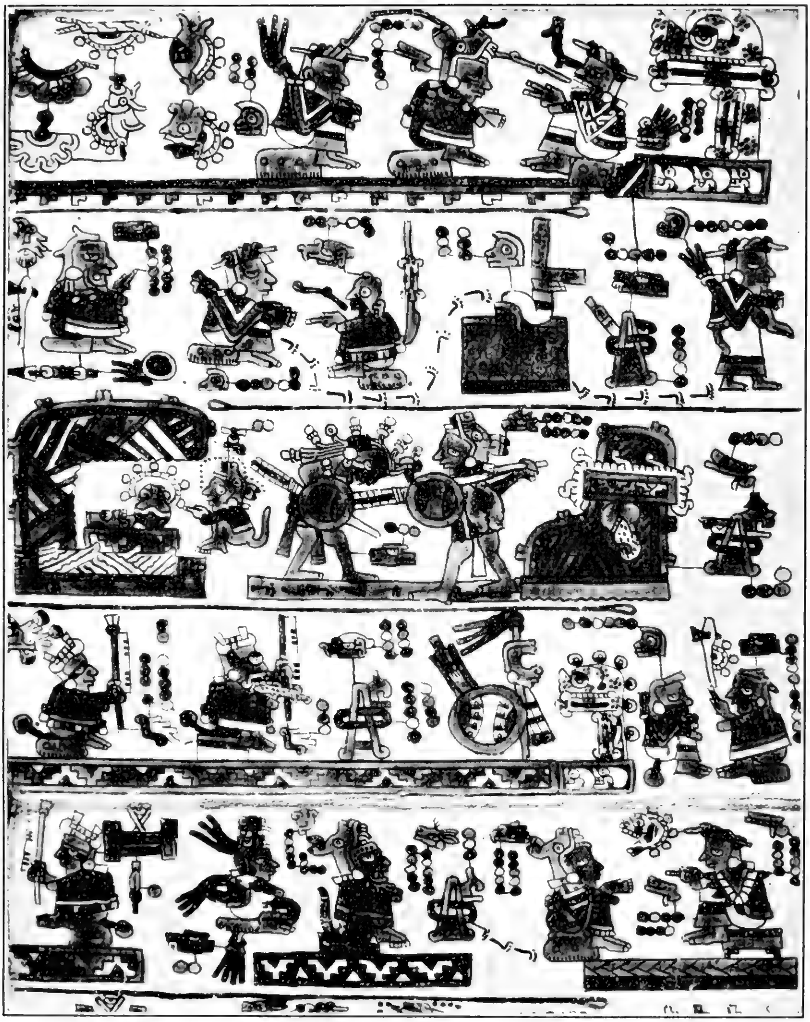


FIGURE 14.—Concentration of ideographic data in cartouches: A and B, same matter; C and D, same matter; E, concentration in Maya glyphs; F, three generations in one statement (but here the calendarial names of the husband and son of Lady Ten Flower are recorded in reverse order); G, H, and I, another family chart.

The 20 graphic signs which recorded the differently named days of the common Central American calendar were for the most part easily recognized pictures. With the meanings apparent it was only necessary to use a sequence of local names which retained these meanings. The 20 day signs which we may assume Quetzalcoatl devised for the undifferentiated use of the Zapotecs, Mixtecs, Mexicans, etc., are much less obscure than the highly conventionalized day signs of the ancient Maya time count but correspond rather strikingly in basic significance.

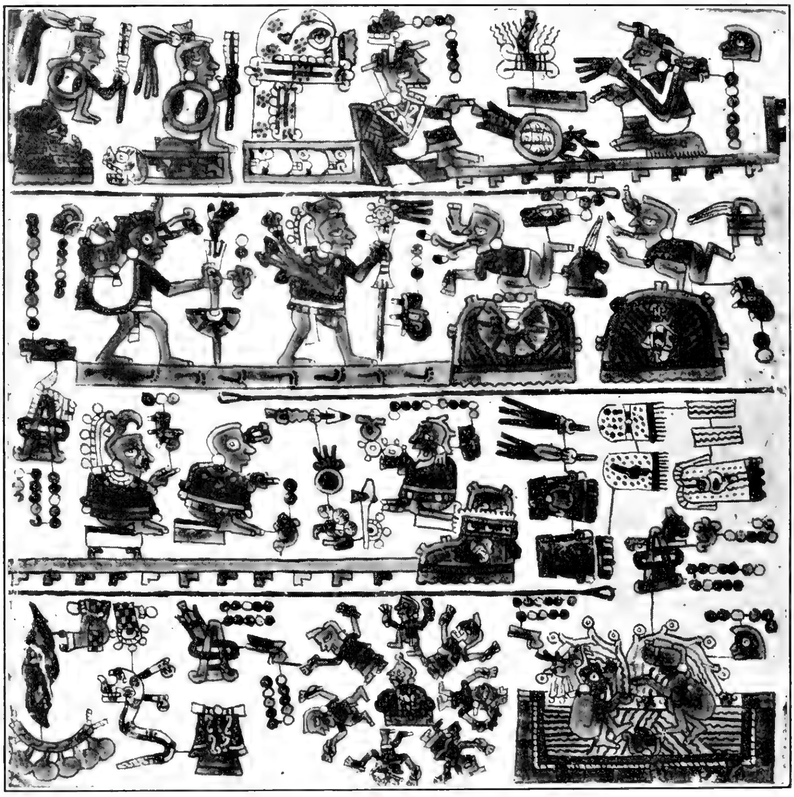
The concentration of pictures into cartouches (see fig. 14) which are clear enough in the usage of southern Mexico, where the calendarial and personal names of both parents are combined with the place name, the mat or palace platform and the footprint, to give the essential facts of genealogy, are enough to suggest that the ancient Mayas proceeded in similar fashion. Only with them the unit characters are so conventionalized that we can no longer interpret them without extensive study. After all, ideographic symbolism forms the great original basis of American Indian art.

72774—35—30



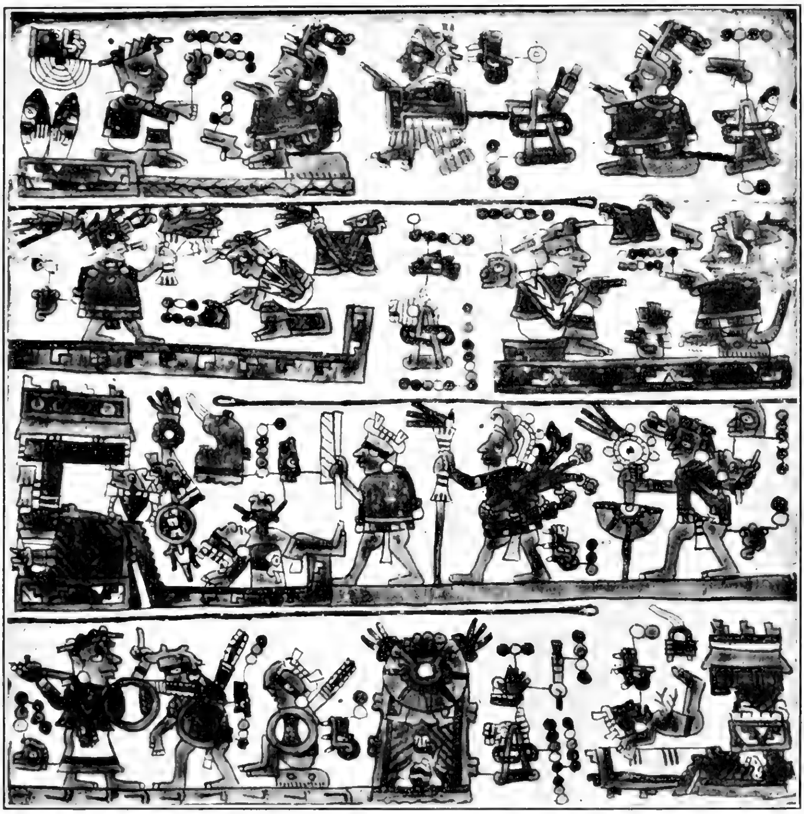
PAGE 5 (TOP SECTION) AND PAGE 6 OF THE SELDEN CODEX WHICH RELATE THE LIFE OF SIX MONKEY.

The text begins at the bottom and runs up, being continued on plate 2.



PAGE 7 OF THE SELDEN CODEX WHICH CONTINUES THE LIFE OF SIX MONKEY.

Continued from plate 1, from the top of page 6, and concluded on plate 3.



PAGE 8 OF THE SELDEN CODEX WHICH CONCLUDES THE LIFE OF SIX MONKEY.

Continued from plates 1 and 2.

ARCHEOLOGY OF THE BERING SEA REGION[1]

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[With 11 plates]

There is probably no spot on the Western Hemisphere that holds a more prominent place in anthropological theory than Bering Strait, the narrow body of water just below the Arctic Circle which barely separates the great land masses of Asia and America; for, according to every indication, this was the gateway through which man first entered the American continent. As yet the theory is based on indirect evidence, by the fact that (1) in physical type the American aborigines are mainly Mongoloid and, in the absence of any evidence that the type originated in America, must therefore be presumed to have spread from eastern Asia, and (2) because Bering Strait is the only place where under existing conditions such an entry could have been easily effected. No human remains or artifacts of any great antiquity have been found around Bering Strait, and local conditions are such that their discovery seems far from likely. If man migrated into America during Pleistocene time, any remains left behind in the far North would be difficult to find, as they would now lie buried beneath the accumulations of frozen muck and ground ice which cover the Pleistocene gravels on the Alaskan mainland around Bering Strait. It may be regarded as significant that although the bones of mammoth, bison, horses, and other Pleistocene mammals have been found in abundance during mining operations or through the erosion of fossil-bearing deposits, there has been as yet no reported find of a human bone or authentic artifact of similar age. If, on the other hand, man entered America in postglacial times and migrated along the coasts or penetrated into the interior along existing water courses, the tracing of such passage would be equally difficult, for considerable topographic changes have taken place in the coast lines even in recent years, and the river banks are being washed away and rebuilt at a rapid rate. From the nature of the circumstances, therefore, it would appear that the discovery in Alaska

[1] Paper presented before Fifth Pacific Science Congress, Vancouver, B.C., June 1933, revised.

of very early man or his handiwork is more likely to come about through accident than by design.

