
FOR·THE·INCREASE·AND·DIFFVSION·OF·KNOWLEDGE·AMONG·MEN·
PER
ORBEM
·SMITHSONIAN·
·INSTITVTION·
·WASHINGTON·1846·

SMITHSONIAN
MISCELLANEOUS COLLECTIONS

VOL. 63

"EVERY MAN IS A VALUABLE MEMBER OF SOCIETY WHO, BY HIS OBSERVATIONS, RESEARCHES, AND EXPERIMENTS, PROCURES KNOWLEDGE FOR MEN"—SMITHSON

(PUBLICATION 2320)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
1914

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

ADVERTISEMENT

The present series, entitled "Smithsonian Miscellaneous Collections," is intended to embrace the principal publications issued directly by the Smithsonian Institution in octavo form; and is designed to contain reports on the present state of our knowledge of particular branches of science, instructions for collecting and digesting facts and materials for research, lists and synopses of species of the organic and inorganic world, reports of explorations, aids to bibliographical investigations, etc., generally prepared at the express request of the Institution.

The "Smithsonian Contributions to Knowledge," in quarto form, embraces the records of extended original investigations and researches, resulting in what are believed to be new truths, and constituting positive additions to the sum of human knowledge.

In both of these series each article bears a distinct number, and is also separately paged unless the entire volume relates to one subject. The date of the publication of each article is that given on its special title-page, and not that of the volume in which it is placed. In many cases papers have been published and largely distributed, several months before their combination into volumes.

CHAS. D. WALCOTT,
Secretary of the Smithsonian Institution.

CONTENTS

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 63, NUMBER 1

Hodgkins Fund

ATMOSPHERIC AIR IN RELATION TO TUBERCULOSIS

(With 93 Plates)

BY

GUY HINSDALE, A. M., M. D.
Hot Springs, Virginia.
Secretary of the American Climatological Association; Ex-President Pennsylvania Society for the Prevention of Tuberculosis; Fellow of the College of Physicians of Philadelphia; Associate Professor of Climatology, Medico-Chirurgical College; Member of the American Neurological Association; Fellow of the Royal Society of Medicine, Great Britain; Corresponding Member of the International Anti-Tuberculosis Association, etc.

(Publication 2254)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
1914

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

ADVERTISEMENT

The accompanying paper, by Dr. Guy Hinsdale, on "Atmospheric Air in Relation to Tuberculosis," is one of nearly a hundred essays entered in competition for a prize of $1,500 offered by the Smithsonian Institution for the best treatise "On the Relation of Atmospheric Air to Tuberculosis," to be presented in connection with the International Congress on Tuberculosis held in Washington, September 21 to October 12, 1908. The essays were submitted to a Committee of Award, consisting of Dr. William H. Welch, of Johns Hopkins University, Chairman; Prof. William M. Davis, of Harvard University; Dr. George M. Sternberg, Surgeon-General, U. S. A., Ret'd; Dr. Simon Flexner, Director of Rockefeller Institute for Medical Research, New York; Dr. Hermann M. Biggs, of New York, General Medical Officer, Department of Health, New York City; Dr. George Dock, Medical Department, Washington University, St. Louis; and Dr. John S. Fulton, of Baltimore, Secretary General of the Congress on Tuberculosis. Upon the recommendation of the committee, the prize was divided equally between Dr. Guy Hinsdale, of Hot Springs, Virginia, and Dr. S. Adolphus Knopf, of New York City.

At the request of the Institution, Dr. Hinsdale has revised his essay so as to indicate some of the advances made in the study of the subject during the past five years.

Charles D. Walcott,
Secretary of the Smithsonian Institution.

Washington, December, 1913.

TERMS OF COMPETITION

SMITHSONIAN INSTITUTION

HODGKINS FUND PRIZE

In October, 1891, Thomas George Hodgkins, Esquire, of Setauket, New York, made a donation to the Smithsonian Institution, the income from a part of which was to be devoted to "the increase and diffusion of more exact knowledge in regard to the nature and properties of atmospheric air in connection with the welfare of man." In furtherance of the donor's wishes, the Smithsonian Institution has from time to time offered prizes, awarded medals, made grants for investigations, and issued publications.

In connection with the approaching International Congress on Tuberculosis, which will be held in Washington, September 21 to October 12, 1908, a prize of $1,500 is offered for the best treatise "On the Relation of Atmospheric Air to Tuberculosis." Memoirs having relation to the cause, spread, prevention, or cure of tuberculosis are included within the general terms of the subject.

Any memoir read before the International Congress on Tuberculosis, or sent to the Smithsonian Institution or to the Secretary-General of the Congress before its close, namely, October 12, 1908, will be considered in the competition.

The memoirs may be written in English, French, German, Spanish or Italian. They should be submitted either in manuscript or typewritten copy, or if in type, printed as manuscript. If written in German, they should be in Latin script. They will be examined and the prize awarded by a Committee appointed by the Secretary of the Smithsonian Institution in conjunction with the officers of the International Congress on Tuberculosis.

Such memoirs must not have been published prior to the Congress. The Smithsonian Institution reserves the right to publish the treatise to which the prize is awarded.

No condition as to the length of the treatises is established, it being expected that the practical results of important investigations will be set forth as convincingly and tersely as the subject will permit.

The right is reserved to award no prize if in the judgment of the Committee no contribution is offered of sufficient merit to warrant such action.

Charles D. Walcott,
Secretary of the Smithsonian Institution.

Washington, D. C., February 3, 1908.

PREFACE

The rapid progress in the antituberculosis movement throughout the world in the last five years has made it necessary to make some changes in the present essay as originally presented to the Smithsonian Institution in 1908. Much that then seemed novel appears almost commonplace now. An extraordinary amount of research has been carried out with reference to the atmospheric air during these later years. The whole theory of ventilation has been stated in new terms; the presence of ozone in the atmosphere, a subject that has always appealed to the popular fancy since its discovery, has been restudied and its physiologic action assigned a value different from that commonly ascribed to it; the properties of strong sunlight and Alpine air have been marshalled for the combat with surgical tuberculosis, particularly in children.

Physiologists in Europe and America have lately made most interesting studies of the blood at the higher altitudes and their observations are constantly throwing new light on the entire subject of aerotherapy, replacing old impressions and beliefs with a scientific basis on which we may confidently build.

There never was a time when the outdoor life and the accessories for the atmospheric treatment of all tuberculous persons were so well systematized and placed in harmony with the other hygienic measures adopted for their cure.

What the result has been we have endeavored to show and what the future holds for us we are eagerly awaiting.

May the Smithsonian Institution, through its Hodgkins Fund, continue to stimulate inquiry and disseminate the fruits of the worldwide efforts to the better understanding of the great problems that yet remain unsolved.

GUY HINSDALE.

HOT SPRINGS, VA., DECEMBER, 1913.

TABLE OF CONTENTS

CHAPTER PAGE

I. Introduction 1

Difficulty of estimating the value of atmospheric air, aside from other agents in treating tubercular disease; prevention of tuberculosis; sanatoria; pioneers in the treatment of tuberculosis in America; the Adirondack Cottage Sanitarium.

II. Value of Forests: Micro-organisms, Atmospheric Impurities...... 4

General benefit of forests; qualities of forest air and soil; carbon dioxide; oxygen; ozone; use of forest reservations for sanatoria; micro-organisms in the respiratory passages; composition of expired air; atmospheric impurities, coal and smoke, carbonic acid, sulphur dioxide, ammonia; oxygen for tuberculous patients.

III. Influence of Sea Air; Inland Seas and Lakes.......... 32

Sea voyages; marine climate of islands; Arctic climate; floating sanatoria; seaside sanatoria for children; seacoast and fogs; fogs on the Pacific coast; radiation fogs; fogs in the mountains; sea air for surgical tuberculosis; air of inland seas and lakes.

IV. Influence of Compressed and Rarefied Air; High and Low Atmospheric Pressure; Altitude 61

Discovery of the advantages of Colorado and California climate for consumptives; works of S. E. Solly, Charles Theodore Williams on Colorado; Jourdanet on Mexico; Paul Bert on diminished barometric pressure, etc.; insolation; diathermancy of the air; Alpine resorts; surgical tuberculosis treatment in Switzerland; cases of high altitude treatment; effect of cold beneficial; expansion of the thorax at the higher altitude; choice of cases for treatment at altitudes.

V. Influence of Increased Atmospheric Pressure, Condensed Air...... 87

The effect of barometric changes on the spirits; artificially compressed air, C. T. Williams, Von Vivenot; pneumatic cabinet; Prof. Bier's treatment of surgical tuberculosis by artificial hyperæmia.

VI. Artificial Pressure; Breathing Exercises 98

Pulmonary gymnastics; exercise at lowered air pressures; atmospheric compression of the affected lung, Murphy's Method, artificial pneumothorax; song cure.

VII. Fresh Air Schools for the Tuberculous; Ventilation.......... 103

Waldschule or fresh air schools for tuberculous children; Providence fresh air school; defects of school buildings; hygienic safeguards in schools; rebreathed air; open air chapels and theatres; ventilation of dwellings.

PAGE

VIII. Exercise in Tuberculosis; Graduated Labor 111

Effect of exercise on the opsonic index of patients suffering from pulmonary tuberculosis; work of Dr. Paterson, Mr. Inman and Sir Almroth Wright.

IX. Accessories for Fresh Air Treatment of Tuberculosis 120

Tents; pavilion tents; tent houses; shacks; disused trolley cars; balconies; day camps; sleeping porches; pavilions; hospital roof wards; detached cottages; sleeping canopies.

X. Conclusions 12

Hodgkins Fund

ATMOSPHERIC AIR IN RELATION TO TUBERCULOSIS

By GUY HINSDALE, A. M., M. D., Hot Springs, Va.

(With 93 Plates)

CHAPTER I. INTRODUCTION

We are compelled to acknowledge at the outset the difficulty or impossibility of analyzing the relationship of atmospheric air to tuberculosis so as to isolate the influence of all other factors. It would be totally useless and impossible to consider air independent of sunlight, heat, rainfall, the configuration of the earth's surface; racial characteristics, social environment, including dwellings, clothing, food, and drink.

As a resultant of all these and many other factors in the tuberculosis problem, we obtain the figures of mortality which are published from time to time by various cities, states, and nations. The problem seems incapable of solution. One might as well survey an oak that has grown for centuries and set out to determine the relative value of the atmospheric air, the sunlight, the rainfall, and the various constituents of the soil and its environment in producing the sturdy, deeply rooted, and wide-spreading tree which has seen ages come and go.

The world-wide efforts now made to determine the nature of this infection and especially its bacteriologic and pathologic character are accompanied by a general effort to limit its spread. We are encouraged to believe that future generations will be provided with a practical and efficient method of destroying this insatiate monster.

Undoubtedly we have begun at the right end, but we only began within the memory of nearly all of us, only thirty-two years ago, when the true cause of the disease was first isolated and revealed to the human eye.

Previously we were as the blind leading the blind, groping about in search of special climates, special foods or medicines, meeting with more or less success in so far as the dietetic, hygienic, out-of-door plan of treatment was carried out. These curative measures succeeded then, as they succeed now, but preventive measures worthy the name were entirely unknown. The enemy once revealed in its hiding place, and various facts in its life history determined, the logical result was a gradual—very gradual—dawn which promised better things. Now the world has seen a great light and we wonder how intelligent men could have dwelt in those caverns of ignorance and even refused to come out for years while the men in the laboratory beckoned with signs which then seemed so uncertain but now so clear. As late as 1890 the medical mind did not grasp the necessity for preventive measures. As one asleep it heard voices but was slow to waken; it starts and rubs its eyes and looks about, waiting for some word or message that will bring it to its senses.

It was in 1891 that the first society for the prevention of tuberculosis was organized. This was started in France by M. Armaingaud, of Bordeaux. The second was the Pennsylvania Society for the Prevention of Tuberculosis organized in Philadelphia in 1892. These were the pioneers in Europe and America. They devoted their energies to a campaign with three cardinal features: (1) the education of the public in reference to the nature of the disease and its means of prevention; (2) the passage of suitable laws regarding notification, the restriction of expectoration, disinfection, etc.; and (3) the care of consumptives and the establishment of sanatoria by public or private means in suitable localities.

The wonderful growth of this movement for preventive measures is now seen in the establishment of 1,228 societies for the prevention of tuberculosis in America alone, and in the erection of 527 sanatoria in this country (1913).[1] The State of Pennsylvania alone has appropriated in one Act of Legislature $2,000,000 for this purpose and one citizen of the state, Mr. Henry Phipps, has given an equal amount for the scientific study as well as the practical treatment of this disease in all its bearings.[2]

---

[1] The State of New York leads all other states in the number of new organizations and institutions established during the last two years. The total number of beds for consumptives in the United States now exceeds 33,000.

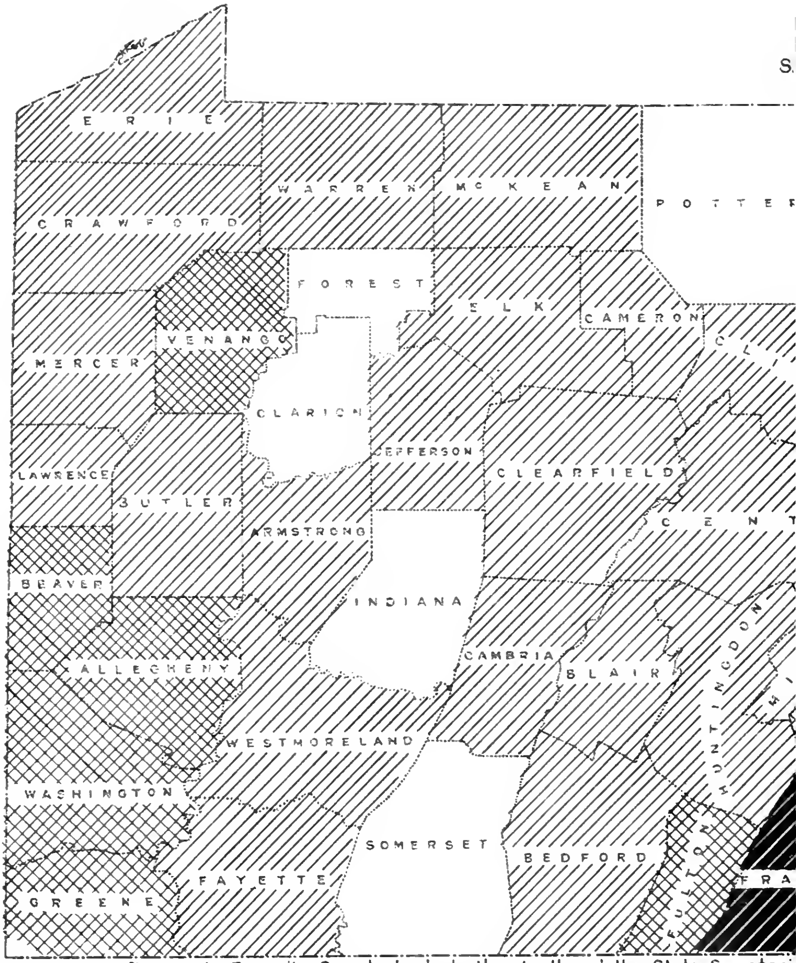
[2] The Pennsylvania legislature appropriated $1,000,000 in 1907, $2,000,000 in 1909, $2,624,808 in 1911, and $2,659,660 in 1913 for tuberculosis work alone. This is under the direction of Dr. Samuel G. Dixon, the Commissioner of Health.

There are at the present time two State Sanatoria in Pennsylvania in operation.

Mont Alto, Franklin Co.

No. of patients under treatment	957
Elevation	1,650 ft.

S.



Note:- The figures in Franklin County include the deaths at the State Sanatori
The death rate for Franklin County exclusive of Mont Alto would be

Death

☐ 0-49

▨ 50-99

MAP SHOWING DISTRIBUTION OF PULMONARY TUBERC

NWEALTH OF PENNSYLVANIA
EPARTMENT OF HEALTH
G. DIXON, M. D., COMMISSIONER

Tuberculosis at Mont Alto, numbering 248 in 1912.

0,000.
49 ▨ 200 and above

99

PENNSYLVANIA BY COUNTIES FOR THE YEAR 1912

The late Dr. Henry I. Bowditch, of Boston, was one of the first physicians in America to recognize the value of constant out-door life in the treatment of tuberculosis and was accustomed to send such patients on easy journeys by carriage so that they might have the benefit of as much out-door air as possible, becoming gradually inured to the elements.

The late Dr. Alfred L. Loomis, of New York, was one of the first to systematically send tuberculous patients to the Adirondack forest that they might have the benefit of the purest and most invigorating air obtainable and, like the physicians of ancient Rome who sent consumptive patients to the pine forests of Libya, he believed that the terebinthinate exhalations from the standing pines exerted a most beneficial influence on pulmonary affections. Dr. Loomis's results were so gratifying that he encouraged Dr. Edward L. Trudeau to care for such patients in the Adirondack Mountains throughout the year, and Dr. Trudeau, with his help, founded in 1884 the first sanatorium for tuberculosis in America.[1]

This Adirondack Cottage Sanitarium, now in its thirtieth year, has been the inspiration of sanatoria for tuberculosis throughout the country. Its success in restoring so many patients to health and usefulness is not wholly estimated in figures. It has established

---

Cresson, Cambria Co.
No. of patients under treatment 337
Elevation .... 2,550 ft.
Hamburg, Berks Co.
In the course of construction and will be completed some time in 1914.
Capacity 480
Elevation .... 550 ft.

These institutions care for both incipient and far advanced cases. The interior arrangement of the sanatoria at Cresson and Hamburg is such that they can be used for the different classes of cases as demand may necessitate. There is a waiting list of those desiring admission to these institutions at all times.

The State maintains 115 Tuberculosis Dispensaries, which are located throughout the 67 counties in the commonwealth. There are 220 physicians and 120 visiting nurses employed in these dispensaries.

By the courtesy of Dr. Samuel G. Dixon, Commissioner of Health, we are able to show in a map the distribution of tuberculosis in the counties of Pennsylvania (pl. 1). This shows, as in an earlier map by the author, that the disease is least prevalent in the higher, forest covered regions of the State.

[1] A. L. Loomis, M. D. Evergreen Forests as a therapeutic agent in pulmonary phthisis (Trans. Amer. Climatological Ass., Vol. 4, 1887). See page 134.

a practical method of cure and has done much to correct the earlier unfounded and mischievous notions that prevailed as to what was necessary for the cure of tuberculosis.

Taking this institution as an example, let us see what bearing it may have on our general subject, the relation of the atmospheric air to tuberculosis:

(a) It is in the midst of an evergreen forest of over 10,000 square miles; (b) the atmosphere is pure, or at least as pure as may be obtained on the continent; (c) the air is moderately moist; (d) the rainfall averages 35 inches; (e) the air is moderately rarified, owing to (f) an elevation of 1,750 feet; (g) owing to its northern situation (latitude 44°) and its elevation (1,750 feet) (h) the climate is cold in winter and (i) subject to rather sudden changes with an annual range of 50° C. or 138° F.

CHAPTER II. VALUE OF FORESTS, MICRO-ORGANISMS, ATMOSPHERIC IMPURITIES.

GENERAL BENEFIT OF FORESTS

It has come to be an axiom in phthisiology that the air of an evergreen forest is eminently suitable for a patient with tuberculosis.[1] As we have previously mentioned, the pine forests of Libya were used two thousand years ago for the cure of "ulcerated lungs." At that period the pines abounded and gave the locality a reputation as a health resort for affections of the lungs. But the ravages of time, aided by fire and sword, not to speak of domestic needs, have obliterated all vestiges of these ancient forests.

The successful institutions located in the Hartz Mountains, the Black Forest of Germany, in the Forest of Ardennes, the State Forest Reserve of Pennsylvania, and the Adirondack Forest in New York owe much of their success to the abundant use of the purest air both day and night.

European Governments have long recognized the great value of

---

[1] The following quotation from Pliny shows that it was generally agreed in his day that the forests and especially those which abound in pitch and balsam are the most beneficial to consumptives or those who do not gather strength after long illness, and that they are of more value than the voyage to Egypt:

"Sylvas, eas duntaxat quae picis resinaeque gratia redantur, utilissimas esse phthisicis, aut qui longa aegritudine non recolligant vires, satis constat; et illum coeli aera plus ita quam navigationem Aegyptian proficere, plus quam lactis herbidos per montium aestiva potus."—C. Plinii, Hist. Nat. lib. xxiv, Cap. 6.

ST. BLASIEN IN THE BADEN BLACK FOREST, GERMANY
Courtesy of Dr Sander

SANATORIUM ST. BLASIEN IN THE BADEN BLACK FOREST, GERMANY. ELEVATION 800 METERS (2,600 FEET). THE AIR OF THE FIR FOREST IN THE CURE OF TUBERCULOSIS

Photograph Furnished by Dr. Albert Sander their forests and have protected them by strictly enforcing intelligent laws so that they may be forever preserved and improved. The history of forestry in the United States and Canada has been that of ruthless, unrestrained, wholesale destruction of nearly all our standing pine, and heavier spruce. In recent years, however, we have seen the establishment of Government reserves, State reserves, and State laws for their protection; the organization of the American Forestry Association, the American Forest Congress, the Society for the Preservation of the Adirondack Forest; the Schools of Forestry at Yale, Harvard University and Mont Alto, Penna. All these remedial measures have come very late, but will undoubtedly exert a strong influence for good.[1]

Aside from the general beneficial influence of forests, universally recognized by climatologists, these natural parks have proved the means of restoring thousands of persons suffering from tuberculosis and diseases of the respiratory system.

QUALITIES OF FOREST AIR AND SOIL

The qualities of forest air and forest soil have been studied by E. Ebermayer[2] who shows that, like that of the sea and mountains, forest air is freer from injurious gases, dust particles, and bacteria. It was shown that the vegetable components of the forest soil contain less nutritive matter (albuminoid, potash, and phosphates and nitrates) for bacterial growth; that the temperature and moisture conditions are less favorable; that the sour humus of the forest soil is antagonistic to pathogenic bacteria; finally that, so far, no pathogenic microbes have ever been found in forest soil; hence this soil may be called hygienically pure.

The soil is protected from high winds by forest growth and undergrowth; the upper soil strata are slow to dry out and wind sweeping over them carries few micro-organisms into the air. As may be expected, fewer microbes are found in forest air than outside their limits. Serafini and Arata have proved this experimentally.[3] They

---

[1] The chief forester of the United States has in 1913 under his care in 160 forest reservations a total of 165,000,000 acres of forest land. The present Chief Forester has done excellent work in the prevention of serious forest fires.

[2] E. Ebermayer: (1) Hygienic significance of forest air and forest soil. (2) Experiments regarding the significance of humus as a soil constituent; and influence of forest, different soils, and soil-covers on composition of air in the soil. Wollny, 1890 (Hygeia, August 15, 1891).

[3] Serafini and Arata: Intorno all 'azione dei boschi sui mikro organismi transportati dai venti.

exposed plates in the forest air and on its outskirts and tabulated their countings of bacteria for forty successive days from May 6. They made three classes—molds, liquefying and non-liquefying bacteria. They found that, with one exception, one or two of these classes were always less numerous in the forest than on its outskirts and generally from twenty-three to twenty-eight times less. Serafini makes the point that bacteria coming from the outside are reduced in number by a sort of filtration process. Thus we see that the air of forests is comparatively free from endogenous and exogenous bacteria—none of them in any case being pathogenic.[1]

CARBON DIOXIDE IN FORESTS

Puchner shows that the air in the forest contains generally more carbonic acid gas than in the open, due to the decomposition of litter.[2] But this difference must be almost inappreciable. As we know, the law of diffusion of gases renders it impossible for variations in the relative proportion of the atmospheric constituents to be more than transitory. Diffusion is greatly favored by the winds which sweep through the tree tops, especially where they are not too crowded.

The fact that so many sanatoria for tuberculosis are located in or near forests makes it very important to dwell a little longer on the constituents of the air in these localities. We know that forests, as well as all other forms of vegetal growth, take up large quantities of carbonic acid, retaining the carbon and rejecting the oxygen, and the question naturally arises, does it sensibly change the relative quality of either constituent so that the composition of the air is slightly different in the woods? Prof. Mark W. Harrington, lately chief of the United States Weather Bureau, undertook to answer that question, both with reference to carbonic acid, oxygen, and ozone, with some interesting results.[3] Repeated observations show that each constituent is curiously uniform in quantity in the free air. It has been thought that carbonic acid is quite variable but the introduction of better methods of observation shows that, except in confined places where the gas is produced, the variations are very

---

[1] See B. E. Fernow: Forest Influences, U. S. Dep. Agriculture, Forestry Division Bulletin No. 7, pp. 171-173.

[2] H. Puchner: Investigations of the Carbonic Acid Contents of the Atmosphere.

[3] M. W. Harrington: Review of Forest Meteorological Observations, U. S. Dep. Agriculture, Forestry Division Bulletin No. 7, p. 105.

DR. WALTHER'S SANATORIUM, NORDRACH-COLONIE, BLACK FOREST, GERMANY

DR. WALTHER'S SANATORIUM, NORDRACH-COLONIE, BLACK FOREST, GERMANY

VIEW FROM THE ADIRONDACK COTTAGE SANITARIUM
"In the foreground are the pines and my only business in life is to sit and look at them"
Courtesy of Journal of The Outdoor Life

small. A little study shows that the carbonic acid gas taken up by a forest is a very small quantity compared with that which passes the forest in the same time with the moving air. Grandeau[1] estimated the annual product of carbon by a forest of beeches, spruces, or pines as about 2,700 pounds per acre. This corresponds to 9,900 pounds of carbonic acid gas or 69,300 cubic feet. Now, if the average motion of the air is five miles an hour, a low estimate, and the layer of air from which the gas is taken be estimated at one hundred feet thick, there would pass over an acre 550 million cubic feet in one hour. This air must contain about three parts in ten thousand of carbonic acid gas and the total amount of the latter per hour is 165,000 cubic feet. But this is two and two-thirds, or more than twice as much as that taken up by the trees in the entire season, so that the air could provide in thirty minutes for the wants of the trees for the entire season. Prof. Harrington shows that the ratio of carbonic acid used to that furnished is only one part in 8,600.

OXYGEN IN FORESTS

Again, the additions of oxygen to the air would form a still smaller percentage of the oxygen already present, for this gas makes up 20.938 per cent of the air against a thirtieth of one per cent obtainable from this source.

OZONE IN FORESTS

The occurrence of ozone in the air of forests, especially coniferous forests, has been credited, since its discovery by Schoenbein in 1840, with affording remarkable health-giving qualities. This opinion has become firmly fixed in the minds of the public and, to a large extent, has been accepted by the medical profession as an evidence of high oxidizing power at once corrective of decaying vegetation and exhilarating and curative to mankind. Popular belief usually has some basis for its existence; indeed, meteorologists made regular estimations of ozone in the atmosphere by testing with sensitized papers and the results were published in connection with statistics of health resorts.[2]

The Schonbein test is based on the power of ozone to free iodine from a solution of potassium iodide in contact with starch, when a violet color is developed in the sensitized paper. Unfortunately the

---

[1] See Belgique Horticole, Vol. 35, 1885, p. 227.

[2] See Transactions American Climatological Association, Vol. 5, p. 118.

discovery of important sources of error has destroyed the value of observations made in this manner. Other substances in the air have been found to act as reducing agents; secondly, the color after having appeared may be altered or destroyed by substances, such as sulphurous acid and many organic substances. Again, the test acts only in a moist atmosphere and, besides that, varies in intensity according to the amount of the wind, so that, in a way, it is a measure of humidity and of wind.

A more recent test, mentioned by Huggard as more sensitive, depends upon the use of what is known as tetra-paper, but is also considered uncertain. The full name of this reagent is tetramethylparaphenylendiamin paper. Notwithstanding the unsatisfactory nature of these tests, the conclusion seems to be accepted that ozone is more abundant in May and June and least abundant in December and January; more abundant in the forests and the seashore and in mid-ocean and least abundant in towns where it commonly cannot be detected. The following quotation is from page 332 *et seq.* of Vol. 1, Watts' Dictionary of Chemistry:

> Very little is known respecting the proportion of ozone in the atmosphere, or of the circumstances which influence its production. The ozonometric methods hitherto devised are incapable of affording accurate quantitative estimations. Air over marshes or in places infested by malaria contains little or no ozone. No ozone can be detected in towns or in inhabited houses.
>
> Houzeau determines the relative amount of ozone in the air by exposing strips of red litmus paper dipped to half their length in a 1 per cent solution of potassium iodide. The paper in contact with ozone acquires a blue color from the action of the liberated potash upon the red litmus. The iodised litmus paper is preferable to iodised starch paper (Schönbein's test-paper) which exhibits a blue coloration with any reagent which liberates iodine, *e. g.*, nitrous acid, chlorine, etc. From observations made with iodised litmus paper Houzeau concludes that ozone exists in the air normally, but the intensity with which it acts at any given point of the atmosphere is very variable. Country air contains at most $\frac{1}{450000}$ of its weight or $\frac{1}{700000}$ of its volume of ozone. The frequency of the ozone manifestations varies with the seasons, being greatest in the spring, strong in summer, weaker in autumn, and weakest in winter. The maximum of ozone is found in May and June, and the minimum in December and January. In general, ozone is more frequently observed on rainy days than in fine weather. Strong atmospheric disturbances, as thunder storms, gales, and hurricanes, are frequently accompanied by great manifestations of ozone. According to Houzeau, atmospheric electricity appears to be the most active cause of the formation of atmospheric ozone.

It has been found that the air immediately above the tree tops and at the margin of the forest is richer in ozone than that of the interior, where a portion of it is utilized by the decaying vegetation. Ozone certainly aids in purifying the air by oxidizing animal or

SANATORIUM ST. BLASIEN IN THE BADEN SCHWARZWALD 800 METERS ABOVE SEA-LEVEL

RHODE ISLAND STATE SANATORIUM FOR TUBERCULOSIS AT WALLUM LAKE

Courtesy of Dr. Harry Lee Barnes

vegetable matter in process of decay and by uniting with the gases produced by their decomposition. It can, therefore, be found in considerable amounts where the air is particularly pure. This amount rarely exceeds one part in 10,000. "There is somewhat more ozone on mountains than on plains and most of all near the sea. Water is said by Carius to absorb 0.8 of its volume of ozone."[1]

This statement by Mr. Russell seems to us extraordinary in view of the minute quantity contained in the atmosphere and apparently needs confirmation, especially in view of Russell's next statement that a great excess of ozone is destructive to life, and oxygen containing one two-hundred and fortieth part of ozone is rapidly fatal, and further, that even the ordinary quantity has bad effects in exacerbating bronchitis and bronchial colds, and some other affections of the lungs.

Ozone is not found in the streets of large towns or usually in inhabited rooms, but in very large, well ventilated rooms it is sometimes, though rarely, detected. According to Russell it may be formed on the slow oxidation of phosphorus and of essential oils in the presence of moisture. When produced by electric discharges its pungency of odor is said to make it easily perceptible when present only to the extent of one volume in 2,500,000 volumes of air and the smell may sometimes be noticed on the sea beach.

Since the discovery of ozone by Schönbein, not much has been learned about the actual origin of this allotropic form of oxygen. Its presence in and near forests and living plants has undoubtedly supported the popular view that the air of the forests is particularly healthful and that living plants in our apartments are likewise beneficial.[2]

The existence of hydrogen peroxide in air was first established by Meissner in 1863, but we have no knowledge of the proportion in which it is present. All information as to its relative distribution is obtained from determinations of its amount in rain water and snow. The proportion seems to vary, like that of ozone, with the seasons of the year and with the temperature of the air. It is not improbable that the amount of hydrogen peroxide in air is greater than that of ozone, and it is possible that many so-called ozone manifestations are in reality due to peroxide of hydrogen. Watts' Dictionary of Chemistry.

---

[1] Francis A. R. Russell: The Atmosphere in Relation to Human Life and Health, Smithsonian Miscellaneous Collections, Vol. 39 (Publication No. 1072), 148 p., Washington, 1896.

[2] See J. M. Anders: House Plants as Sanitary Agents, Lippincott & Co., 1887.

A recent paper by Sawyer, Beckwith and Skolfield[1] of the Hygienic Laboratory of the California State Board of Health, is one of the latest researches which discredit the claim made for ozone as a purifier of air. During recent years circulars have been issued in great numbers by manufacturers of apparatus stating that ozone is a "necessity" for the destruction of infectious germs and bacterial life, for the sterilization of air in operating rooms for the purification of air in homes of persons suffering from contagious diseases and for giving to offices and homes the invigorating air of the country, seashore and mountains.[2]

How false these claims are can readily be seen from the systematic work of these investigators, the details of which we cannot give here but to which the reader is referred. Among their conclusions are the following:

> During these tests certain physiologic effects of the "ozone" were noticed by the experimenters after they had been working around the machines. The immediate effect of inhaling the diluted gas was a feeling of dryness or tickling in the nasopharynx, and sometimes the irritation was felt in the chest. If the exposure was prolonged, watering of the eyes, and occasionally a slight headache, resulted. The smell of the "ozone" and its irritation was much more noticeable to persons who came suddenly under its influence than to those who were continuously exposed.
>
> 1. The gaseous products of the two well-known ozone machines examined are irritating to the respiratory tract and, in considerable concentration, they will produce edema of the lungs and death in guinea-pigs.
>
> 2. A concentration of the gaseous products sufficiently high to kill typhoid bacilli, staphylococci and streptococci, dried on glass rods, in the course of several hours, will kill guinea-pigs in a shorter time. Therefore these products have no value as bactericides in breathable air.
>
> 3. Because the products of the ozone machines are irritating to the mucous membranes and are probably injurious in other ways, the machines should not be allowed in schools, offices or other places in which people remain for considerable periods of time.
>
> 4. The ozone machines produce gases which mask disagreeable odors of moderate strength. In this way the machines can conceal faults in ventilation while not correcting them. Because the ozone machine covers unhygienic conditions in the air and at the same time produces new injurious substances, it cannot properly be classed as a hygienic device.

Another paper even more elaborate than this was published at the same time by Edwin O. Jordan, Ph. D., and A. J. Carlson, Ph. D.,

---

[1] The Alleged Purification of Air by the Ozone Machine. Journ. Amer. Med. Ass., Sept. 27, 1913, p. 1013.

[2] See Amer. Journ. Physiologic Therapeutics, Nov.-Dec., 1911.

of Chicago.[1] This investigation was carried on at the suggestion of and under a grant from the Journal of the American Medical Association. Their experiments were carried out (1) to determine the germicidal action of ozone on pure cultures under the conditions commonly used in testing disinfectants, and (2) to determine the effect of ozone on the ordinary air bacteria. They found, after a long series of experiments detailed in full in their paper, that no surely germicidal action on certain species of bacteria could be demonstrated by the usual disinfection tests with amounts of gaseous ozone ranging from 3 to 4.6 parts per million. The alleged effect of ozone on the ordinary air bacteria, if it occurs at all, is slight and irregular even when amounts of ozone far beyond the limit of physiologic tolerance are employed.[2] The toxication of strong concentrations of ozone through injury to the lungs was marked. Even in moderate amounts it produced an irritation of the sensory nerve endings of the throat and a headache due to irritation, corrosion and consequent hyperemia of the frontal sinuses. Consequently the use of this poisonous gas as a therapeutic agent is either valueless or injurious.

USE OF FOREST RESERVATIONS FOR SANATORIA

We cannot leave the subjects of forests and forest air without strongly advocating the use of forests and especially State and Governmental forest reserves for institutions, hospitals, and camps for the tuberculous. The State of Pennsylvania has large forestry reservations, amounting at present to 1,000 square miles in 23 counties, and maintains a State School of Forestry, where young men are in training for its forest service. Acting under liberal forest laws, Dr. J. T. Rothrock, then State Forestry Commissioner, in 1903, announced that citizens of Pennsylvania are entitled to the privilege of using the forestry reservation of the state under proper restrictions as a residence while regaining health and recommended it especially to those in need of fresh air treatment of tuberculosis. In the spring of that year Dr. Rothrock, with State aid, started the construction of a few small cabins for the use of such patients and called it the South Mountain Camp Sanatorium.[3] This is situated

---

[1] Ozone: Its Bactericidal Physiologic and Deodorizing Action. (Journ. Amer. Med. Ass., Sept. 27, 1913, Vol. 61, pp. 1007-1012).