Meanwhile, an orderly approach calls for investigations directed toward the solution of a more immediate problem—that of the origin and early history of the Eskimos who at present occupy the Bering Strait region. Until we have full information as to the nature and extent of the prehistoric remains left by the Eskimo, an objective approach toward the more fundamental problem of original migrations will remain very difficult. Fortunately, progress has been made in this direction within the past few years, and although the recent investigations have thrown no new light on original migrations nor revealed the existence of any pre-Eskimo remains, they have added materially to our knowledge of Eskimo prehistory and have necessitated a reexamination in its entirety of the complex problem of Eskimo origins and migrations.

Aside from the usually fragmentary and general accounts of the early explorers, our knowledge of the Alaskan Eskimo is based principally on the pioneer ethnological studies of Dall, Nelson, and Murdoch, made under the auspices of the Smithsonian Institution in the latter part of the nineteenth century. Somewhat later a comprehensive program of ethnological and archeological investigations in neighboring regions was inaugurated under the direction of Dr. Franz Boas.[2] The results, embodied in the reports of the Jesup North Pacific Expedition of the American Museum of Natural History, include a number of valuable studies on the language, material culture, and social organization of the tribes of the North Pacific coast of America and of eastern Siberia by Boas, Swanton, Bogoras, Jochelson, Laufer, and Teit; and on the archeology of British Columbia and Washington by Harlan I. Smith. An outstanding accomplishment of the Jesup expedition was the clear demonstration of cultural affinities existing between these now separated tribes. Some of the resemblances, particularly in the field of folk lore, were remarkably close and led to the formulation of the theory that there had been in the past an intimate and extensive contact between the tribes of northeastern Asia and of northwestern America, exclusive of the Eskimo. The latter, according to the theory, were thought to have entered Alaska from the eastward, forming a wedge which separated the northwestern Indians from the related tribes of northeastern Siberia.

The groundwork for a systematic investigation was thus laid through studies on the present aborigines, but the necessary extension of the problem into the more remote past was not attempted

[2] Boas, F., The Jesup North Pacific Expedition, 13th Internat. Congr. Amer., pp. 91–100, New York, 1902.

until some 20 years later. It was not until 1926, in fact, that attention was directed to archeological remains in northern Alaska. In that year Dr. Aleš Hrdlička, of the Smithsonian Institution, on an anthropological survey of the Alaskan coast, obtained a number of harpoon heads and other objects of " fossil " walrus ivory which had been excavated from old Eskimo sites on St. Lawrence Island and at Bering Strait—objects which differed both in form and ornamentation from those used by the modern Eskimo.[3] In the same year Dr. Diamond Jenness, of the National Museum of Canada, undertook the first systematic investigation of prehistoric Eskimo sites in northern Alaska, excavating at Cape Prince of Wales and the nearby Little Diomede Island in Bering Strait.[4] Here Jenness obtained additional artifacts bearing the same rich ornamentation—a style of art that he regarded as characteristic of a prehistoric phase of Eskimo culture which he designated the Bering Sea culture.[5] The objects decorated in the Bering Sea style were of walrus ivory, which through many years of burial in the frozen ground had taken on a discoloration ranging in hue from a soft rich cream to a dark brown or almost black. The designs themselves consisted principally of curving and flowing lines, circles, and ellipses, and were much more graceful and elaborate than those employed by the modern Eskimo. The chronological position of this old art style and its validity as representing a distinct phase of Eskimo culture, as postulated by Jenness and Hrdlička, has been fully borne out by subsequent Smithsonian investigations on St. Lawrence Island conducted by the writer in 1928, 1929, and 1930, and by M. B. Chambers in 1931.[6]

ST. LAWRENCE ISLAND

St. Lawrence Island lies 150 miles south of Bering Strait and is the largest island in Bering Sea, with a length of 100 miles and an average width of 20 miles. Its western extremity is only 40 miles from the Siberian mainland, its eastern end 100 miles from Alaska. The island is of volcanic origin, with a rugged mountainous interior and a dreary coast line of low-lying tundra or steep, dark-colored

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[3] Hrdlička, A., Anthropological Work in Alaska, Explorations and Field-Work of the Smithsonian Institution in 1926, Smithsonian Publ. No. 2912, pp. 137–158, 1927; Anthropological Survey in Alaska, 46th Ann. Rep. Bur. Ethnol., pp. 173–176, 362–363, 1930.

[4] Jenness, D., Archeological Investigations in Bering Strait, Nat. Mus. Canada, Bull. 50 (Ann. Rep. for 1926), pp. 71–81, 1928; Ethnological Problems of Arctic America, Amer. Geogr. Soc. Special Publ. No. 7, pp. 167–175, 1928.

[5] Here called the Old Bering Sea culture to distinguish it from a later transitional phase.

[6] Collins, H. B., jr., Ancient Culture of St. Lawrence Island, Alaska, Explorations and Field-Work of the Smithsonian Institution in 1930, Smithsonian Publ. no. 3111, pp. 135–144, 1931; Prehistoric Eskimo Culture on St. Lawrence Island, Geogr. Rev., vol. 22, pp. 107–119, 1932.

cliffs of granite. From late fall until spring the shores of the island are locked in ice.

The island is now treeless, and vegetation is of the usual Arctic variety, consisting of dwarf willows, mosses, grasses, and flowering plants. In Tertiary time, however, there existed a markedly different assemblage of plants—the giant redwood or sequoia, poplar, rhododendron, sycamore, and alder—as shown by fossil remains found in coal and shale outcrops at several places.[7]

The present inhabitants of St. Lawrence Island are Eskimos belonging to the Yuit or Siberian group. They number some 400 individuals, most of them living at the village of Gambell (Sevuokuk) at the northwestern end of the island and at Sevunga, 30 miles to the eastward. They represent the remnants of a considerably larger population, which was greatly reduced by a severe famine and epidemic in 1878–79.

Numerous old village sites are found at the now abandoned eastern end of the island as well as along the north and west coasts. At certain of these old sites the Smithsonian Institution during the summers of 1928–31 has carried on excavations which have thrown considerable light on successive culture stages and have made possible the establishment of a chronology which promises to be applicable for a large part of northern Alaska and northeastern Siberia.

In 1928 a period of 2 months was devoted to excavations at an ancient village site on Punuk (Poongook), a small island 4 miles off the eastern end of St. Lawrence. Although today there are no Eskimos living within 100 miles of Punuk, the huge kitchenmidden marking the site of the old village is conclusive evidence that for many years this barren little island had supported a sizable Eskimo population. The midden is 400 feet long and has a visible height of about 10 feet, but excavation proved that it extended 6 feet below the present beach, giving it a total height—or depth—of 16 feet (pl. 2, fig. 1). In 1929 excavations were made at another large abandoned site at Cape Kialegak, 30 miles to the southward (pl. 2, fig. 2).

Ordinarily the excavation of such refuse heaps would be a comparatively simple matter. In northern Alaska, however, a particular obstacle to excavation is offered by the frozen ground, which even during the summer thaws out only on the surface. Artificial methods of thawing the ground by the use of steam or cold water such as are employed in mining, are not only expensive and usually impracticable but have the added disadvantage of being destructive to the more fragile objects. The most practical method has been found to

[7] Chaney, Ralph W., A Sequoia Forest of Tertiary Age on St. Lawrence Island, Science, vol. 72, pp. 653–654, Dec. 26, 1930.

be the slow but certain one of taking the excavation down inch by inch as the frozen soil thaws out through exposure to the atmosphere.

As a result of the excavations at Punuk and Cape Kialegak it was found that the graceful, curvilinear art of the Old Bering Sea period had not suddenly disappeared, to be succeeded immediately by the comparatively simple art of the modern Eskimo, but that on St. Lawrence Island, at least, it had entered upon a period of transition. This transitional or Punuk stage, as it is called, employed simple designs composed of dots and circles and straight or slightly curving lines.[8] There is also a marked difference in the techniques of the two styles. The Old Bering Sea circles and ellipses usually surmounted a slight elevation and were somewhat irregular in outline, having been made freehand; most of the lines were lightly incised, although deeper lines were often employed to afford contrast (pls. 3 and 4). Punuk ornamentation, on the other hand, is much more uniform, with deeply and evenly incised lines and mechanically perfect circles which could have been produced only with metal tools (pl. 5). This supposition is borne out by the finding of a few engraving implements with small iron points in deposits of Punuk age.

This raises the question as to how the Eskimo came to possess iron in prehistoric times. Eskimo ruins dating from the Russian period are easily distinguished from those of greater age by the presence of glass beads and metal and by certain late types of artifacts. That the Punuk technique antedated this period is shown by the fact that at the old site on Punuk Island this art, with its metal-engraved lines, was found from top to bottom of the 16-foot kitchen-midden, which, according to the above-mentioned criteria, appeared to have been abandoned for around 200 years. Under these circumstances it would appear that small quantities of metal, probably derived originally from central Siberia, reached St. Lawrence Island some centuries before the arrival of the Russians. There are references in early Chinese literature to the use of iron in the third century, A.D., by the Su-chen, a tribe dwelling in eastern Siberia to the north of Korea.[9] The Su-chen possessed on the whole a stone-age culture and no doubt had relations with neighboring tribes of similar status; it would not appear an unreasonable assumption, therefore, that the Eskimo, along with the other tribes of northeastern Siberia, had acquired iron as early as a thousand years ago.

In 1930 and 1931 the Smithsonian investigations were carried on at the northwestern end of St. Lawrence Island in the immediate vicinity of the Eskimo settlement of Gambell. Here, at the sites of

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[8] Collins, H. B. Jr., Prehistoric Art of the Alaskan Eskimo, Smithsonian Misc. Coll., vol. 81, no. 14, pp. 1–52, 1929.

[9] Laufer, Berthold, Chinese Clay Figures, Field Mus. Nat. Hist. Publ. 177 (Anthrop. Ser., vol. 13, no. 2), pp. 262 et seq., 1914.

five old villages which had been abandoned successively one after another, stratigraphic studies were made which revealed for St. Lawrence Island a cultural cross-section extending from the present time back through the oldest known stage of Eskimo culture. A brief résumé of the Gambell excavations will be given below with particular emphasis on those features which were found to have undergone significant modifications, principally house types, harpoon heads, art styles, etc.

Four of the old villages were situated on a broad gravel plain, which extends for three-quarters of a mile westward from the base of the Gambell cape or plateau—Cape Chibukak (Sevuokuk). These old villages, now only low grass-covered middens, are known to the Eskimos at Gambell as "Miyowagh" (the climbing-up place) from its location at the foot of the plateau; "Ievoghiyoq" (place of the walrus); and "Seklowaghyaget" (many caches); the fourth and most recent site was merely a continuation of the latter and bore no particular name. For convenience these four old sites are here designated as D, C, B, and A, respectively.

Excavations proved the relative antiquity of the sites to have been in the order named. D had been established when the Old Bering Sea culture was at its height, for the lower levels of the midden yielded the complicated harpoon heads and elaborate art style known to have been characteristic of that period. But the material from the upper levels of D showed that during the later occupancy of the village important cultural modifications had set in, resulting in the decline of the rich Old Bering Sea ornamentation and its degeneration into the simpler art of the Punuk period. The next oldest site, C, proved to be a pure site of the Punuk period, with no trace of Old Bering Sea art or harpoon types. B was likewise of Punuk age but of a later phase, for harpoon heads from the upper levels included a type which at the latest site, A, was found to have evolved directly into the modern St. Lawrence type. The presence of a few glass beads and pieces of metal at A showed that this site could hardly have been more than 200 years old.

The cultural sequence revealed by these four old sites, although clear enough in itself and unusually complete in detail, still left unanswered one important question. This was the identification of the type forms of the Old Bering Sea culture, that is, the common implement types aside from the decorated objects. It might be considered that the implements from the lower levels of D, where only Old Bering Sea art was found, were the types of the Old Bering Sea culture. Although such an assumption would appear to be reasonable, a degree of uncertainty would be present owing to the fact that both Old Bering Sea and Punuk art occurred in the same midden. There would always be the possibility, therefore, that an object when found might not occupy its original position, owing to disturbances resulting from sloughing or from excavations for houses.

This deficiency was fortunately removed by the discovery of a site of pure Old Bering Sea culture. On the lower slope of the mountain and immediately back of D we found, almost by accident, a buried site, E, the decorated objects of which, from top to bottom, were all of the Old Bering Sea style. The presence of an old village at this spot had not been suspected by the Eskimos, although the trail to the mountain top which they and their ancestors had followed for generations passed directly over it. There was visible none of the refuse commonly seen about old Eskimo villages, no projecting bones or timbers, no elevations or depressions. The site was completely covered over with sod, moss, and stones and in appearance was a normal section of the mountain side. A single small patch of refuse which had become exposed in a rock crevice led to its discovery. Excavation showed that the refuse extended over an area (though possibly not continuous) of several hundred feet, and reached a total depth of 3 feet. It was apparent, however, that the site had been disturbed in at least one place by a rock slide and some of the surface had no doubt been removed by erosion.

ART AND HARPOON HEADS

The style of ornamentation found at E was Old Bering Sea, but it differed from most of the previously known examples of this art in being of a somewhat more generalized stamp (pl. 3; pl. 6, 1–4). Most of the lines and circles were less perfectly executed and the designs as a whole lacked the elaboration and finish that they later attained.

On plate 4 are shown examples of the later style of Old Bering Sea art from D. The overlapping "animal heads", which were found in three instances at the oldest site, E, were retained at D and developed into such artistic productions as figures 1, 2, 6, and 7 of plate 4; the more common small circles between converging or parallel lines (pl. 3, figs. 1, 3, 5) were also retained (pl. 4, fig. 2). On the other hand the numerous radiating lines and rather carelessly applied shorter detached lines, which occurred at E (pl. 3, figs. 7–8, 10–12), were not incorporated in the later and more developed Old Bering Sea patterns of D.

On plate 5 are shown 10 objects from D, C, and B, decorated in the Punuk style. The earliest examples of Punuk art at Gambell were found in the later sections of D, overlying the Old Bering Sea strata. Early Punuk art employed lightly incised lines and spurs and dots (pl. 5, figs. 1–3; pl. 6, figs. 16, 17, 19–22); later the lines and spurs became deeper and compass-made circles appeared (pl. 5, figs. 4–10).

The harpoon heads from the oldest site, E, were of a wide variety of forms, with open and closed sockets for the foreshaft, with end and side blades, with single and double line holes (pl. 6, figs. 1–5).

Harpoon heads from the lower levels of D were of the same forms as those from E, although there was a tendency toward increased size and elaboration of the base (pl. 6, figs. 7–14). Those from the later sections of D (pl. 6, figs. 15–23), belonging to what may be called the Early Punuk stage, were similar in form, but the pronounced spurs at the base had been reduced, resulting in a slightly irregular or plain spur; and there was only a slight elevation and dot where earlier there had been a raised circle and dot. Harpoon heads of the Birnirk type, so common at Point Barrow on the Arctic coast, also appeared during the Early Punuk stage (pl. 6, fig. 18). It should be noted, however, that multiple basal spurs and side blades of stone, the features which mark the Birnirk type, had been present even at the oldest Gambell site, E.

Some of the harpoon heads from the next site, C (pl. 6, figs. 24, 25), corresponded in form and decoration with those from the upper levels of D, but most of them were either undecorated or bore the late Punuk ornamentation of deep, evenly incised lines (pl. 6, figs. 29, 30). Another type was a modification of the Birnirk, with side blades and a bifurcated symmetrical spur (pl. 6, fig. 26). Lastly, we note the presence of the Thule no. 2 type (pl. 6, fig. 27), with open socket, lashing slots, and two barbs. This is one of the characteristic forms of the prehistoric Thule culture of the central and eastern Eskimo regions.[10]

From the lower levels of the next site, B, came harpoon heads which differed in no way from those found at C and the later sections of D (pl. 6, figs. 31, 32). The upper levels, however, yielded harpoon heads of simpler types. One was the small bladeless form known as Thule no. 1 (pl. 6, figs. 33, 34); the other was a modification of the typical open-socketed Punuk head, but smaller and thinner and with the sides of the socket inclined inward so that it became practically closed, thus allowing the foreshaft to remain in place without the aid of a lashing (pl. 6, figs. 35–37). Punuk art was found throughout the midden at B.

The two types of harpoon heads just described were found also at the next site, A, which was of post-Russian age, as shown by the presence of a few glass beads and pieces of iron (pl. 6, figs. 28–40).

[10] Mathiassen, Therkel, Archaeology of the Central Eskimos (Rep. Fifth Thule Expedition, 1921–24, vol. 4) 2, vols., Copenhagen, 1927.

Somewhat later the simplification of the harpoon head reached its limit, when the thin type with the barely open, wedge-shaped socket became thicker and evolved into the modern St. Lawrence form with closed socket (pl. 6, fig. 41).

STONE AND OTHER IMPLEMENTS

Some of the Old Bering Sea implement types are shown on plate 7, and Punuk types on plate 8. One of the striking differences between the Old Bering Sea and Punuk cultures was in stone technique. The older culture abounded in chipped-stone immplements, many of them being merely flakes with finely chipped edges; ground slate blades were also common, and 2- to 5-sided rubbing stones were characteristic. The Punuk sites, on the other hand, yielded very few chipped-stone implements, the great majority having been produced by rubbing.

Changes were found to have occured in other implement types, such as adz sockets, pottery lamps and vessels, ice creepers, fish-line sinkers, heavy ivory sled runners, bone and ivory arrowpoints. On the other hand, there were types such as ivory picks, wedges, walrus-scapula shovels, knife handles, baleen pails, drill rests, and bone drills, which remained unchanged from the Old Bering Sea period down to historic times.

Slat armor, wrist guards, and bird bolas did not come into use until the Punuk period; and the flat, narrow sled runners of bone and other evidences of dog traction were not found at any of the prehistoric sites.