[2] This is corroborated by the recent article by Konrich, Zur Verwendung der Ozone in der Lüftung. (Zeitschr. Hyg., 1913, Vol. 73, 443.)

[3] Charities and Commonwealth, Dec. 1, 1906. Journ. Amer. Med. Ass., 1907. Journal of the Outdoor Life, Jan., 1907, and Feb., 1908.

in Franklin County, Pennsylvania, in the southern tier of counties where the state owns 55,000 acres. The altitude of the camp is 1,650 to 1,700 feet. It is now the site of the great State Sanatorium known as Mont Alto with a capacity of over 1,000 patients.

At first the patients were obliged to provide and to prepare their own food, but the legislature afterward appropriated enough to enable the management to furnish food, and the results were better than before. Only patients in the incipient stages were admitted, and of the 141 so cared for (up to the year 1908) about 75 per cent were either much improved or cured. The charge to the patients was one dollar per week for all supplies and services, excepting washing and the care of their cabins and their persons. The large forestry reserve allows of an indefinite extension of this method of dealing with the disease, and the small expense seems to point to it as a way to provide for the large class of patients who must be cared for in the incipient stages if the disease is to be checked and its victims restored to society as safe and potent factors in industrial progress. Dr. Rothrock, who has just closed twenty years of distinguished service to the state in the forestry commission, believes that the forest reservations furnish an answer to the further problem of how to care for the consumptive whose disease is arrested, but whose financial condition demands that he must still be cared for until able to return to his home. Pennsylvania has nearly a million acres of forest reservation, much of which needs replanting with young trees. To do this requires a large number of men, and the task of raising and transplanting trees is mostly light outdoor labor, well suited to the convalescent consumptive. In addition, there are various forms of woodcraft, such as basket making and the manufacture of small rustic articles that could easily be carried on under healthful conditions in the forests. The example of Pennsylvania suggests the propriety of other states taking similar steps and providing for the large number of consumptives who need care in an inexpensive and at the same time effective manner.

The United States Government should establish without delay large forest reserves in the Eastern, Middle, and Southern States. The White Mountains of New Hampshire and the Southern Appalachians should be placed under a system of Federal protection. It is encouraging to note that by a recent decision (November, 1913) of the Courts of New Hampshire the way is opened for the condemnation of mountain land in that State and indemnity has been awarded private owners for land so taken.

The United States has 165,000,000 acres of national forests and France and Germany combined, 14,500,000 acres.

The site of a model sanatorium for tuberculosis has the purest air or air nearly devoid of floating matter. It is only on very high mountain tops or in mid ocean, or in the Polar ice fields that we can have air free from suspended matter. The good results obtained in the higher Alpine sanatoria and in long sea voyages, in given cases of tuberculosis, are attributable in some degree to this absence of irritating or polluted atmosphere. In the more northern sanatoria, of which the Adirondack Cottage Sanitarium is a type, the long winter in which snow covers the ground for possibly five months, is always recognized as the best season for patients. The gain in health acquired during one winter equals that of two summers. The added freedom which the snow covering provides against dust and other atmospheric impurities may have its hygienic influence for the cure of tuberculosis.

MICRO-ORGANISMS IN RESPIRATORY PASSAGES

It is interesting to learn something of the fate of micro-organisms when inhaled by a person in health or by those whose respiratory passages are already suffering from irritation or disease. It has been calculated that upward of 14,000 organisms pass into the nasal cavities in one hour's quiet respiration in the ordinary London atmosphere.[1] Tyndall showed by his experiments with a ray of light in a dark chamber that expired air, or more exactly the last portion of the air of expiration is optically pure. In other words, respiration has freed the inhaled air from the particles of suspended matter with which it is laden. These experiments coincide with those of Gunning of Amsterdam in 1882 and those of Strauss and Dubreuil in 1887. Grancher has made many experiments with the expired air of phthisical patients and has never found in it the tubercle bacillus or its spores. Charrin, Karth, Cadéac, and Mallet have had corresponding results.

These germs are probably all arrested before reaching the trachea; they halt in the upper air passages. The interior of the great majority of normal nasal cavities is perfectly aseptic. On the other hand the vestibules of the nares, the vibrissæ lining them and all crusts formed there are generally swarming with bacteria. All germs are arrested here and the ciliated epithelium rapidly ejects them.

---

[1] On Researches by Drs. St. Clair Thomson and R. T. Hewlet. Lancet, January 11, 1896.

By experiments on the mucous membrane of the dorsal wall of the pharynx, Thomson and Hewlet found that a particle of wet cork was conveyed at the rate of 25 mm. or one inch per minute.

Wurtz and Lermoyez have published researches on the action of nasal mucus upon the anthrax bacillus and they hold that it exerts a bactericidal influence on all or nearly all pathogenic agents in different degrees of intensity.

Thomson and Hewlet corroborate this to the extent of saying that the nasal mucus "is possessed of the important property of exerting an inhibitory action on the growth of micro-organisms." Their experiments upon each other were very ingenious and highly interesting. They were able to demonstrate that in ordinary air of the laboratory under the conditions observed, 29 moulds and nine bacterial colonies developed; whereas after passing through the nose the air contained only two moulds and no bacteria.

On another occasion they found in nine liters of laboratory air, six moulds and four bacterial colonies, while the same quantity of air after passing through the nose exhibited one mould and no bacteria. Thus they show that practically all, or nearly all, the micro-organisms of the air are arrested before reaching the naso-pharynx; probably a majority are stopped by the vibrissæ at the very entrance to the nose and those which do penetrate as far as the mucous membrane are rapidly eliminated. They state that the nasal mucus is an unfavorable soil for the growth of organisms and in this it is aided by the ciliated epithelium and lacrymal secretion.

COMPOSITION OF EXPIRED AIR

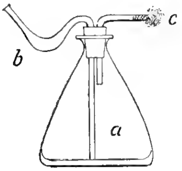
Dr. D. H. Bergey in 1893-4 made some experiments in the Laboratory of Hygiene of the University of Pennsylvania under the provisions of the Hodgkins Fund of the Smithsonian Institution which are pertinent to this subject.[1] These were conducted to ascertain whether the condensed moisture of air expired by men in ordinary, quiet respiration, contains any particulate organic matters, such as micro-organisms, epithelial scales, etc. The expired breath was conducted through melted gelatin contained in a half liter Erlenmayer flask, for twenty to thirty minutes. The gelatin was then hardened

---

[1] J. S. Billings, S. Weir Mitchell, and D. H. Bergey: The Composition of Expired Air and Its Effects on Animal Life. Smithsonian Contributions to Knowledge, Vol. 29 (Publication 989), Washington, 1895. This investigation seemed to disprove the renowned experiments of Brown-Séquard and D'Arsonval in 1887.

by rolling the flask in a shallow basin of ice-water, thus distributing the culture in a thin layer over the bottom and sides of the flask.

These cultures were kept under observation for 20 to 30 days. About 150 cc. of gelatin was used for each experiment. The glass tube (b) of the apparatus used, which served for the entrance of the expired air, was inserted far enough to just impinge on the fluid culture medium in the flask, so that the air produced a slight agitation of the fluid in passing through the apparatus. The tube of entrance (b) is provided with a bulb-shaped enlargement which serves to retain any saliva that may flow into the tube. The tube (c) is closed with cotton so as to prevent the entrance of micro-organisms from this side of the apparatus, and a similar cotton plug is inserted in *b* when the apparatus is not in use.



Apparatus for Determining the Presence of Bacteria in Expired Breath.

It was found that the organisms developed in the cultures were all of the same character—a small yellow bacillus, common in laboratory air. When special precautions were taken to sterilize the apparatus with dry heat for an hour previous to introducing the gelatin, besides the subsequent sterilization of the gelatin, the results were negative—no growths developed. If, after standing in the working room for several days, it was found that the culture medium was sterile, the expired breath was then conducted through the apparatus and the culture was kept under observation (for the specified time in the table) at the room temperature. The nature of the organisms that developed in the first two experiments, and the absence of any growth in the others, make it probable that they developed from spores that survived the fractional sterilization of the culture medium. It is improbable that they were carried in the expired breath. Dr. Bergey also made a careful examination of the fluid condensed from the expired air with high powers, both in hanging drops and in six dried and stained preparations, but nothing resembling bacteria or epithelium was found.

The conclusion was reached that there is no evidence of a special toxicity of the expired air. Billings, Mitchell, and Bergey say, in the monograph referred to, that the injurious effects of such air observed appeared to be due entirely to the diminution of oxygen, or the increase of carbonic acid, or to a combination of these two factors. They consider that the principal, though not the only, causes of discomfort to people in crowded rooms are excessive temperature and unpleasant odors.

We shall see, further on, that later studies show that the relative proportions of oxygen and carbonic acid are not *per se* such important factors.

Dr. Milton J. Rosenau, professor of preventive medicine and hygiene in Harvard Medical School, said in his recent address[1] on "Ether Day" at the Massachusetts General Hospital:

> One of the fallacies that has fallen is the relation of the air to the spread of infection. The virus of most communicable diseases was believed to be in the expired breath, or exhaled as emanations of some sort from the body. These emanations were said to be carried long distances—miles—on the wind. The easiest, and therefore the most natural way, to account for the spread of epidemic diseases was to consider them as air-borne. Nowadays the sanitarian pays little heed to infection in the air except in droplet infection, and the radius of danger in the fine spray from the mouth and nose in coughing, sneezing and talking is limited to a few feet or yards at most. The more the air is studied the more it is acquitted as a vehicle for the spread of the communicable diseases.
>
> It was a great surprise when bacteriologists demonstrated that the expired breath ordinarily contains no bacteria. Most micro-organisms, even if wafted into the air soon die on account of the dryness, and especially if exposed to sunshine. The relation of the air to infection is nowhere better illustrated than in the practice of surgery. At first Lister and his followers attempted to disinfect the air in contact with the wound by carbolic sprays. Now the surgeon pays no heed to the air of a clean operating room, but ties a piece of gauze over his mouth and nose, and also over his hair, to prevent infective agents from falling into the wound from these sources.

How complicated this entire subject is we can readily see from the review[2] made by Dr. Henry Sewall, of Denver, of recent experimental studies by Zuntz, Haldane, Rosenau and Amoss, Heymann, Paul, Ercklentz and Flügge, Leonard Hill and others. This review deserves to be read carefully. It sums up our latest knowledge and leads to some surprising conclusions. After describing the Black Hole of Calcutta, in which one hundred and forty-six Europeans

---

[1] Boston Medical and Surgical Journal, November 6, 1913.

[2] On What do the Hygiene and Therapeutic Virtues of the Open Air Depend? by Henry Sewall, Ph. D., M. D. (Journ. Amer. Med. Ass., Jan. 20, 1912).

were confined on the night of June, 1756, and only twenty-three survived, he shows that numberless observations have all led to the one conclusion that prolonged confinement in close air tends to lower vitality and increase the incidence of certain infections, especially pulmonary tuberculosis. However, it was found many years ago that animals and men can tolerate without distress an increase of carbon dioxide in the air far beyond any concentration which it is likely to acquire under the worst conditions of crowding, provided the oxygen tension is maintained at a high level. Zuntz and Haldane and his associates show that the normal excitement of the respiratory nerve-center depends on the accumulation within it of carbon dioxide, a waste product, which it is a prime object of respiration to remove. Sewall refers to Brown-Séquard and D'Arsonval's work and, as bearing on it, the very recent work of Rosenau and Amoss.[1] These workers condensed the vapor of human expiration and injected the liquid into guinea-pigs. No symptoms followed this procedure. But after an appropriate interval of some weeks a little of the blood-serum from the person supplying the moisture was injected into the same animals. The outcome was an unmistakable anaphylactic reaction. According to current beliefs the result showed that the expired air must have contained proteid matter which sensitized the pigs toward proteids in the blood of persons from whom the first proteid was derived. The authors offer, as yet, no opinion as to whether the proteid in the expired air possesses hygienic significance.

Prof. Sewall finds a suggestive analogy in the physiologic relations of carbon dioxide which it is one of the chief objects of respiration to remove. Added to air in sufficient percentage it is deadly to animals, yet so far from its being useless in the body, Haldane and Priestley found that it must form four to five per cent of the alveolar air for the maintenance of normal respiratory movement, and a considerable lowering of its tension in the body would be followed by speedy death. Boycott and Haldane note that the subjective sense of invigoration and well-being excited by cold weather is associated with a high tension of carbon dioxide in the alveolar air.[2] After summarizing the experiments of Heyman, Paul,

---

[1] Organic Matter in the Expired Breath (Journal of Medical Research, 1911, Vol. 25, 35).

[2] Haldane and Priestley: The Regulation of the Lung Ventilation (Journal of Physiology, 1905, Vol. 27, p. 225).

Boycott and Haldane: The Effects of Low Atmospheric Pressure on Respiand Ercklentz in Flügge's laboratory[1] which seem to show that, in people both well and sick, chemical changes in the character of the air in inhabited rooms exercise no deleterious effect on the health of the dwellers Dr. Sewall reviews Leonard Hill's work which shows that the motion of the air in the experimental chamber by means of electric fans almost entirely annulled the sense of discomfort.[2] He then cites the astonishing experiments of F. G. Benedict and R. D. Milner[3] who kept a subject for twenty-four hours in a chamber, the air of which held an average carbon dioxide content of 220 parts per 10,000 or over seventy times the normal, together with a reduction of oxygen to less than 19 per cent. The humidity was kept down and the temperature held uniform. The subject of the experiment suffered no discomfort.

Boycott and Haldane, referred to above, express the opinion that "the alveolar carbon dioxide tends to a lower level in warm weather" and that this diminution in the alveolar carbon dioxide is associated with a feeling of warmth of a rather unpleasant kind rather than with any absolute point on the thermometer; they hold that the rise in the carbon dioxide tension is associated with the general exhilaration and stimulation produced by cold air.

And now comes Leonard Hill, the physiologist, of London, who with his staff at the London Hospital conducted several noteworthy experiments which he described before the Institution of Heating and Ventilating Engineers in March, 1911.[4] In view of the fact that

---

ration (Journal of Physiology, 1908, Vol. 37, p. 359). See also Preventive Medicine and Hygiene, by Milton J. Rosenau, M. D., Chapter 4, D. Appleton & Co., 1913. Prof. Rosenau's work contains the latest word on the bacteria and poisonous gases in the air, ventilation, etc.

Thomas R. Crowder, M. D.: A Study of the Ventilation of Sleeping Cars (Archives of Internal Medicine, January, 1911, and January, 1913). This elaborate investigation is illustrated by numerous diagrams showing the carbon dioxide content in the air from the aisles, the upper and lower berths and smoking rooms.

[1] Zeitschrift f. Hygien. u. Infectionskr., 1905, Vol. 59.

[2] Leonard Hill: The Relative Influence of Heat and Chemical Impurity of Close Air (Journal of Physiology, 1910, Vol. 41, p. 3).

See also Leonard Hill, Martin Flack, James McIntosh, R. A. Rowlands, H. B. Walker: The Influence of the Atmosphere on our Health and Comfort in Confined and Crowded Places, Smithsonian Miscellaneous Collections, Vol. 60, No. 23, p. 96 (Publication 2170), 1913.

[3] Experiments on the Metabolism of Matter and Energy in the Human Body, Bulletin 175, U. S. Dep. Agriculture Office Experiment Station, 1907.

[4] Journ. Amer. Med. Ass., April 8, 1911.

the London health authorities insist that in factories the percentage of carbon dioxide must not rise above the usual amount allowed, say ten parts in ten thousand, he remarks that the regulations do not prescribe any limitations of the wet-bulb temperature adding that while carbon dioxide does not do any harm whatever a wet-bulb temperature of 75° F. is very bad and ought not to be tolerated in any factory. All the current teaching of the hygiene of ventilation runs on the subject of chemical purity of the air; but according to Prof. Hill the essential thing in ventilation is heat, not chemical purity. It does not matter if there is 1 per cent more carbon dioxide and 1 per cent less of oxygen. In the worst ventilated rooms there is not 1 per cent less oxygen. The only effect of an excess of carbon dioxide is to make one breathe a little more deeply. A much higher amount has to be attained to have any toxic effect. As to organic impurities derived from respiration there is no physiologic evidence of their toxicity or that they are of any importance except as an indicator of the number of bacteria in air. The way to keep air best from the physiologic point of view is shown by the following experiment performed by Hill at the London Hospital: Into a small chamber which holds about three cubic meters he put eight students and sealed them up air tight. They entered joking and lively and at the end of 44 minutes the wet bulb temperature had risen to 83° F. They had ceased to laugh and joke and the dry bulb stood at 87° F. They were wet with sweat and their faces were congested. The carbon dioxide had risen to 5.26 per cent and the oxygen had fallen to 15.1 per cent. Hill then put on three electric fans and merely whirled the air about just as it was. The effect was like magic; the students at once felt perfectly comfortable, but as soon as the fans stopped they felt as bad as ever and they cried out for the fans. These and other experiments related, according to Hill, show that all the discomfort from breathing air in a confined space is due to heat and moisture and not to carbon dioxide. Even after five repetitions of the experiment there were no after-effects, such as headache. The obvious inference is that the air must be kept in motion to avoid bad effects. The open air treatment of disease is not altogether a matter of fresh air, but the constant cooling of the body by the circulation of air which makes us eat more and promotes activity. This leads to the general strengthening of the body because the blood is not only circulated by the heart but by every muscle in the body.

There cannot be efficient circulation without constant movement and activity. If there is constant cooling by ventilation, then a person is kept more active and the general health is improved.

As Dr. M. J. Rosenau said in his recent address:

> Thus our entire conception of ventilation has changed, owing to the fact that we now do not believe that fresh air is particularly necessary in order to furnish us with more oxygen or to remove the slight excess of carbon dioxide. It is plain that it is heat stagnation that makes us feel so uncomfortable in a poorly ventilated room rather than any change in the chemical composition of the air. It has been made perfectly clear from the work of Flügge that one of the chief functions of fresh air is to help our heat-regulating mechanism maintain the normal temperature of the body. It is necessary to have some 2,000 to 3,000 cubic feet of air an hour to maintain our thermic equilibrium—just the amount that was formerly stated to be necessary to dilute the carbon dioxide and supply fresh oxygen. The practice of ventilation, therefore, has not altered so much as has our reason for attaching importance to clean, cool, moving air, which has completely changed.[1]

The foregoing résumé is perhaps not complete without mentioning the recent work of Prof. Yandell Henderson, of Yale University, who has brought forward his "Acapnia" theory (acapnia meaning diminished carbon dioxide in the blood). He says:[2]

> We have really at the present time no adequate scientific explanation for the health-stimulating properties of fresh air and the health-destroying influence of bad ventilation. . . . The subject needs investigating along new lines rather than a rehearsal of old data.

Dr. Crowder's recent experiments[3] also furnish additional evidence against the theory that efficient ventilation consists in the chemical purity of the air, in its freedom from "a toxic organic substance." Even were a poisonous protein substance present in the expired air—a fact no experimenter has yet been able to demonstrate—the human organism under every-day conditions is apparently well able to adjust itself to the reinhalation of this hypothetic substance, since a considerable quantity of the expired air is always taken back into the lungs.[4]

We consider that experiments like these demonstrate most valuable and practical truths and that is our excuse for introducing them so particularly in this place. When we consider that the average man exhales from 9,000 to 10,800 liters of air in twenty-four

---

[1] Boston Medical and Surgical Journal, Nov. 6, 1913.

[2] Trans. Fifteenth International Congress on Hygiene and Demography, Vol. 7, p. 622.

[3] Crowder, Thomas R.: The Reinspiration of Expired Air (Arch. Int. Med., October, 1913, p. 420).

[4] Editorial in Journ. Amer. Med. Ass., Nov. 29, 1913. See also page 108.

hours[1] it would indeed be a terrible situation if it were true that the expired breath could convey pathogenic or other bacilli. The millions of bacilli which we take into the air passages are arrested in the air passages and for the most part mercifully destroyed by the secretion.[2] In any event we have the assurance that the expired air is free from micro-organisms. With reference to tuberculosis this means that if healthy persons are exposed only to the expired air of tuberculous subjects no infection can occur. Only through bacilli contained in the sputum or in tiny drops of moisture coughed by the patient is the disease communicated; and it is further probable that, as in the case of other infectious organisms, when once received into the nose and mouth and upper air passages, they quickly lose their activity or are soon extruded. (See page 13 *et seq.*)

ATMOSPHERIC IMPURITIES

In view of these facts it would scarcely seem necessary to state that for the treatment of all respiratory diseases and especially for the treatment of infections such as tuberculosis, which invades the larynx and the lungs, or for the treatment of patients whose throats and lungs owing to other infections, such as tonsillitis, pneumonia, or influenza, may be specially susceptible, no city air can be considered favorable. It is our duty to provide as nearly as possible air with a very low bacterial content such as may be obtained in forests or in the neighborhood of the seashore.

COAL AND SMOKE

Aside from the presence of bacteria in the air of cities and towns there are other impurities which are of great disadvantage to tuberculous patients. The prevalent use of soft, or bituminous coal in Great Britain and America, especially in manufacturing centers, undoubtedly shortens human life and hastens many a consumptive to his end. Volumes have been written on this subject and most valuable contributions have been made by Dr. J. B. Cohen, of Leeds, Mr. Francis A. R. Russell, Henry de Varigny and others, published in connection with the Hodgkins Fund.[3]

---

[1] About 380 cubic feet which is equal to a volume 7⅓ feet (220 cm.) in height, width, and thickness.

[2] It has been calculated that in a town like London or Manchester, a man breathes in during ten hours 37,500,000 spores and germs. F. A. R. Russell.

[3] See Smithsonian Miscellaneous Collections, Vol. 39, 1896 (Publications 1071, 1072, 1073).

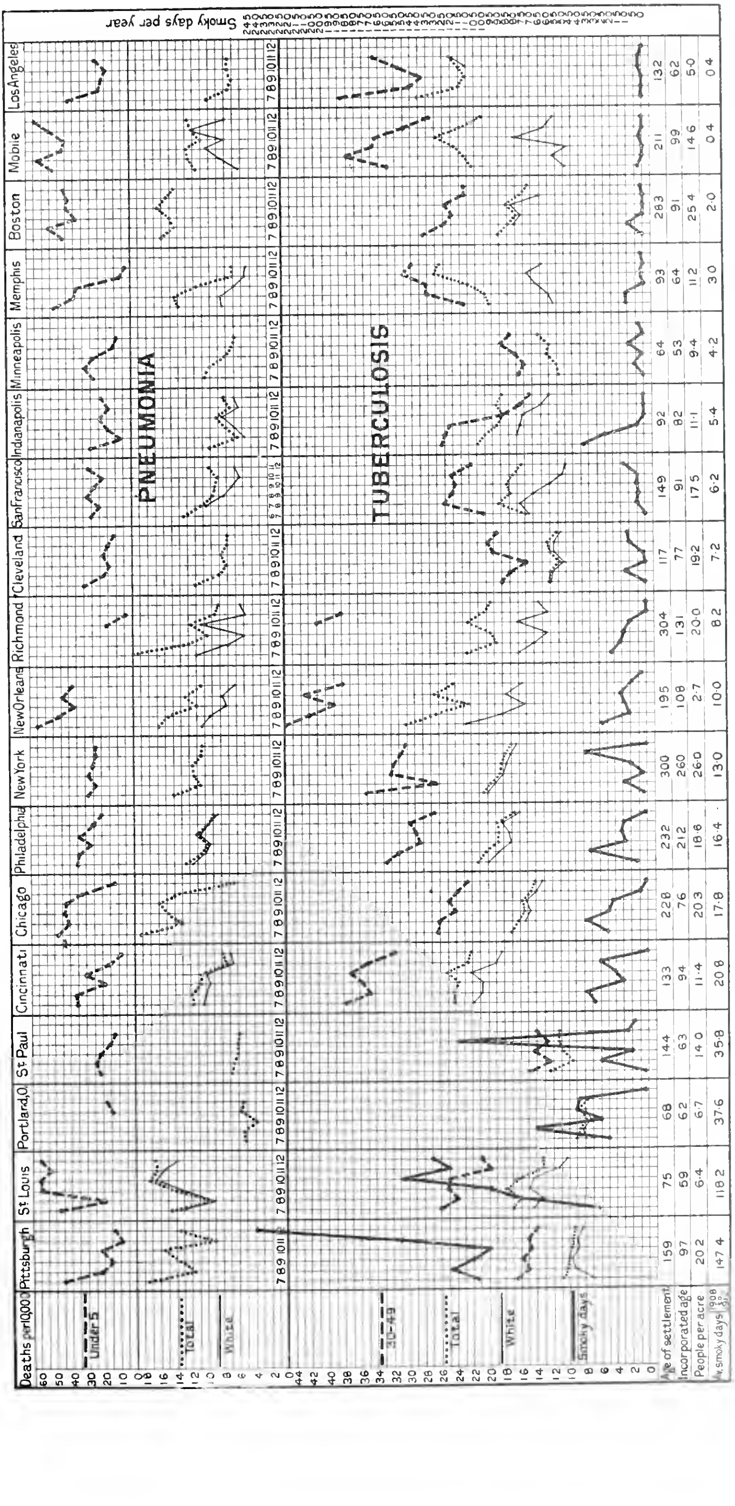
See also "The Influence of Smoke on Acute and Chronic Lung Infections," by Wm. Charles White, M. D., and Paul Shuey, Pittsburg. Trans. Amer. Climatological Association, 1913.

Dr. William Charles White and Paul Shuey, of Pittsburgh, have recently made a study of the influence of smoke on acute and chronic lung infections, selecting pneumonia and tuberculosis as a cause of death in Pittsburgh, St. Louis, Portland, Oregon, St. Paul, Cincinnati, Chicago, Philadelphia, New York, New Orleans, Richmond, Cleveland, San Francisco, Indianapolis, Minneapolis, Memphis, Boston, Mobile, and Los Angeles. They plotted the number of smoky days per year, 1907 to 1912, with the smokiest cities first and so on to the least in the order indicated above. The mortality for white population and total population and other data are noted on the accompanying chart. This study is in some respects unsatisfactory, because of the difficulty of getting data as to smoky days. The conclusion was that if we except Portland and St. Paul there is a general tendency of the tuberculosis death rate to rise as the number of smoky days in the city decreases. On the other hand, it will be seen that there is a general tendency for the number of deaths from pneumonia to fall as the number of smoky days in the city decreases. In this instance, also, Portland, St. Paul, and Boston must be excepted. All this needs confirmation.

It is a matter of common knowledge that coal miners are liable to a disease called fibrosis, anthracosis, or miners' consumption, in which the lungs receive and retain coal dust, which penetrates every nook and cranny of the lungs and adds one more element of danger to a most hazardous occupation. But we have it on the authority of Sir Frederick Treves that he had seen the lungs of many persons, who had lived in London, which were black from their surface to their innermost recesses. Such a condition, in his opinion, not only made it more difficult to resist disease, but started disease, and it was entirely due to dirt and soot inhaled. The black fog of London owes its color to coal smoke, which gives it its filthy, choking constituents, and kills people by thousands. Experiments showed that during a bad fog six tons of soot were deposited to the square mile.[1]

---

[1] Some six hundred years ago, the citizens of London petitioned King Edward I to prohibit the use of "sea coal." He replied by making its use punishable by death. This stringent measure was repealed, however, but there was again considerable complaint in Queen Elizabeth's reign, and the nuisance created by coal smoke seems to have been definitely recognized at this period. Since this time there has been continual agitation, together with much legislation, both abroad and in this country. In the seventeenth century, King Charles II adopted repressive measures in London, and in the present century anti-smoke crusades have been frequent. In fact, the smoke problem will undoubtedly continue to demand attention until it is either



	Pittsburgh	St. Louis	Portland, O.	St. Paul	Cincinnati	Chicago	Philadelphia	New York	New Orleans	Richmond	Cleveland	San Francisco	Indianapolis	Minneapolis	Memphis	Boston	Mobile	Los Angeles
Age of settlement	159	75	68	144	133	228	232	300	195	304	117	149	92	64	93	283	211	132
Incorporated age	97	59	62	63	94	76	212	260	108	131	77	91	82	53	64	91	99	62
People per acre	20.2	6.4	6.7	14.0	11.4	20.3	18.6	26.0	2.7	20.0	19.2	17.5	11.1	9.4	11.2	25.4	14.6	5.0
Av. smoky days 1908	147.4	118.2	37.6	35.8	20.8	17.8	16.4	13.0	10.0	8.2	7.2	6.2	5.4	4.2	3.0	2.0	0.4	0.4

Death-rates per 10,000 for Pneumonia and Tuberculosis in Eighteen Cities, 1907-1912. The number of smoky days are noted, for each year (heavy line). Total death-rates (dotted line). Age of settlement and population per acre noted.

The Lancet undertook by means of a system of gauges of its own design to estimate the annual deposit in London of all adventitious matter from the atmosphere. In the city proper it was calculated to be nearly five hundred tons to the square mile or about four and a half pounds per acre each day. Were it mere dirt it would not be so serious, but it is charged with gases and fluids of a deleterious character such as sulphates, chlorides, ammonia, and carbon that is more or less oily and tarry. One of the experts employed by the Meteorological Council in connection with the County Council of London, found that the sulphur contents of the coal ranged from one to two per cent and that from half a million to a million tons of sulphuric acid were diffused in the air every year. The loss to property from this erosive influence he estimated at about five and a half million pounds sterling. The effect upon health was a more elusive question, but stress was laid on the rise in death rate during foggy weather in which coal smoke plays a prominent part. Owing to the activity of the Coal Smoke Abatement Society, under the presidency of Sir William Richmond, atmospheric conditions are greatly improved, and it is claimed that there is a steady diminution in the number and density of the black fogs.

In an article on London as a Health Resort and as a Sanitary City, by S. D. Clippingdale, M. D., Trans. Royal Society of Medicine, February, 1914, there is an interesting historical account of London air and fog, with a bibliography.

CARBON DIOXIDE

Parallel conditions are observed in cities like Leeds, Liverpool, Manchester, and Glasgow, and in less degree in cities like Pittsburgh, Cincinnati, Chicago, Cleveland, and St. Louis, during periods of comparatively calm, and of heavy and humid atmosphere. Egbert[1] states that "it has been calculated that for every ton of coal burnt in London something like three tons of carbon dioxide are produced," and as the city's coal consumption is over 30,000 tons per diem, its atmosphere must receive the enormous daily contamination of about 300 tons of soot and 90,000 tons of carbonic acid every day! How important, then, the adoption of practical means to abate the smoke nuisance! Engineers assure us that such means

---

entirely solved by the abolishment of the use of solid fuel or by the installation of devices and methods which shall prevent the formation of smoke in furnaces, regardless of the nature of the fuel.

[1] Seneca Egbert: A Manual of Hygiene and Sanitation, Philadelphia, 1900. p. 74.

are perfectly feasible and economical. It does not need an engineer to assure us that they are hygienic.

Prof. Charles Baskerville, of the College of the City of New York, has vigorously attacked the problem of smoke and other air impurities. He shows[1] that the sticky properties of soot are due to the tar contained in it. This tar adheres so tenaciously to everything that it is not easily removed by rain. In large manufacturing districts, particularly in those where bituminous coal is used as fuel, vegetation is blackened, the leaves of trees are covered and the stomata are filled up, thus inhibiting the natural processes of transpiration and assimilation. In addition, the soot is frequently acid and the deposition of acid along with soot is probably one of the principal causes of the early withering which is characteristic of the many forms of town vegetation.

SULPHUR DIOXIDE

Aside from the solid material which pollutes the atmosphere of cities, there are correspondingly enormous quantities of noxious gases which are equally injurious to persons with tubercular disease or other diseases of the respiratory tract. Mention has already been made of the vast amounts of carbonic acid gas generated by furnaces, not to speak of the quantities exhaled by human beings. The production of this carbon dioxide by the combustion of coal offers a definite measure of the production of sulphur dioxide. These two gases have the same origin and the measure of one is the measure of the other. Recent studies by Prof. Theodore W. Schaefer, who has made many observations of the air of Kansas City during fogs, tend to show that the presence of sulphur dioxide has an unfavorable effect on persons suffering from bronchitis, pharyngitis, pneumonia, and asthma. In January, 1902, the heavy fogs occurring in St. Louis, Missouri, caused serious injury to the throat and lungs of prominent singers and in an action brought against the city and its chief smoke inspector, it was alleged that owing to the additional presence of smoke, suffocating gases, and acid, the health of the complainant was injured. In a mandamus proceeding it was asked that the authorities be compelled to abate the smoke nuisance.

Prof. Schaefer has used the data mentioned previously as to the output of carbonic acid in London and states that he finds that at least 2,700 tons of sulphur dioxide are generated daily in that city and pass into surrounding atmosphere. This gas, after uniting with

---

[1] Medical Record, New York, November 23, 30, 1912.

the oxygen and aqueous vapor of the air, is converted into sulphuric acid.[1]

The presence of sulphur in coal, or in iron pyrites contained in coal, is responsible for this acid product and Prof. Schaefer believes that sulphur dioxide, being a very heavy gas, with a specific gravity of 2.25, is alone capable of creating a fog, or is at once shown when it is brought in contact with the atmosphere, from which it absorbs aqueous vapor, causing dense, heavy fumes. The dust or carbon particles, coming in contact with this acid vapor, enhance its gravity materially.

Prof. Baskerville some time ago made a number of determinations of the sulphur dioxide content of the air of New York city. Stations were established throughout greater New York city, including high office buildings, parks, subways, stations, and railroad tunnels; and very variable results, as might be expected, were obtained. The determinations may, in part, be thus summarized:

Locality	*SO_2 in parts in a million*
Elevated portion of city, near a high stack	3.14
Various parks	0.84 (maximum; others negative)
Railroad tunnels	8.54—31.50
Subway	None
Downtown region	1.05—5.60
Localities near a railroad	1.12—8.40

In 1907, the residents of Staten Island, as well as some on Long Island, complained of the noxious nature of the air wafted over from various plants in New Jersey. This induced the Department of Health of the City of New York to investigate the air and vegetation in the vicinity of the Borough of Richmond, Staten Island, and some of the results obtained are given below by permission of the Department.

Substance	*Impurity*
Air	Trace of sulphuric acid
Air	0.0066 per cent. SO_2 by weight
Air	Trace of sulphuric acid
Grass (three samples)	Sulphuric acid present
Grass	0.24 per cent SO_3
Grass	0.70 per cent SO_3
Leaves	0.19 per cent SO_3
Leaves	0.28 per cent SO_3
Soil	0.0015 per cent SO_3

---

[1] Theodore W. Schaefer: The Contamination of the Air of our Cities with Sulphur Dioxide, the Cause of Respiratory Disease. Boston Medical and Surgical Journal, July 25, 1907.

These results do not really give us anything definite, as the comparative factor is absent.

Fog usually collects in the lower portions of a city, especially in depressed localities known as hollows, where it remains until dispersed by air currents. The well-known increase of mortality in cities during the continued presence of heavy fog with these additional contaminations have been recorded and commented upon for years. The heavy, suffocating, poisonous quality of sulphur dioxide is well known and has been the subject of several investigations. In general, it may be said that the chief symptoms of poisoning with sulphurous acid are those of irritation of the mucous membranes. Even in five parts in 10,000 it acts as an irritant, causing sneezing, coughing and lacrymation, bronchial irritation and catarrh (Cushny). It is also credited with causing pneumonia and Prof. Schaefer notes its power to produce asthma.[1] Undoubtedly it would aggravate pulmonary and laryngeal tuberculosis and either delay or prevent a cure under the conditions described.

AMMONIA IN THE AIR

This gas is constantly present in the atmosphere, but in very minute quantities. Fifty years ago Boussingault and, later, Schloesing made careful investigations of this impurity of the atmosphere and devised ingenious methods of estimating its amount in air and rain water. It usually exists only in combination with carbonic or nitric acid; very little is free. Water absorbs it freely and it has been estimated that in France the annual rainfall brings to the earth in the form of nitrogen nearly 5 kilograms per acre. The presence of ammonia indicates organic putrefaction. Its amount does not usually exceed a very few parts per million. It is usually perceptible, as we all know, in and about stables.