HOUSES

From two ruins excavated, the Old Bering Sea type of house was found to have been a small, semisubterranean, rectangular structure, with stone floor and a long narrow entrance passage (pl. 9, fig. 1, in background); the walls were made of small driftwood timbers laid horizontally and held in place with bone and wooden stakes; the roof may also have been of wood.

Early Punuk houses were identical in structure to those of the Old Bering Sea period, but larger, with dimensions around 19 by 21 feet (pl. 9, fig. 1, in foreground, and fig. 2). Later in the Punuk stage there came into use another type of house, likewise square to rectangular, semisubterranean and with stone floor, but with walls made of stones, whalebones, and walrus skulls instead of timbers; the narrow entrance passage was roofed with whale ribs or stones. Another and quite different type of Punuk house continued in use up to about 40 years ago (pl. 10, figs. 1 and 2). It was semisubterranean, square to rectangular, with floor of heavy planks and walls of small timbers and whale jaws set on end and leaning slightly inward. Low sleeping platforms extended along the floor on two or three sides. Heavy logs set in the floor supported two or three large whale jaws or timbers which served as roof beams. There was a very long and narrow entrance passage.

THE ARCTIC COAST

While Eskimo culture on St. Lawrence Island was passing through the several stages outlined above, it was undergoing modifications of a somewhat different nature around Bering Strait and northward. Punuk influence was felt in this region, for examples of the art have been found in middens and house ruins at Wales and the Diomedes as well as at Point Hope and Point Belcher on the Arctic coast. But in these regions the Punuk as an intermediate culture was overshadowed by the Thule. Dr. Therkel Mathiassen, the discoverer of the Thule culture in northern Canada, was able to show that it had originated in the west.[11] Just where the Thule fitted into the Alaskan sequence, however, was not clear, although it appeared to be more closely related to the Punuk and to modern Alaskan culture than to the Old Bering Sea culture. In order to obtain definite evidence on this point, James A. Ford was detailed by the Smithsonian Institution in 1931 and 1932 to carry on excavations around Point Barrow.[12] This region was selected because it seems to have been the easternmost point to which Old Bering Sea influence extended, and the most westerly point at which the Thule culture existed as a type.

The oldest site at which Ford excavated was Birnirk. Here the bulk of the harpoon heads were of the type which had been previously designated by that name—the Birnirk type—being made usually of bone, with an open socket, a side blade of chipped flint with an opposite barb (sometimes with another blade in place of the barb) and with two or more asymmetrical spurs at the base (pl. 11, fig. 1). Other types of harpoon heads from Birnirk are shown on plate 11, figures 5–7. Only one harpoon head of the Thule No. 2 type (with two barbs) was found at Birnirk. However, this type (pl. 11, fig. 2), was common at the more recent site of Utkiavik, where somewhat later it developed into forms characteristic of the period just preceding the historic, as shown by their association with metal and late types of implements (pl. 11, figs. 3, 4). The harpoon head shown on plate 11, figure 8, came from a house ruin at Point Belcher, 60 miles below Barrow, and is of particular interest because it is a Punuk type. From the same ruin Ford obtained several objects

[11] Mathiassen, Therkel, op. cit.

[12] Collins, H. B., Jr., Archeological Investigations at Point Barrow, Alaska, Explorations and Field-Work of the Smithsonian Institution in 1932, Smithsonian Publ. no. 3213, pp. 45–48, 1933.

bearing Punuk ornamentation, which seems to indicate the direct migration of a small group of Eskimos from around Bering Strait, bringing typical Punuk culture to a region where it had not existed previously.

Old Bering Sea art seems not to have played a very important role around Barrow; however, a few examples were found in old burial mounds contemporaneous with the Birnirk settlement.

The exact relationship between the several north Alaskan culture stages and the Thule culture of Canada is still somewhat uncertain. Harpoon heads, art, and a number of implement types link the oldest of the Barrow sites—Birnirk—with the Old Bering Sea culture. There are also resemblances to the Thule culture, but these are found for the most part in simple traits of wide distribution, most of which are also common to the Old Bering Sea culture. When we come to consider the protohistoric and modern sites on the Arctic coast the situation is entirely different. Here the resemblances to the Thule culture are numerous and striking. Such important Thule elements as soapstone lamps, pictographic art, small ivory bird figures, drilled lashing holes on harpoon heads, and objects connected with dog traction (flat bone sled shoes, trace buckles, also swivels and ferrules) are common at the modern or late prehistoric Alaskan sites, but have not been found at any of the older sites either at Barrow, around Bering Strait, or on St. Lawrence Island.

The hypothesis that would seem best to explain this situation would be that such elements as those last mentioned were brought to northern Alaska within the past few centuries by a return or westward migration of Thule peoples subsequent to the original eastward spread of the Thule culture. There is reason for believing that the Point Barrow house should also be included among the elements thus introduced, for although built of different materials, it resembles the Thule house and the related Polar Eskimo house of northwestern Greenland in platform arrangement and to a certain extent in roof structure; whereas it is in these very features—and also in wall construction—that the Point Barrow house differs from other Alaskan houses, both on the Arctic coast and below Norton Sound.

Language seems to afford further evidence in the same direction.

* * * the dialects of the Siberian coast and of the Yukon and Kuskokwim deltas [diverge] more widely from those spoken north of Norton Sound than the latter from the dialects of far-distant Greenland and Labrador.[13]

* * * it is a remarkable fact that a Greenlander can still travel from his own country right across Arctic America as far as Bering Strait and make his dialect understood everywhere with little difficulty * * * south of Bering Strait, however, with the exception of a few oases like Inglestat, at the head of Norton Bay, where the dialect differs but little from that of Barrow, the

[13] Jenness, D., Ethnological Problems of Arctic America, Amer. Geogr. Soc. Special Publ. no. 7, p. 174, 1928.

dialects change rapidly, so that a Greenlander would probably require three different interpreters to converse with the Eskimo of St. Lawrence Island, of the Kuskokwim River, and of Cook Inlet.[14]

Here again we find a condition that might well be explained on the theory that the Arctic coast of Alaska had been subjected to a late wave of migration from the eastward.

SOUTH ALASKA

The excavations of Dall [15] and Jochelson [16] on the Aleutian Islands and of Weyer [17] on the Alaska Peninsula have shown that the prehistoric culture of this region, although Eskimoid in its general character, was, except for a few isolated resemblances, far removed from the Old Bering Sea, Punuk, and Thule cultures. Striking differences are seen in the shapes of dart points, foreshafts, and fish hooks, and the scarcity of pottery as well as the presence of stone lamps, labrets, and masks gives the southern culture a distinctive appearance. Variants of this general type of culture are revealed by the excavations of Hrdlička [18] on Kodiak Island and of Frederica de Laguna [19] on Kenai Peninsula and Prince William Sound. Excavations in the intervening Bristol Bay-Norton Sound district should throw light on the relationship between the prehistoric remains of the Bering Strait region and those of southern Alaska.

NORTHEASTERN SIBERIA

No archeological work has been done on the Asiatic side of the Bering Sea north of Kamchatka. However, from various objects which have found their way into museums, it is evident that settlements of the Old Bering Sea culture existed in northeastern Siberia, from Indian Point to East Cape, and possibly as far westward along the Arctic coast as the Kolyma River. Jochelson's excavations have shown that in earlier times the Kamchadal used earthenware pottery of Ainu type with looped handles on the inside of the rim.[20] Small stone lamps of the Aleutian type were also used. Otherwise, the Kamchadal sites have yielded little that is distinctive. To the

[14] Jenness, D., The Problem of the Eskimo, in The American Aborigines, their Origin and Antiquity, Univ. Toronto Press, pp. 379–380, 1933.

[15] Dall, W. H., On Succession in the Shell-Heaps of the Aleutian Islands, Contr. North Amer. Ethnol., vol. 1, pp. 41–91, 1877.

[16] Jochelson, W., Archeological Investigations in the Aleutian Islands, Carnegie Inst. Washington, Publ. no. 367, pp. 1–145, 1925.

[17] Weyer, E. M., Jr., Archeological Material from the Village Site at Hot Springs, Port Möller, Alaska, Anthrop. Papers Amer. Mus. Nat. Hist., vol. 31, pt. 4, pp. 239–279, 1930.

[18] Hrdlička, A., Anthropological Work in Alaska, Explorations and Field Work of the Smithsonian Institution in 1931, Smithsonian Publ. no. 3134, pp. 91–102, 1932.

[19] de Laguna, Frederica, The archeology of Cook Inlet, Alaska, The University Museum, Philadelphia, 263 pp., 72 pls., 1934.

[20] Jochelson, W., Archeological Investigations in Kamchatka, Carnegie Inst. Washington, Publ. no. 388, pp. 1–88, 1928.

southward, it should be noted that harpoon heads of Eskimo type have been found at prehistoric sites on the Kurile Islands and in Japan.[21]

SUMMARY AND CONCLUSIONS

The excavations at Bering Strait, St. Lawrence Island, and Barrow have furnished data which make possible a partial reconstruction of early culture growths and contracts in the western Arctic and sub-Arctic regions of America. Thus we see that St. Lawrence and the Diomede Islands and the Alaskan and Siberian coasts around Bering Strait were inhabited many centuries ago by groups of Eskimos who possessed a common culture, which has been designated as the Old Bering Sea culture. This oldest known Alaskan culture, far from being a simple or primitive one, was already highly developed, with an art style more elaborate and sophisticated than any previously known to have existed in Arctic or sub-Arctic regions. Other features of material culture show a similar condition; implements, utensils, and hunting gear all appear more as the end results of evolutionary processes than as beginning stages.

Having flourished for an unknown period of time, the Old Bering Sea culture entered upon a stage of transition probably about a thousand years ago. Changes were made in certain implement types, others were discontinued, to be replaced by new types; and the rich, curvilinear Old Bering Sea art degenerated into the much simpler art of the Punuk period. On St. Lawrence Island a number of harpoon heads and art designs have been found that are intermediate between the Old Bering Sea and the Punuk. Consequently, the changes there observed might be explained as having arisen locally, stimulated only by the acquisition of small quantities of Asiatic metal. However, in other respects the changes are so marked that such an explanation alone is not sufficient. Strong influence from some outside source must have been received, either through the normal process of culture dissemination or through the migration of new elements of population into the Bering Strait region. Demonstration of the latter might be possible if more skeletal material were available. A sufficient number of crania from Punuk sites on St. Lawrence Island have been found to show that the Eskimos of that time, like the modern St. Lawrence Islanders, were mesocephalic. But of the three Old Bering Sea skulls thus far found, one is mesocephalic and the other two strongly dolichocephalic.

The close relationship between late Punuk art and that of the modern Eskimos of the Yukon-Kuskokwim region may indicate a

[21] Torii, R., Etudes Archeologiques et Ethnologiques. Les Ainou des Iles Kouriles, Journ. Coll. Sci., Imp. Univ. Tokyo, vol. 42, art. 1, pls. 30, 31, Jan. 29, 1919; Kishinouye, K., Prehistoric Fishing in Japan, Journ. Coll. Agri., Imp. Univ. Tokyo, vol. 2, no. 7, pl. 22, Dec. 26, 1911.

southward migration or culture drift from St. Lawrence Island or Bering Strait within the past few centuries. An earlier influence, possibly dating from the Old Bering Sea period, may be reflected in the bone and ivory dart foreshafts which the Eskimos of this region carve to represent a sea otter or other mammal with open jaws. However, it is not yet possible to speak definitely of culture sequences in the Yukon-Kuskokwim region as excavations have not been made there.

Northward of Norton Sound the Punuk played a relatively unimportant role; there the Thule, as the dominant intermediate culture, provided the principal basis for the modern Eskimo culture of northern Alaska. The sequence—Old Bering Sea-Birnirk to Thule to modern—may be assumed for the region around Barrow, but the place of origin of the Thule is uncertain. From the present indications it may have been at Bering Strait, at Barrow, or along the coast between Barrow and the Mackenzie delta. We know little of the archeology of the Arctic coast from Barrow eastward to the Arctic Archipelago; somewhere along this broad stretch of coast there should be older Thule sites than those excavated by Mathiassen in the Hudson Bay region—sites established by the ancestors of the Thule Eskimos as they migrated eastward from Alaska probably during the period that Birnirk was inhabited.

From the recent investigations of Jenness and Wintemburg, it seems not unlikely that when the Thule Eskimos entered the Hudson Bay region they found other Eskimos—those of the Cape Dorset culture—already established there.[22] The origin of the Dorset culture and the influence it may have exerted on later cultures are problems for the future. Until this old Eastern Eskimo culture has been revealed in its entirety and its origin determined, it will hardly be possible to seek a solution to the ultimate problem of the origin of Eskimo culture.

Excavations in the lower Amur valley and in the territory of the Kamchadal, Koryak, and Chukchee should clarify to some extent the problem of the relationship between these northeastern Asiatics and the Eskimo and Indian tribes of northwestern America. The widely held theory that the Eskimo originated in north-central Canada and that some of them later moved westward along the Arctic coast to Bering Strait is not supported by recent investigations, for these seem to have revealed an older stage of Eskimo culture in Alaska than in the central or eastern regions. In the light of the present evidence, the Eskimo, instead of constituting an intrusive wedge which disrupted a former continuity of culture on

[22] Jenness, D., The Problem of the Eskimo, in The American Aborigines, their Origin and Antiquity, Univ. Toronto Press, pp. 373–396, 1933.

both sides of Bering Strait, seem more likely to have been the central link or filter through which cultural and even physical elements passed from one continent to the other. It should be noted that the theory that the Eskimos were late comers into the Bering Strait region took into consideration only the modern groups. However, as we have seen, the material culture of the modern Eskimos of northern Alaska appears to have been profoundly influenced by a late return migration of Thule peoples from the eastward, and it would be entirely reasonable to suppose that other aspects of their culture had been affected in a like manner. This late wave of eastern culture may therefore be the explanation of the "intrusive" appearance of the Alaskan Eskimo. According to this view, the observed cultural resemblances between northeastern Asiatics and Northwest Coast Indians could be explained as the result of contacts established at an earlier period, when the Old Bering Sea culture was flourishing on St. Lawrence Island, the Diomedes, and the adjacent coasts of Siberia and Alaska.

Additional excavation will be necessary to reveal the age of the Old Bering Sea culture. Physiographic changes have occurred since that period, but unfortunately these cannot be interpreted in terms of years. Sites of Punuk age at the eastern end of St. Lawrence Island now lie as much as 6 feet below the present beach, indicating a sinking of the shore-line or an encroachment of the sea. At the western end of the island the opposite condition exists, for the oldest site at Gambell seems to have been established before the formation of the present extensive gravel spit and lake. It should be recognized, however, that changes in shore-line topography in the Arctic carry no certain implication of antiquity, since it is known that such changes may be effected with considerable rapidity through the action of sea ice and ocean currents.

The origin of the Old Bering Sea culture is a problem requiring excavations not only around Bering Strait, where it reached its highest development, but also in northeastern Siberia, where it may have existed in an earlier form. The ultimate roots of this old Eskimo culture may lie still farther westward. The oldest phase of the Old Bering Sea culture has yielded a few examples of geometric art and carving in the round which resemble the upper Paleolithic art of Europe. These may or may not be significant. Of more importance, perhaps, is the fact that some of the oldest known Eskimo harpoon heads—those of the Old Bering Sea and Birnirk cultures—are equipped with small stone side blades, a technique which was also common in northern Europe during the Maglemosian period. It should be noted also that certain Iron Age objects from Scandi-

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navia, particularly bronze fibulae from southern Sweden and the adjacent islands of Bornholm and Öland,[23] bear designs which are suggestive of Old Bering Sea art and even more so of prehistoric Ainu art.[24] It may be because of the limitation of our knowledge that these appear now as only isolated resemblances. Little is known of the archeology of the greater part of central Siberia and nothing at all of the Siberian Arctic coast. Excavations in these regions might close the gaps and bring to light a series of old related cultures, forming an earlier parallel to the present general uniformity of culture in the circumpolar zone.

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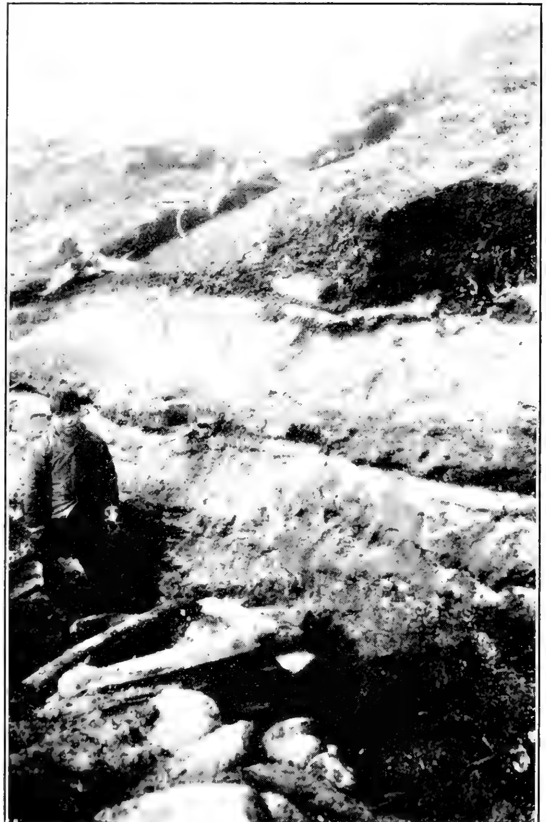
[23] Stjerna, Kunt, Bidrag till Bornholms befolkningshistoria under Järnåldern, pp. 144–145, Stockholm, 1905.

[24] Torii, R., op. cit., pl. 32, fig. 1.