As far as any relation to tuberculosis is concerned, ammoniacal air has for us only a remote interest. At one time it was strongly advocated as a cure for pulmonary consumption and perhaps some historic details may be of interest here.

Dr. Thomas Beddoes, of London, published in 1803, "Considerations on a Modified Atmosphere in Consumption Cases," and strongly advocated residence in a cow stable for such cases. One of his patients was Mrs. Finch, a daughter of Dr. Joseph Priestley,

---

[1] This accords with the conclusions of W. C. White and Paul Shuey, *loc. cit.* The relation of Sea Fog to Tuberculosis is considered in the next chapter, page 52.

famous for his epoch-making discovery of Oxygen. The patient, from the description given, had a well-marked case of pulmonary tuberculosis in the second or third stage. She was placed in a stable 14 by 20 feet and 9 feet high, and her bed was in a small recess a few inches above the ground of the stable, where two or three cows were kept. The temperature was maintained at 60° to 70° F. Mrs. Finch remained in this cow house nearly all the time from the autumn of 1799 until the spring of 1800. In a letter, dated August 15, 1800, the patient wrote, "I am happy in being able to say that my chest continues perfectly well; and from the difference of my feelings now, and some years back, I am more than ever a friend of the cows. I avoid colds and night air; and by rides in the country am anxious to brace myself against winter and the necessity of a sea voyage."

OXYGEN FOR TUBERCULOUS PATIENTS

Shortly after the discovery of oxygen, physicians were stimulated to try the effect of various gases in the treatment of phthisis. Fourcroy and Beddoes both observed the effects of the inhalation of oxygen and found that it accelerated the pulse and respiration, and, as they believed, increased inflammatory action so that they concluded that its effect was prejudicial. Beddoes held that in phthisis there is an excess of oxygen in the system and consequently, that free air was injurious to the patient. He says in the essay quoted previously:[1] "As it seemed to me hopeless to propose residence in a cow house, I advised that the patient should live during the winter in a room fitted up so as to ensure the command of a steady temperature. This advice was followed. Double doors and double windows were added to the bed room. The fire place was bricked up round the flue of a cast iron stove for giving out heated air." What a contrast to the fresh air cure of the present day! But the doctor persisted in his plan of treatment until the patient died.

The amount of oxygen present in the atmosphere, 20.938 per cent, is precisely adapted to the needs of animal life and the same proportion of oxygen is preserved in the atmosphere everywhere, without regard to altitude.[2] It has been found that animals die if the ratio of oxygen is artificially decreased by as much as twenty-five per

---

[1] Thomas Beddoes: Observations on the Medical and Domestic Management of the Consumptive. American edition, Troy, 1803, p. 42.

[2] Analyses by Gay-Lussac of Air Collected at 7,000 meters; and observations by Dumas and Boussingault.

cent; but Paul Bert[1] also showed that too much oxygen was equally prejudicial to life and, indeed, poisonous, animals dying in a super-oxygenated atmosphere as soon as their blood contains one-third more than the normal ratio of oxygen, because in such an atmosphere the hemoglobin of the red blood corpuscles is saturated with oxygen—a fact which never occurs under normal conditions—and a proportion of this gas then dissolves in the serum of the blood. Here lies the danger, for the tissues cannot withstand the presence of free, uncombined oxygen and death follows. The question immediately arises: Why do the tissues require combined oxygen and why does free oxygen kill them? No one knows. Henry de Varigny, who deals with this subject with reference to ærobic and anærobic organisms deals with this curious fact and acknowledges our limited knowledge on this point. He states, however, that while a certain increase in the ratio of oxygen results in death, lesser increases of a temporary character may be beneficial. Every poison kills, doubtless, but there are doses which not only do not kill, but even confer benefit and improve health.

Lorrain Smith has shown that oxygen at the tension of the atmosphere stimulates the lung-cells to active absorption; at a higher tension it acts as an irritant, or pathologic stimulant, and produces inflammation.[2]

As far as the respiratory processes are concerned the respiration of pure oxygen takes place without disturbing them for even in an atmosphere of pure oxygen animals breathe as though they were respiring normal atmospheric air.[3]

Sir Humphrey Davy believed that when pure oxygen was inspired there is no more chemical change induced than occurs when atmospheric air is breathed; in other words, let the vital actions be a constant quantity, the addition of oxygen to the inspired air does not materially increase vital transformation. Fifty years ago there was great confusion in the minds of otherwise intelligent observers and false reasoning led them into grave errors. Those who, like Beddoes, believed that there was too much oxygen in the system held that the inhalation of air containing carbonic acid was the proper plan of treatment and this theory of hyper-oxidation was revived

---

[1] Paul Bert: La Pression Barometrique, 1878.
See also monograph by F. G. Benedict quoted on page 31.

[2] Lorrain Smith, in Journal of Physiology, 1899, Vol. 24, p. 19.

[3] An American Text Book of Physiology, Vol. 1.

by Baron von Liebig, who recommended that in phthisis the respiratory action should be lessened.[1]

The Boston Nutrition Laboratory of the Carnegie Institution of Washington has undertaken a most painstaking series of investigations bearing on this subject. They include an examination of the comparative oxygen-content of uncontaminated outdoor air under all conditions as to wind direction and strength, temperature, cloud formation, barometer, and weather. In addition, samples of air were collected on the Atlantic Ocean, on the top of Pike's Peak, in the crowded streets of Boston, and in the New York and Boston subways. The results of the analyses of uncontaminated outdoor air showed no material fluctuation in oxygen percentage in observations extending over many months and in spite of all possible alterations in weather and vegetative conditions. The average figures are 0.031 per cent of carbon dioxide and 20.938 per cent oxygen. The ocean air and that from Pike's Peak gave essentially similar results.

The extraordinary rapidity with which the local variations in the composition of the air are equalized is accentuated by the observations on street air in the heart of the city, where the contaminating factors might be expected to be of sufficient magnitude to affect perceptibly the analytic data. Only the slightest trace of oxygen deficit is shown, with a minute corresponding carbon-dioxide increment. Observations such as these tend to demonstrate the extent of the diffusion of gases and the establishment of equilibrium by air-currents.

Most unexpected are the figures in regard to the extremely small extent to which the air was vitiated in the modern "tube" or subway, even during "rush" hours. There was, on the average, a fall of 0.03 per cent in oxygen accompanied by a rise of 0.032 per cent in the carbon dioxide. Professor Benedict points out that while the measurement of carbon dioxide has been taken as an index of good or bad ventilation, the fact that the proportion of oxygen is actually lowered by an increase in the carbon dioxide has never before been clearly demonstrated. As a result of this, the determination of the content of carbon dioxide in the air, which can be made with ease and accuracy, suffices to establish the approximate percentage of oxygen. For every 0.01 per cent increase in the atmospheric carbon dioxide one may safely assume a corresponding decrease in the percentage of oxygen. Aside from minor fluctuations ex-

---

[1] See Edward Smith: Consumption, Its Early and Remediable Stages. Blanchard and Lea, Philadelphia, 1865.

plained above, it may now truly be said that "the air is a physical mixture with the definiteness of composition of a chemical compound."[1]

Since the introduction[2] into medical practice of oxygen compressed in cylinders its use has been tried in tuberculous cases, but no satisfactory results have been obtained and its use is discontinued, except, so far as we know, in the hands of charlatans.

The inhalation of oxygen gas may not *per se* exert any curative action on a tuberculous lung, but that fact should not lead us to the conclusion that the voluntary respiration of an increased quantity of air is not beneficial. It is stated that the air in the central parts of the lungs is richer in carbonic acid than that found in the larger tubes and hence deep inspiration followed by deep expiration causes a larger amount of the air richer in carbonic acid, to be exhaled. From this the conclusion is drawn that increased chemical change will result, for if the carbon dioxide be removed from the air cells its place will be filled by quantities of the same gas which will escape from the blood. Furthermore, the removal of carbon dioxide from the blood facilitates and makes possible those metabolic changes which with a supply of suitable food improve nutrition.

Nowadays we often speak of oxygen as synonymous with atmospheric air and in this sense we give it a prominent place in pulmonary therapeutics. We are tempted to reproduce the placard of an old boot-maker and chiropodist of fifty years ago which read:

> The best medicine! Two miles of oxygen three times a day. This is not only the best, but cheap and pleasant to take. It suits all ages and constitutions. It is patented by Infinite Wisdom, sealed with a signet divine. It cures cold feet, hot heads, pale faces, feeble lungs and bad tempers. If two or three take it together it has a still more striking effect. It has often been known to reconcile enemies, settle matrimonial quarrels and bring reluctant parties to a state of double blessedness. This medicine never fails. Spurious compounds are found in large towns; but get into the country lanes, among green fields, or on the mountain top, and you have it in perfection as prepared in the great laboratory of nature.
>
> Before taking this medicine . . . should be consulted on the understanding that corns, bunions, or bad nails, prevent its proper effects.

---

[1] See the recent monograph by Benedict, F. G.: The Composition of the Atmosphere with Special Reference to Its Oxygen Content, Carnegie Institution of Washington, Publication 166, 1912. Review in Journ. Amer. Med. Ass., Jan. 25, 1913.

[2] The late Dr. Andrew H. Smith, of New York, was the first in the United States to use Oxygen in medical practice, 1860. "Oxygen gas as a Remedy in Disease," A. H. Smith, 1870.

The old London boot-maker had more wisdom than most of the doctors of his time.

CHAPTER III. INFLUENCE OF SEA AIR; INLAND SEAS AND LAKES.

SEA VOYAGES

The value of sea air in tuberculosis has been discussed *pro* and *con* for ages and, like the tide, there is an ebb and flow of sentiment regarding its value in the treatment of tuberculosis. Undoubtedly there is, at present, a stronger belief in the efficacy of sea air in the various forms of tuberculosis than at any previous time. This is especially true as regards tuberculosis of the bones, the tuberculosis of children and in the important class of cases termed fibroid phthisis.

Aretaeus, about 250 B. C., recommended sea voyages for the cure of consumption, and 300 years later Celsus advocated voyages from Italy to Egypt, if the patient were strong enough. Celsus was a layman whose learning was truly encyclopedic, but only his medical writings have survived. When the Roman sufferer from tuberculosis was not able to make the sea voyage to Egypt he was sometimes advised to pass a large portion of his time sailing on the Tiber.[1]

At Kreuznach, Ems, and other continental resorts, salt inhalations are given to patients with scrofulous and chronic bronchial affections. Instead of trusting to sea breezes the patients are taken to halls where saline particles are present in a higher precentage than they can ever be at the sea side. They inhale the salt-laden air and make use of pulverization apparatus. Hours are spent in the open air near the "evaporating fences" so as to inhale salt air at interior stations. At Ems this treatment is carried out in pneumatic chambers capable of holding ten people in compressed atmosphere for about 1¾ hours.

Sea air is of acknowledged purity as to micro-organisms, dust and adventitious gases. As previously remarked, there is at sea a maximum of ozone and a minimum of all foreign deleterious substances. (See page 9.) Without considering, as yet, the amount of watery vapor in the air of the ocean and other features of ocean air such as its movement and temperature, we recognize some physical contents such as a minute quantity of sodium chloride, iodine and bromine as characteristic of sea air when contrasted with air from any other

---

[1] "Opus est, si vires patiuntur, longa navigatione, coeli mutatione, sic ut densius quam id est, ex quo discedit aeger, petatur; ideoque aptissime Alexandriam ex Italia itur." Celsus, De Med. lib. III, Cap. 22.

STORM AT BLACKPOOL ENGLAND. SHOWING HOW SALINE PARTICLES ENTER THE ATMOSPHERE
Photographs by Courtesy of Dr. Leonard Malloy

locality. The wind carries aloft fine particles derived from the crests of the waves and this saline matter from sea water and foam is constantly present near the surface and is carried for miles inland.[1] It is well known that plants near the seashore have a perceptible coating of saline matter which modifies their growth.

As far as the present subject is concerned we have to deal with the influence on the tuberculous processes exerted by a marine climate. This can be obtained by undertaking sea voyages or by a residence on islands, or on the seaboard.

Ocean voyages were formerly strongly advocated as a means of cure in tuberculosis and were given an extended trial especially by English physicians. The constant commercial intercourse between England and her possessions all over the world made the practice easy and the results have been carefully weighed. Before the days of steam the typical ocean voyage from London to China or India involved vastly different conditions, as to time, route and accommodations. Some features will always be the same. Seasickness, the confined air of cabins, storm and wet will remain to harrass and terrify the traveler. But the clipper ships of the past are now, for the most part, doing duty as coal barges and the steam "tramp" and ocean liner carry the cargoes of the world.

After ruling out the tramps, cattle ships, and the coasting schooners, we have left a few sailing vessels still engaged in the East India trade and the fast liners. Modern systems of ventilation and cold storage have corrected some of the great disadvantages of the past and the presence of competent surgeons on board all the larger passenger steamers make the trip comparatively safe for a tuberculous patient if the necessity arises for him to make the voyage. But as a strictly therapeutic measure such trips are not to be recommended and in this we are supported by nearly all good authorities.[2]

---

[1] Two illustrations from a storm at Blackpool, England, are supplied by the courtesy of Dr. Leonard Molloy.

[2] Huggard, A., Handbook of Climatic Treatment, London, 1906, says: "Sea voyages were formerly in great repute for persons with phthisis; but it is now recognized that, except in certain well-defined instances they generally do harm. Only slight or mild cases without fever and without active symptoms, are likely to benefit. The patients most suitable for a sea voyage are those in whom the disease has become partly or entirely arrested." Dr. Burney yet doubts whether phthisis at any stage is benefited by ocean travel. Prof. Charteris, of Glasgow, approves of a sea voyage in the early stage of phthisis in a young person, but after that stage all experience testifies that degeneration proceeds more rapidly on sea than on shore and the patient, if he reaches land, only does this to find a grave far away from the surroundings of friends and home.

Dr. W. E. Fisher, for many years surgeon to the Pacific Mail Steamship Co., while observing that patients affected with chronic diseases, such as phthisis, dyspepsia, etc., are not so liable to seasickness as others, states that a large percentage of tuberculous patients stand the sea voyage badly. Dr. Fisher's experience relates to the trip from New York to San Francisco by way of Panama. During the first part of the voyage until the Bahama Islands are reached, the invalid experiences bracing weather. From that point to the Isthmus and thence up the coast during the long voyage of three weeks or more, a distance of nearly three thousand miles, the temperature averages 90° in the shade and on many days rises as high as 95° or 96° F. This occurs during the winter months and is the direct cause of deaths on the voyage or shortly after arrival on the California coast.

Dr. R. W. Felkin, of Edinburgh, says:[1] "Fifteen years ago I used to advocate sea voyages in my lectures on Climatology in Edinburgh, with great confidence; now I am more cautious. I do not send phthisical patients to sea as I once did. The risk of spreading infection is, to my thinking, too serious to be incurred. I well remember once sending two sisters to Australia; the elder suffered from phthisis; the younger was healthy. The elder certainly did gain some temporary benefit, but the younger sister and also a cabin companion became infected, and all three girls were in their graves within a year of their return to this country. I am sure that occupying a joint cabin as they did caused the mischief."

Dr. F. Parkes Weber, of London, takes a more hopeful view.[2] He says that sea voyages are often useful in the milder and quiescent forms of pulmonary tuberculosis, provided the patient's general condition be such as otherwise to fit him for life on shipboard. "Long voyages are to be preferred to all other methods of treatment in the case of male patients who have a taste for the sea, who are strong physically, or who possessed an originally strong constitution and were infected by 'chance' or when weakened by overwork, worry, improper hygienic conditions, or acute diseases."

In pulmonary tuberculosis complicated by syphilis, or syphilitic phthisis, as it was formerly designated, a marine climate seems to be particularly suitable.[3]

---

[1] Journal of Balneology and Climatology, January, 1906.

[2] F. Parkes Weber: System of Physiologic Therapeutics, Vol. 3, p. 87, Philadelphia, 1901.

[3] See Roland G. Curtin, Trans. Amer. Climatological Ass., Vol. 4, p. 31.

The vicissitudes of sea-travel, the narrow cabins and the difficulty of obtaining a suitable diet, even such common requisites as milk and eggs, should be enough to condemn this plan. Tuberculosis patients ought not to travel more than is absolutely necessary. Imagine the bacteriological condition of a consumptive's stateroom, for instance, at the end of a month's voyage! What sea-captain or steward would ever put such a cabin into a sanitary condition for the next passenger?

The author has some experience of life at sea under both sail and steam, although he has never taken very prolonged voyages. Taking into account the character of the food supply and the necessity of at least sleeping in small cabins and probably spending days in them, with uncertain medical attention; and, besides this, the dangers of various kinds that pertain to seaports, the author feels bound to condemn sea voyages for the tuberculous in any stage.

"Non mutant morbum qui transeunt mare."

MARINE CLIMATE OF ISLANDS

It is far better for the tuberculous patient to remain on *terra firma* than to traverse the sea. Whatever is of value in the sea air can be obtained in islands such as Ireland, the Isle of Man, the Isle of Wight, Nantucket, the Isles of Shoals, Newfoundland, Long Island, the Bahamas, the Canaries, the Philippines, Samoa, and many other islands.

Just as in the case of sea voyages, there are concomitant influences, many of which are notoriously unfavorable, that in themselves over-balance any possible advantage from sea air. Take, for instance, the problem as it presents itself in Ireland or the Isle of Man.

Among the various countries of the world Ireland stood fourth in the order of mortality from tuberculosis, being exceeded by Hungary, Austria, and Servia. During the last thirty-five years the mortality in Great Britain has been reduced one-half among females and one-third among males but, until 1907, there had been no such fall in Ireland.

Sir John Byers, of Belfast, in his address[1] entitled "Why is Tuberculosis so Common in Ireland?" characterized its prevalence in that country as "appalling." Among the nine causes which are assigned for this condition of affairs attention is first directed to the *damp climate*. An investigation of places with rather worse con-

---

[1] The Lancet, January 25, 1908. See also Alfred E. Boyd, M. B.: Tuberculosis and Pauperism in Ireland, British Journ. Tuberculosis, July, 1908, p. 159.

ditions of climate led Sir John to say on this point: "I cannot, therefore, admit that there is much in the dampness of the atmosphere as a cause of tuberculosis in Ireland." Sir William Osler takes precisely the same ground and pointed out at the opening of the Tuberculosis Exhibit in Dublin, that Cornwall, with a much damper atmosphere than that of Ireland, was so free from the disease that consumptives were sent there. In Cardiff, Wales, with a damp climate and with the ground water in many places near the surface in the gravel and with the lower part of the town on a stiff marine clay, very retentive of moisture, the tuberculosis death rate for 1906 was only 1.20 per 1,000. On the other hand in Belfast, with a smaller rainfall (34.57 inches as against 42.43 inches) the mortality was more than twice as much, or 2.77 per 1,000. The figures for 1906 were:

	Rainfall inches	Death rate from tuberculosis per 1000
Manchester, notoriously damp, foggy and smoky....	....	1.82
Liverpool	....	1.82
London	....	1.42
Cardiff, Wales	42.81	1.20
Bolton, England	42.43	1.11
Belfast, Ireland	34.57	2.77
Cork	....	4.53
Dublin, Ireland	27.73	2.91
North Dublin, Ireland	....	4.70

After taking up in turn dampness of soil, emigration as a cause for tuberculosis, the asserted susceptibility of the Irish to tuberculosis, poverty and social position, food and drink and industries, and after weighing them carefully they were all discarded as insufficient causes of this mortality. The prime cause was declared to be *want of Sanitary Reform* and the *prevalent domestic or home treatment of the advanced cases of pulmonary tuberculosis.*

Since 1907 an encouraging decline in the mortality from tuberculosis has been noted. Whereas the rate for both sexes throughout Ireland was 273.6 per 100,000 in 1907 it had dropped by gradual stages to 215.2 in 1912. Sir William Thompson, the General Register for Ireland, justly attributes this well marked decrease during the past six years to the exertion of Her Excellency, the Countess of Aberdeen.[1]

---

[1] Trans. National Association for the Prevention of Consumption and Other Forms of Tuberculosis, 5th Annual Conference, London, August 4 and 5, 1913. See also Sir John Moore, Interstate Medical Journ., April, 1914.

Sir William shows that this decrease indicates 17,000 fewer people suffering from tuberculosis in Ireland in 1912 than there were in 1907. This corresponds to a decrease of nearly one-fifth of the total number of cases of tuberculosis. He seems hopeful that within the next few years the death-rate from tuberculosis in Ireland will not be above the average in other countries.

Undoubtedly hygienic and philanthropic measures are entitled to the credit for this marked improvement and it gives us pleasure to note in this connection the remarkable work of Her Excellency, the Countess of Aberdeen. This noble woman founded in 1907 the Women's National Health Association of Ireland and a vigorous campaign was started which soon roused the whole country to a sense of responsibility in matters of public health and, in particular, to measures necessary for the prevention and cure of tuberculosis. The influence of this organization rapidly spread and within eighteen months no less than seventy branches had been opened throughout Ireland, for the most part opened in person by their excellencies, the Lord Lieutenant and Countess of Aberdeen, and now it has 150 branches and 18,000 members.

While undertaking the reduction of infant mortality, the improvement in the milk supply and better school hygiene, the association made a systematic attack on the prevalence of tuberculosis. This included home treatment and its strong ally, the tuberculosis dispensary, on a plan similar to that originated by Sir Robert Philip, of Edinburgh; it included sanatorium treatment; and it provided special treatment for advanced cases of tuberculosis. In this phase of the work the association had the benefit of £145,623. through the provisions of the National Insurance Act. Charitable Americans also contributed handsomely toward the erection of sanatoria now comprising one thousand beds, the maintenance of dispensaries and of depots for the supply of pasteurized milk.[1]

It is interesting to note that the Association also lent its support to the formation of an "Irish Goat Society," believing that the best way to meet the scarcity of milk experienced in many parts of Ireland is to encourage the keeping of a good breed of milking goats. Then, too, through the administration of the Laborer's Acts nearly fifty thousand cottages with garden plots ranging up to one acre have been built for rural laborers by rural sanitary authorities at an outlay of over £8,000,000.

We have cited this remarkable campaign of the anti-tuberculosis

---

[1] The late Mr. R. J. Collier and Mr. Nathan Straus.

movement in Ireland to show how close are its relation to the broader field of general hygiene and sanitation and to show that such work pays; and furthermore what great service one person of noble birth, by her foresight, solicitous care and untiring devotion, can initiate and carry out. As Prof. Thompson says: There is no doubt that it will rank as one of the greatest philanthropic efforts of our time.

Take the Isle of Man. This island in the Irish Sea has a population of over ten thousand and for six hundred years has been singularly free from the admixture of English, Irish, or Scotch blood. The island has a more equable climate than any other part of the British Isles. The mean annual temperature is 49° F. There is comparative absence of frost, fog, or snow. But careful records since 1880 show that the Manx tuberculosis death rate is about double that on the mainland.[1]

	1880-82	1883-1897
Isle of Man	31.63	25.70 per 10,000
	1887	1893
England and Wales	15.08	13.07 per 10,000
	1888	1894
	14.28	12.17 per 10,000
	1889	1895
	14.35	12.43 per 10,000
	1890	1896
	15.06	11.39 per 10,000

The Bahamas and Bermuda in the Atlantic Ocean have a subtropical marine climate that experience shows to be far too relaxing and enervating for tuberculous patients.

The Philippines and all other tropical islands are likewise entirely unsuited for tuberculous patients for the same reasons.[2] Newfoundland, with a harsh, damp, colder air, is equally bad.

Dr. Newsholme, of Brighton, President of the Epidemiological Section of the Royal Society of Medicine, in an elaborate inquiry into the principal causes of the reduction of the death rate from phthisis in different countries, came to the conclusion that the one

---

[1] Charles A. Davies, M. D.: Tuberculosis in the Isle of Man (Tuberculosis, London, Oct., 1900).

[2] According to Dr. Issac W. Brewer, U. S. A., "Notes on the Vital Statistics of the Philippine Census of 1903," American Medicine, Oct., 1906, the death rate from tuberculosis is one-third that in the United States.

common factor present in all cases where a fall was noted was the segregation of the patients in hospitals or sanatoria. In each country where the institutional has replaced the domestic relief of destitution there has been a reduction of the death rate from phthisis which is roughly proportional to the change.

As to the cause, then, of the spread of tuberculosis, we shall find that it probably always lies in ignorance, indifference and other moral or sociologic causes, and, in many of the cases cited, not to climatic or atmospheric conditions.

Our opinion of sea air is fortunately not confined to that of the high seas or even that of islands. The sea air sweeps the mainland and, as we know, modifies the climate of all adjacent portions of the Continent. The great source of atmospheric moisture is found ultimately in the oceans. The invisible watery vapor and the visible clouds are carried inland and deposit their water over the Continent. The monsoons which are most highly developed in India and other parts of Asia, prevail also in Texas and on the Pacific coast of the United States. These seasonal winds are of great importance from a climatic standpoint and hence should be taken into account in reference to the climatic treatment of tuberculosis.[1] During the summer and autumn in India these seasonal winds sweep inland from the sea and deluge the country with rain. This amounts, in the Khasi Hills, 200 miles north of the Bay of Bengal, to between 500 and 600 inches a year and reaches its maximum at points about 1,400 meters, 4,600 feet, above sea level.

Fortunately in the United States these seasonal winds, while present, are not so dominant as climatic factors. We are more concerned in the present study with the diurnal winds of the seashore. The sea breeze which tempers the heat of our coasts is a distinctly beneficial feature of the shore and not only tends to moderate the heat of the summer day, but sweeps inland for fifty or a hundred miles the pure ocean air and provides all the desirable features of a marine climate.

ARCTIC CLIMATE

Passing still farther north we have the Arctic climate. It is marine or insular and cold. Arctic voyages have been proposed for the treatment of tuberculosis and, as adjuncts to the voyage, a summer sojourn in the northern fjords of Greenland. A trip of this

---

[1] See William Gordon: The Influence of Strong, Rainbearing Winds on the Prevalence of Phthisis, H. K. Lewis, London, 1910, Observations in Devonshire.

kind has been seriously planned by Dr. Frederick Sohon, of Washington, D. C., but has never yet been carried out.[1]

It is a significant fact that Arctic explorers from Dr. Elisha Kent Kane down, including General A. W. Greely, Admiral Peary, Mr. W. S. Champ, Mr. Herbert L. Bridgman, the late Dr. Nicholas Senn, and others comment on the healthfulness of the Polar climate. Dr. Sohon made two voyages with Commander Peary, in 1896 and in 1902, and states his opinion that in summer the Arctic regions are entirely suitable for, and beneficial to, the tuberculous, and that the unequaled natural advantages for a cure can be practically utilized. Few understand the fascination which the Polar regions undoubtedly exert on all who enter that charmed circle. The expressions used by Arctic explorers seem so extravagant to the average mind. The late Professor Senn says: "Nature there lends such efforts toward prophylaxis, as to leave no need for therapeutics."[2]

The air of the Arctic regions is free from dust and germs. It is not, in itself, responsible for any disease which may be carried into Arctic settlements by ships' crews, or by means of the migration of animals or birds. Colds and catarrhal conditions are conspicuously absent. There is no pneumonia. The only "Arctic Fever" is that which explorers are almost sure to contract on their first visit and which has an annual periodicity. It is not a self-limited disease, as Admiral Peary can testify after nearly fourteen consecutive summers in the Polar regions.

Another feature of the atmosphere in the Arctic is absolute clearness and abundance of sunshine. Dr. Sohon, in 1902, exposed dishes of agar and introduced into culture tubes pebbles, bits of vegetation and water from the ground and from pools at Commander Peary's winter quarters. Of six dishes exposed for from one-half to two hours, two were sterile and four gathered only a common white mould (P. glaucum). Only the hay bacillus was obtained from the pebbles. Water yielded the hay bacillus, *B. liquefaciens, B. fluorescens* and an unclassified non-pathogenic saprophytic rod organism.

---

[1] Frederick Sohon, M. D.: Personal Observations on the Advantages of Certain Arctic Localities in the Treatment of Tuberculosis (American Medicine, April 23, 1904).

Idem. The Therapeutic Merits of the Arctic Climate Meteorological Data of a Summer Cruise (Journal American Medical Association, February 3, 1906).

[2] Nicholas Senn: Medical Affairs in the Heart of the Arctics (Journal American Medical Association, 1905, Vol. 45, pp. 1564, 1647).

The atmosphere has a bracing quality and is always credited with developing a prodigious appetite. It is pointed out that a taste is developed for the kind of food the tuberculous patient needs, viz., fatty food and meat. The craving for this kind of food is usually accompanied by a corresponding adaptability to digest it and, in healthy subjects, flesh is always gained. Dr. Sohon says that in both of his trips to Greenland he has exceeded his usual maximum weight, gaining the first time thirty pounds in two months, and the second time nineteen pounds in six weeks. In the latter voyage even the crew made an average gain of ten pounds in weight.

A large share of the beneficial influence of any atmospheric change is that which conduces to a good appetite and digestion. In this respect the summer Arctic voyage may fairly claim preeminence. With qualities such as these it is natural that, for a portion of the year at least, the merits of the Arctic climate in the treatment of tuberculosis should at least be considered.

An atmospheric feature is its great penetrability for light and especially for the actinic and ultra-violet rays. Tanning of the skin always occurs and sunburn is not uncommon. During summer the sun never sets and, though not very high in the heavens, its generous rays must exert a very beneficial influence on any morbid process, especially of a tubercular type. Arctic plants develop rapidly from seed to flower and seed again in surprising manner and the wild animals seem to be the largest and most vigorous of their kind.

In judging of the weather to be encountered in the Arctic regions, we are too much inclined to recall the harrowing accounts of the ill-fated expeditions of the past; but in the Northern fjords of Greenland, some miles from the coast, or in the protected inland bays, the atmospheric conditions of summer are quite agreeable and are especially suitable for the open air treatment.

The fluctuations of temperature are very moderate. The average minimum temperature between July 28 and September 6, between 69° and 78° north latitude on these Greenland Fjords, was about 38 F.; the average maximum was 49° to 50°. Temperatures as high as 56° were recorded at North Star Bay and about 52° at Etah.

The humidity averaged low. The records were made at 8 a. m. and 8 p. m., and, owing to the constant daylight, are much more representative estimates of relative humidity than in the case of records of relative humidity at those same hours in temperate latitudes.

	Maximum Humidity		Minimum Humidity		Average	
	8 a. m.	8 p. m.	8 a. m.	8 p. m.	8 a. m.	8 p. m.
New York	100	95	62	50	81.3	74.1
Denver	90	90	41	13	66.1	37.1
North Star Bay	72	71	56	39	63.1	54.
Etah, Greenland	81	70	40	35	57.6	52.4

The relative humidity was much lower while at anchor in the harbors of Northern Greenland than while en route through the Strait of Belle Isle and off Labrador and in Davis Strait and Smith's Sound.

We have given some attention to this subject on account of the very enthusiastic claims made on behalf of the atmosphere of the Arctic regions during summer treatment of tuberculosis. Although the plans for sending a ship with tuberculous passengers on this voyage failed to be carried out owing to inability to get the necessary permission from the Danish Government to land at the northern ports of Greenland, it is possible that at some future time the attempt will again be made.

The fact that Icelanders and Greenlanders may contract tuberculosis in numbers and may die from it is not to be overlooked; but the filth of winter quarters in the far North and the foul air of these huts is responsible for much of the illness of the native inhabitants. The Eskimo survives the dangers of the winter because he leads a totally different life in summer. It is difficult for those who have never been to the Polar regions to realize what a change is wrought by the advent of constant sunlight. This unique feature of the summer climate contributes to health and energy. The atmosphere, free from all germs and dust, bracing in its quality, is a strong stimulant to bodily functions as gain in weight testifies.

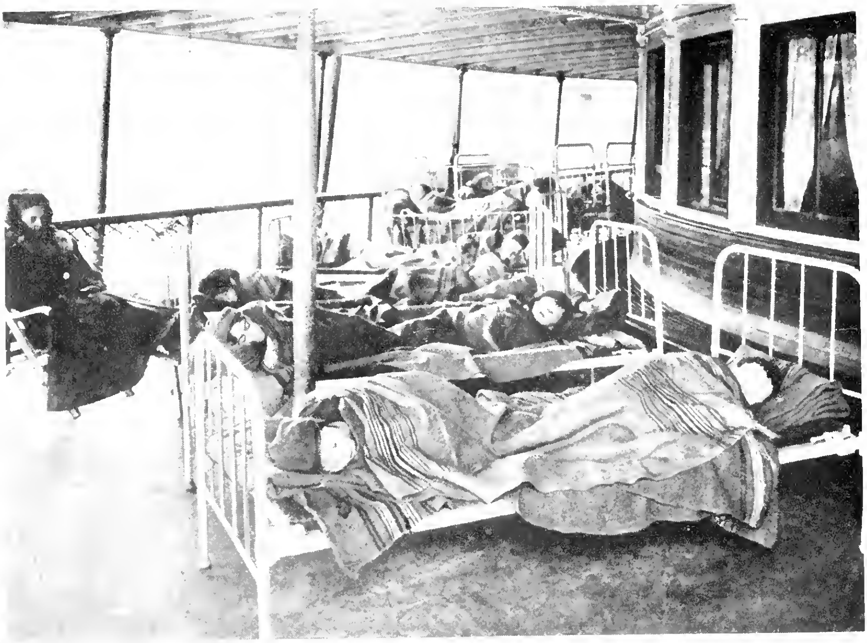
As a practical measure for the treatment of tuberculosis Arctic voyages have not yet been proved to be beneficial, although there is some presumptive evidence in their favor and, in view of the abundance of proof that the disease can be successfully combated at numberless places on the continent, such expeditions will scarcely meet with favor.

FLOATING SANATORIA

In 1896, Mr. M. O. Motschoutkovsky[1] advocated floating sanatoria for patients with incipient tuberculosis. These specially fitted vessels were to be shifted from port to port according to the season so as to get the most favorable climatic conditions.

---

[1] The Lancet, April 4, 1906, p. 939.



OPEN AIR CLASS ON FERRY BOAT "SOUTHFIELD," EAST RIVER, NEW YORK CITY. SLEEPING HOUR
Courtesy of Dr. J. W. Brannan

OPEN AIR SCHOOL FOR TUBERCULOUS CHILDREN. FERRY BOAT "SOUTHFIELD," BELLEVUE HOSPITAL. SEE PAGE 43

The vicissitudes of sea-travel, the narrow cabins and the difficulty of obtaining a suitable diet, even such common requisites as milk and eggs, ought to be enough to condemn this plan. Tuberculous patients ought not to travel more than is absolutely necessary. Old ferry boats have been recently utilized in New York as class-rooms for tuberculous scholars. The ferry boat " Southfield " has been equipped for this work through the Miss Spence's School Society under the direction and courtesy of Bellevue Hospital in cooperation with Dr. John Winters Brannan and Dr. J. Alexander Miller.

There are three classes on the " Southfield "; two for pulmonary cases of about thirty-six children; these classes being part of the regular Bellevue Clinic work and entirely supported by Bellevue.

The third class is for tuberculous cripples with about twenty children. The cost of nurses and special equipment for this class together with incidental expenses is borne by the Spence School Society.

The teachers for all three classes are supplied by the New York Board of Education so that they are a part of the regular school system.[1]

Owing to the fact that these old ferry boats seem to answer a useful purpose and in view of the reported use by the Italian Government of three discarded men-of-war as floating sanatoria in the treatment of tuberculous patients, a request was made to the Navy Department of the United States for similar ships by the Fourth International Congress on School Hygiene at Buffalo, N. Y., August 29, 1913, in a resolution, a portion of which is as follows:

> WHEREAS, It has been demonstrated in New York and other cities that discarded vessels lend themselves admirably to transformation into all-year-round hospitals and sanatoria for consumptive adults, sanatoria for children afflicted with joint and other types of tuberculosis, and into open air schools for tuberculous, anemic, and nervous children;
>
> *Resolved,* That the fourth International Congress on School Hygiene petitions the United States Government to place at the disposal of the various States of the Union as many of the discarded battleships and cruisers as possible to be anchored according to their size in the rivers or at the seashore and to be utilized by the respective communities for open air schools, preventoria, sanatorium schools for children, or hospital sanatoria for adults.