1. MAP OF THE BERING SEA REGION.

2. RUINS OF OLD ESKIMO HOUSE ON PUNUK ISLAND, 4 MILES OFF SOUTHEAST END OF ST. LAWRENCE ISLAND.

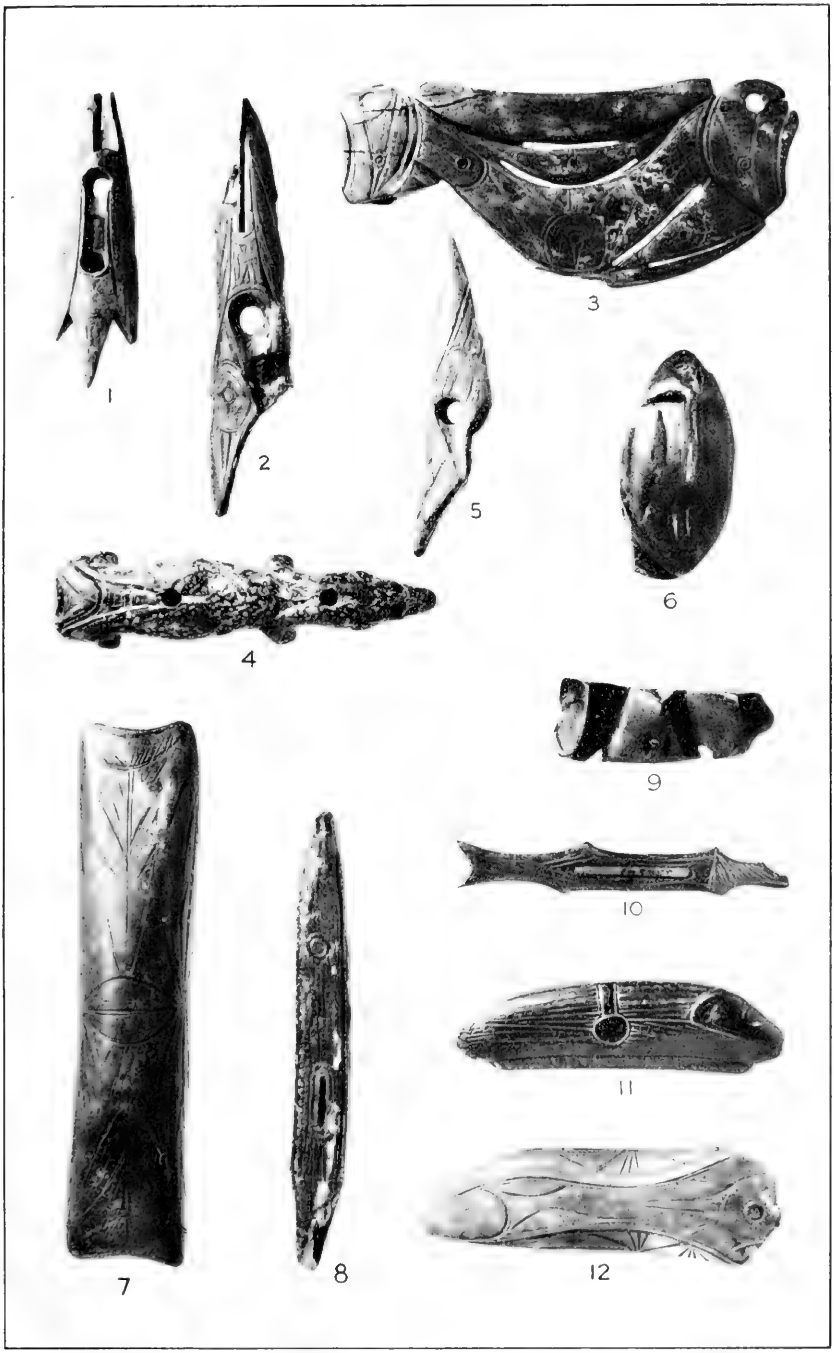


1. WHALE JAWS FORMING THE ENTRANCE TO AN OLD HOUSE AT BASE OF 16-FOOT MIDDEN ON PUNUK ISLAND.

Paul Silook standing.

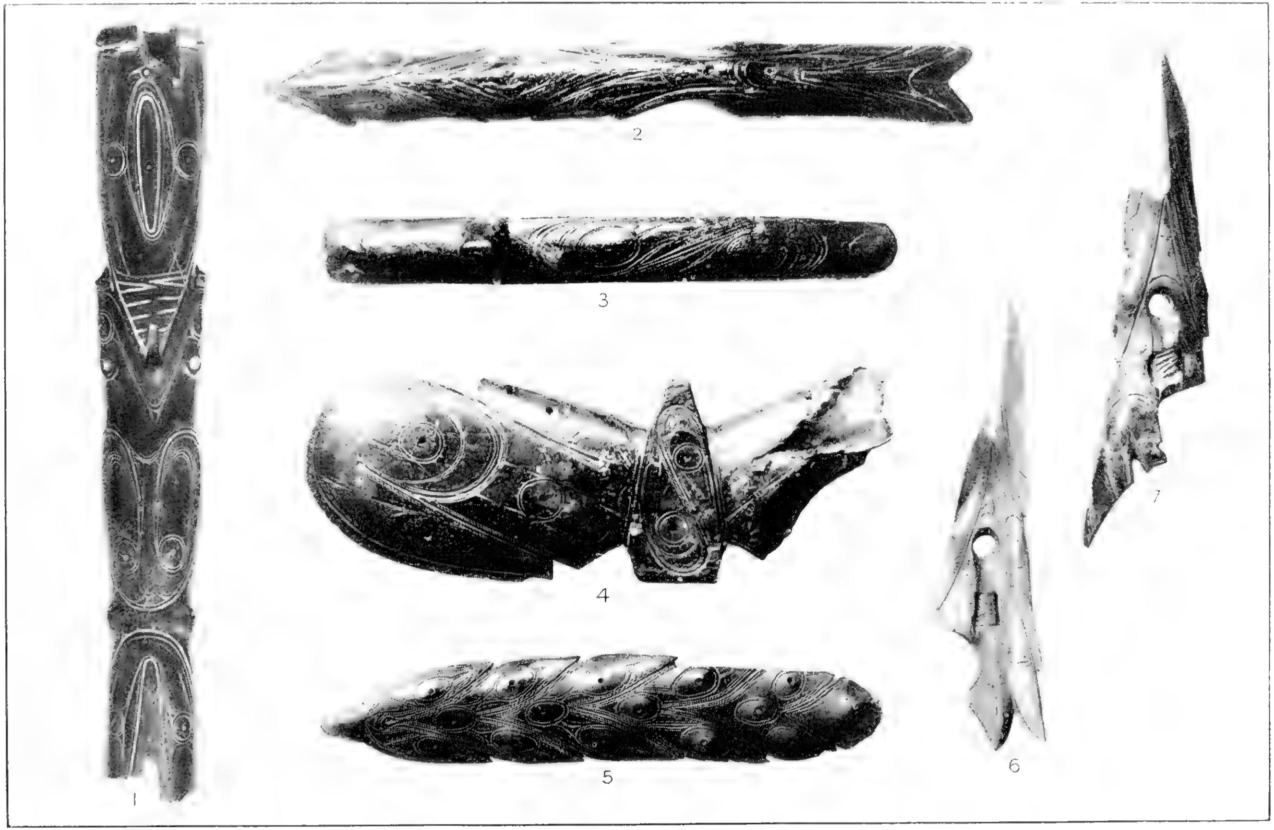
2. SECTION OF MIDDEN AT CAPE KIALEGAK, SOUTHEAST END OF ST. LAWRENCE ISLAND.

G. Herman Brandt above ladder.



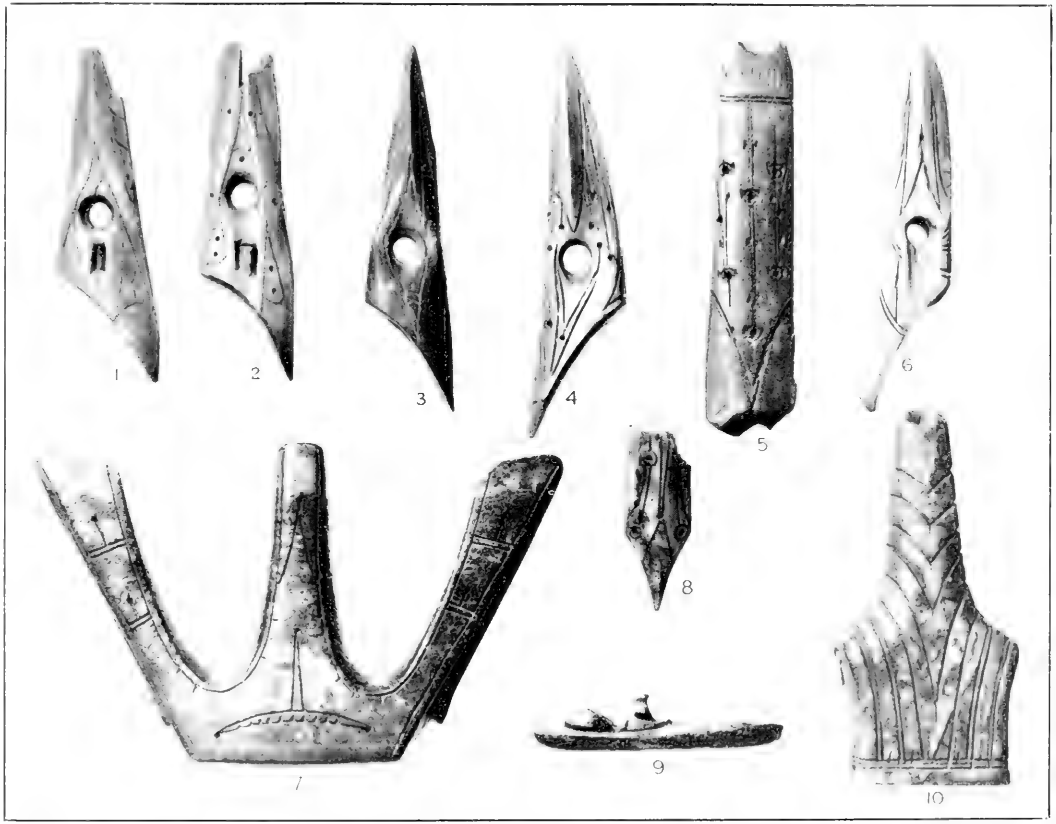
IVORY OBJECTS FROM THE OLDEST SITE AT GAMBELL, E, DECORATED IN OLD BERING SEA STYLE.

1, 2, 5, Harpoon heads; 3, gorget (?); 4, polar bear; 6, human head; 7, fat scraper; 8, harpoon foreshaft; 9, use unknown, possibly "wing" for butt of light harpoon shaft; 10, 12, use unknown; 11, knife handle. (Reduced about ½.)



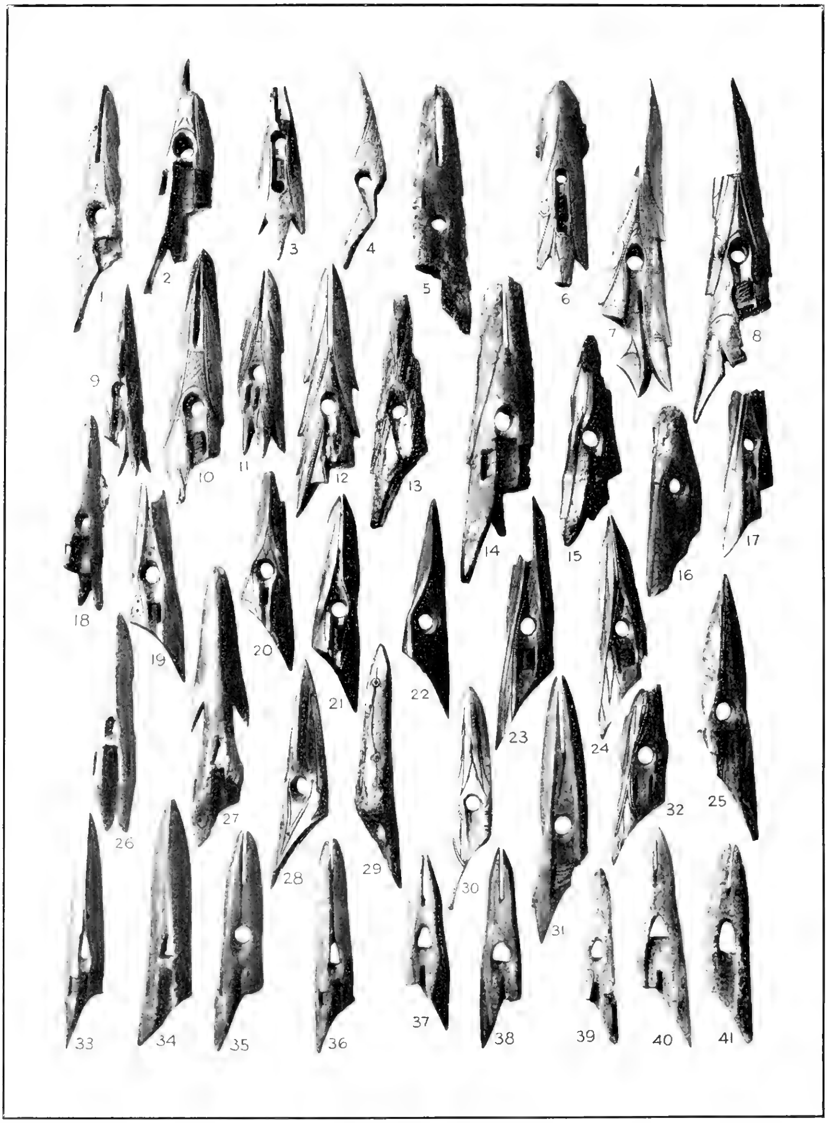
EXAMPLES OF THE HIGHEST DEVELOPED STAGE OF OLD BERING SEA ART.

1, Harpoon socket piece, from Kukuliak, property of Capt. E. D. Jones; 2-7 from Miyowagh, D. 2, fat scraper (?); 3, 5, pail handles; 4, use unknown; 6, 7, harpoon heads. (Reduced about ½.)



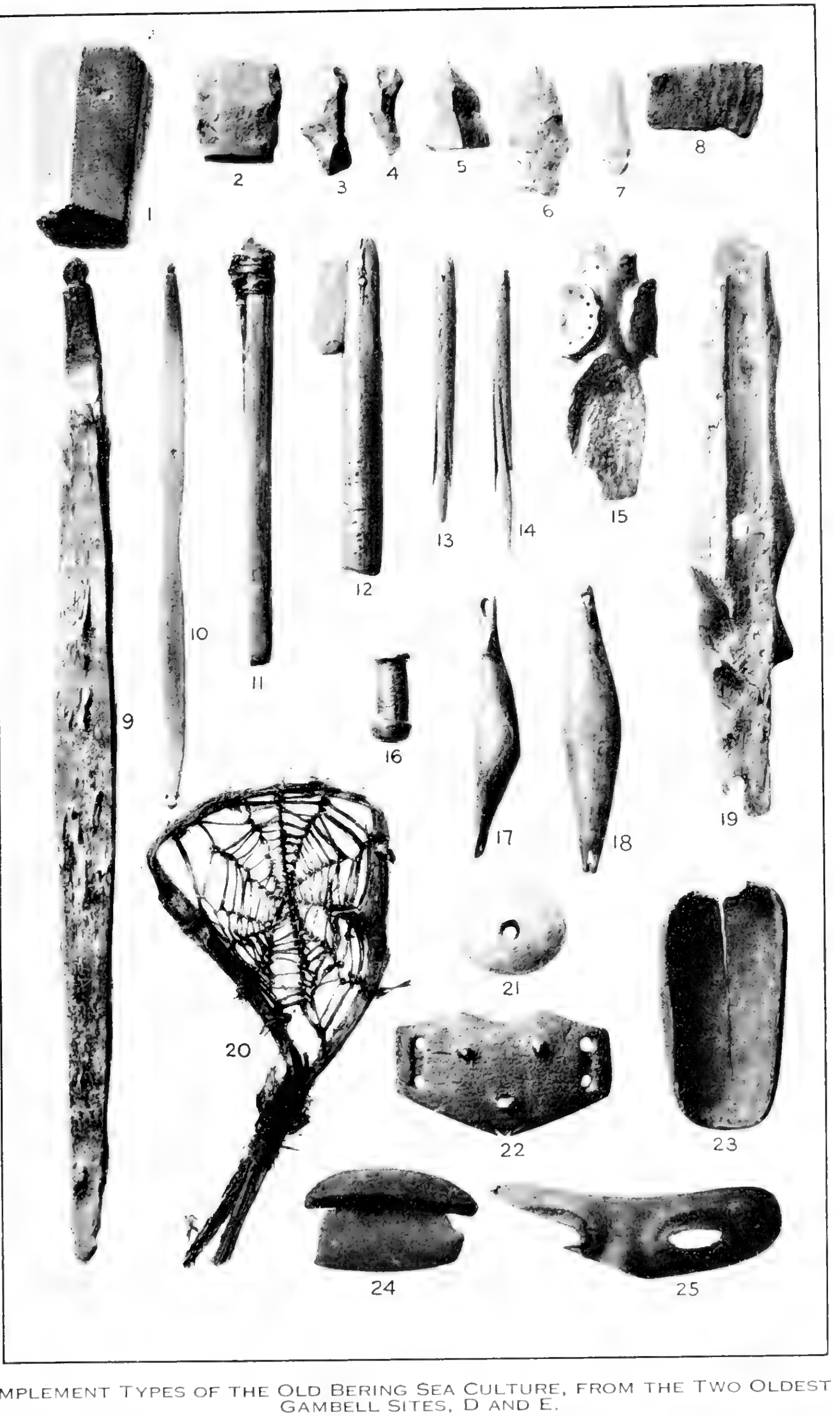
EXAMPLES OF PUNUK ART, IN IVORY, FROM THREE OLD SITES AT GAMBELL.

1-3, Harpoon heads, from D; 4, 6, 8, harpoon heads and fragment, from C; 5, use unknown, and 9, man in kayak, from C; 7, 10, objects related to plate 3, fig. 9 and plate 4, fig. 4 from B. (Reduced about ½.)



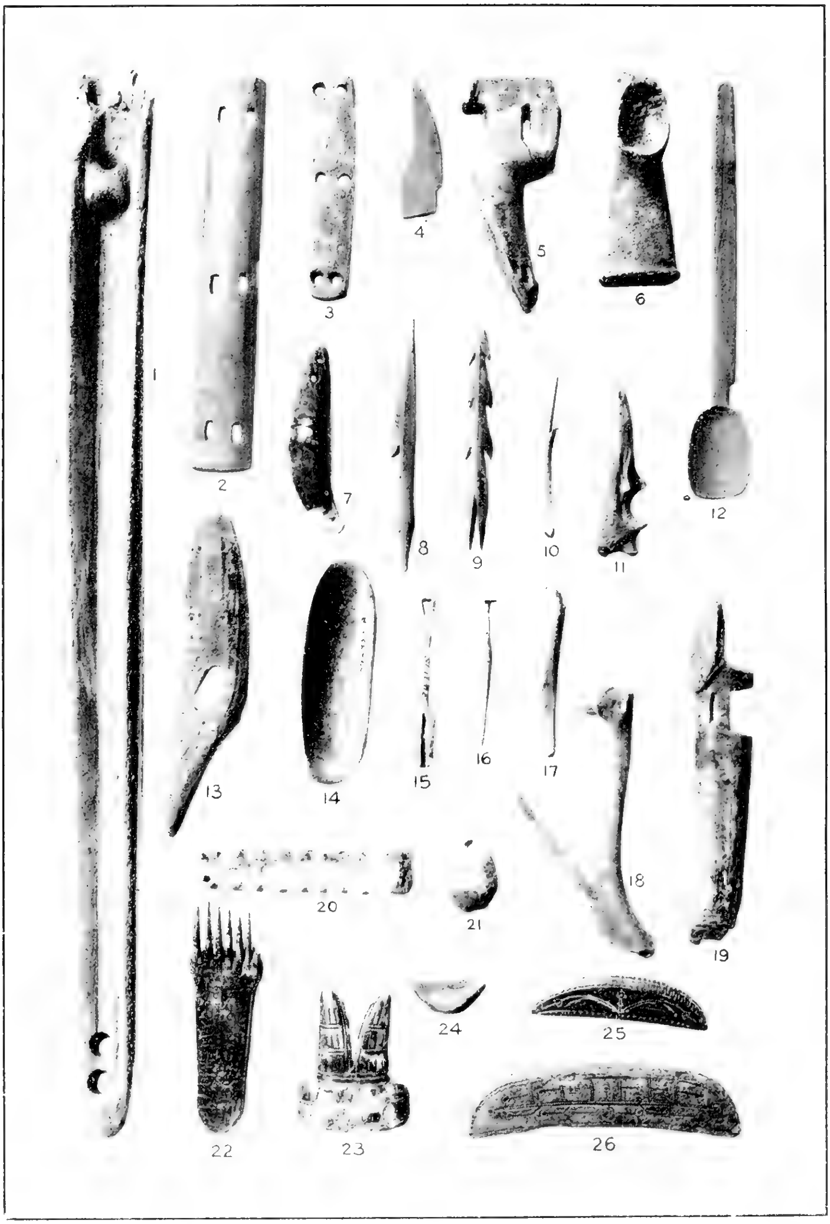
HARPOON HEADS FROM FIVE OLD ESKIMO SITES AT GAMBELL, ST. LAWRENCE ISLAND.