The Secretary of the Navy, however, for the following very good reasons, declined.

---

[1] See Buffalo Medical Journal, 1907-8, Vol. 63, 41.

I am of the opinion that battleships are not suitable for floating sanatoria. This opinion is based on the following reasons.

The cost of maintaining a battleship in proper sanitary and structural condition is very high.

Battleships, particularly the older types, have very limited deck space, and this is so cut up by hatches, turrets, davits, cranes and winches that there are few spaces large enough for a cot. The cost of removing these obstructions would be equivalent to that of building more suitable floating hospitals.

The ventilation in the enclosed spaces of these vessels is so poor that it often has an unfavorable effect on those chosen especially for their health and vigor. Its effect on those already diseased could not be favorable. The openings are very small and admit but little sunlight; it is necessary to use artificial light for a large part of the day. To correct these conditions would involve great expense, even if it were possible of accomplishment.

The passages are narrow, the ladders steep and the hatches small, making transportation of the sick very difficult.

Very respectfully,

JOSEPHUS DANIELS,

Secretary of the Navy.

Under the title " Una nave-scula-sanatorio per fanciulli predisposti " Federico di Donato has urged this plan in Italy but up to the present the Italian Government has not assented.

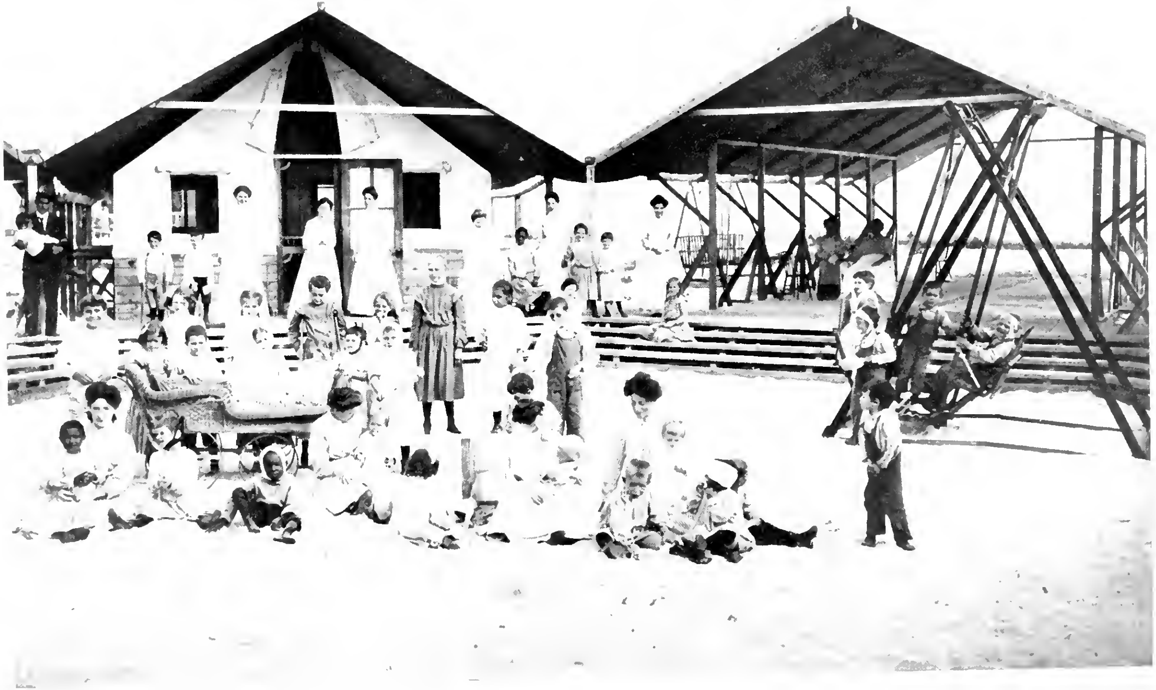
The remark has been made that: " If the right sort of ship could be sent to the right place in the right kind of weather with the right sort of patients, a great deal of good might result."

SEASIDE SANATORIA FOR CHILDREN

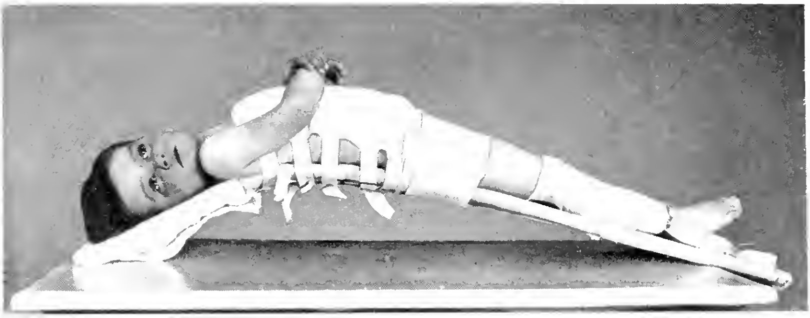
In the United States notable attempts have been made to utilize sea air in treating tubercular disease in children. Individual cases have been treated by sea air, but on a larger scale we should mention the experience of two institutions.

In 1872, Dr. William H. Bennett, of Philadelphia, established the Children's Seashore House at Atlantic City, New Jersey. This institution is open during the entire year, and in 1912 more than 3,500 mothers and children were cared for. Among the first patients admitted to the Institution at its inception were the hospital children suffering from tubercular diseases of the bones, glands, and joints. The wonderful improvement wrought in such cases by the sea air led to a steadily increasing demand for their admission, and now throughout the year seventy beds are set apart for their care and treatment.

The most notable and most recent attempt in the United States to treat cases of tuberculosis of the bones, joints and lymph nodes is at the Sea Breeze Hospital at Coney Island on the Atlantic



SEA BREEZE HOSPITAL, SEA GATE, CONEY ISLAND, NEW YORK. TUBERCULOUS CHILDREN ON THE BEACH



TREATMENT OF POTT'S DISEASE OF THE SPINE ON A BRADFORD FRAME. SEA BREEZE HOSPITAL, SEA GATE, NEW YORK. PATIENTS REMAIN FOR MONTHS, NIGHT AND DAY, ON THESE FRAMES, BUT ARE REMOVED TWICE DAILY FOR BATHING AND POWDERING

Courtesy of Dr. J. W. Brannan

SEA BREEZE HOSPITAL, SEA GATE, CONEY ISLAND, NEW YORK. MORE CITY CHILDREN ARE STARVED FOR SLEEP THAN FOR FOOD. VIEW AT 6 A. M. IN SPRING. CHILDREN SLEEPING TEN HOURS ON PORCH ALL NIGHT. CANVAS OVERHEAD ROLLED BACK.

Ocean, ten miles from New York City. This was undertaken by the New York Association for Improving the Condition of the Poor. Ten tents were erected on the beach and were opened to children between the ages of two and fourteen on June 6, 1904. These tents had a capacity of fifty patients. In the autumn permanent buildings were occupied and have since been used. While the main reliance has been on fresh sea air and good food, the very best surgical aid has been employed, and for all major operations the children were temporarily removed to hospitals in New York City. This co-operative arrangement is a great advantage to the seashore institution, as the distance is not great and avoids the necessity of enlarging the surgical staff and at the same time provides the highest surgical skill. To avoid mistakes most of the cases admitted are seen by at least one other surgeon besides the attending surgeon. While pulmonary cases are refused the staff admits severe, desperate, and even hopeless cases.

In a recent report by two of the members of the staff[1] there are histories of forty-two cases and illustrations of the methods of treatment; but the noteworthy feature of the report is the prominence given to residence at the seashore as the chief means of cure. The conclusions from seventy-six histories which form a basis of the report are as follows:

(1) The seashore is the best place for treating children with tuberculous adenitis. The children make a better recovery here than elsewhere. Those with adenoids and enlarged tonsils should be submitted to an operation as a start of the cure. Sea air does not permit us to dispense with this.

(2) The seashore is probably the best place for children with tuberculous joints, provided they can have there the same skilled orthopedic care as elsewhere. Their disease runs a somewhat milder and probably a shorter course, and the functional results are better than those obtained elsewhere.

(3) Our results have been largely due to the careful attention (including feeding and nursing) which has been given the children.

(4) Our results justify pushing the work.

(5) A hospital such as this does better work than a public hospital under control of the municipality.

(6) Many cases of co-called bone tuberculosis are in reality syphilis.

We do not know whether there is anything "specific" about the seashore,

---

[1] Leonard W. Ely and B. H. Whitbeck, Medical Record, March 7, 1908. See also Charlton Wallace, Medical Record, July 22, 1905; John Winters Brannan, Trans. American Climatological Association, 1905, p. 107; John Winters Brannan, Trans. National Association for the Study and Prevention of Tuberculosis, 1906. Roland Hammond: Heliotherapy as an Adjunct in the Treatment of Bone Disease, Amer. Journ. Orthopedic Surgery, May and October, 1913.

or whether children simply thrive better and so overcome more quickly their disease.[1]

As to treatment other than diet and fresh air, little need be said. We use plaster when we can in preference to braces. In Pott's disease we use first the Bradford frame, then plaster jackets; in hip joints, the short Lorenz spica. In knee-joint disease after the acute stages, we also use plaster-of-Paris. Patients with large cold abscesses are transferred to the Manhattan hospitals, where their abscesses are opened, wiped out, and sewn up again with proper asceptic precautions.

On January 21st of the present year, 1914, the author revisited Sea Breeze Hospital, Coney Island, New York, in order to see what is being accomplished. Six cases of hip disease were being treated by partial exposure of the body to the sun. The patients were in bed on the balcony with the usual extension apparatus in place. General exposure, beginning with the feet and gradually involving the entire body, is not adopted at Sea Breeze, as a rule, and only the area of abdomen, hip and thigh adjacent to the diseased joint was exposed to the air and sun. Continued cloudy and unfavorable weather had prevented much progress in the newer patients who were then undergoing treatment; others who had been cured of serious tuberculous disease by the open-air method had recently been discharged. The fresh-air system is, however, well carried out, but not upon the naked body as in Switzerland and France.

The temperature on the open balcony next to the wooden wall of the building was 62° F. at noon in the sun. It was the first bright day after weeks of storm and cloud. It is probable that the very encouraging experience of the last two years will lead to the adoption of Rollier's method in all its details as modified by the less favorable climatic conditions of this part of the Atlantic seaboard.[2]

Results at Sea Breeze Hospital in the treatment of tuberculosis of the bones, joints and glands have been so good that the city of New York has acquired a new location with 1,000 feet of beach front on what is known as Rockaway Point, ten miles beyond Coney Island. The plot runs back about 600 feet to Jamaica Bay and cost the city, after condemnation proceedings, $1,250,000. The plans include an arrangement of grounds and buildings which will involve a total

---

[1] Charlton Wallace, M. D.: Surgical Tuberculosis and Its Treatment (Journal of the Outdoor Life, March, 1913). This author, who is Orthopedic Surgeon to St. Charles' Hospital, Long Island, and the East Side Free School for Crippled Children, New York, says: The author is not in a position to produce scientific proof that sea air is better than country air, but he does believe such to be the case, although there are some individual patients who do better in the country than at the seashore.

[2] Heliotherapy is used at the Crawford Allen Hospital, Rhode Island.

outlay of $2,500,000 and there will be accommodation for 1,000 patients in the eight pavilions. Contracts for two of these pavilions have been let and will be paid for by a fund raised by the New York Association for Improving the Condition of the Poor. The new hospital will be turned over to the city of New York and will be conducted by Bellevue and Allied Hospitals. The plans include an immense playground running back to Jamaica Bay for the use of the public.

Credit is due to Dr. John Winters Brannan, of New York, president of Bellevue and Allied Hospitals, for much of the great work which has so far taken about nine years to accomplish and for which America will be justly proud.

Encouraged by the success at Sea Breeze, another hospital for surgical tuberculosis in children was started six years ago at Port Jefferson, on the north shore of Long Island, opposite the Sound. The situation is said to be ideal. It accommodates two hundred children and is a handsome fireproof structure. It is called St. Charles' Hospital; it is under the active care of the "Daughters of Wisdom," a Roman Catholic Society. The children, according to Dr. Wallace, receive every physical, mental, spiritual and industrial care necessary to produce good moral men and women. It is an active orthopedic hospital admitting any deserving case and keeping him there until the lesions are healed. Patients in advanced stages of bone tuberculosis are received as well as those with pulmonary complication. Under the good hygienic surroundings at St. Charles' Hospital, the children have shown great improvement in every way. Dr. Wallace adds: "The removal of the diseased bone with the knife is no longer attempted, because such a procedure not only takes away the root from which the bone grows, but also fails to eradicate the affected area. Reliance must therefore be placed on other than cutting methods for local treatment of the affected parts." Immobilization by plaster-of-Paris, properly applied and fresh air on the shore of Long Island Sound, conjoined with every other hygienic aid possible, constitute the line of treatment.

The New York Hospital for Ruptured and Crippled has lately removed to a new site on a hill near the East River, where the outdoor treatment for the tuberculous cripple is carried out as well as it can be in a large city.

In England it has long been customary to send scrofulous children and those with surgical tuberculosis to the eastern and southeast coast. At Margate the Royal Sea-Bathing Hospital, founded by

Lettsom and Latham in 1791, is the oldest institution of the kind in Great Britain, and retains its pre-eminence. There are similar institutions at Brighton, Bournemouth, Folkestone, and Ventnor, Isle of Wight (see plate 12).

The impression prevails at present in England that sea air is the best for these cases. The bracing air suits them perfectly and children with tuberculous bones, joints, or glands can stand a much colder and fresher air than children with pulmonary disease. Sea air improves the general health and keeps nutrition at the highest level. Italy and France, however, take the lead in seashore sanatoria exclusively devoted to tuberculous children. They have been in existence on the Italian shore at Viareggio since 1856, and on the French coast since 1860, and are conducted on a very extensive and systematic scale. The first sanatorium at Berck-sur-Mer was established in 1860 by the city of Paris, and is almost exclusively for children suffering from tuberculous disease of the joints, bones and glands, and has at present considerably over one thousand beds and accommodates children from the poorest quarters of Paris.[1]

Two private hospitals for similar cases are located at Berck-Plage. One was founded by Baron Rothschild and is maintained by his widow and contains 600 beds. Four-fifths of the cases are surgical; one-fifth, medical.[2] The other is in Cazin Perrochaud and accommodates 200. At Pol-sur-Mer there is a similar institution maintained by the city of Lille, which is designed to have 900 beds.[3] At Cannes there is an excellent private institution, the Villa Santa Maria, for the " cure helio-marine des tuberculoses chirurgicales " under the direction of D. A. Pascal.

Besides these institutions for surgical tuberculosis there are others which are intended mainly for pulmonary tuberculosis. These are located at Hendaye, Ormesson, Villiers-sur-Marne and Noisy le Grand. There are now fifteen sanatoria on the French coast open throughout the year and, in addition, a number open for only a part of the year, containing in all over four thousand beds. In 1904 there were twenty-three Italian hospitals distributed along the Mediterranean and Adriatic shores of Italy, with over ten thousand beds.

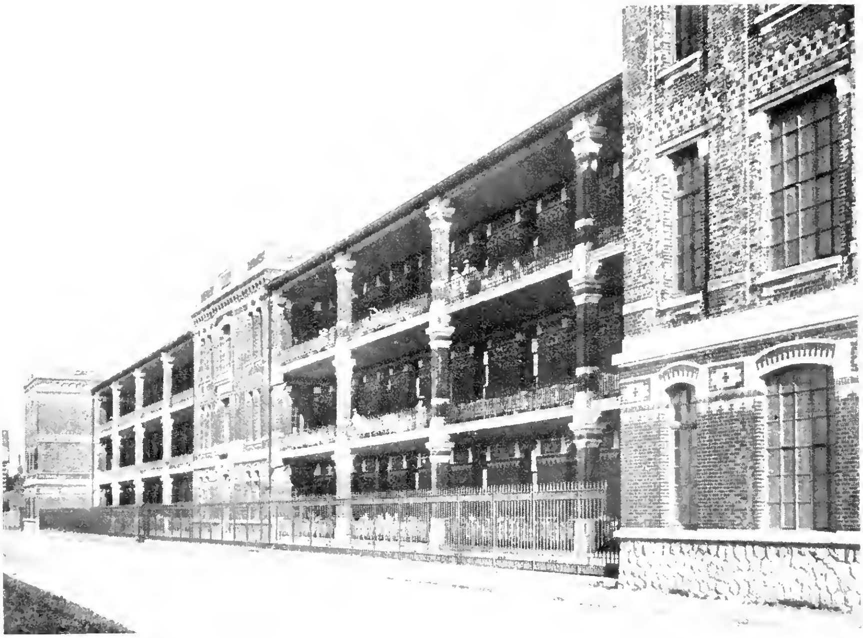
---

[1] See article by the author on " The Treatment of Surgical Tuberculosis," etc. Interstate Medical Journal, St. Louis, March, 1914.

[2] See article by Douglas C. McMurtrie, Boston Medical and Surgical Journal, Jan. 2, 1913.

[3] See article by John W. Brannan, *loc. cit.*

VENTNOR, ISLE OF WIGHT, ENGLAND. SITE OF THE ROYAL NATIONAL HOSPITAL FOR CONSUMPTION
Courtesy of Dr. T. A. Ross



WEST GALLERIES, MARITIME HOSPITAL FOR TUBERCULOSIS, BERCK-PLAGE, FRANCE. 300 BEDS

SOUTH GALLERIES, MARITIME HOSPITAL FOR TUBERCULOSIS, BERCK-PLAGE, FRANCE. 216 BEDS

These hospitals are said to be closed in winter. (Brannan.) Every other country in Europe, with the exception of Turkey and Greece, has one or more seashore sanatoria for tuberculous children, so that there are as many as seventy-five such hospitals on the shores of Europe. The Argentine Republic has two seashore sanatoria, one established twenty-three years ago with three hundred beds and a new one with five hundred beds.

The plan of treatment at all these institutions is very simple and ought to have been carried out on this side of the Atlantic long ago. The brilliant experience at Sea Breeze, Coney Island, is simply due to a repetition of the methods adopted for decades in France and England. The régime at all these sanatoria is about the same. The patients are kept out of doors all day on the beach or on verandas, which are covered but are open on the front and sides. Four meals a day with unlimited milk are provided. All through the winter the children occupy themselves on the grounds or on the beach; those confined to bed are on the open porches enjoying the sunshine and the sea air, the best tonics in the world, and developing a ruddy color and better general circulation than they have ever known. Their warm hands in the coldest winter weather is the wonder of all who visit them. At night the windows are wide open and the air has practically the same temperature as at any point on the coast, varying from 12° to 40° F. If the snow drifts in at night, as sometimes happens, nobody seems to be the worse. The windows are, however, closed for a half hour morning and evening while the children are being washed and dressed.

The surgeons at Berck-Plage, although engaged in active orthopedic work, are all firmly convinced that residence at the seashore, with the greater part of the twenty-four hours spent in the open air, does more for the children than could be accomplished even in the best appointed hospitals in the cities.[1] One of the surgeons at Margate, after fifteen years of constant work in the wards, states his opinion that the knife plays a very secondary part to climatic and general influences.

For an institution of this kind to attain the highest efficiency one thing seems plain; the patients must be admitted at a very early age, not from six years old and upwards, but as early as two years of age. In this respect the French and American sanatoria have the advantage of the English. The point has been made that at six years

---

[1] Each year during the early part of August vacation clinics are held, which are attended by large numbers of French and foreign physicians.

of age a child with tuberculous disease is often past cure. Much can be done with a tuberculosis case if "caught young."

After serious operations, the surgeons at the seaside sanatoria note that progress is much more rapid when patients can live in the open air and the practical point has been discovered that subsequent dressings of a much more simple character are permissible under the open air régime. For instance, in Metropolitan hospitals the practice of packing and draining wounds has untold terrors for the unfortunate patients. Dr. Charlton Wallace found that at "Sea Breeze" tuberculous sinuses heal more rapidly and permanently when all packing and drainage are omitted and only a sterile absorbent dressing is applied. As the general instability of these patients is such as to cause them almost to collapse at the thought of having their wounds probed and packed, it led him to believe that they would gain strength and local resistance if they were not nervously upset at the time of each dressing. In the beginning, in order to ascertain whether there would be full drainage, comparisons were made of the amount of discharge, with and without the full dressing, and as there was no diminution he concluded that packing or tubing was not essential to drainage. Not only was the danger of infection less, no infected wound being observed, but he found that no sinus healed which still contained pus. This certainly simplifies the treatment of surgical wounds and the credit is given to the favorable atmospheric conditions.

At Sea Breeze the children receive from one to two hours instruction daily, the teachers being furnished by the Brooklyn Board of Education. It has been noted that the educational training given at this Sea Breeze Hospital has a most happy effect on the morals of the patients and at this early age much more can be accomplished in combating vice and ignorance, which constitute the greatest obstacles in dealing with the tuberculosis problem.

(For open air schools for tuberculosis children, Waldschule, etc., see pp. 103-107).

In estimating the value of sea air in non-pulmonary tuberculosis in children, we naturally look to France for some data based on the enormous experience now extending over a period of nearly fifty years. During the last twenty years in France alone 60,000 children have been treated in these sanatoria and Dr. Brannan is authority for the following statement:

Cures, 59 per cent. Decidedly improved..25 per cent
Total of favorable results ....84 per cent
Cures in Pott's Disease ....32 per cent
Cures in glandular tuberculosis ....74 per cent

HELIOTHERAPY. VIEW OF THE SOUTH GALLERIES OF THE MARINE HOSPITAL, BERCK-PLAGE, FRANCE. THE CHILDREN ARE EXPOSED ALL DAY NAKED TO THE SUN

SEA BREEZE HOSPITAL, SEA GATE, NEW YORK. OPEN AIR SCHOOL
Courtesy of Dr. J. W. Brannan

HELIOTHERAPY. SEA BREEZE HOSPITAL, SEA GATE, NEW YORK, MARCH 18, 1913. CURED CASE OF TUBERCULOSIS OF THE KNEE. NO SINUS.

Courtesy of Dr. Brannan

HELIOTHERAPY AT SEA BREEZE HOSPITAL, SEA GATE, NEW YORK, OCTOBER, 1912. CHILDREN ON THE BEACH. CURED CASES OF TUBERCULOSIS OF THE WRIST AND ANKLE. THERE WERE OPEN SINUSES IN EACH CASE.

These results of the treatment of surgical tuberculosis at seashore sanatoria are much more favorable than in the case of pulmonary tuberculosis, in adults, in corresponding localities (see pp. 71-73).

Nevertheless, the Department of Public Charities of the City of New York has just built and equipped at an expense of $3,500,000, a new hospital for adults having pulmonary tuberculosis in the second or third stage. The site selected is on the highest point of Staten Island in New York Bay, 400 feet above tide and only five miles from

---

[1] See R. Russell, M. D.: Glandular Tabes, or the Use of Sea Water in Diseases of the Glands. London, 1750.

Ebenezer Gilchrist, M. D.: The Use of Sea Voyages in Medicine. London, 1771.

Albert L. Gihon, M. D., U. S. N.: The Therapy of Ocean Climate (Trans. Amer. Climat. Ass., 1889, p. 50).

M. Charteris, M. D.: Ocean Climate (Trans. Amer. Climat. Ass., 1890, p. 278).

Wm. Ewart, M. D., F. R. C. P.: The Present Position of the Treatment of Tuberculosis by Marine Climates (Journ. Balneology and Climatology, July, 1907).

W. S. Wilson: The Ocean as a Health Resort, London, 1880.

J. V. Shoemaker, M. D.: Ocean Travel for Health and Disease (The Lancet, July 23, 30, 1892).

Hughes Bennett, M. D.: Life at Sea Medically Considered (Medical Times and Gazette, Vol. 1, 1884, p. 244).

Thomas B. Peacock, M. D.: Beneficial Influence of Sea Voyages in Some Forms of Disease (Medical Times and Gazette, Vol. 2, 1873, p. 687).

John L. Adams: Report of 17 cases of Surgical Tuberculosis in Children (Boston Medical and Surgical Journal, 1906, Vol. 154, p. 17).

A. Crosbee Dixey, M. R. C. P.: Edinb. Lancet, Vol. 2, 1888, p. 264.

Boardman Reed: Effects of Sea Air Upon Diseases of the Respiratory Organs (Trans. Amer. Climat. Ass., Vol. 1, 1884, p. 51).

D'Espine, of Geneva. International Congress on Tuberculosis, Paris, October, 1905.

Armaingaud, of Bordeaux: International Congress on Tuberculosis, Paris, 1905.

Guy Hinsdale, M. D.: Treatment of Surgical Tuberculosis at the French Marine Hospitals and Alpine Sanatoria (Interstate Medical Journal, St. Louis, March, 1914).

Trans. Congrés de L'Association Internationale de Thalassotherapie. Cannes, April, 1914.

See also Willy Meyer: Open-Air and Hyperdermic Treatment as Powerful Aids in the Management of Complicated Surgical Tuberculosis in Adults (Trans. Sixth International Congress on Tuberculosis, Washington, 1908, Vol. 2, twenty illustrations).

See also "Open Air Treatment of Tuberculosis," by the late Dr. DeForest Willard, *ibid.*, page 257. Also Trans. Amer. Orthopedic Ass., 1808. Shacks, bungalows, sleeping tents, sanatoria and day camps are discussed.

the ocean. This new addition to New York's equipment has one thousand beds and is called the "Sea View Hospital."

At the Second Annual Meeting of the National Association for the Study and Prevention of Tuberculosis held in Washington in 1906, the following resolution was offered by Dr. John W. Brannan and unanimously adopted:

> WHEREAS, Recent experience in Europe and in this country has shown that out-door life in pure air has the same curative effect in surgical tuberculosis as in tuberculosis of the lungs, therefore, be it
>
> *Resolved,* That in the opinion of members of this Association hospitals and sanatoria should be established outside of cities either in the country or on the seashore for the treatment from its incipiency, of tuberculosis of bones, joints, and glands in children.

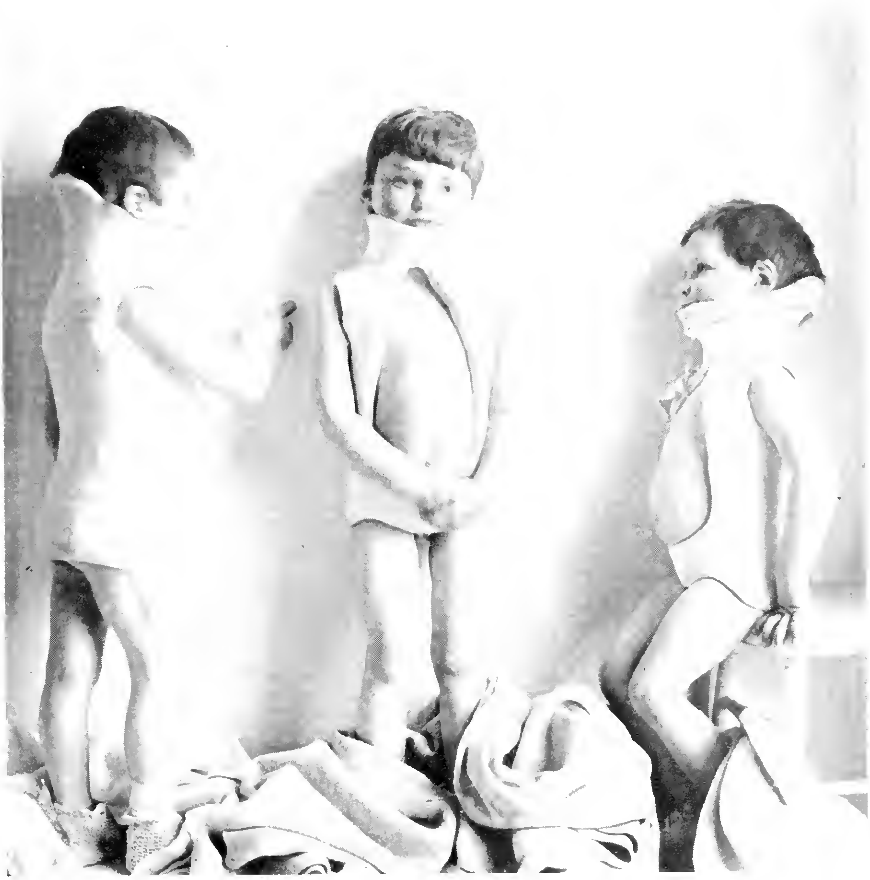
SEACOAST AND FOGS

Marine climates naturally include the strictly ocean climate and that of the seacoast. In the former sea air comes from every point of the compass. It is always moist and it is the most equable air that blows; it is of infinite variety from the dead calm of the doldrums to the fierce gales of the North Atlantic.

The atmosphere of the seacoast is naturally modified at times by continental influences. Indeed the characteristic "sea breeze" which springs up in the morning and subsides toward sun-down is brought about by the ascent of heated air back of the coast. The hotter the interior and the more rapidly this air ascends the stronger is the sea breeze which rushes shoreward from the ocean and penetrates for fifty or a hundred miles the adjoining country.

But under other conditions land breezes occur and bring to the shore the Continental atmosphere of a totally different type. These atmospheric conflicts between sea and land involve most interesting meteorological problems; they tend to lessen the equability of the purely marine or oceanic climate. Freezing weather is the product of the Continent and the descent of cold waves from the interior; it brings to our northern seacoast frost and snow for a time, and never trespassing far upon the high seas. The seacoast has thus a mixture of two climates, but the sea air predominates and is never absent very long.

There are well-known places in America and in the British Islands where the sea breeze greatly predominates; Nova Scotia, Cape Cod, and Cape May in the United States; Land's End and the Cornish Coast in England are cases in point. In such exposed situations the air is generally poorly adapted to the tuberculous patient. The air



SEA BREEZE HOSPITAL, SEA GATE, NEW YORK. TREATMENT OF POTT'S DISEASE OF THE SPINE WITH PLASTER JACKETS AND HELIOTHERAPY

Courtesy of Dr. J. W. Brannan

FIG. 1. HELIOTHERAPY FOR SURGICAL TUBERCULOSIS. DR. ROLLIER'S SANATORIUM, LEYSIN, SWITZERLAND. DORSAL EXPOSURE

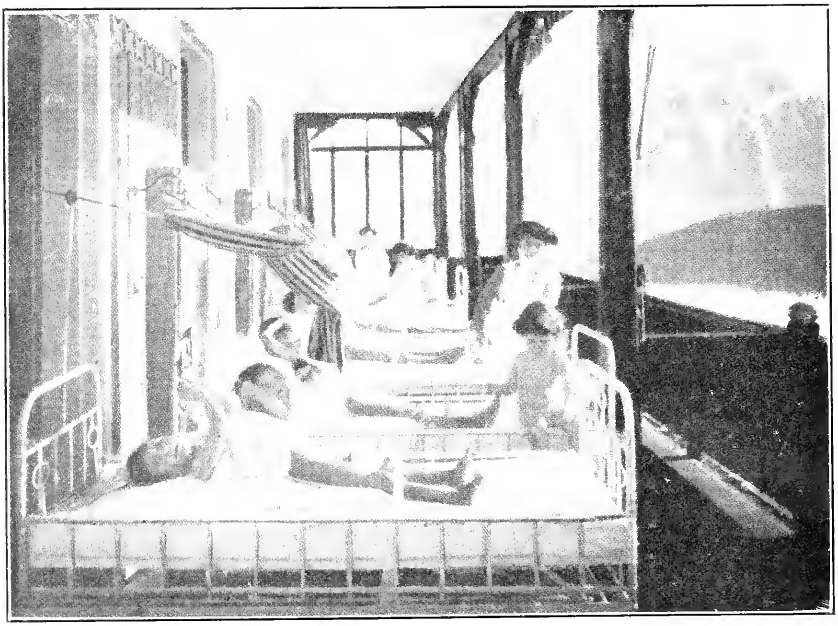


FIG. 2. HELIOTHERAPY FOR SURGICAL TUBERCULOSIS. DR. ROLLIER'S SANATORIUM.
From the author's article in Interstate Medical Journal, March, 1914

is said to be "too strong" and certainly for an all-the-year-round residence the capes and headlands are too much at the mercy of high winds which render out-door life disagreeable. About Cape Cod, Nantucket, and Martha's Vineyard there is a peculiar liability to fog which is as unwelcome to the consumptive as it is to the mariner.

The author has had experience with the fogs in these waters and considers it one of the great drawbacks to an otherwise agreeable climate. The summer and early autumn fogs of the eastern Maine coast and of the Bay of Fundy and Nova Scotia are worse in their chilly and penetrating qualities. The towns of Massachusetts on or near the seacoast seem to have somewhat more tuberculosis than those of the interior.

DEATHS FROM PULMONARY TUBERCULOSIS IN MASSACHUSETTS PER 100,000 POPULATION

Five Maritime Towns	1905	1908-1912	*Five Inland Towns*	1905	1908-1912
Boston	224	155	Pittsfield	168	98
Salem	154	111	Springfield	125	89
New Bedford	164	124	Chicopee	125	109
Newburyport	181	131	Holyoke	154	131
Plymouth	162	90	North Adams	81	98
Average	177	122	Average	131	105

Mr. Hiram F. Mills, of the Massachusetts State Board of Health, has lately published a most painstaking analysis of the mortality from tuberculosis in all the towns and cities of that state.[1]

He shows that there are sixty cities and towns bordering on the sea having a total population of about one-third of the entire state, or 1,293,625, in which the average death-rate per 100,000 for the five years, 1908-1912, was 135. During this period the rate for the entire state was 131. Omitting Boston, which has peculiar conditions, from both calculations the rate was 111 for the remaining 59 maritime towns and cities against 124 for the remainder of the State. This throws the balance in favor of the seaboard. It should be noted that all the small and sparsely settled towns have low rates in almost regular gradation when compared with more and more populated districts.

Boston has had a noteworthy decrease in its tuberculosis death rate as shown by the following figures representing the rate for the last five years, namely, 271, 283, 254, 176, 182, or a decrease of one-third in five years. There are sixteen small towns having an aggre-

---

[1] Address to the State Inspectors of Massachusetts, November 3, 1913.

gate population of 5,540, in which there have been no deaths in all of the five years.

The map shows several inland towns with a large death rate owing to the presence of tuberculosis hospitals, asylums, and other institutions. These are marked with an H (not readily seen in the reduced map) and include Rutland, Sharon, Lakeville, Bridgewater, North Reading, Medfield, Westborough, Westfield, Taunton, Danvers, and Monson.

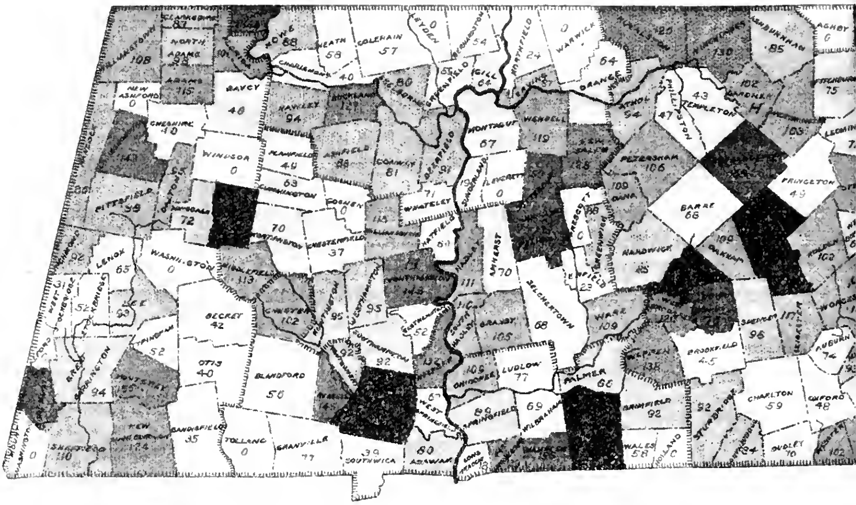
As Mr. Mills says:

> Forty years ago the death rate from consumption in Massachusetts was three times as great as it is now; thirteen years ago it had been reduced one-half in the previous forty years; to-day it has been reduced one-half in the past twenty years. There is no other State in the Union, in which records have been kept, where the reduction has been so much. From 1885 to 1909 it was more than twice as great as in England, Scotland, Ireland, The Netherlands, Belgium, Switzerland and Italy. The reduction is Prussia was 90 per cent of that in Massachusetts and that in Austria only 57 per cent. The registration system in Massachusetts is of the highest grade and in no other State or country of the world has such effective work been done and so much accomplished in reducing the death rate from tuberculosis as in that Commonwealth.