1–5, From the oldest site, E, Old Bering Sea period; 6–23, from D (6–13, decorated in Old Bering Sea style, 15–17 and 19–22 in early Punuk, 23 in Punuk); 24–30 from C, decoration, Punuk; 31–37 from B; 38–40 from latest site, A; 41, modern. (Reduced about ⅔.)



IMPLEMENT TYPES OF THE OLD BERING SEA CULTURE, FROM THE TWO OLDEST GAMBELL SITES, D AND E.

1, Rubbing stone; 2, scraper; 3–6, chipped stone implements; 7, rubbed slate knife blade; 8, pottery fragment; 9, baleen bow; 10, toy wooden bow; 11, stone graving tool, wooden handle; 12, knife; 13, 14, bone arrow points; 15, ivory adz socket; 16, 21, mouth pieces for floats; 17, 18, ivory fish line sinkers; 19, lower end of dart thrower; 20, baleen ice scoop; 22, ice creeper, with inserted ivory spikes; 23, ivory fat scraper; 24, woman's knife; 25, wooden snow goggles. (Reduced about ⅔.)



IMPLEMENT TYPES OF THE PUNUK CULTURE.

1. Ivory sled runner; 2, 3, plates of bone armor; 4, slate harpoon blade; 5, 6, ivory adz sockets; 7, knife sharpener, bear tooth; 8, 9, arrow points; 10, bird bone inserted in another; 11, bone drill; 12, ivory spoon; 13, whaling harpoon head; 14, fat scraper; 15, fish hook shank; 16, handle of engraving tool; 17, drill or reamer; 18, hook, made of dog humerus; 19, ivory drum handle; 20, ice creeper; 21, bola weight; 22, ivory comb; 23, wrist guard; 24, drill mouth piece; 25, 26, ivory knife handles. (Reduced about ¾.)

1. RUINS OF TWO HOUSES EXCAVATED AT D. OLD SITE AT GAMBELL, ST. LAWRENCE ISLAND.

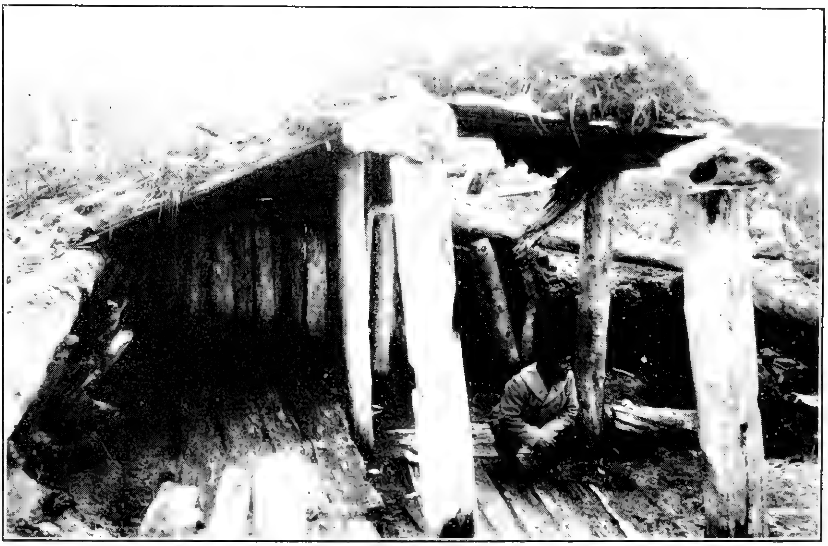
In background is a house of Old Bering Sea age partly underlying the walls of a later house, in foreground, of early Punuk age.

2. VIEW OF THE EARLY PUNUK HOUSE SHOWN IN FOREGROUND OF FIGURE 1.

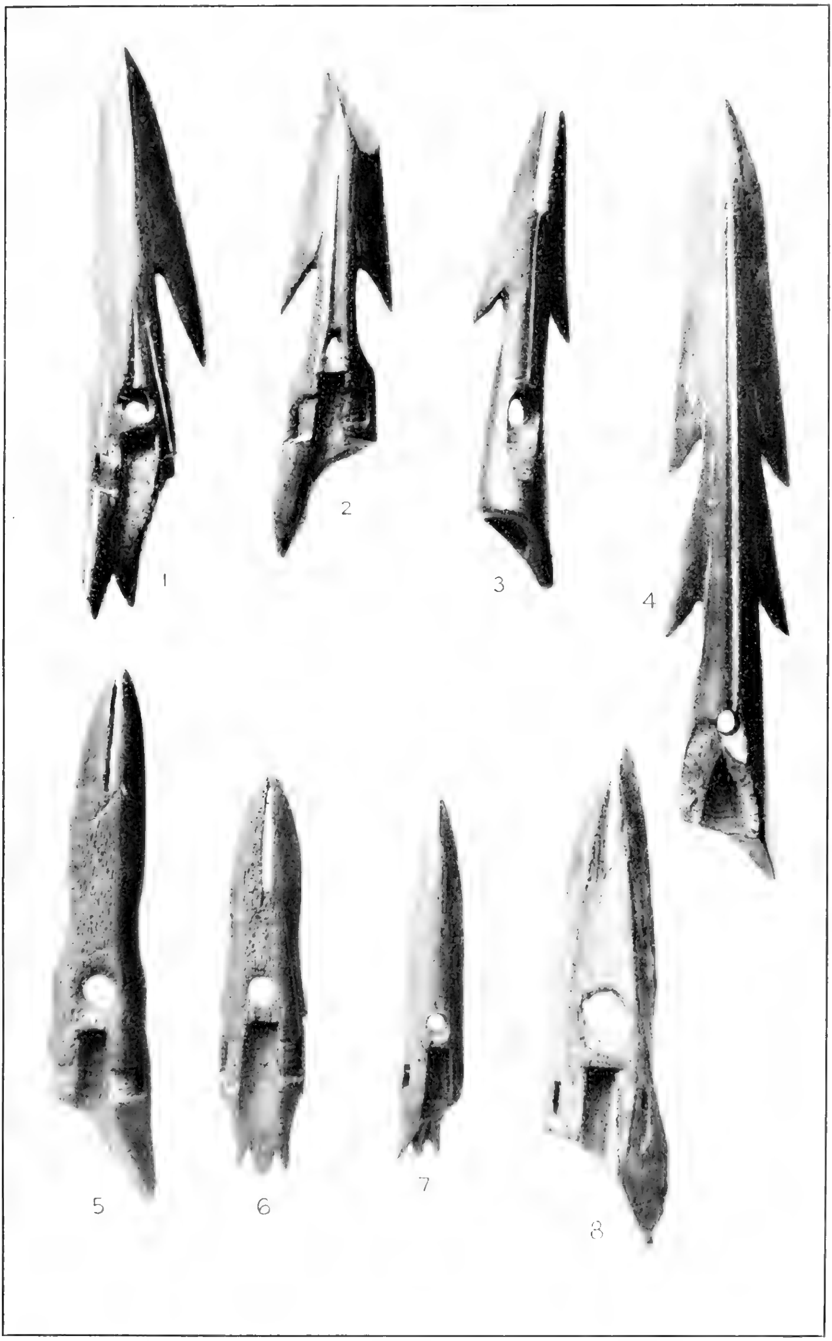
The entrance passage, roofed with driftwood timbers, is shown in background.

1, RUINED HOUSE ON PUNUK ISLAND, ABANDONED ABOUT 50 YEARS AGO.

Floor of heavy, hewed planks; low sleeping platform; framework of driftwood timbers and whale bones. This is the latest of several types of semisubterranean houses formerly used on St. Lawrence Island.



2. INTERIOR VIEW OF SAME.



HARPOON HEADS FROM OLD SITES AROUND POINT BARROW, ON THE ARCTIC COAST.

1, 5-7, From Birnirk, the oldest site; 2-4, from Utkiavik; 8, from Point Belcher. (Reduced about 1/3.)

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