FOGS ON THE PACIFIC COAST

It is this element of fog which renders so much of the Pacific coast of the United States unsuitable for tuberculous patients. The morning fogs are conspicuous features of the climate and are acknowledged sources of danger to tuberculous cases. They penetrate as far as Los Angeles and Pasadena in the south, some eighteen miles from the coast; they are common in San Francisco, and are carried by ocean atmospheric currents through the Golden Gate, sweeping the bay and up the Sacramento and San Joaquin valleys.

There are portions of the California coast, as for example in the neighborhood of Santa Barbara, where the mountains are near the shore; and beyond the mountains are deserts and necessarily an exceedingly dry atmosphere. The night air from the mountains brings with it a dry Continental quality; the morning breezes bring a more humid air and possibly fog. In such localities fog is quickly scattered by the sun's heat and never penetrates very far inland. A suitable residence for tuberculous patients on the Pacific coast, as every native knows, is not found on the shore line but at some elevation above the sea fairly well up on the hillsides or in well-situated valleys, like the Montecito Valley, where the dryer air of the interior



STATE BOARD OF HEALTH

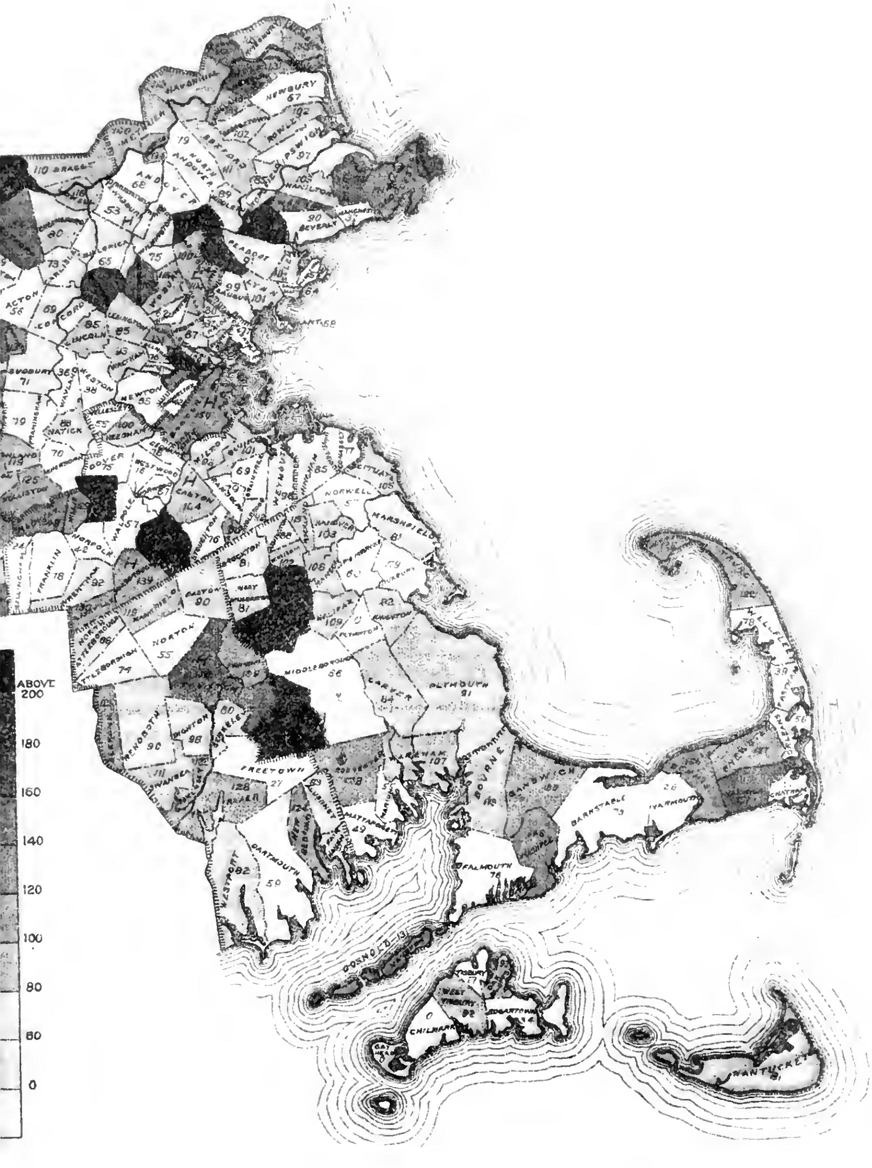
MAP OF THE

STATE OF MASSACHUSETTS.

DEATHS FROM CONSUMPTION

SCALE OF MILES

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50


ABOVE 200
180
160
140
120
100
80
60
0
NEWBURY
67
ROWLEY
IPSWICH
97
HAMILTON
BEVERLY
90
ANDOVER
68
NORTH ANDOVER
ACTON
56
CONCORD
69
LINCOLN
85
SUDBURY
71
WESTON
98
NEWTON
85
NATICK
NEEDHAM
100
DOVER
75
WESTWOOD
WALPOLE
57
NORFOLK
48
FRANKLIN
78
CANTON
164
EASTON
90
NORTON
55
BROCKTON
NORWELL
57
MARSHFIELD
SCITUATE
105
HALIFAX
109
PLYMPTON
KINGSTON
DUXBURY
MIDDLEBORO
66
CARVER
84
PLYMOUTH
91
FREETOWN
27
REHOBOTH
90
DIGHTON
98
SWANSEA
111
WAREHAM
107
DARTMOUTH
59
WESTPORT
82
BOURNE
FALMOUTH
76
SANDWICH
168
MASHPEE
BARNSTABLE
YARMOUTH
28
CHATHAM
WELLFLEET
78
GOSNOLD
13
TISBURY
WEST TISBURY
EDGARTOWN
CHILMARK
0
GAY HEAD
NANTUCKET
81

checks the advent of fog and where the early morning hours are as bright and dry as the afternoons.[1]

RADIATION FOGS

Fogs are born of the sea and of the land. The sea fog is obviously purer and less injurious than the smoke-laden fog of cities. There are fogs and fogs; "dry" fogs and "wet" fogs; the fogs of the coast and the fogs of mountain valleys and river courses; but rarely of the plains. Radiation fogs are different from sea fogs; in dry weather, on a cold still night when the lowest stratum of air is rapidly cooled by contact with the cold radiating earth, the watery vapor is precipitated as minute globules. The colder the ground or the deeper and colder the water on which fog rests, the more persistent is the fog; but as the sun warms the watery particles and overcomes the heat lost by radiation, the fog lifts and floats upward. It is bound to lift as its specific gravity diminishes. Slopes of hills, especially their southern sides, some hundreds of feet above the lowland or seashore, are thus comparatively free from these fogs and are much drier and warmer than lower places in the neighborhood. Such locations are far preferable to those of lower altitude. (Russell.)

FOGS IN THE MOUNTAINS

And here we see how local geographic conditions modify the whole aspect of the question. On the North Atlantic Coast of the United States there are no mountain ranges; one cannot get away from the fogs if he would; while on the Pacific Coast, the mountains and their foot hills are comparatively near and one can be in full view of the seashore and yet be above the fog line.

At Santa Barbara, one of the favorite California resorts for tuberculous patients, fogs occur frequently from May until October, but are comparatively rare at other times. Dr. William H. Flint, who practiced there for thirteen years, says that the fogs creep in from the sea in the late afternoon, in the evening, or in the early morning, disappearing at an uncertain hour the following forenoon. Occasionally fogs will persist all day and for a number of days consecutively. In May and June, 1903, a foggy period continued for seventeen days.[2]

---

[1] See A. G. McAdie: The Sun as a Fog Producer, Monthly Weather Review, Washington, 1913 (778-779).

[2] Trans. Amer. Climat. Ass., 1904, p. 20.

The late Dr. C. H. Alden, Asst. Surgeon General, U. S. A., who passed his later years, and died of tuberculosis, in Pasadena, California, says:

> The climate of Southern California is not a dry one, as some suppose. As this region lies along the coast, and its most frequented portions are nowhere very distant from the water, the climate cannot be dry. The humidity lessens as one goes inland, but is always considerable, except in the uninhabited desert. The fogs which, in the absence of much rain, are a large factor in sustaining vegetation, penetrate many miles from the sea and add to the humidity. *The fact that the humidity is not favorable for pulmonary tuberculosis which is at all advanced is evidently not appreciated as it should be.* [Italics, author's.]

Even as far as Redlands, over fifty miles from the coast, according to General Alden, who lived there for two winters, " fogs come up from the sea during the spring, but they are shorn of most of their moisture." Nevertheless, Redlands, from its comparative dryness, is a favorite place in winter for patients with pulmonary tuberculosis and they no doubt do better there than at Los Angeles, Pasadena, or at resorts directly on the coast. General Alden's conclusion is that while the mild temperatures and continuous sunshine of this region are favorable for the aged and the feeble from many causes, needing an out-door life, the warmth and moisture are unfavorable for cases of pulmonary tuberculosis that are at all advanced.

In June, 1902, the author traveled through the mountains and visited the principal resorts throughout California. The sea air with its frequent accompaniment of fog seemed to him too strong or fresh for tuberculous patients. North of Santa Barbara or Monterey the sea air is certainly cold and harsh during most of the year and, wherever it penetrates, tuberculous patients feel worse. This is particularly true of the neighborhood of San Francisco. From the summit of Mt. Tamalpais, elevation 2,375 feet, on almost any summer afternoon fog can be seen driving in from the Pacific and spreading over San Francisco Bay. As the sun descends the temperature of the air drops, so that saturation is reached. Fog results. Now on the southern California coast the cold, ocean atmospheric currents contain much less actual moisture than the warm, clear air on shore and the resultant mixture will now contain less water than the warm air did before and hence it is claimed with reason that notwithstanding the dripping roofs and wet pavements, there is less absolute moisture in the air than before the fog appeared.

We did not find the California fog either so cold or chilling as we have observed it on the extreme eastern coast of Maine; nor is it so

FOG WAVES. FROM THE SUMMIT OF MOUNT TAMALPAIS, OVERLOOKING SAN FRANCISCO BAY
Photograph by Prof. A. G. McAdie. Courtesy of the Chief of the United States Weather Bureau

"Banked in a serried drift beside the sea,
Rolling, wind harried in a snowy spray,
Majestic and mysterious, swirling free
The ghostly flood is massing cold and gray."

MORNING FOG OVER VALLEYS
Photograph by Prof. A. G. McAdie. Courtesy of the Chief of the United States Weather Bureau

depressing and relaxing as the heavy misty weather observed in central and western Virginia mountain valleys during the rains of early summer and autumn, certainly not so depressing as the relaxing moisture of the tropics. The California fogs have been likened to the Scotch mist. They never deter the fishermen from curing their fish on their racks along the seashore. Raisins and other fruit are dried in the open fields and residents claim that during the rainiest weather nothing molds or rots. (P. C. Remondino.)

Mr. Ford A. Carpenter, of the U. S. Weather Bureau, has published an interesting book, in which he gives a lucid description of the fogs of the Pacific Coast.[1] He shows that on that coast the maximum fog is reached in San Francisco, with moderately high averages north to the Canadian boundary and decreasing in frequency and duration with the latitude, San Diego having the least on the coast. He says that daylight fogs are practically unknown in San Diego. A "day with fog" is one on which there is one hour or more of fog dense enough to obscure objects one thousand feet distant. At San Diego the hours of greatest frequency were between eleven at night and six in the morning. Mr. Carpenter notes the beneficial effect of California fogs and says that it is impossible to measure accurately the amount of moisture conveyed by fog. There is no doubt that over a region covered by vegetation exposing a natural condensing surface, such as eucalyptus, palm, iceplant, etc., not less than a ton of water to the acre is thus distributed during the prevalence of every dense fog. It also checks evaporation.

"It is not fog in the generally accepted meaning, for this 'light veil' is neither cold nor excessively moisture-laden. Neither is it high, for its altitude is less than a thousand feet. To one who has spent a few weeks of spring, summer or fall in southern California, the picturesque description of the musical Spanish *el velo* is quickly recognized as both expressive and truthful." *"El velo de la luz"*: "the veil that hides the light." *"Velo qui cubre la luz del so"*: "The veil which shades (covers) the light of the Sun." *"El velo de la mañana"*: *"The veil of the morning."*

There is probably no place on the entire coast line of the United States that offers so many climatic advantages for tuberculous patient as San Diego and its attractive neighbor, Coronado.

It is a mistake to believe that because there is fog, the humidity is necessarily high during its presence. The United States Weather

---

[1] The climate and weather of San Diego, California. San Diego, 1913. See Review in Journ. Royal Meteorological Society, Jan., 1914.

Bureau has taken pains to determine the relative humidity during fogs observed during ten years at Chicago on Lake Michigan. Observations were made on 118 foggy days by Dr. Frankenfield, whose results are given as follows:

Relative humidity 90 per cent (or more) in 75 per cent of days.
Relative humidity 80 to 90 per cent in 13 per cent of days.
Relative humidity below 80 per cent in 12 per cent of days.

The observer noted dense fog on one occasion when the relative humidity was as low as 52 per cent; on another, when it was 58 per cent.

The Pacific coast, as a whole, is much foggier than the Atlantic coast, because the winds on the Atlantic are mostly off-shore and consequently carry less moisture than the westerly on-shore winds of the Pacific.

In the interior of the United States, especially the western half, the average number of foggy days per year is less than ten each year; in the Lake region the number rises to fifteen or twenty per annum. In isolated localities, local conditions increase this number greatly.

At Colorado Springs genuine fogs occur, sometimes very dense and lasting all day, but they are uncommon and scarcely worth mentioning were not their existence so often denied. (Ely.)

In the Adirondack Mountains fogs and mists are not uncommon along the rivers and on the lake shores in the early morning in the summer and autumn. They are examples of the radiation fogs already referred to and, like dew and frost, they are associated with clear weather. The presence of a light fog over an Adirondack lake in the early morning foretells a bright, sunny, warm day.

Fogs are not at all unusual in the Alleghany and Blue Ridge Mountains. They follow river courses and settle in low valleys. The humidity attendant on the melting of snow or during the rains of early summer or autumn is not so readily exchanged for dryer air in the long narrow valleys as at the seaboard. In many localities the high ridges on either side shut out the direct rays of sunlight for several hours; while at the seaboard there are no such natural barriers.

At some of the higher elevations in the Blue Ridge Mountains of Pennsylvania, fog is noted during the summer and autumn. One observer, himself a tuberculous patient, recorded at Mount Pocono, in Monroe County, Pa., elevation 2,000 feet, fifteen days with fog part of the day, usually early morning, and seven with fog all day,

FOG LIFTING, SAN FRANCISCO BAY

Photograph by Prof. A. G. McAdie. Courtesy of the Chief of the United States Weather Bureau

SEA OF FOG FROM SUMMIT OF MOUNT WILSON, CALIFORNIA
From Photograph by Ferdinand Ellerman

FIG. 1. RUTLAND, MASSACHUSETTS STATE HOSPITAL FOR CONSUMPTIVES

DAY CAMP FOR TUBERCULOUS PATIENTS, HOLYOKE, MASS.

UNDERCLIFF, A CAMP ON LAKE PLACID, ADIRONDACKS, NEW YORK
Courtesy of Dr. C. D. Alton

between June 1 and December 1. But this patient adds the significant remark: "However, it seems ridiculous for me to find fault with Mount Pocono when I did so well there. My cough and expectoration decreased considerably; I gained five pounds and grew somewhat stronger."[1]

At Rutland, Massachusetts, the site of the Massachusetts State Sanatorium, there were 24 days with fog for the year ending November 30, 1907. Nevertheless, out of 4,334 cases of pulmonary tuberculosis treated since its opening, 43.39 per cent of cases were arrested or apparently cured, and in addition, 47.38 per cent were improved.[2]

From what has been said, it is, therefore, not surprising that claims are made that there is a noticeable difference in the character of fogs on the New England Coast.[3] Dr. Bowditch has described the fogs on the Maine Coast as sometimes "dry fogs." "The light vapory mist which drives in frequently from the sea has no definite sense of moisture as it strikes the face, and in the midst of it the air frequently feels dry. In the vicinity of Mount Desert, the presence of the mountains has, doubtless, an effect upon the quality of the atmosphere, and would partly account for what is often spoken of—the effect of sea and mountain air combined. Its peculiar dryness, even though on the coast, has been often so marked that I have frequently thought that certain phthisical patients, who need a dry bracing atmosphere, might improve there, although I have never quite dared to recommend it for such cases."

SEA AIR FOR SURGICAL TUBERCULOSIS

Halsted, of Baltimore, however, has recorded a favorable result in a case of tuberculous glands of the neck, treated simply by an outdoor life on the Maine coast. The patient was a young lady of seventeen, whose cervical glands were actively inflamed and softened, the overlying skin having rapidly reddened and thinned during a treatment of six hours a day out of doors at a seashore further south. No operation was done, but she was sent to the Maine coast and lived *out-of-doors day and night* for four months. At the end of this period no one could tell, from the appearances, which side had been affected, and Halsted remarked that, to surgeons whose daily bread not long ago was tuberculous glands of the neck, such a

---

[1] Journal of the Outdoor Life, February, 1908, p. 15.

[2] Eleventh Annual Report, 1907.

[3] Vincent Y. Bowditch, Trans. Amer. Climat. Ass., 1897, p. 25.

resolution foretells a revolution in treatment.[1] That revolution is, fortunately, to-day *un fait accompli.*

Some of the European sanatoria of the best grade are in situations not altogether free from fogs and mists. This is true of Falkenstein, elevation 1,378 feet (420 m.), whose atmosphere is a little misty and foggy.

AIR OF INLAND SEAS AND LAKES

The region of the Great Lakes lying between the United States and Canada has been studiously avoided in selecting a site for any of the large sanatoria for tuberculosis. It is a matter of common observation that nasal, pharyngeal, and bronchial catarrhs are exceedingly common in adjacent districts. The lake winds are damp and are partly frozen during several months in the year, giving to the surrounding country a harsh climate.

The lower lake region is also the favorite track of storms or cyclonic atmospheric movements which sweep the lakes and the St. Lawrence valley on their way to the seaboard. As these areas of low atmospheric pressure advance they are attended by increasing cloudiness in front and are usually followed by colder air from the Northwest, the fall in temperature being sufficient at times to constitute a cold wave.[2]

The winter storms on the Great Lakes are quite as violent as any on the seacoast, and on Lake Superior and Lake Huron floating ice may be seen in May and sometimes, in Lake Superior, as late as June. Lakes Michigan, Erie and Ontario are more southerly, but their shores are low and the skies are notably cloudy. The author has experience of the cold fogs of Lake Superior in July and August, and was impressed with their penetrating quality. A summer spent on both the northern and southern shores of Lake Superior was wonderfully exhilarating; the air has a purity and stimulus such as one might expect from millions of miles of forest roundabout. But not a single place on that vast shore can be recommended as a residence for a tuberculous patient. The vicissitudes of the weather are such that the approved methods of cure could not well be carried out.

---

[1] Trans. Nat'l Ass. for the Study and Prevention of Tuberculosis, 1906.

[2] To constitute a cold wave, so called, there must be a fall of twenty degrees or more in twenty-four hours, free of diurnal range and extending over an area of at least 50,000 square miles, the temperature somewhere in the area going as low as 36° F.

WALLUM LAKE RHODE ISLAND. PATIENTS OF THE STATE SANATORIUM FOR TUBERCULOSIS
Courtesy of Dr. Harry Lee Barnes

In the location of the state sanatorium for tuberculous patients in Minnesota, an interior and northerly location was wisely chosen, 150 miles south of Lake Superior, at Lake Pokegama, near the headwaters of the Mississippi.

The Wisconsin State Sanatorium has been located on Lake Nebagamon, thirty miles from Lake Superior.

Such small lakes as Lake Pokegama in Minnesota; the Muskoka Lakes in Ontario, where the Canadian National Sanitarium Association has established two sanatoria for consumptives; and the Saranac Lakes in the Adirondack Mountains, have no such power to modify the qualities of the atmosphere. Whatever influences are attributable to these smaller bodies of water are small, compared with that of the forest and mountains. Undoubtedly a small lake is a desirable feature in connection with a sanatorium, as it provides sources of amusement throughout the year and adds greatly to the beauty of the landscape. The writer spent six summers at Lake Placid in the Adirondack Mountains at an elevation of 1,860 feet. This is somewhat more protected than the Saranac Lakes, St. Regis Lake or Long Lake, and, in his opinion, is quite as well suited as a residence for tuberculous patients as any other locality in the Adirondacks. The State of New York has built its large State Sanatorium at Ray Brook only four miles distant from Lake Placid. The State of Rhode Island has chosen Wallum Lake for its new Sanatorium, views of which are here given.[1]

CHAPTER IV. INFLUENCE OF COMPRESSED AND RAREFIED AIR; HIGH AND LOW ATMOSPHERIC PRESSURE; ALTITUDE

No phase of the tuberculosis question has been so vigorously debated as the influence of altitude; no feature of the subject is so far from satisfactory solution. The battles between the Highlanders and the Lowlanders of Scotland seem to have been revived in the attempts to settle this question. Instead of the claymore and battle-axe, we have an array of statistics in serried columns marshalled by the leaders of the opposing forces. This history of the conflict would make as large a record as the Medical and Surgical History of the War of the Rebellion. And the end is not yet in sight.

After trying for years to cure consumption by means of an "equable climate" obtained at home by housing the patient behind double

---

[1] The large German Sanatorium Grabosee is located on the shores of Lake Grabow.

windows, or by sending him to the islands of the sea, such as Madeira and the West Indies, the medical profession began to be impressed with the good results reported from the Rocky Mountains and the plains of the Western states and territories.

In the rush to the California gold fields in 1849 and in the rapid emigration from Eastern states to Colorado, Utah, California, overland in the " prairie schooner " and on horseback during subsequent years, the Western country became known for wonderful health-giving qualities. It was not long before Colorado became widely heralded as a health resort for consumptives. English physicians sent their patients to Colorado instead of sending them to Australia, Algiers, or to the Riviera and the results obtained were remarkable. The late Dr. S. E. Solly, who practiced in Colorado for thirty-three years, was sent from London on account of the higher altitude and better air of Colorado, and was one of a large number of English residents who have made their home in that state on account of pulmonary tuberculosis.

In 1876, the late Dr. Charles Theodore Williams, of London, published his report to the International Medical Congress and in 1894 issued his work on Aero-Therapeutics, in which are detailed the histories of 202 consumptives who were sent to Colorado at an altitude of 5,000 or 6,000 feet. They represented a residence of 350 years at this elevation and the results were exceedingly satisfactory.

Jourdanet, a French physician practicing in Mexico, published two works, one in 1861 and one in 1875, which undertook to explain the influence of barometric pressure and, incidentally, why, on the plain of Anahuac, 6,000 feet in elevation, there is an entire absence of pulmonary phthisis.[1]

Jourdanet aided the great French physiologist, Paul Bert, in establishing costly apparatus for investigating the physiological action of compressed and rarefied air and Paul Bert's classic work is an accepted authority on this subject. Later studies by Mosso and Marcet[2] should be noted, but it is impossible here to give more than passing notice. They show that a diminution of the barometric pressure increases the respiration rate and the volume of air respired, but if allowances are made for the increase of volume of the air at the lower pressure, the actual volume respired is less. Conversely,

---

[1] D. Jourdanet: Influence de la Pression de l'Air, Paris, 1875. Herrera and Lope: La Vie Sur Hauts Plateaux, Hodgkins Prize Memoir, 1898.

[2] An American Text-Book of Physiology, Phila., 1901, Vol. 1, p. 434. Angello Mosso: Man in the High Alps (Der Mensch auf den Hochalpen, Leipsig, 1899), Translation by E. L. Kiesow, 1898.

an increase of pressure lowers the rate and the volume of air respired. The effects of the respiration of rarefied air and compressed air on the circulation and on the composition of the blood are very marked and are of a complex character owing to the additional influences of the abnormal pressure on the peripheral circulation. Not only is the circulation affected but, in the case of residence at high altitudes, the proportion of red blood corpuscles and of hemoglobin is notably increased. This increase in the red blood count at the higher altitudes, while not so great or so permanent as was at first supposed, is an established clinical fact and adds undoubted strength to the claim that altitude *per se* is a characteristic of the favorable climate for tuberculous patients.

DIMINISHED ATMOSPHERIC PRESSURE

The influence of diminished atmospheric pressure on the blood has been studied by Paul Bert in 1882,[1] Zuntz,[2] P. Regnard,[3] Viault,[4] Egger,[5] Woolff,[6] Koeppe,[7] Solly,[8] by W. A. Campbell and Gardiner and Hoagland,[9] by L. S. Peters[10] and by F. Laquer.[11] One of the

---

[1] Paul Bert, *loc. cit.*, studied the blood of animals at La Paz, in Mexico, at an altitude of 12,140 feet (3,700 meters) and found that they had an oxygen-carrying capacity far in excess of that exhibited by the animals on the lower plains.

[2] Zuntz: Experiments on the Pic du Midi, Elevation 9,000 feet. He emphasized the possibility of an altered distribution of corpuscles.

[3] Regnard, P.: La Cure d'Altitude, 2eime Ed. Paris, 1898.

[4] Viault: Experiments at Merococha, Peru, elevation 14,275 feet. 1890. He noted that his blood contained 7 to 8 million red corpuscles per cubic millimeter.

[5] Egger: The Blood Changes in High Mountains. Verhandlungen d. xii, Congr. Inner. Med., 1893.

[6] Woolff: Verhandlungen d. xii. Congr. Inner Med. 1893, pp. 262-276.

[7] Koeppe, xii. Congress für Inner. Med., 1893; Arch. Anat. Physiol., 1895, pp. 154-184.

[8] S. E. Solly: Blood Changes Induced by Altitude. Trans. American Climatological Association, 1899, p. 144; also 1900, p. 204.

S. E. Solly, Therapeutic Gazette, February, 1896.

[9] Campbell and Hoagland: Trans. American Climatological Association, 1901, p. 107.

[10] For the effect of altitude, 6,000 feet, on blood pressure in tuberculous patients, see article by L. S. Peters, Silver City, New Mexico, in Archives of Internal Medicine, August, 1908 and October, 1913. The latter report covers 600 cases and shows that altitude tends to raise blood pressure rather than lower it both in consumptives and in normal persons living at high altitudes.

[11] F. Laquer: Höhenclima und Blutneubildung, Deutsches Archiv für klin. Med. Leipzig, 1913, cx, Nos. 3 and 4, p. 189.

most thorough original studies is by Drs. Ossian, Schaumann and Emil Rosenquist, of Helsingfors, Finland.[1] Turban, also, has made a study of this subject.[2]

Much of the earlier work has been proved incorrect as instrumental and laboratory technic has been improved. Hematologic work has made rapid strides and several important correcting factors have been introduced. Attention has been called to the more rapid evaporation of blood samples at high altitudes where the climate is always dry and errors from this source are considerable.

Not only that, but the human organism itself loses water more readily than at lower levels and so do animals used for experimental purposes. How much value should be given to these corrections we do not know, but there is evidently a revision downwards noticeable in nearly all the later studies of the blood count at high altitudes. Prof. Bürker, of Tübingen, and his colleagues show at best only a comparatively small increase amounting to only four to eleven and a half per cent at an altitude of six thousand feet.[3]

These observers made comparative observations at Tübingen (altitude 1,030 feet or 314 meters), and at the Sanatorium Schatzalp (altitude 6,150 feet or 1,874 meters, about 300 meters above Davos).

Bürker's findings, which appear to result from an exceptionally careful personal investigation with every precaution to avoid experimental error, show that altitude does exert an unquestionable influence on the blood in the direction of an increase in both the number of erythrocytes and the content of hemoglobin. The increase is an absolute one, not merely relative. The red cells increased from 4 to 11.5 per cent, the hemoglobin from 7 to 10 per cent. These figures, it will be noted, are smaller than those usually given for the effect of moderate altitudes, yet they represent substantial and undeniable gains quite in harmony with other previous observations.

The responses of the different persons in Bürker's Alpine expedition varied in degree; but the qualitative examination of the blood established the fact that no hemoglobin derivative other than oxyhemoglobin was concerned in

---

[1] Ossian, Schaumann and Rosenquist: Ueber die Natur d. Blutveranderungen in Hohen Klima, Zeitschr. f. klin. Med., 1898, Band xxxv, Heft 1-4, pp. 126-170 and 315-349.

[2] Turban, Münch. Med. Wochenschr., 1899. p. 792.

[3] See Editorial Altitude and the Blood Corpuscles, Journ. Amer. Med. Ass., February 3, 1912, p. 344; September 21, 1912 and November 1, 1913.

Bürker, K.; Jooss, E.; Moll, E., and Neumann, E.: Die physiologischen Wirkungen des Höhenklimas: II. Die Wirkung auf das Blut, geprüft durch tägliche Erythrozytenzählungen und tägliche qualitative und quantitative Hämoglobinbestimmlungen im Blute von vier Versuchspersonen während eines Monats, Ztschr. f. Biol., 1913, Vol. 61, 379.

the increment at altitudes. In agreement with most observers the adjustment of the blood to the new atmospheric conditions in ascending to higher levels occurs promptly; there is a rapid increase in the factors involved at the start followed by a more gradual continuation of the effect; but on returning toward the sea-level the blood does not resume its "low altitude" composition so promptly. There may be a prolonged delay in the adjustment and return to normal figures.[1]

Cohnheim[2] regards evaporation as the cause of the concentration of blood under these conditions and that this is not due to a lack of oxygen. These studies in hematology have an important bearing on the course of tuberculosis at high altitudes, and constitute a very live question at the present day.

Professor Cohnheim and Dr. Weber[3] have recently reported the results of examination of the blood of twenty-three persons who have been engaged for long periods in the operations of the railway ascending the Jungfrau peak in the Alps. Most of them spent considerable portions of their time at altitudes from 2,300 meters (7,546 feet, Eigergletscher Station) upward to 3,450 meters (11,319 feet, Jungfraujoch Station). The importance of these observations lies in the fact that they furnish data regarding persons who have had prolonged experience in the higher altitudes so that the incidents of temporary residence and change of scene may be regarded as equalized or eliminated. They supplement the earlier records from the South American plateaus by results obtained with approved and up-to-date procedures. The new statistics agree in exhibiting values both for red blood-corpuscles and hemoglobin distinctly higher than the "normals" of sea level. Cohnheim maintains that the high figures thus obtained on a large scale from subjects accustomed to live at high atmospheric levels leave no alternative except to assume a new formation of corpuscles under such conditions. Where contrary conclusions have been reached—and there are many such—it is not unlikely that the period of residence was too brief to permit the stimulating effects of altitude to manifest themselves in any conspicuous way.

The renewed assumption of an increased functioning of the hemopoietic organs at high altitudes has further been supported by observations conducted on Monte Rosa in the Alps relating to the regeneration of blood after severe anemias. In the international laboratory built on the Col d'Olen at an altitude of 2,900 meters (9,515 feet) and dedicated to the memory of Angelo Mosso, Laquer[3] has found that dogs deprived by hemorrhage of half their blood-supply regenerate it in about sixteen days. Under precisely comparable experimental conditions twenty-seven days are required at lower levels for the restoration of the same blood loss. Laquer believes that the lower partial pressure of the oxygen is the effective stimulating factor in this more pro-

---

[1] Editorial in Journ. Amer. Med. Ass., Nov. 1, 1913, *q. v.*

[2] For a recent review of this subject see Cohnheim, O.: Physiologie des Alpinismus, II. Ergebn. d. Physiol., 1912, xii, 628; also Anglo-American Expedition to Pike's Peak, Journal Amer. Med. Ass., Aug. 10, 1912, p. 449.

[3] Cohnheim, O., and Weber: Die Blutbildung im Hochgebirge, Deutsch. Arch. f. klin. Med., 1913, cx, 225.

nounced regeneration so strikingly shown at great heights. How long this latest explanation will withstand the attacks of the increasing number of Alpine physiologists remains to be seen.[1]

The latest observations show that arterial blood contains considerably more oxygen at high altitudes than at sea level. The pulmonary alveoli have a special power of extracting or secreting oxygen and this power is increased in high altitudes, this increase not disappearing until a considerable time after descent to sea level.

W. R. Huggard, of London, an unbiassed and judicial observer, says: "The diminished frequency of tuberculosis with altitude may, I think, be taken as established."[2] Hirsch[3] held the same opinion and based his statement on statistics from various places.

Thirteen years ago, Dr. Solly endeavored to show this statistically and arranged three tables which we append.

TABLE I

Comparative Results in Sanatoria in High and Low Climates

COMBINED FIRST AND SECOND-STAGE CASES ONLY

(Taken from Dr. Walters, pp. 52 and 53)

1876–1886	Altitude	Number of Cases	Number Benefited	Per Cent
LOWLAND CLIMATES				
Goerbersdorf (Manasse)	1,840 ft.	3,615	1,294	36
Falkenstein (Dettweiler)	1,375 ft.	1,022	746	73 } 71
Reiboldsgrün (Driver)	2,300 ft.	2,000	1,400	70 }
Total		6,637	3,440	Average, 51
HIGHLAND CLIMATES				
Leysin (Bernier)	4,150 ft.	37	34	92
Davos (Turban)	5,115 ft.	302	269	89
Arosa (Jacobi)	6,000 ft.	259	212	82
Total		598	515	Average, 86

The total average of benefited in low climates was 71 per cent[1]
" " " " " high " " 86 "

[1] Without Goerbersdorf.

The Goerbersdorf reports up to 1884 are so much lower in the percent of benefited to the others—owing, perhaps, to some different method of estimating results, or, perhaps, to their being taken so many years ago, when the material was worse and the treatment perhaps not as efficient—that probably it would bring out the truth better to omit them.

---

[1] Editorial in Journ. Amer. Med. Ass., July 26, 1913.

[2] W. R. Huggard: A Handbook of Climatic Treatment, London, 1906, p. 124.

[3] Hirsch: Geographical and Historical Pathology, New Sydenham Society Translation, 1886, Vol. 3, p. 440.

TABLE II

Comparative Results in Open Resorts in Low and High Climates

ALL STAGES

(Taken from Handbook of Climatology, Solly, pp. 132 and 133)

	Number of Cases	Number Benefited	Per Cent
LOWLAND CLIMATES			
Desert Climates	154	100	65
Island Climates	568	295	52
Coast Climates	2,328	1,369	59
Inland Climates	136	77	57
Total	3,186	1,841	Average, 58
HIGHLAND CLIMATES			
Alps (Davos)	2,027	1,551	77
Colorado	571	420	73
Total	2,598	1,971	Average, 76

The total average of benefited in lowland climates was 57 per cent
“ “ “ “ “ “ highland “ “ 76 per cent

The first table, Table I, deals with the comparative results in sanatoria in high and low climates, first and second stage cases combined being alone taken, and the different variety of forms of improvement being grouped under the head of benefited. Of the lowland sanatoria the lowest elevation above sea-level was 1,840 feet, and the highest 3,300 feet. Of the highland climates the lowest elevation was 4,150 feet, and the highest, 6,000 feet. The total average percentage of benefited in low climates was 71, and in high climates 86.

Table II gives comparative results in open resorts in low and high climates. The total average of benefited in lowland climates was 57 per cent, in highland climates 76 per cent.

TABLE III

Comparative Results in High and Low Climates in Open and Closed Resorts

Sanatoriums	Per Cent Benefited	Open Resorts
LOWLAND CLIMATES		
Hygeia (A. Klebs)	69	
Goerbersdorf (Brehmer)	76	
Adirondacks (Trudeau)	77	
Average	74	Average percent of benefited, 58
HIGHLAND CLIMATES		
Davos (Turban)		
Arosa (Jacobi)		
Average	84	Average percent of benefited, 76

Table III shows the comparative results in high and low climates in open and closed resorts. The cases, however, could not be obtained in first and second stage cases alone, but only of all stages combined. In lowland climates the closed sanatoria show 74 per cent benefited, and the open resorts 58 per cent benefited. In highland climates the closed sanatoria show 84 per cent benefited and the open resorts 76 per cent, exhibiting the relative superiority of sanatorium over open resort treatment in the two classes of climates, respectively. Doubtless the sanatorium cases were on the whole in better condition upon first coming under treatment than those in the open resorts and, therefore, the superiority of sanatorium treatment over open methods is probably not as great as it appears here; but, nevertheless, even if the material were exactly the same, the sanatoria would show a greater percentage of benefited over the open resorts.

Table III also proves that climate exercises a beneficial influence over patients in closed sanatoriums as well as in open resorts. In all stages combined the percentage of benefited in sanatoria in low climates was 74 per cent, while in high climates it was 84 per cent.

In the first and second stage cases combined (see in Table I), the difference in favor of mountain sanatoria is still greater—lowland sanatoria 71 per cent; highland sanatoria 86 per cent.[1]

The following is the classification of the National Association for the Study and Prevention of Tuberculosis adopted in May, 1913. The data given in the table on page 69 are given in terms generally used up to that time.

CLASSIFICATION OF SUBSEQUENT OBSERVATIONS

Apparently Cured: All constitutional symptoms and expectoration with bacilli absent for a period of two years under ordinary conditions of life.

Arrested: All constitutional symptoms and expectoration with bacilli absent for a period of six months; the physical signs to be those of a healed lesion.

Apparently Arrested: All constitutional symptoms and expectoration with bacilli absent for a period of three months; the physical signs to be those of a healed lesion.

Quiescent: Absence of all constitutional symptoms; expectoration and bacilli may or may not be present; physical signs stationary or retrogressive; the foregoing conditions to have existed for at least two months.

Improved: Constitutional symptoms lessened or entirely absent; physical signs improved or unchanged; cough and expectoration with bacilli usually present.

Unimproved: All essential symptoms and signs unabated or increased.

Died.

---

[1] Dr. S. E. Solly, in the Philadelphia Medical Journal, December 1, 1900.

It is practically impossible to draw accurate conclusions from data furnished by different institutions, under such wide variations as to the character of the patients and varying standards as to what constitutes an apparent cure or arrested disease. A glance at the chart or table shows that good results are obtained at all elevations. The best results are claimed in incipient cases by the Pottenger (Private) Sanatorium, Monrovia, California, 1,000 feet, and New Mexico Cottage Sanatorium, Silver City, New Mexico, 6,000 feet.

Sanatoria	Elevation	Apparently Cured	Disease Arrested	Improved	Unimproved	Died	Year	Stage
	feet	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*		
Sharon, Mass.	250	56	18	33	9	......	1891-1911	All
Barlow, Los Angeles, Cal.	300	3	4	40	35	13	1907	All
		3.5	6	39.5	27.5	22	1903-7	Chiefly advanced
		16	16	42.8	9	1.7	1912	
		31.14	14.7	32.8	9.8	6.5	1913	
Wallum Lake, R. I. (State)	650	8.5	32.9	33.6	23.7	1	Previous to 1912	All
		6.7	27.4	38.3	24.9	2.5	1912	
Muskoka, Canada	700	5.54	20.8	45.41	24.56	3.67	1902-12	All
Pottenger, Monrovia, Cal. (Private)	1000	68	21	11	......	......	1909 to 1912	Incipient
		25	50	17	4	4		Second
		8	33	36	8	15		Third
Otisville, N. Y. (State)	1200	12	47.3	27.7	10.5	1.3	1913	All
Rutland, Mass. (State)	1165	26.1	35.6	29.5	9	......	1906	Early
New Jersey State (Glen Gardner)	900	12	29	42	16	1	1912	All
White Haven, Pa. (Free Hospital)	1250	......	17.1	59.9	13.7	3.3	1901-13	All
Adirondack Cott. Sanitarium, Saranac Lake, N. Y.	1750	48.3	36.3	......	15.4	......	1885-1911	Incipient
		8.8	48.2	......	43	4.2	....	Moderately and far advanced
Ray Brook, Adirondacks, N. Y. (State)	1635	34.4	31.6	17.3	14	.9	1912	All
New Mexico Cottage Sanitarium, Silver City (600 cases, Private)	6000	83	17	......	......	......	1904-13	Incipient 19%
		50	33	8	6	2	....	Moderately advanced, 19%
		13	30	25	26	4	....	Far advanced 62%
U. S. Public Health Service Sanatorium, Fort Stanton, N. M. (For Sailors)	6231	11.7	15	29.1	9.5	34.5	1899-1912	All
U. S. Army Hospital, Fort Bayard, N. M.	6400	2.02	2.87	69.25	19.59	6.25	1911	All
		4.78	11.40	52.38	23.80	7.64	1912	All

INSOLATION. DIATHERMANCY OF AIR. ALPINE RESORTS

Associated with diminished atmospheric pressure are other important and inseparable atmospheric qualities which contribute largely to the resultant influence on man's welfare in the higher altitudes. These other qualities have a special influence on pulmonary tuberculosis and should be recognized in estimating the effect on patients of this class.

We have, first, greater insolation. The part played by the earth's atmosphere in arresting the sun's rays is very important and second only to the influence of the atmosphere of the sun itself in arresting the radiation of light and heat from the sun. Slight changes in the sun's atmosphere would speedily alter the terrestrial climate. On the earth's surface at sea level the energy of light of the sun and that of the heat rays are considerably less than at the higher altitudes and recent measurements are of great interest and practical value.

Dr. Julius Hann, the great meteorologist of Vienna, has noted that on the lower plains thirty to forty per cent of the total amount of the sun's heat was absorbed by the earth's atmosphere, whereas at the summit of Mt. Blanc, at 15,730 feet (4,810 meters) elevation, nearly one-half of the absorbing mass of the air is lost and the amount of the sun's heat absorbed was not more than 6 per cent. One can readily understand that when the resistance is removed the light rays are more effective than at sea level. The late Prof. S. P. Langley showed by delicate measurements at this height that the blue end of the spectrum grows to many times its intensity at sea level.[1] This marked diathermancy of the atmosphere goes hand in hand with altitude. The increased facility with which the solar rays are transmitted through an attenuated air accounts for the tan and sunburn so readily acquired on mountain tops and this quality is, in the author's opinion, of value in the prevention and treatment of tuberculosis.

Owing to the increased diathermancy of the atmosphere at elevated stations there is a remarkable difference between the atmospheric temperature in the sun and in the shade. At the higher Alpine resorts for tuberculous patients, such as Davos (5,200 feet), St. Moritz (6,000 feet), Arosa (6,100 feet), and Leysin (4,757 feet), the excessive heat in the sun compared with shade temperatures in winter favors the outdoor life during the "invalid's day." It also, incidentally, impresses all newly arrived visitors as a marvellous climatic feature. At St. Moritz, now a fashionable winter resort, ladies find parasols almost a necessity while friends are skating, and those

---

[1] S. P. Langley: Researches on Solar Heat and Its Absorption by the Earth's Atmosphere. Papers of the U. S. Weather Bureau, No. 15, Washington, 1884, p. 242.

who indulge in this Alpine pastime revel in summer clothing. Although the climate is a cold one it is characterized by great diurnal ranges of temperature, freedom from dust, winds and fogs, and eminently suitable for the climatic cure.

As the snow lies on the ground at these resorts for from three to five months, sleighing, skating, skiing and tobogganing are popular and some of these sports are allowable in suitable cases of tuberculosis. In March or April the snow melts and the roads become slushy and muddy, so that the air becomes very damp, and patients are accustomed to make temporary visits to lower stations, such as Wiesen (4,760 feet), Seewis (2,985 feet), Thusis (2,448 feet), Gais in Appenzell (2,820 feet), or Ragaz (1,709 feet), returning later to the higher stations.[1]

SURGICAL TUBERCULOSIS TREATMENT IN SWITZERLAND

No chapter on high altitude treatment would be complete at the present time without noting the brilliant success of Dr. A. Rollier in the treatment of surgical tuberculosis at Leysin, in the Vaudois Alps, Switzerland. This station has an altitude of about 4,500 feet above sea level. The hospital buildings face the south and are protected by mountain ranges from the cold winds of the north and west.[2] Rollier states that even in midwinter, with snow on the ground, the temperature on the sunny balconies is often as high as 95° to 120° F. Owing to the purity of the atmosphere and the absence of moisture there is little loss of the luminous and caloric radiation of the sun. Rollier established his first hospital for the treatment of tuberculosis of the bones and joints in 1903, but it is only during the last two or three years that his method has attracted so much attention, though Bernard, of Samaden, had practiced it in the pure mountain air of Graubunden in the Engadine; and probably this influenced Rollier to select an elevated site for his hospitals. These are three in number and are located at 1,250, 1,350 and 1,500 meters, or 3,800, 4,100 and 4,500 feet. The exposure of

---

[1] See Walter B. Platt, M. D.: The Climate of St. Moritz, Upper Engadine, Switzerland (Trans. Amer. Climat. Ass., Vol. 4, p. 137).

Arnold C. Klebs: St. Moritz, Engadine (Trans. Amer. Climat. Ass., 1906, Vol. 22, p. 15).

[2] See description by John Winters Brannan, M. D., Medical Record, June 7, 1913. Also Rollier, Paris Médical, January 7, 1911, and February, 1913. The author is indebted to Dr. Brannan for his data and to Dr. Rollier for the illustrations and descriptions of his method.

the patient to the sun is the essential feature and after three to ten days of acclimatization indoors he begins with five minute exposures of the feet, five times a day. This is steadily increased as pigmentation appears until finally the entire surface of the body is exposed from sunrise to sunset. The head is, however, protected with white caps and shaded glasses. With the development of the pigmentation the cure progresses until recovery is complete. Dr. Rollier has sent us photographs of a boy who had 32 foci of tuberculosis, even the lungs being involved. This boy was considered cured after fifteen months of treatment. See plate 26.

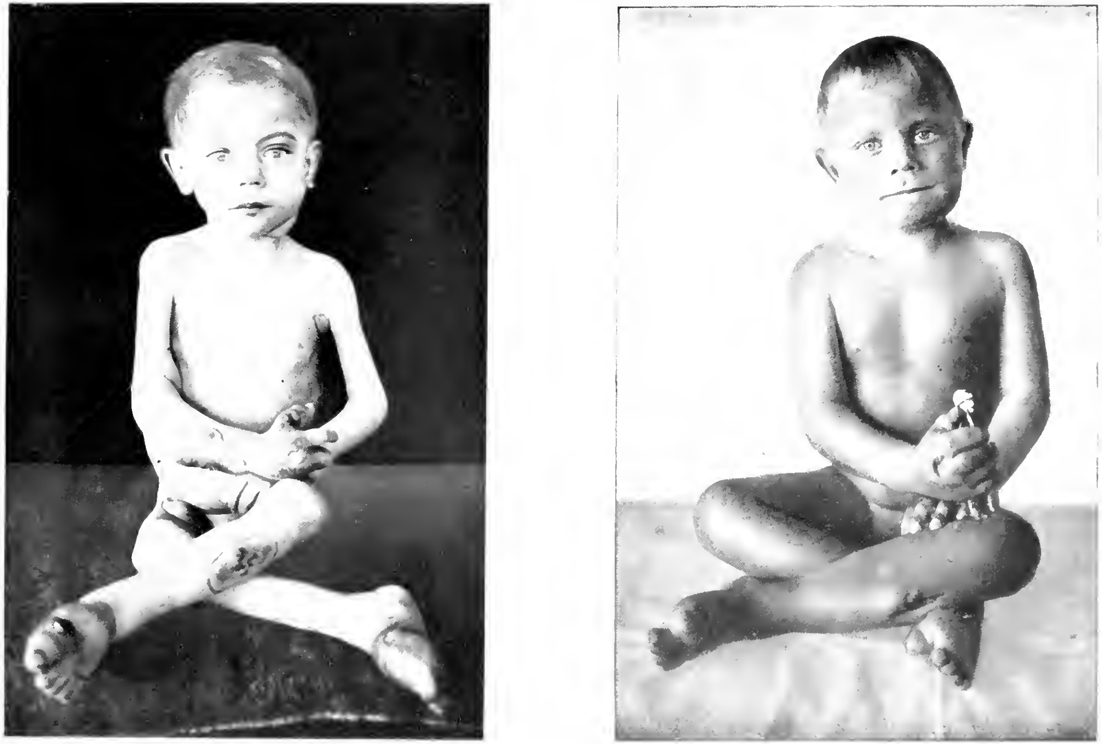
In another case there were multiple lesions, including a badly disorganized and anchylosed elbow with seven sinuses and a history of three resections of the joint and forearm. This boy also made a good recovery with complete return of function, full flexion and full extension. See plate 27. Dr. Brannan adds that he has seen many such cures at " See Breeze " and has kindly furnished photographs of some of these patients. See plate 16.

According to Rollier the pigmentation is the important element in the cure, inasmuch as it affords to the skin a remarkable resistance, favors the cicatrization of wounds and confers a local immunity to microbic infections. On days when there is no sunshine recourse is had to radiotherapy for the adults and the Bier treatment (local lowering of atmospheric pressure) for the children; at all times, whether the sun shines or not, the skin has its bath of air and light.

Two hundred beds in Rollier's sanatoria are reserved for children.

Dr. Rollier presented to the XVII International Medical Congress at London in 1913, a résumé of his method of heliotherapy and refers to eighteen separate communications to medical literature, in which he and his associates have described the method. Among other things we notice that he reports the number of adults having external tuberculosis treated by him as greater than that of children, 522 to 477. The prognosis for the former is as favorable as for the latter and the duration of treatment is never much longer. In Rollier's paper, referred to, all his cases for the past eleven years are tabulated and out of 1,129 patients, 951 are reported cured. Of the total number only three underwent the operation of resection. These were cases of gonorrheal arthritis; one was adult of over fifty years. Two cases of tuberculosis of the foot were treated by amputation; both were adults of over sixty years.

Rollier uses fixation by means of plaster, especially in Pott's Disease, but in all cases insists strenuously that the tuberculous joint



TWO VIEWS OF THE SAME CHILD. THERE WERE 32 FOCI OF LUNG, GLANDULAR AND BONE TUBERCULOSIS; GENERAL CONDITION VERY BAD. AFTER ONE YEAR OF HELIOTHERAPY AT DR. ROLLIER'S SANATORIUM WELL ESTABLISHED CURE. HEALED SCARS AT SIGHT OF OPEN SORES; VIGOROUS.

FOUR ILLUSTRATIONS OF THE SAME CHILD. HE WAS ADMITTED TO DR. ROLLIER'S SANATORIUM, LEYSIN, AT THE AGE OF FIVE, WITH NUMEROUS TUBERCULOUS FOCI IN THE BONE AND PERIOSTEUM AND ABOUT THE RIGHT EYE. THERE WAS TUBERCULOSIS OF THE ELBOW AND RIGHT FOREARM. THREE PREVIOUS OPERATIONS. SEVEN FISTULOUS OPENINGS IN THE ELBOW; SEVEN IN THE FACE. JOINTS IMMOVABLE; GENERAL CONDITION BAD. THE TWO LOWER VIEWS SHOW THAT AT THE END OF ONE YEAR THE OPEN SORE HAD HEALED. CHILD VIGOROUS.

or other site of the disease must not be covered over by any unremovable apparatus so as to interfere with the full exposure to the sunlight. Rollier's last paper goes very fully into the technic of heliotherapy and the reader is referred to this and to the fully illustrated paper in "Paris Médical," February, 1913, in which there are forty-five remarkable photographs covering the most interesting features of this work. It is at present attracting great attention and American physicians can find in the recent review of Rollier's work by Dr. Henry Dietrich, of Los Angeles, California, an excellent summary of its theory and practice.[1]

Rollier,[2] in his address before the Gesellschaft deutscher Naturforscher and Aerzte in Münster in 1912, says:

> It is in surgical tuberculosis that we have seen the best results from heliotherapy, and we have made the treatment of it our life work. As a result of my experience in the use of the light-cure in higher altitudes, based on an experience of nine years, I maintain to-day that the cure of surgical tuberculosis in all its forms, in all stages, as well as at every age of life, can be accomplished.
>
> The closed surgical tuberculosis always heals, if one will only be patient, and above all if one understands how to keep it closed. To transform a closed tuberculosis into an open one means to increase the gravity of the case a hundredfold. A diminution of the vitality of the tissues is the inevitable consequence. . . . . To regard a surgical tuberculosis as a local disease which can be cured by local treatment alone is a ruinous error. On the contrary,

---

[1] Journ. Amer. Med. Ass., December 20, 1913, p. 2232.

[2] References: Rollier (Verhandl. d. Gesellsch. f. Kinderheilk. d. 84 Versamml. d. Gesellsch. deutsch. Naturforsch. u. Aerzte in Münster), 1912. A report of 650 cases in which 355 patients were adults and 295 children. There were 450 cases of closed surgical tuberculosis and 200 cases of open surgical tuberculosis. In the cases of closed surgical tuberculosis 393 patients were cured, 41 improved, 11 remained stationary, and 5 died. Of the patients with open surgical tuberculosis, 137 were cured, 29 improved, 14 remained stationary, and 20 died.

Rollier and Rosselet: Sur le rôle du pigment épidermique et de la chlorophylle (Bulletin de la Soc. des sciences nat. 1908).

Rollier and Hallopeau: Sur les cures solaires directes des tuberculoses dans les stations d'altitude. Communication à l'Académie de Médecine, Paris (Bulletin de l'A. d. Méd., 1908, page 422).

Rollier and Borel: Héliothérapie de la tuberculose primaire de la conjonctive (Rev. méd. de la Suisse romande, 20 avril 1912).

Witmer, T. and Franzoni, A.: Deutsch. Zeitschrift für Chirurgie, No. 114.

P. F. Armand-Delille: L'Heliotherapie, Masson et Cie, Paris, 1914.

P. Vignard and P. Jouffray: La Cure Solaire des Tuberculoses Chirurgicales, Masson et Cie, Paris.

it is a general affection which requires general treatment. Of all infectious diseases it is the one in which the individual resistance plays a deciding part. Our first effort, therefore, is directed to improve general conditions and thus to bring about a healing of the local focus by treatment of the entire system. A rational local treatment is necessary as well, provided it is not too one-sided.

In cases of spondylitis, or Pott's disease, the children wear jackets having a large fenestrum cut anteriorly, as the vertebræ in children are not much further removed from the surface of the abdomen than from that of the back. After healing is verified by X-ray a celluloid corset is worn. One or two years are required for the cure. Plate 29 shows a girl thus cured of pronounced Pott's disease with gibbosity, and paraplegia and muscular atrophy. There was complete healing after fifteen months of the solar cure which the illustration well shows.

CASES OF HIGH ALTITUDE TREATMENT

As illustrations of the good effect of high altitude treatment, two cases from the practice of the late Dr. Charles Theodore Williams, of London, may be cited. They were both cured at St. Moritz (6,000 feet).

Miss C., aged 18, was first seen by Dr. Williams, July 20, 1887. She had lost a sister from tuberculosis and she had a history of cough and expectoration for five months and wasting and night sweats for two months; total loss of appetite and aspect very pallid. Slight dulness, crepitation in first interspace to the right. Ordered to St. Moritz for the winter. In the spring the patient spent six weeks in Wiesen, elevation 4,760 feet. She entirely lost her cough and expectoration, gained twenty-four pounds in weight and became well bronzed, looking the picture of health. Her chest increased enormously in circumference and measured, on full expiration, five inches more at the level of the second rib than before she left England. She stated that she had burst all her clothes. Careful examination at the end of eleven months, when these later notes were taken, showed great development of the thorax and hyper-resonance everywhere, but no abnormal physical signs. After more than three years in England the chest measurement had somewhat decreased.

Another patient, Miss R., aged 21, was seen in November, 1879, with a history of cough with expectoration, loss of flesh, night sweats, pain in the left chest and evening pyrexia of a month's dura-

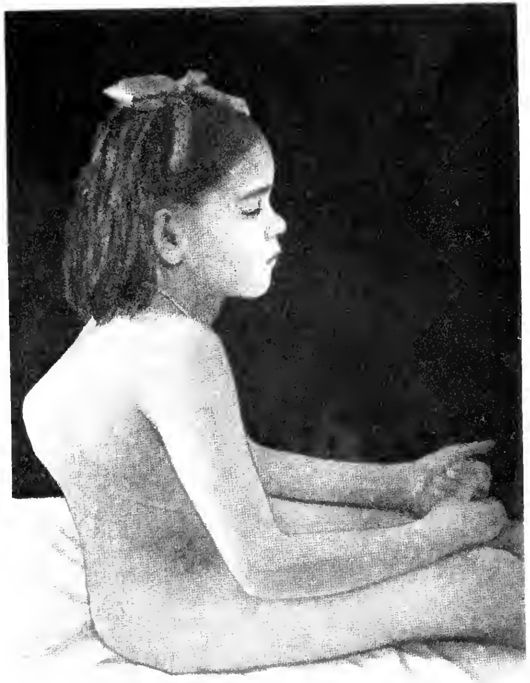


FIG. 1. POTT'S DISEASE WITH PRONOUNCED DEFORMITY, PARAPLEGIA AND MUSCULAR ATROPHY. CLINIC OF DR. ROLLIER, LEYSIN.

FIG. 2. THE SAME PATIENT AFTER FIFTEEN MONTHS OF HELIOTHERAPY. CORRECTION OF DEFORMITY. COMPLETE RESTORATION OF MUSCULATURE AND GENERAL STATE. CLINIC OF DR. ROLLIER.

FIG. 1. HELIOTHERAPY AND IMMOBILIZATION IN PLASTER FOR SURGICAL TUBERCULOSIS. BALCONY OF DR. ROLLIER'S SANATORIUM, "LE CHALET," LEYSIN, SWITZERLAND. THE JACKETS HAVE LARGE OPENINGS TO ALLOW ACCESS OF SUNLIGHT TO THE DISEASED SPINES. SOME PATIENTS IN DORSAL POSITION; OTHERS IN VENTRAL POSITION.

FIG. 2. CHILDREN WHO CAME TO DR. ROLLIER VERY SICK NOW INDULGE IN WINTER SPORTS. NO CLOTHING BUT CAPS AND LOIN CLOTHS. NOTE THE MUSCULATURE OF THE CHILDREN FORMERLY SUBJECTS OF COXALGIA, ARTHRITIS, PERITONITIS AND ADENITIS.

tion. Dullness and deficient breath sounds were detected close to the left scapula. After three years of unsuccessful treatment in England, during which time two winters were spent at Hyères, on the Mediterranean, losing ground and growing thinner and showing evidence of commencing disease in the opposite lung, she was sent for the winter to St. Moritz. She returned the following May vigorous and well bronzed, having taken plenty of exercise, skating, walking, and tobogganing. She had lost all cough and had gained much strength. The chest measurement showed an increase of one inch. The whole thorax was found hyper-resonant and no physical signs of consolidation could be detected. After eleven years of residence subsequently in England, she was free from chest symptoms.

In this case, notwithstanding the improvement following two winters spent at Hyères, at sea level, the disease was not arrested and increased the following year. But during one winter's residence at St. Moritz, elevation 6,000 feet (diminished atmospheric pressure and out-door life with winter sports), there was complete arrest of the disease, as the experience of eleven years with absence of physical signs testifies.

There is a wealth of clinical material to show the advantages of high altitude treatment at the well-known European and American resorts. Sir Hermann Weber, of London, and his son, Dr. F. Parkes Weber, have had a long and favorable experience in the treatment of pulmonary tuberculosis in high altitudes and they support Dr. C. T. Williams in a higher estimate of treatment of this disease at high elevations as contrasted with results at the sea level.

Twenty-five years ago Sir Hermann Weber stated that out of 106 tuberculous patients sent to high altitudes, 38 were cured, either permanently or temporarily, 16 were stationary or but slightly improved and 10 deteriorated. More than half of the cases in the first stage were cured.

The American statistics of Drs. Samuel A. Fisk,[1] W. A. Jayne,[2] S. E. Solly,[3] Charles Denison and S. G. Bonney, all of Colorado,

---

[1] Fisk, Samuel A.: Concerning Colorado (Medical News, Sept. 16, 1899); Climate of Colorado (Trans. Amer. Climat. Ass., 1888, p. 11).

[2] Jayne, W. A.: Climate of Colorado and Its Effects (Trans. Amer. Climat. Ass., 1888).

[3] Solly, S. E.: Invalids Suited for Colorado Springs (Trans. Amer. Climat. Ass., 1888, p. 34).

are certainly convincing as to the effect of high altitude treatment in the cure of pulmonary tuberculosis.[1]

Solly said in 1888, "Taking the medical profession throughout the world, it is unquestionable that a large majority of those who have made a study of the subject believe that where a change is made, a change to an elevated country is the most likely to benefit a consumptive."

Solly lived for thirty-three years in Colorado after having removed, as a tuberculous invalid, from England. Every one of the physicians mentioned above went to Denver or Colorado Springs as a tuberculous patient, recovered his health there, acquired a reputation and successful practice during fifteen to thirty years of residence and the majority are alive to-day (1913). Those who died succumbed to other affections.

According to Solly, 76 per cent of all patients, good, bad and indifferent, and 89 per cent of those in the first stage that undergo climatic treatment in Colorado are benefited. Would such patients as we have mentioned have derived equal and as lasting benefit at Alpine Stations, such as Davos or St. Moritz, which have a corresponding altitude and an equal barometric pressure? Judging from recorded clinical experience, we believe that they probably would have done equally well. We can never know absolutely. Would they have done equally well at sea-level or at very moderate altitude? None of the physician-patients whose names are quoted would admit it.

Dr. Solly, with his inimitable humor once remarked, "If I were living in London to-day, I'd be dead." In all human probability most, if not all of them, are fair examples of the curative power of the Colorado climate.

Of late there have been dissenting voices, challenging some of the cardinal principles involved in the altitude treatment of tuberculosis. Not only altitude, with its concomitant rarefied atmosphere, but even sunlight itself which lightens the heart of every invalid, have both been denied the value so generally assigned them in tuberculo-

---

[1] Charles Theodore Williams: Aerotherapeutics, or the Treatment of Lung Diseases by Climate. The Lumleian Lectures, 1893; Macmillan, 1894, pp. 111-179.

Charles Denison: Dryness and Elevation the Most Important Elements in the Climatic Treatment of Phthisis (Trans. Amer. Climat. Ass., Vol. 1, 1884, p. 22).

therapy. These discordant notes find utterances among those who have been compelled to treat the poorer class of consumptives in our cities at the seaboard and who have obtained some excellent results. Stress is laid on the beneficial influence, for example, of cold.[1] The fact that patients improve more in winter than in summer is cited to prove that "cold air in itself seems to cure in a manner which nothing else can accomplish. * * * Sunshine is not essential—excellent results may be obtained in climates where the sun is rarely seen. Mere outdoor living seems to be the essential element, and yet there does not seem to be any doubt that quicker results are obtained in the cold season than in the summer."

EFFECT OF COLD AIR

There is truth in the proposition that cold air is better for the consumptive than heated air. It is usually purer and is unquestionably more stimulating to the vital forces. Warm sleeping rooms are positively bad because of deficient ventilation. Warmth debilitates and opens the way to bacterial invasion. Hot weather is relaxing, while moderate cold, or greater cold with proper safeguards, acts as a tonic and fortifies the well and sick alike against disease.

The good effect of cold air in tuberculosis is commonly noted by physicians and patients. The following extract from a letter from a tuberculous patient, dated Saranac Lake, New York, February 19, 1908, is interesting:

> I have not felt the cold up here this winter as I feared I might, although the mercury has nearly disappeared on one or two memorable nights. 46° below zero is the coldest I have seen it but it was reported 50° below in the village. I am quite used to the cold now as I sit out on the porch all day and have not missed a day yet; but there is one redeeming feature about the cold up here and that is that zero weather does not seem nearly so cold as 20° above in Philadelphia. I really do not begin to feel it until it gets to 20° below, although it is usually too cold to use my hands even in milder weather. J. D.

This patient was 22 years old, had been at Saranac fifteen months and is reported perfectly well and weighs 180 pounds. He is apparently cured. He remains well, Nov., 1913.

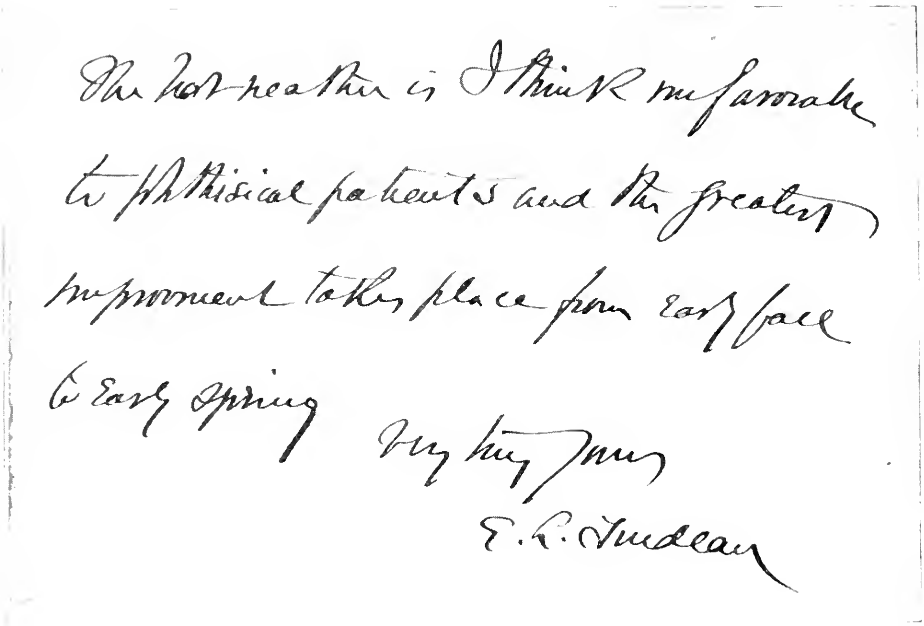
---

[1] Editorial, American Medicine, Philadelphia, January 20, 1906.

See A. D. Blackader, M. D.: The Advantages of a Cold, Dry Climate in the Treatment of Some Forms of Disease (N. Y. Med. Journ., Aug. 3, 1912).

The minimum temperature at Saranac Lake for 1912 was —32° F. on January 25, and the maximum was 88° F. on July 10. The mean temperature was 40.98° F. The total precipitation was 43.19 inches, with a total snowfall of 124.24 inches. Clear days, 153; partly cloudy, 77; cloudy, 136.

The extract here reproduced from a letter dated Saranac Lake, July, 1886, is interesting. It was addressed to the author.



The hot weather is I think unfavorable
to phthisical patients and the greatest
improvement takes place from early fall
to early spring
Very truly yours
E. L. Trudeau

The best and clearest statement of seasonal influence on body weight of consumptives that we know of was made by Dr. N. B. Burns, of the North Reading State Sanatorium, Massachusetts. His observations are based on one thousand patients during three years. Fully forty per cent of the cases admitted to this sanatorium were of the far advanced and progressive type. It was noted that August, September and October show that the largest percentage of patients gaining, while the three months immediately preceding show the opposite.

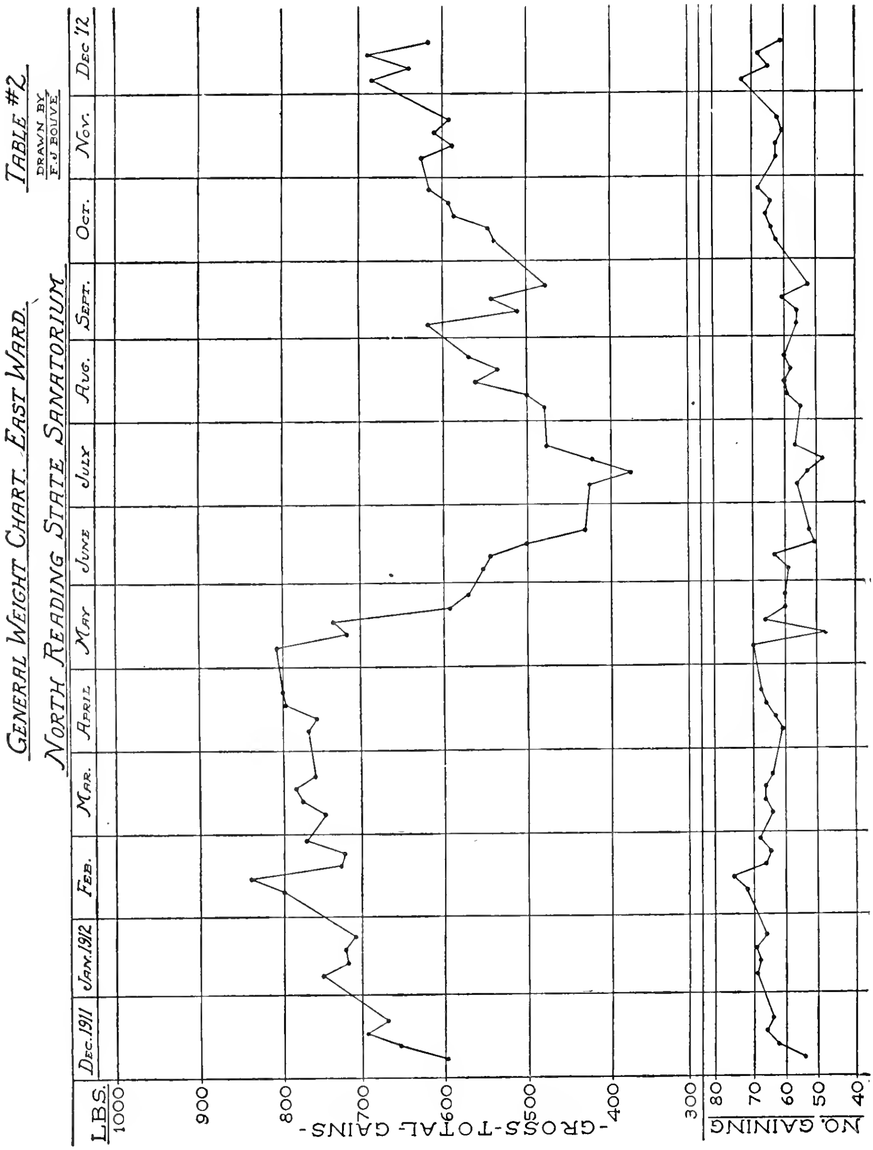
Dr. Burns also charted the aggregate gain in pounds of the male patients treated at North Reading, December, 1911 to 1912, inclusive. There was a rise in January and February, 1912, to 850 pounds for 76 patients which was maintained well through March and April.

NORTH READING STATE SANATORIUM, MASSACHUSETTS

TABLE ONE

N. B. BURNS, M. D.

PER CENT	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Patients Gaining	64.5	59.4	42.7	47.2	42.0	44.2	46.9	71.9	74.9	66.4	60.7	64.9
Patients Losing	27.9	35.4	50.2	44.5	50.7	50.4	47.6	27.3	17.3	25.5	29.8	27.8
Patients Stationary	7.6	5.2	7.1	8.3	7.3	5.4	5.5	0.8	7.8	8.1	9.5	7.3


General Weight Chart. East Ward.
North Reading State Sanatorium
Table #2
Drawn by F. J. Bouvé
Dec. 1911
Jan. 1912
Feb.
Mar.
April
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec '12
LBS.
1000
900
800
700
600
500
400
300
-Gross-Total Gains-
80
70
60
50
40
No. Gaining

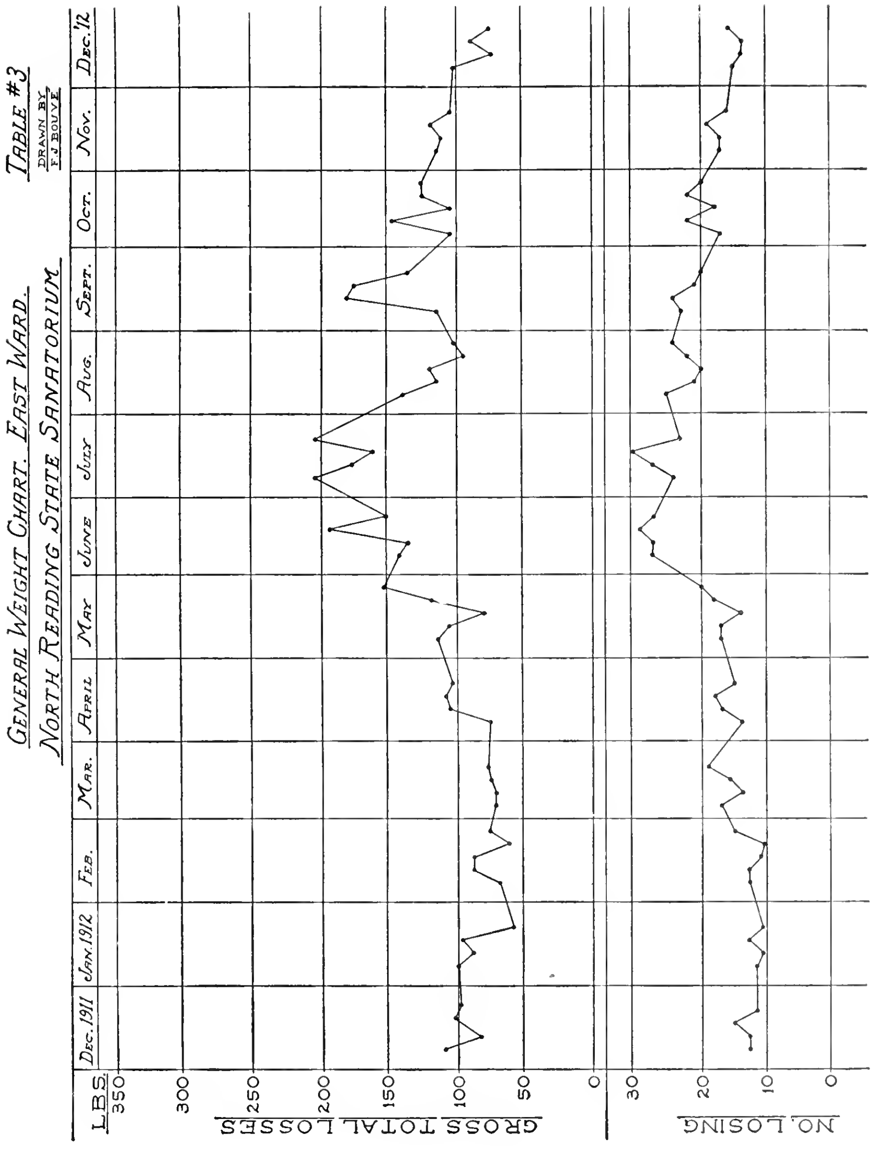


TABLE #3
DRAWN BY F J BOUVÉ
GENERAL WEIGHT CHART. EAST WARD.
NORTH READING STATE SANATORIUM
DEC. 1911
JAN. 1912
FEB.
MAR.
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC. '12
LBS.
350
300
250
200
150
100
50
0
GROSS TOTAL LOSSES
30
20
10
0
NO. LOSING

There was a subsequent sharp decline in May, the index dropping 250 points. This fall continued without interruption in June, to culminate July 11, at the low point for 1912.

The conclusion of this study was:

Phthisical patients are apt to lose rapidly in weight and general condition in May, June, and the first two weeks in July, which season constitutes an unfavorable and critical period.

Phthisical patients make an extraordinary recovery in weight and general condition in the month of August, which is a surprisingly favorable time of the year.

August, September, January and February are the most propitious months for obtaining successful results in treating pulmonary tuberculosis.

Forced feeding in the unfavorable season seems to have availed very little in limited number of cases studied at North Reading.

We have already referred to the beneficial influences of the Arctic summer climate (see pages 39-42), and we attributed much of it to the perpetual sunshine; consequently we cannot agree to the illogical statement that sunshine is not essential. We believe that the "Fireside Cure" has no place in the treatment of tuberculosis and we must admit that whereas only a few years ago the cold air fiend, who slept with windows wide open in the coldest winter, was considered a crank, he now has been proved to be the only sensible one among us.[1]

EXPANSION OF THORAX AT HIGH ALTITUDES

Without dwelling further at this time on the effect of cold air compared with warm air on tuberculous disease (see pp. 28, 40, 71), we must note some of the undeniable effects of diminished atmospheric pressure on physical development and especially on the thorax and pulmonary tissue.

One striking change is the expansion of the thorax in various directions and a corresponding increase in the mobility of the thoracic walls. We have previously referred to one case in which the circumference increased five inches during a residence at St. Moritz, elevation 6,100 feet. (See page 74.) Changes of from one to three inches are more commonly noted even at much more moderate elevations. These changes are conveniently recorded by means of

---

[1] American Medicine, *loc. cit.*

the instrument known as the cyrtometer which gives accurate tracings for recording the progress of the patient.[1]

Inasmuch as tuberculous patients in whom the disease is actively progressing show a shrinking of the perimeter *pari passu* with the advance of the disease, and those who are recovering show an increasing circumference, it is a fair inference that the physiologic increase in thoracic measurements due to residence in the higher altitudes is an advantage in the prevention and treatment of pulmonary tuberculosis. Man is not adapted to live permanently at altitudes above 13,000 to 16,000 feet (4,000-5,000 meters), but at somewhat lower elevations as, for instance, at 10,000 feet we have some thriving cities such as Leadville and Cripple Creek in Colorado, and Quito in Equador, elevations 10,000 and 9,350 feet (3,000 and 2,850 meters). The altitude of the permanent habitations in the Ortler Alps is about 5,450 feet (1,640 meters), and that of the highest health stations from 5,000 to 7,000 feet (Arosa). It is a well-known fact that the Indians of the Andes, the Swiss guides, the Tyrolese hunters and other mountain dwellers have a large thorax with correspondingly deep inspiratory power and remarkable endurance.[2] The increased respiration and the quickening of the circulation promote health and vigor in mountain races and comparisons between the highlanders and those in deep and flat valleys are always in favor of the former. All observers have remarked on the immunity from disease, and especially scrofulous and tuberculous disease, characteristic of mountain races, provided they live in the open, avoid overcrowding, have sufficient and suitable food and observe ordinary hygienic methods of life. Failure in this respect provides an opening for tuberculosis which, as we well know, is the scourge of the North American Indian and his relatives in Mexico and South America. Even in Quito, that city of remarkable equability, where it is perpetual spring, tuberculosis has effected an entrance, and enters largely into the mortality lists.[3] In Bogota, South America, in La-Paz, Mexico (elevation 11,000 feet, 3,360 meters) and in other densely populated towns in these countries, the later records show increasing numbers of cases of tuberculosis. This fact, however,

---

[1] See Minor, Charles L.: The Cyrtometer: A Neglected Instrument of Pulmonary Diagnosis and Prognosis (Trans. Amer. Climat. Ass., 1903, p. 221).

[2] "Mexican Indians, though of medium height, have unusually large and wide chests, quite out of proportion to their size." Jourdanet.

[3] Jacoby: Thèse de Paris, 1888. Quoted by Huggard.

should not afford the slightest ground for controverting the general proposition that life at altitudes of from 3,000 to 6,000 feet favors immunity from tuberculosis and the cure of the disease in suitable cases.

CHOICE OF CASES FOR HIGH ALTITUDE

The question then arises, what are suitable cases for altitude treatment? What kind of patients may be sent to stations of lower barometric pressure?

In choosing a location, the late Dr. F. I. Knight, of Boston, formulated some opinions based on his long experience.[1] He limited the age of those resorting to altitudes to fifty years. In temperament he preferred the phlegmatic to the nervous, with an irritable heart, frequent pulse, and inability to resist cold; and with the latter we must be careful not to include those who show nervous irritability from *disease,* not temperament, as they are generally benefited in high places. As regards disease, he first considered cases of early infection of the apices of the lungs with little constitutional disturbance, and, although these generally do well under most conditions, yet considerable experience assured him that more recover in high altitudes than elsewhere.

It is best to begin with low altitude in patients with more advanced disease showing some consolidation but no excavation; also when both apices or much of one lung is involved and the pulse and temperature are both over 100.

Hemorrhagic cases, early cases with hemoptysis and without much fever are benefited by high altitudes. Patients with advanced disease, those with cavities or severe hectic symptoms should not be sent to high altitudes. A small, quiet cavity is not a counter-indication; hectic symptoms are counter-indications.

This accords with the latest report from the U. S. Public Health Service Sanatorium at Fort Stanton, New Mexico, altitude 6,231 feet. Dr. F. C. Smith reports 56 deaths from pulmonary hemorrhage in a total of 524 patients since the hospital was opened in 1899. His conclusion is that pulmonary hemorrhage is not more frequent at high altitude than at sea level, but the results are perhaps more often serious, especially in those with impaired circulation.[2]

---

[1] Trans. Amer. Climat. Ass., 1888, p. 50.

[2] Public Health Reports, U. S. Public Health Service, No. 51, by F. C. Smith, Passed Ass't Surgeon, Washington, 1910. See also Report No. 93. Washington, 1912.

SNOW SCENE AT UNITED STATES PUBLIC HEALTH SANATORIUM, FORT STANTON, NEW MEXICO. HOUSE AT RIGHT, WITH PORCH, QUARTERS OF OFFICER IN CHARGE. ROW IN CENTER SETS OF QUARTERS USED BY JUNIOR OFFICERS AND OTHERS

TUBERCULOSIS SANATORIUM OF THE UNITED STATES PUBLIC HEALTH SERVICE, FORT STANTON, NEW MEXICO. AMBULANT SICK CALL.
PATIENTS TAKING BREATHING EXERCISES

Patients in an acute condition should not be sent. Cases of fibroid phthisis, in Dr. Knight's opinion, are not suitable. Convalescents from pneumonia or pleurisy are usually well suited for elevated regions. Advanced cases of tubercular laryngitis, if good local treatment and freedom from dust can be obtained, may do no worse in elevated regions than elsewhere.

In cases complicated by cardiac dilatation we cannot advise altitude; but a cardiac murmur resulting from a long-past attack of endocarditis with no sign of enlargement or deranged circulation should not prevent. Nervous derangements of the heart are usually counter-indications.

The observations made at the United States Public Health Sanatorium at Fort Stanton, New Mexico, by Surgeon F. C. Smith, of the service are commended as a valuable contribution to the Relation of Climate to the Treatment of Pulmonary Tuberculosis. This sanatorium is open to sailors in the merchant marine and they are transferred from the twenty-two marine hospitals on the coasts and rivers to this admirable inland sanatorium. It was found that the results have been nearly three times as good in the cases which left the home stations, *i. e.*, the local marine hospitals, without fever as in those who had a temperature of 38° C. (100.4° F.) or more within two weeks of departure. The deaths in those leaving afebrile were to those leaving with fever as 22 to 59; the arrests, as 19 to 7½; the apparent cures, as 10 to 3. Dr. Smith holds that the case that should be sent to a distant climate immediately upon diagnosis is exceptional and he also adds that neglect to make an early diagnosis does not warrant precipitate haste in sending the victim away when it is finally established. The psychologic moment for a climatic change is when there is a comparative quiescence of the lung process under treatment at home, when nutrition is improved and further improvement is slow (Francine). Climatic change, however, must sometimes be made, as we will see later on, when the hoped for stage of quiescence does not occur.

Before allowing patients with pulmonary diseases to go long distances or to make any great change to higher altitudes, some caution should be given. In the first place, patients should not make any physical exertion for two or three weeks after arrival. The air may be stimulating, there may be sights to see and many dangerous invitations given, but it is absolutely necessary that the patient should be adjusted to the new atmospheric conditions. Acclimatization is necessary to comfort and safety. In the old days it was accomplished by the slow ride in the stage-coach over the plains. We cannot go back to the old methods, and therefore we must exercise greater caution. No febrile case should be sent on these journeys or to any elevated resort. Hemorrhage is not a counter-indication to a change of altitude, and it is not any more liable to occur at five to six thousand feet than at sea-level. However, no advanced case of pulmonary tuberculosis should be sent away. Financial considerations are highly important. Expenses are usually underestimated, and the want of sufficient means, the need to economize as regards the necessities, not to speak of the luxuries, of life, is a dreadful handicap, and should bar out many a case that succumbs for want of the very comforts he had left behind. It would be far better for such patients if they should enter some special hospital or sanitarium for consumption, such as are found in most of our Eastern States.

No one should be sent away without definite and satisfactory knowledge of the place to which he is sent, and without a letter of introduction to some favorably known practitioner containing a statement of the main points in the case.

In matters of climate, as in many other fields, it is the man behind the climate who will help the patient, save him from errors and indiscretions, advise him and direct him as to local surroundings, and enable him so to live that his disease shall be arrested.

Some localities favorable for tuberculous patients have already been mentioned. Taking the country as a whole we naturally look to the elevated, sparsely settled regions of Colorado, New Mexico, Wyoming, Montana, Nevada, Utah, Arizona and California. The slopes of the Rocky Mountains and the Great Basin are justly entitled to first choice, provided always that other safeguards than climate are to had for the protection, the comfort and nutriment of the patient. Texas, especially the central and higher western portion, must be included in this great area. Life in Texas was formerly rather too rough and food and accommodations were too primitive for fastidious people, but now at places like San Antonio and El Paso, these defects have been remedied. The winter climate of Texas is very agreeable, except when the Texas norther descends and holds everything in an icy clasp. However, this is not altogether a disadvantage, if not too severe.

Florida suits some cases of phthisis. The interior of the state is sandy and the winter and spring climate is excellent. The cultivation of orange groves and other agricultural features of the state have given many a patient a profitable occupation that he would never have found elsewhere.

Thomasville, in Georgia, sixteen miles from the Florida line, and Aiken and Camden, in South Carolina, have long had a reputation for the relief of pulmonary affections. Asheville, North Carolina, is more elevated (2,300 feet) and has an excellent "all the year round" climate. Special attention is given to tuberculous patients at this resort, and this is something that cannot be said of all the good places. In Pennsylvania, suitable places are found in the Pocono Mountains, at White Haven, Kane, Cresson, Mont Alto and Hamburg. In New Jersey, there are Lakewood, Brown's Mills, Haddonfield, Vineland, and, for special cases, such as chronic fibroid phthisis, we may advise Atlantic City.

In New York, there are the Adirondacks, especially the vicinity of Saranac; Loomis, in Sullivan County, where there is an excellent sanatorium. In New England, there are institutions at Rutland and Sharon, Massachusetts; Wallum Lake, Rhode Island; Wallingford, Connecticut. But, as we have said before, the choice of a place, whether near home or at a distant point involves all the questions of diagnosis, of temperament, of financial resources, all of which the physician must weigh as conscientiously as though his own life depended on it.

Of late, English physicians have been making more extended use of the higher Alpine resorts. Among these, Davos Platz, altitude 5,200 feet; St. Moritz, 6,000 feet; Arosa, 6,100 feet; and Leysin, 4,712 feet, are usually chosen. Their chief characteristics are an atmosphere of dry, still, cold, rarefied air; absence of fog, few clouds and very little wind. There is, therefore, strong sunlight with a grateful warmth in the sun's rays.

In selecting cases for treatment by change of climate, we must exercise as much discrimination as in applying any other remedial measure. Indeed, more caution should be used, for the patient will pass out of observation and in most cases the advice given involves the most vital consequences.

CHAPTER V. INFLUENCE OF INCREASED ATMOSPHERIC PRESSURE; CONDENSED AIR

Celsus, in treating of pulmonary tuberculosis in the first century A. D., advocated a change of climate and to "seek a denser air than one lives in."[1]

A few places in California and in Asia Minor are below sea-level.

---

[1] De Medicina, Paris edition, Delahay, 1855.

But the consequent increased atmospheric pressure in these localities is not in itself worthy of note. Such desolate regions as the Dead Sea, the Mojave Desert, Death Valley, and Salton Lake, California, are entirely unsuited for the tuberculous, and, for obvious reasons, all subterranean pressures are out of the question. Divers and caisson workers become anemic and hence artificial pressures increased beyond the normal at sea level are injurious.

Even the natural variations in atmospheric pressure at any given station may be sufficient to have some appreciable influence, *per se,* on the course of pulmonary tuberculosis. Changes of pressure of 20 mm. (.7874 inches) occasionally take place, but they are comparable to a gradual change of level amounting to only 200 meters (656 feet), and it has been assumed that no appreciable physiologic effects can be attributed to these gradual alterations, at least as far as tubercular diseases are concerned. Hann[1] and Thomas[2] state that in experiments with pneumatic chambers, pressure changes amounting to 300 mm. (11.8 inches) a day have been produced without causing any notable injurious effects upon the sick persons concerned in these experiments.

EFFECT OF BAROMETRIC CHANGES ON THE SPIRITS

As the barometric pressure in any given place falls the cloudiness usually increases, the temperature rises, the wind increases, and precipitation is liable to occur; as the pressure rises the skies clear, the temperature falls and the winds shift to the west or northwest. The spirits and general morale of all patients usually improve with a rising barometer unless prolonged wind storms accompany such a change. Whatever improvement accompanies a rising barometer is due to the stimulus of cold or the return of sunshine and dryer air.

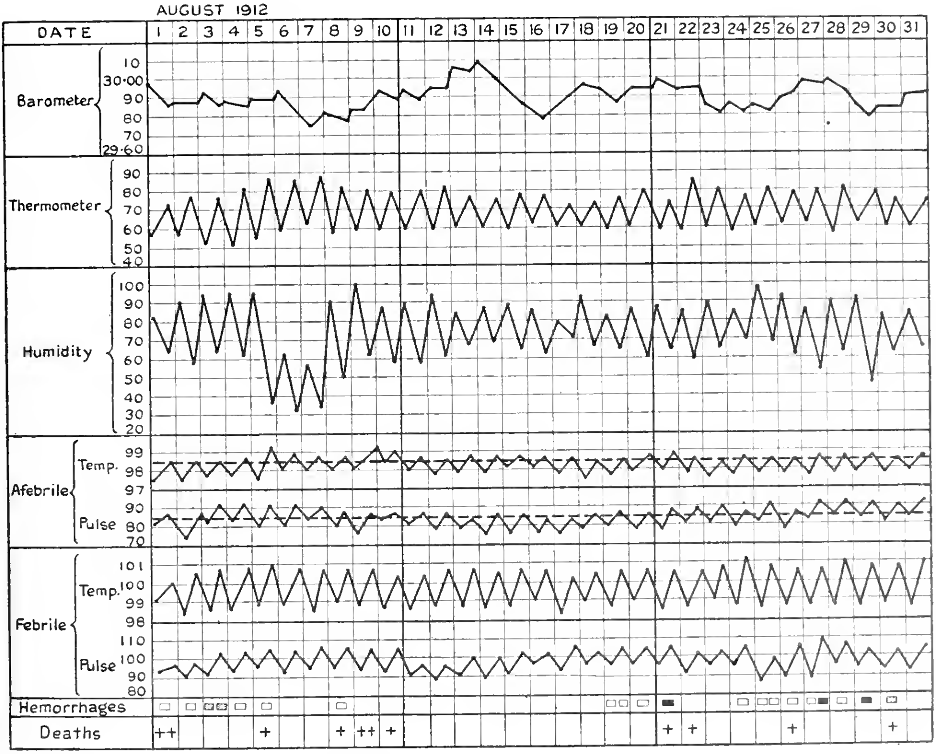
Dr. Charles C. Browning, of Los Angeles, has studied the effect of some atmospheric conditions on tuberculous patients.[3] In his first report it appeared that unseasonable or very sudden changes in temperature influenced temperature of patients, while equal or greater changes occurring slowly did not. Of hemorrhages occurring in groups about four times the number occurred when there

---

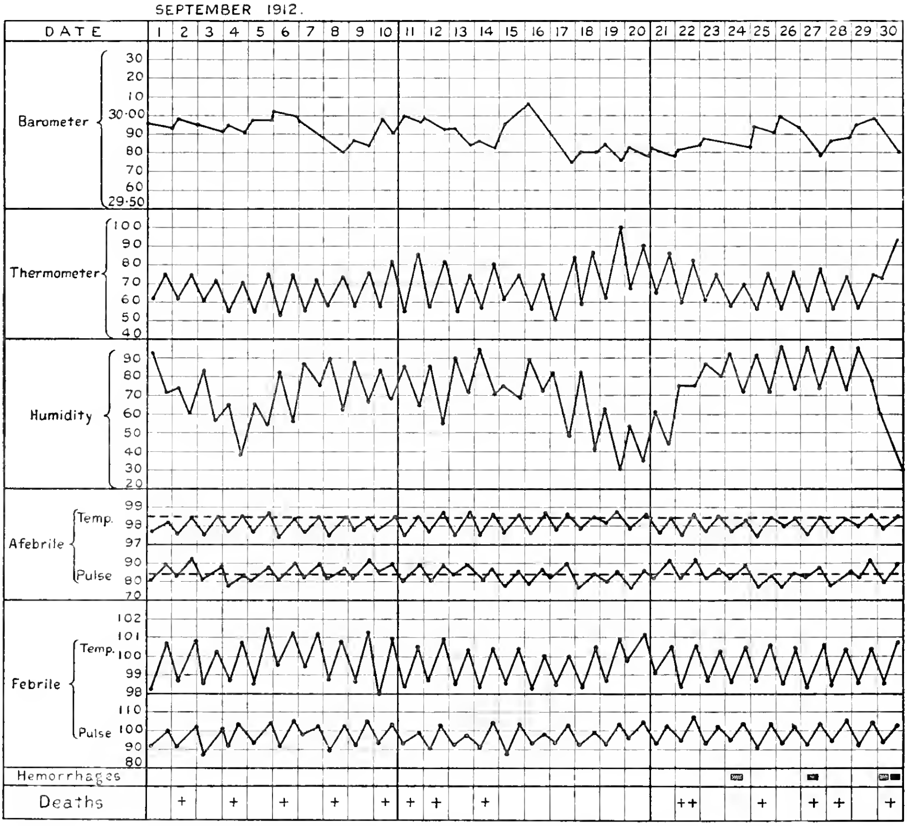
[1] Julius Hann: Handbook of Climatology, Macmillan, 1903, p. 71.

[2] Thomas, in Beiträge zur Allgemeinen Klimatologie, Erlangen, 1872.

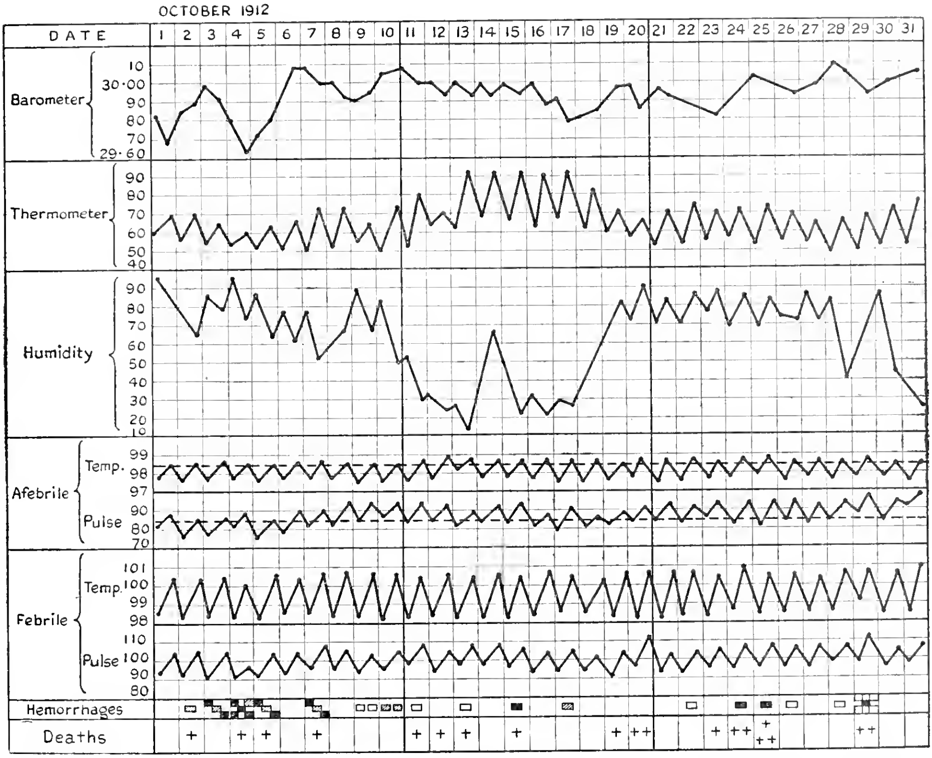
[3] Trans. American Climatological Ass., 1908; *idem,* 1913, p. 189.



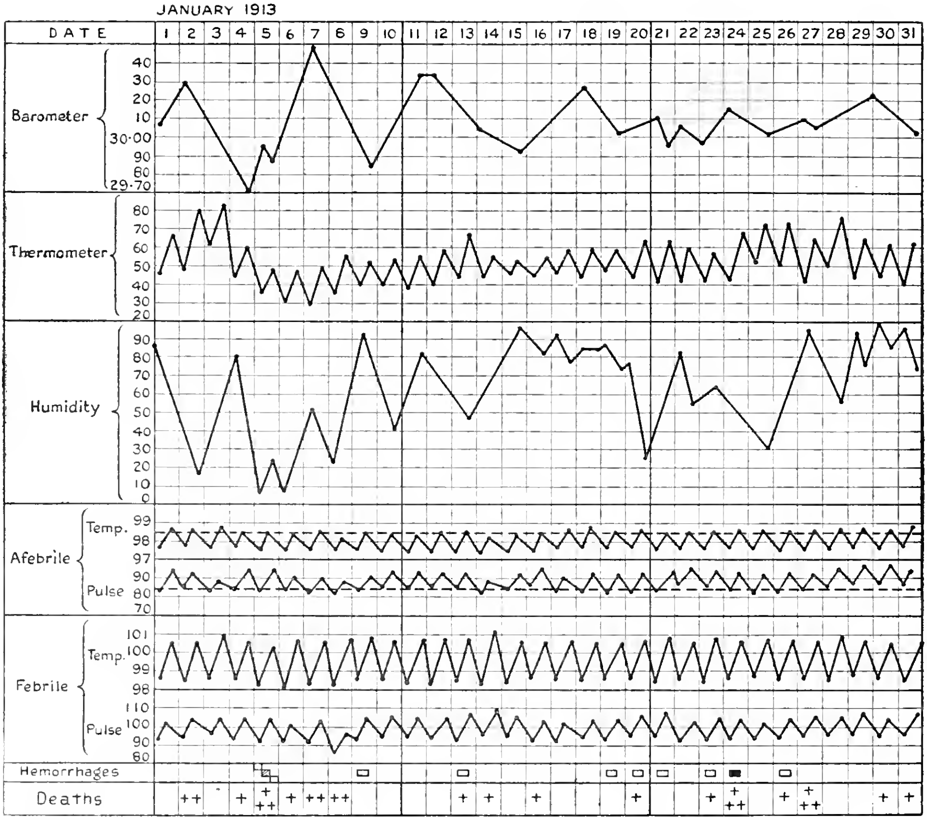
Relation of pulmonary hemorrhages and deaths from tuberculosis to barometric pressure, temperature and humidity. Courtesy of Dr. C. C. Browning, Los Angeles, Cal.



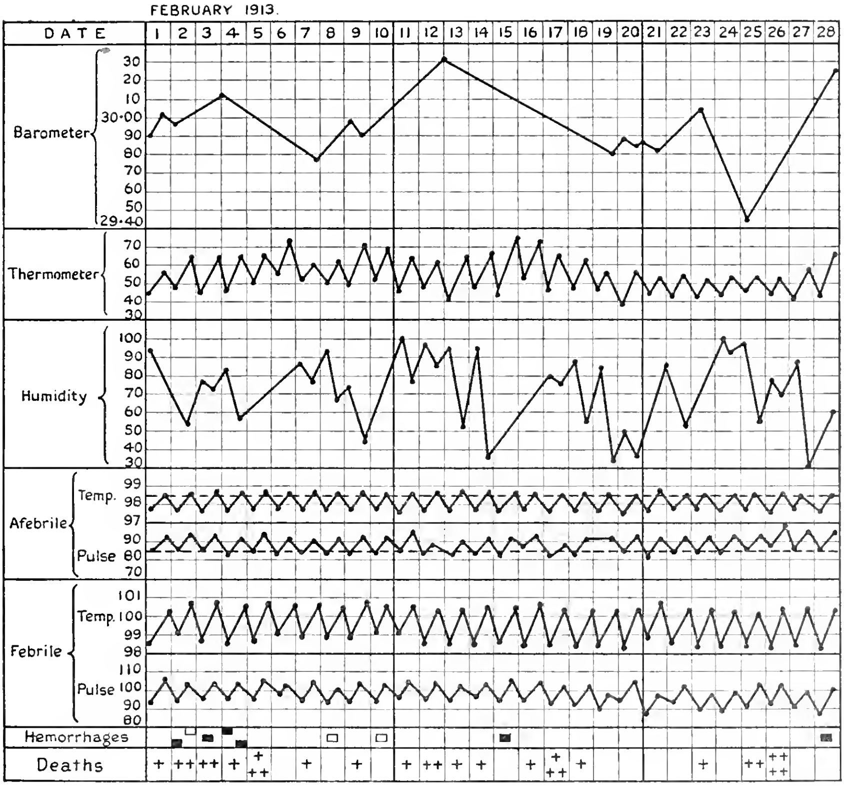
Relation of pulmonary hemorrhages and deaths from tuberculosis to barometric pressure, temperature and humidity. Courtesy of Dr. C. C. Browning, Los Angeles, Cal.



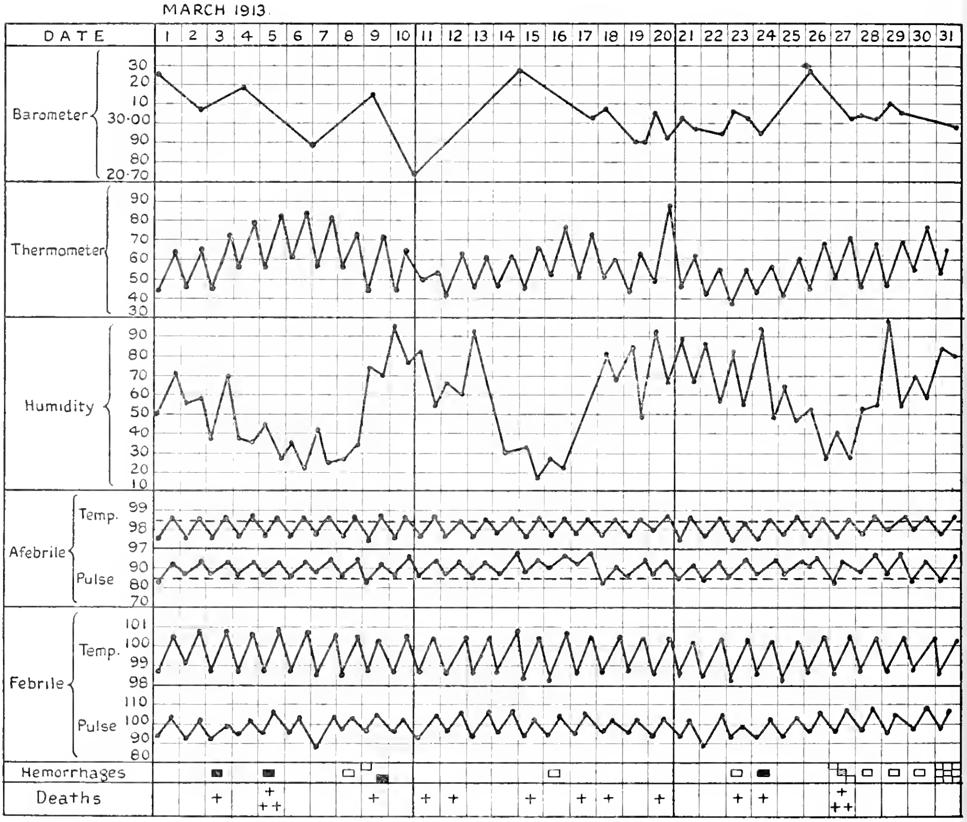
Relation of pulmonary hemorrhages and deaths from tuberculosis to barometric pressure, temperature and humidity. Courtesy of Dr. C. C. Browning, Los Angeles, Cal.



Relation of pulmonary hemorrhages and deaths from tuberculosis to barometric pressure, temperature and humidity. Courtesy of Dr. C. C. Browning, Los Angeles, Cal.



Relation of pulmonary hemorrhages and deaths from tuberculosis to barometric pressure, temperature and humidity. Courtesy of Dr. C. C. Browning, Los Angeles, Cal.



Relation of pulmonary hemorrhages and deaths from tuberculosis to barometric pressure, temperature and humidity. Courtesy of Dr. C. C. Browning, Los Angeles, Cal.

was a barometric pressure change exceeding .3 of an inch within twenty-four hours than when the change was less. The hemorrhages appeared to be more frequent if there had been a change in the opposite direction—a sudden fall. The cases observed were all in the advanced stage. The conditions which appear to influence groups of hemorrhages and deaths are barometric pressure, humidity and cloudiness, each in turn appearing to be the most prominent index in exerting a limited determining influence. This is shown in the two charts for November and December, 1912. Dr. Browning's paper contains charts for six other months.

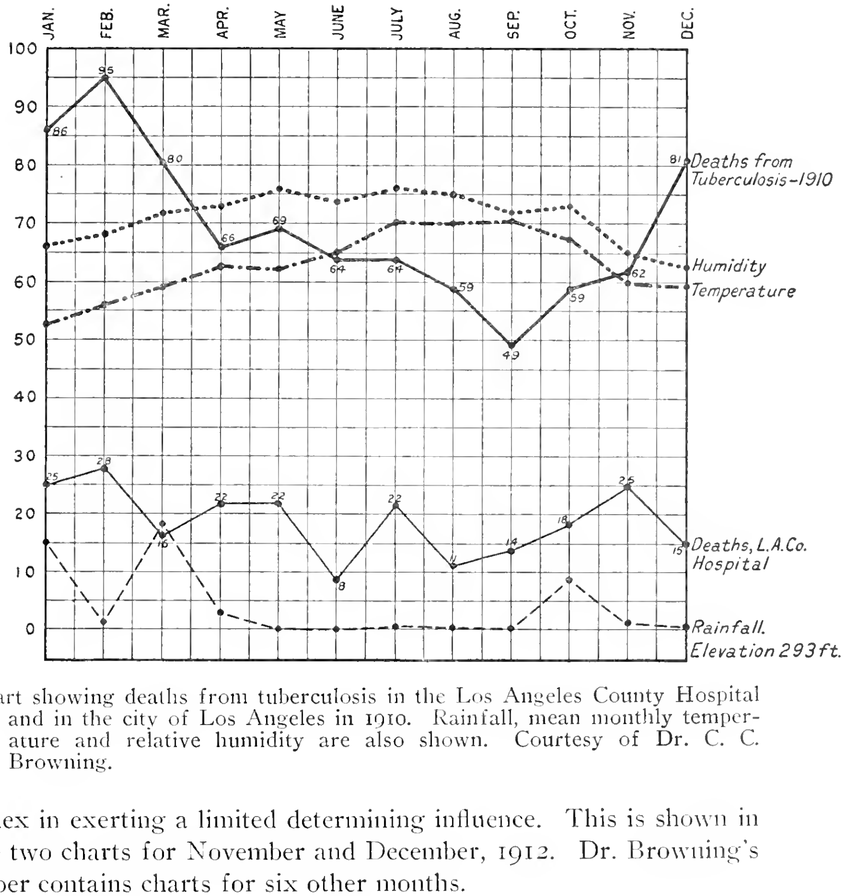


Chart showing deaths from tuberculosis in the Los Angeles County Hospital and in the city of Los Angeles in 1910. Rainfall, mean monthly temperature and relative humidity are also shown. Courtesy of Dr. C. C. Browning.

Dr. Browning notes the influence of fog and remarks that the "high fog" is regarded by many as one of the most desirable factors of the Southern California climatic condition. It is not fog in the generally accepted meaning, for this "light veil" is neither cold nor excessively moisture laden; neither is it high, for its altitude is less than a thousand feet.

When the barometer is gradually rising and the humidity slowly falling and the sky clear or clearing, patients are pleasant, in some cases jovial and inclined to be optimistic as to the future.

When the barometer is either gradually or rapidly falling and the humidity rising and becoming more oppressive as the hours go by, and the day is foggy with little or no sunshine, the effect on patients is entirely different. They become pessimistic, cross and very irritable. During the so-called "northers," when the barometer falls, then rises rapidly with clear weather and a quick drop in the humidity as from 75 per cent to 20 per cent in twenty-four hours, there is a marked drying of the mucous membrane, causing great discomfort in some and comfort in others.

ARTIFICIALLY COMPRESSED AIR

Artificially compressed air has been used by Oertel, Simonoff and Charles Theodore Williams in pulmonary tuberculosis. The first two claimed great improvement resulting from its use; but Williams did not find such favorable effects.[1] In nine cases submitted to the compressed air bath, hemorrhage was brought on in two while in the bath; in four others hemorrhage occurred but could not be distinctly connected with this form of treatment. There was usually some gain in weight and diminished cough and expectoration, and apparently the respiration became freer in the unaffected portions of the lungs. Beyond the opening up or aeration of portions of the lung which had not been brought into play for some time, there seemed to be no special change for the better. Compressed air in Williams's experience did not facilitate the absorption of lung consolidation or infiltration.

At the Brompton Hospital a large wrought iron chamber was constructed about ten feet in diameter by eight feet in height, and accommodated four patients. It had thick glass windows and a closely fitting door. By means of inlet and outlet pipes compressed air was introduced and allowed to escape. The outer air from a pure source was filtered through cotton and pumped into the receiver. The pressure was gradually increased after the patients were inside the tank until it reached ten pounds or two-thirds of an atmosphere above the normal. Half an hour was spent in increasing the pressure, one hour in maintaining it at the highest point required, and half an hour in

---

[1] Charles Theodore Williams: Compressed Air Bath and Its Uses in the Treatment of Disease, London; Smith, Elder & Co., 1885, and Aerotherapeutics. Macmillan, London, 1894, p. 106.

reducing it; so that two hours were consumed in its application therapeutically.

A practical difficulty was encountered in keeping the compressed air sufficiently cool to be comfortable, owing to the fact that air invariably rises in temperature during compression and cools during rarefaction; so that in warm days ice had to be used about the reservoir.

Von Vivenot, in a careful series of experiments, showed that the influence of compressed air on the respiratory capacity was to permanently raise it. When used for two hours every day it is found to increase daily from 20 ccm. to 30 ccm. above the previous day's record. Von Vivenot took 122 compressed air baths during 143 days and his respiratory capacity was raised from 3051 ccm. to 3794 ccm. and, in compressed air, to 3981 ccm. This increased capacity was reached in three and a half months, after 91 baths and was afterward maintained at practically the same level.[1]

An increase in respiratory capacity has been noted by other observers, but the respiration rate is always lowered and in almost all cases there is a similar lowering of the pulse rate.

PNEUMATIC CABINET

These experimental results naturally appealed to phthisiologists and patients were treated at Brompton, as we have mentioned, and in the United States by means of Ketchum's pneumatic cabinet or similar devices. There is no doubt but that the method was given a fair trial, but it has been found wanting. The pneumatic cabinets installed at considerable expense at the Loomis Sanitarium at Liberty, at the Rush Hospital in Philadelphia and at Saranac, are rusting away or consigned to the scrap heap. The simpler and more natural method of outdoor life is found much more safe, rational and effective.[2]

See J. Solis Cohen: The Use of Compressed and Rarefied Air as a Substitute for Change of Climate in the Treatment of Pulmonary Phthisis. (Trans. Amer. Climat. Ass., Vol. 1, 1885).

V. Y. Bowditch: Ten Months Experience with Pneumatic Differentiation, *ibid.*, 1886, 47.

A. S. Houghton, Journ. Amer. Med. Ass., Nov. 7, 1885.

C. E. Quimby, Trans. Amer. Climat. Ass., Vol. 9, p. 33.

Isaac Hull Platt, Trans. Amer. Climat. Ass., Vol. 3, p. 76.

---

[1] Paul Bert, *op. cit.*, p. 439.
Huggard, W. R.: Handbook of Climatic Treatment, p. 109.

[2] At Sharon Sanatorium it is still used in some cases as a means of calisthenics for the chest and is thought to be of value

Tiegel, New Yorker Medicinische Presse, April, 1887.
E. L. Trudeau, Trans. Amer. Climat. Ass., 1886, p. 41.
Ketchum: Physics of Pneumatic Differentiation (Medical Record, Jan. 9, 1886).
Waldenburg, Pneumatische Behandlung, Berlin.
J. T. Whittaker, Gaillard's Med. Journ., August, 1885, p. 208.
Herbert F. Williams, Journ. Amer. Med. Ass., Aug. 14, 1885.
Herbert F. Williams, Trans. Amer. Climat. Ass., 1886, p. 17.
B. F. Westbrook, Trans. Amer. Climat. Ass., 1887, p. 102.

ARTIFICIAL HYPERÆMIA

We must here refer to an important advance in the treatment of surgical tuberculosis in which artificial changes in the atmospheric pressure play a prominent part. Prof. Bier, of Bonn, first used his famous method in treating tuberculosis of joints; he used the "Stauungsbinde." He also uses cupping glasses of various shapes so that they may be applied to various parts. The rarefaction of the air is accomplished by a rubber ball or a pump, according to the size of the glass. After opening tuberculosis lymphatic glands and tuberculous abscesses in connection with joints, the cupping glasses are applied and the claim is made that this process avoids mixed infections. Tampons and drains, also, are found to be unnecessary.

In treating a member, for instance the hand, Bier uses a glass cylinder provided with a cuff and a rubber band, so that the whole hand is hermetically sealed and by means of the pump the air is partially exhausted. By similar apparatus Prof. Bier, Dr. V. Schmieden, Dr. Willy Meyer, Ewart, and others all over the world have treated successfully cases of surgical tuberculosis so that the method has an established place in tuberculo-therapy.[1]

CHAPTER VI. ARTIFICIAL PRESSURE; BREATHING EXERCISES

Radical differences of opinion exist as to the use of artificial variations of pressure, or pneumatic differentiation, in pulmonary tuberculosis and also as to the larger question as to whether the diseased lung should be set at rest or invited to expand.

The respiration of artificially compressed or rarefied air for limited periods, such as half an hour or two hours, has been considered, but this form of pulmonary gymnastics has given way to

---

[1] August Bier: Hyperæmie als Heilmittel, 5th edition. Prof. Bier advises a long continued residence at the seashore in cases of surgical tuberculosis.

more natural methods of accomplishing the results aimed at. The judicious use of exercises has been advocated for centuries and this plan of treatment has passed through most interesting phases, long advocated, then condemned and later revived. Some of the recent advocates of exercise by graduated labor invoke the very latest knowledge of the pathology of tuberculosis in support of this method.

The bad effects of exercise on tuberculosis patients at the well-known climatic stations have been widely commented on and numberless histories of patients going to their death when caution might have saved them are on record. Patients going from the lower elevations to altitudes of five and six thousand feet do not seem to realize at first how necessary are rest and thorough acclimatization for their safety during the earlier weeks or months of treatment. The higher stations are natural gymnasia where diseased lungs may be trained or overtrained; where accidents may happen to the inexperienced and rash, or even to the old time expert if he neglects to exercise proper judgment. No fall from the trapeze is more fatal in its effect than some mountain expedition or other adventure by the tuberculous patient. Dr. Solly was wont to say that nowhere is the invalid fool more quickly punished for his folly than in Colorado.

We are concerned, at present, with exercise as it relates to the breathing habit and the aeration of the diseased lung. Exercises and improved breathing habits can be carried out and acquired at the sea-level or at higher elevations. We believe that at the moderate or higher altitudes breathing exercises are more effective for good and tend more fully to develop the thoracic movements and capacity than at the lower levels (see page 62). Minor has recently reviewed this subject in a paper on the "Use and Abuse of Pulmonary Gymnastics in the Treatment of Tuberculosis" and holds that they are beneficial in properly selected cases. That such measures are abused by those who use them indiscriminately and unintelligently we all know.

ATMOSPHERIC COMPRESSION OF LUNG

Fifteen years ago Cornet came out strongly against exercises and others of experience take even more radical ground. The principle of rest has been carried to such an extreme that surgical measures, such as strapping the affected side to insure complete immobilization, have been adopted.[1] The most radical measure was the introduction

---

[1] Charles Denison, Trans. Amer. Climat. Ass., Vol. 21, 1905.

into the pleural cavity of nitrogen gas, or atmospheric air, so as to compress the lung and prevent as nearly as possible all motion. The credit for devising this operation and first performing it, belongs to Forlanini, but it was first practiced in America by Dr. John B. Murphy,[1] of Chicago, and has been repeatedly used by many others in Europe and America, including the late Dr. Henry P. Loomis,[2] Dr. Cleaveland Floyd and Dr. Samuel Robinson, of Boston, Dr. L. Brauer, Prof. T. Beneke, of Hamburg, Dr. H. L. Barnes and Dr. F. T. Fulton, of Rhode Island.

ARTIFICIAL PNEUMOTHORAX

Prof. Theodore Beneke, of Hamburg, says[3] that Forlanini conceived the idea of placing the affected lung at rest by artificial pneumothorax as early as 1882; he put it in practice in 1888; Brauer and Ad. Schmidt performed it in 1906. Murphy seems to have developed his operation without any knowledge of Forlanini's work. The operation has been performed in Germany, according to Beneke, by hundreds of physicians on several thousand patients. The operation is meeting with great favor in America.[4]

The clinical observation that the occurrence of pleuritic effusion in tuberculous cases was followed by an arrest of the symptoms of the primary disease if the effusion were left undisturbed; and, further, the unfavorable results which follow tapping in other cases, or when later adopted in cases of quiescent during the presence of the effusion led to this method of artificially producing immobility. Pleuritic effusion is intimately connected with pulmonary tuberculosis in a majority of cases and, if not purulent, should probably be left undisturbed.

Loomis followed Murphy's technique, using a special apparatus for the injection of pure nitrogen gas by means of which from fifty

---

[1] John B. Murphy: The Surgery of the Lungs (Journ. Amer. Med. Ass., 1898). Also Surgical Clinics of Dr. John B. Murphy, December, 1913. W. B. Saunders Co., Phila.; also Interstate Medical Journ., March, 1914.

[2] Henry P. Loomis: Some Personal Observations on the Effects of Intrapleural Injections of Nitrogen Gas in Tuberculosis (Trans. Amer. Climat. Ass., 1900; Med. Record, Sept. 29, 1900).

This method was first proposed by Prof. Carlo Forlanini, of Pavia, Italy, at the International Medical Congress, Rome, 1894.

[3] Ueber den kunstlichen Pneumothorax, "Tuberculosis." Berlin, Nov., 1913.

[4] See article by Dunham and Rockhill, with discussion by C. L. Minor, Journ. Amer. Med. Ass., Sept. 13, 1913.

to two hundred cubic inches were introduced into the pleural cavity on the affected side[1]

The nitrogen gas introduced into the pleural cavity does not remain long without being absorbed, and in order to keep the lung immobilized for six months or more, repeated injections are required. When ordinary atmospheric air gains entrance to the pleural cavity it constitutes the condition known as pneumothorax, and if the pneumothorax becomes closed, the oxygen steadily diminishes and finally disappears, the carbon dioxide decreases and the last element to disappear is the nitrogen. This fact has been determined by chemical analysis by Dory, Bouveret, LeConte, Ewald (Loomis). The respirations are always increased after the injections and the pulse rate is lowered. A notable effect in Dr. Loomis' cases was the absolute control of pulmonary hemorrhage in cases where all other measures failed.

Dr. Loomis' experience in eighteen cases treated by injections of nitrogen gas was uniformly favorable, although not curative. Probably the fact that pulmonary hemorrhage is controlled is the chief value of the method, though gain in weight followed the adoption of this measure in all the cases.

SONG CURE

One method of pulmonary exercise lately advocated for tuberculous patients is by singing.[2] Singing invokes correct nasal breathing and a maintenance of the elasticity and proper expansion of the chest. The necessary breathing exercises promote an increased functional activity of all parts of the lungs, including the apices where tuberculosis usually first becomes evident. It is here that expansion is most limited and the prevalent opinion is that this comparative inactivity is a strong factor in the tendency of the disease.

The "song cure" may be suitable in some cases of pulmonary

---

[1] For a good description of the latest apparatus and a discussion of the most approved methods see articles by Harry Lee Barnes and Frank Taylor Fulton, and by Samuel Robinson and Cleaveland Floyd, Transactions of the American Climatological Association, 1913, pp. 160-188, and 1911, pp. 289-383. A bibliography is given in Transactions, 1913, p. 170.

See also Trans. American Sanatorium Association, 8th spring meeting, p. 16. Discussion by H. D. Chadwick, W. A. Griffin, E. S. Bullock, G. W. Holden, J. J. Lloyd, Jr., L. Brown, J. Roddick Byers.

See also Samuel Robinson, "Practical Treatment," edited by Musser and Kelly, W. B. Saunders Co., Philadelphia, 1911, Vol. 3, p. 254.

[2] Drs. Leslie and Horsford, The Hospital, London, Jan. 25, 1908.

tuberculosis, but in laryngeal cases it would be counter-indicated. Its practice in pulmonary cases has not been adopted to any very great extent; but it would seem to have some advantages as it does not involve great muscular fatigue.

It is well known that public speakers with pulmonary tuberculosis cannot continue this practice with impunity. Their tendency to attempt to increase their weakening vocal powers by forcing the air outward has a bad influence on the lungs. Bad habits of speaking and lack of training are probably accountable for these bad results. Artistic breathing should be cultivated and all public speaking in crowded and badly ventilated halls should be avoided.[1] Knopf refers to cases of phthisis[1] which had even passed the incipient stage and were cured after following the occupation of street singer or speaker. He cites the case of an English lady who became an evangelist, addressing crowds of people every night in open air meetings and who was actually cured of her tuberculous disease after following this calling for a year.

Our own experience leads us to believe this to be an exceptional result. Having had some experience in treating members of the Salvation Army in various grades of the service, the impression gained was that tubercular disease was quite common among them and that their life of exposure, unhygienic quarters, insufficient food and excessive use of the voice rendered them an easy prey to consumption. The voice is almost always over-strained and hoarse and the open air life the members lead is accompanied by hardships which over-balance any favorable features in their nomadic existence.

Open air singing, properly employed, as in the German Army, is, no doubt, beneficial. This should be encouraged by all military authorities. It relieves the tedium of the march and invigorates the soldier. Barth, of Koslin, has made a thorough study of the effects of singing on the action of the lungs and heart, on diseases of the heart, on the pulmonary circulation, on the blood, the vocal apparatus, the upper air passages, the general health, the development of

---

[1] George Hudson Makuen: Artistic Breathing (Philadelphia Medical Journal, Sept. 3, 1898).

[2] S. A. Knopf: Respiratory Exercises in the Prevention and Treatment of Pulmonary Diseases (Johns Hopkins Medical Bulletin, Sept. 1901).

See also John H. Pryor, Deep Breathing as a Therapeutic and Preventive Measure in Certain Diseases of the Lungs (Trans. Amer. Climat. Ass., Vol. 22, 1906, p. 251).

the chest, on metabolism and on the activity of the digestive organs, and has come to the conclusion that singing is one of the exercises most conducive to health. (Knopf.)

CHAPTER VII. FRESH AIR SCHOOLS FOR THE TUBERCULOUS; VENTILATION

Under the name of "Waldschule" these have recently been established in Germany. The first was opened at Charlottenburg, Berlin, August 1, 1904, and closed its first term October 29th of the same year with 120 scholars. The results of the first year were very encouraging, the average increase in the weight of the children was five pounds, and the Forest School has been regularly opened each year.

The credit of its establishment belongs to the "Vaterländischer Frauenverein" of Charlottenburg. This patriotic association of women selected children either suspected of tuberculosis or with the disease already established for the Forest School. In this way educational facilities are provided for children whose condition renders them unsuitable for the public schools and at the same time avoids the necessity of sending them to sanatoria where there is little or no provision for teaching.

At Charlottenburg they put up so-called "Doecker barracks" or transportable buildings of light construction. There was one school barrack, containing two class-rooms and one teachers' room. The second barrack was used for household purposes. There was also an open "liege-halle" towards the south where the children may remain during bad weather. A light frame structure contains wash rooms and a bath-room with tub and douche. Three schoolmasters and one schoolmistress give instruction. The children were distributed in six classes of about twenty each. This is smaller than in the public schools where there are from forty-five to sixty in a class. The sessions never lasted over two hours continuously.[1]

This school has now grown so as to accommodate 240 children.

A second school is located in M.-Gladbach in the Rheinprovinz. It was opened in 1906 for sixty children between eight and fourteen years of age.

A third one is in Muhlhausen, Reichslande, Elsass-Lothringen, Southwest Germany. It was opened in 1906 and the physician in charge is Dr. Bienstock.

---

[1] For further particulars of this school, see article by Dr. J. Nietner, Tuberculosis, May, 1905.

A fourth is the Forest School in the Victoria Louise Children's Sanatorium at Hohenlychen. It was established August 1, 1903. Pastor Mickley is in charge. These are the pioneer schools and many others have since been established.

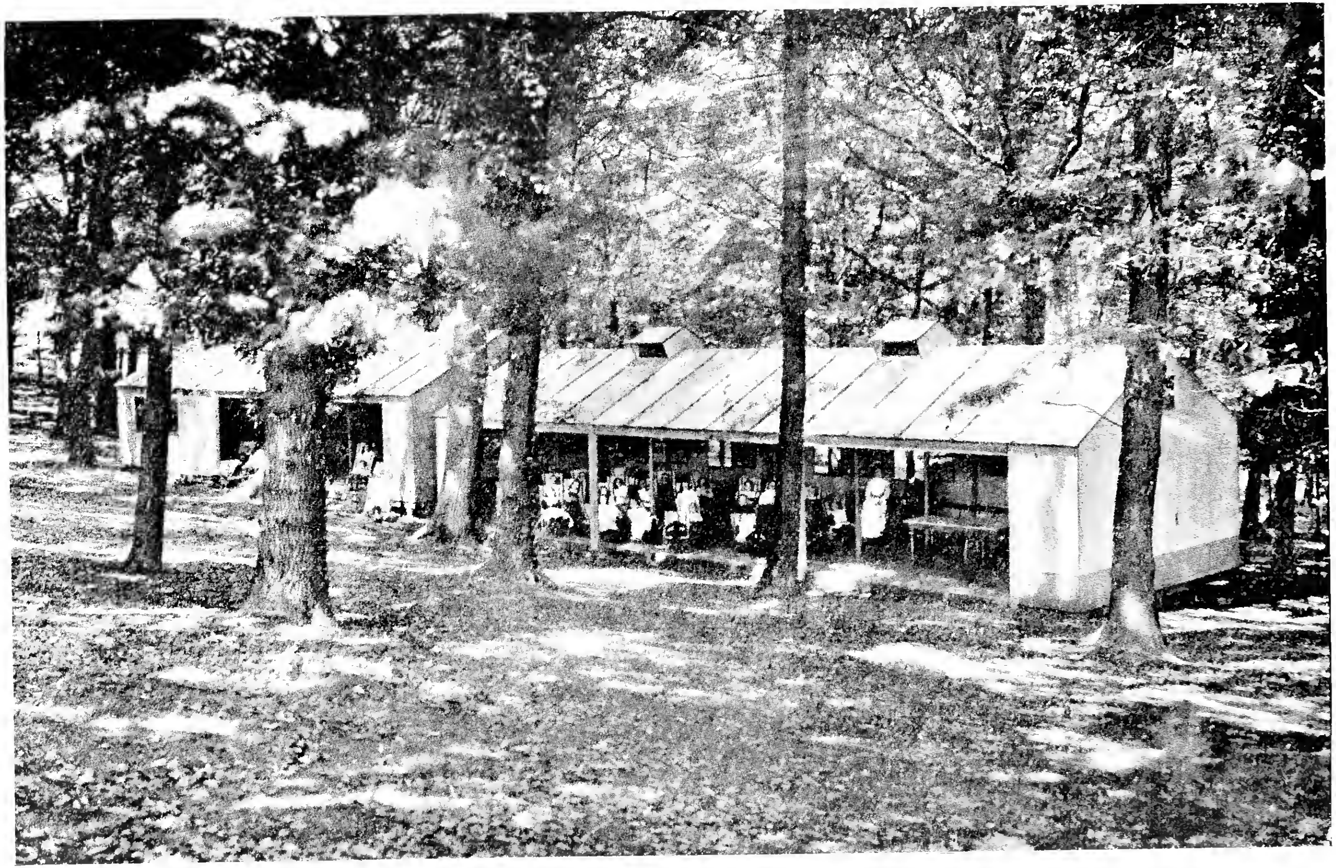
The most successful private open air schools in Germany are conducted by Prof. Dr. Gustav Pannwitz, the honorary secretary of the International Association for the Prevention of Tuberculosis. They are situated at Hohenlychen, about two hours by rail from Berlin, near Templin, on the hilly plateau which is called the "Mecklenburgisch—Pommersche—Seenplatte," between the East Sea and Spree Rivers. There are extensive forests of fir, a large lake with an island of 240 acres belonging to the school. It is conducted on the most modern hygienic principles.

An open air school was established at Bostall-Heath, near Woolwich, England, in 1907; in France, at Lyons, Vincennes and Boulogne; in Switzerland, at Lausanne, open from June 5 to September 23, at Zurich and Geneva. The "Rayon de Soleil" at Geneva, is for very young children; so also "Les Oisillons" at Lausanne.

In the United States the first fresh air school for tuberculous children was established in Providence, Rhode Island. Dr. Ellen A. Stone and Dr. Mary S. Packard had a small day camp during the summer of 1907 for children suspected of having tuberculosis. They soon became convinced that a fresh air school ought to be started for the benefit of the tuberculous children of Providence and they asked the help of Dr. Jay Perkins, Chairman of the Providence League for the Suppression of Tuberculosis in getting a single small school, necessarily ungraded, for those children, arranged so as to approximate an out of door school. At the camp which these physicians had been conducting there were about ten children who would soon have to go back to the ordinary schools or else would be at home in close rooms.

In response to this appeal Dr. Perkins enlisted the sympathy of the Superintendent of Schools, Mr. Walter H. Small, and with Judge Rueckert and Dr. Charles V. Chapin, the school committee established the first fresh air public school in America.

A school house not then in use and centrally located was requested for use and granted, and the necessary changes were made. The result was that they had to begin with a room on the second floor the full size of the building, about 40 by 25 feet, with windows on three sides. The brick wall on one-half of the southerly side was removed and windows substituted, these windows extending from near the floor to the ceiling, with hinges at the top and pulleys ar-



LONDON COUNTY COUNCIL'S OPEN AIR SCHOOL AT SHOOTER'S HILL. PAVILIONS
Courtesy of D. Walter Lindley

LONDON COUNTY COUNCIL'S OPEN AIR SCHOOL AT HORNIMAN PARK, LORDSHIP LANE. REST HOUR ranged so that the lower end can be raised to the ceiling, thus leaving this half of the room completely open to the south. Each school desk and its accompanying seat is arranged on an individual wooden support so that, while stationary as regards each other, each desk and seat can be moved as desired, and thus any arrangement of seats may be made. The school is an ungraded one (the ages running from 7 to 13 years), and as such limited to 25 pupils. The school hours are from 9 to 11.45 a. m., and from 1.45 to 3.30 p. m., with a recess from 10.15 to 10.45. Towards the end of this recess each pupil is served a cup of hot soup. Each pupil has a sitting-out bag of the standard type and in very cold weather has a hot soapstone in the bottom of the bag. In the end of the room not open to the south a good fire is kept going, thus partially warming the air and keeping that end of the room moderately warm, the pupils' seats all being in the other end.

One interesting feature in connection with the school is that, though these children come from poor homes and there has been an extensive epidemic of "colds" in winter, especially affecting the nose and throat, no child in the school has had even a "cold in the head." On being enrolled, each child is weighed, measured, and the hemoglobin tested. The League furnishes the sitting-out bags and soapstones and some clothing, the city paying all other expenses.

Thus the credit for suggesting the school belongs to Drs. Packard and Stone, but the work was developed and carried on through the efforts of the League. Most of the children for the school are selected in the first instance by the head tuberculosis nurse and secondly by the physicians on the League Committee. All of them are from within walking distance of the school. Dr. Stone is one of the Medical Inspectors of the Public Schools and the other Medical Inspector, Dr. Charles E. Hawkes, was added to the committee.

Providence was the first city in the country to establish special schools for the mentally deficient and the school department is to be highly complimented because of the enthusiasm and energy with which they took up the establishment of a special school for the physically deficient as soon as the matter was presented to them.

This Fresh Air School in Providence was opened on January 27, 1908, with ten pupils, and soon twenty were enrolled. Hot soapstones, sitting-out bags, hot drinks at recess, frequent trips to the stove, breathing exercises, marching, bending movements, and uniform work in singing are prominent features of the pioneer fresh-air school in America.[1]

---

[1] Ellen A. Stone, M. D., Journal of the Outdoor Life, May, 1908.

The instruction of children at the Sea Breeze Hospital for Tuberculous Children at Coney Island is provided by the Board of Public Education of Brooklyn, New York, and the Board deserves credit for thus cooperating with the Sanatorium. Provision is now made in the larger cities for the regular and systematic education out of doors of tuberculous children in the community at large and the success of this movement is attested by the fact that on May 1, 1913, there were 177 open air schools in the United States, five of these are in Rhode Island; thirty in Manhattan; twenty in Brooklyn.

See also Jay Perkins, M. D.: Fresh Air Schools—How They Accomplish Their Result (Journal of the Outdoor Life, New York, June, 1912).

Les EColes de Plein Air, leur valeur prophylatique dans la Lutte Anti-Tuberculose, "Tuberculosis," Berlin, Nov., 1911.

The Open-Air School, Anna Garlin Spencer, Trans. Sixth International Congress, Washington, 1908, Vol. 2, p. 612.

Open Air Schools, Thomas Wray Grayson, M. D., Therapeutic Gazette, Nov., 1913, p. 27. Also John V. Van Pelt, Interstate Med. Journ., April, 1914.

In order to control tuberculosis effectively we shall have to make more determined efforts to reach the school children and even those of earlier years. Tuberculosis is latent in thousands of children in every large city; sooner or later it becomes manifest as vital resistance becomes lowered. A recent view, prevailing in France and Germany, is that all tuberculous infections are made in infancy and childhood, the disease lying latent, from one cause or another, until the individual resistance, weakened by successive colds, pneumonia, grippe or other infections, or exposure to reinfection, finally yields and tuberculosis is actively established. Both laboratory and clinical experience point to a much earlier primary infection than we have been accustomed to believe and hence too much stress cannot be laid on the importance of better ventilated schools and the establishment of more "fresh-air schools" in every city of the country. These should be located near parks, if possible, or at least have extensive play grounds.[1] They should be conducted also for the benefit of children who may be anemic, nervous, and not necessarily tuberculous; and also for apparently healthy children. The best example of the outdoor school for normal children has been opened at Bryn Mawr College, Pennsylvania, as the Phebe Anna Thorne Model School.

---

[1] Henry Barton Jacobs, M. D., Journal of the Outdoor Life, April, 1908.

J. H. Lowman, M. D., Trans. Nat. Ass. for the Study and Prevention of Tuberculosis, 1907.

The three Elizabeth McCormick Schools, in Chicago, are admirable examples of the open air school.

FIG. 1. "RAYON DE SOLEIL," GENEVA, SWITZERLAND. DAY CAMP FOR ANEMIC AND DELICATE CHILDREN

FIG. 2. FOREST SCHOOL, GENEVA, SWITZERLAND

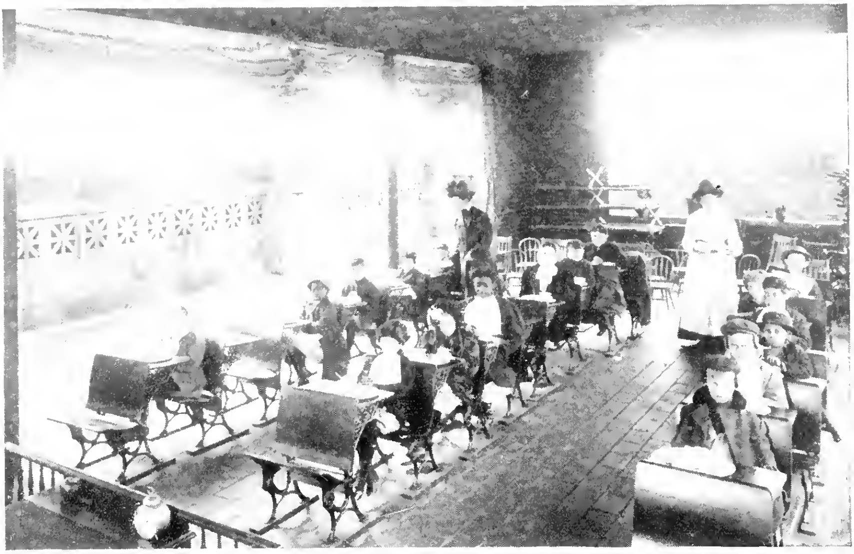
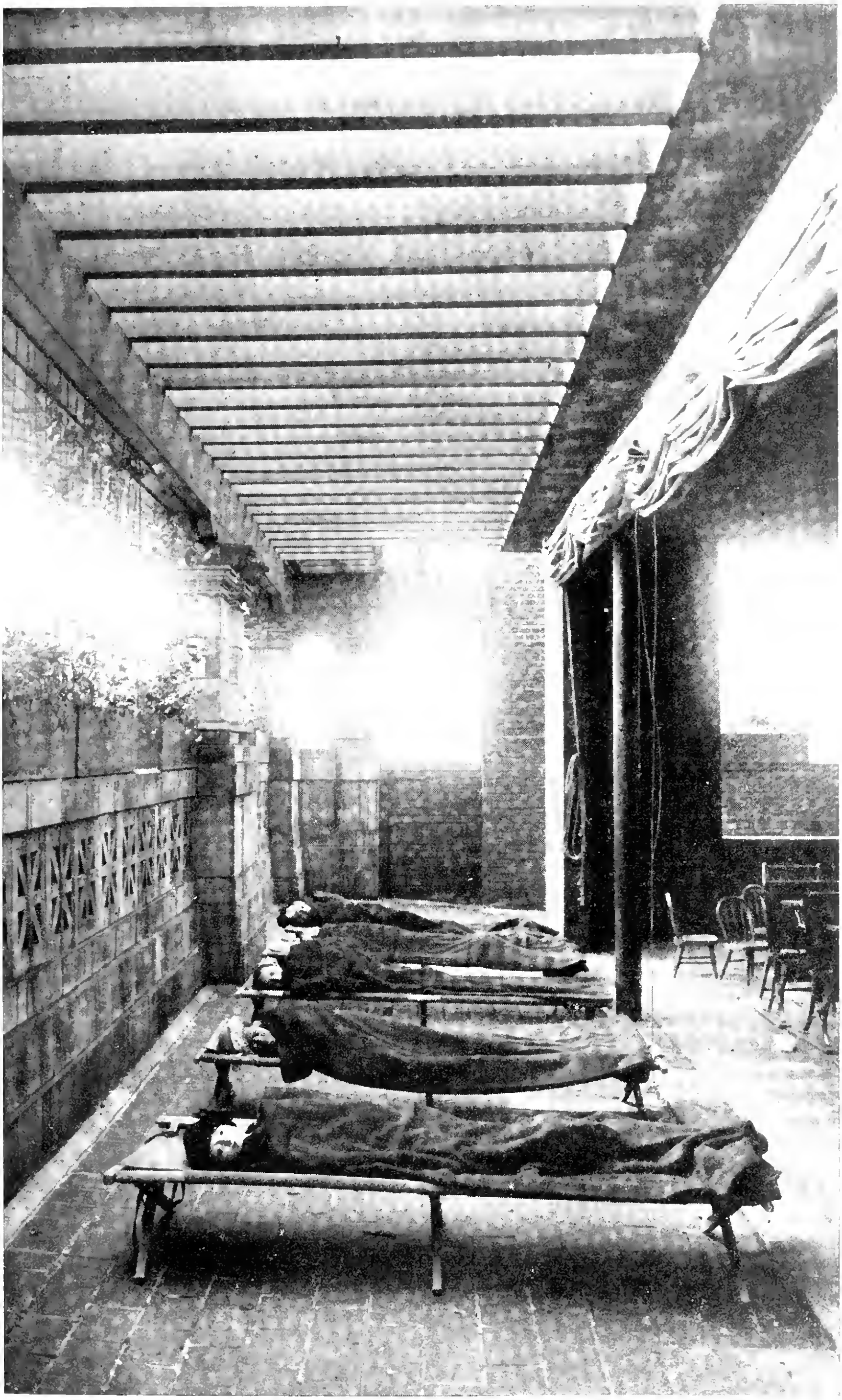


FIG. 1. OPEN AIR SCHOOL ESTABLISHED BY THE CIVIC CLUB, PITTSBURGH, PENNA. STUDY HOUR; WARM WEATHER

FIG. 2. OPEN AIR SCHOOL ESTABLISHED BY THE CIVIC CLUB, PITTSBURGH. STUDY HOUR; COLD WEATHER



OPEN AIR SCHOOL ESTABLISHED BY THE CIVIC CLUB, PITTSBURGH, PENNA. RESTING HOUR

OPEN AIR SCHOOL ESTABLISHED BY THE CIVIC CLUB, PITTSBURGH, PENNA. LUNCH HOUR

FIG. 1 FRESH AIR SCHOOL ESTABLISHED BY THE CIVIC CLUB, PITTSBURGH, PENNA

FIG. 2. OPEN AIR CLASS FOR ANEMIC CHILDREN AT PUBLIC SCHOOL NO. 21, NEW YORK CITY
Courtesy of Dr. J. W. Brannan

OPEN AIR CLASS, ROYAL VICTORIA HOSPITAL, EDINBURGH, SCOTLAND

Courtesy of Sir Robert Philip

Other private schools are advertising open air classrooms, *e. g.*, the Horace Mann School, the Packer Institute of Brooklyn and the Brooklyn High School.

All measures to preserve the purity of air and its freedom from dust should be rigidly enforced in schools. Bad ventilation is the rule except in the most modern school buildings. After two hours the air is depressing and carbonic acid is usually found in excess. The problem of how to deal with dust is a difficult one in schools, owing to the expense of really efficient methods. The floors should not have open crevices and dry sweeping should not be allowed. Sweeping with wet saw dust is probably the most effective, and at the end of each term a thorough bacteriological dust disinfection should be carried out by the Department of Health. Dr. J. H. Lowman, of Cleveland, who has instituted great reforms in the hygiene of the schools of that city, recommends not formaldehyde, but that the walls should be cleaned or painted, the furniture washed and the floors treated with dilute solutions of chloride of lime.

We recognize tuberculosis to be one of the greatest dangers to school children, for at the tenth year the Prussian statistics show that out of 100 boys who die, 9.26 die of tuberculosis, and out of 100 girls, 12.02 die of tuberculosis; hence the importance of all hygienic safeguards against this malady.

Tracheo-bronchial tuberculosis and tuberculosis of the lymphatic system are the forms most commonly encountered and strict medical inspection will reveal large numbers of children for whom fresh air schools or sanatorium schools should be provided. In New York City, out of about one hundred thousand children examined in 1905-1906, over one thousand were found to have pulmonary disease, and in almost every case it was the first intimation to the mother that her child had pulmonary tuberculosis.

Besides the Waldschule of Germany there are specially constructed sanatorium schools in Milan, Italy, and vacation colonies have been established near Geneva, the Swiss Government supplying the teacher while philanthropy supports the schools. In Denmark, where the outing vacations are so thoroughly systematized, the teachers are supplied by the state. The United States show promise of carrying out this enlightened method of dealing with the tuberculous problem. Outdoor schools are conducted successfully in connection with private camps for boys and girls. Many of these are in New Hampshire and Maine, in the vicinity of the Rangeley Lakes, and in Oxford County.

IMPORTANCE OF VENTILATION

The first desideratum in tuberculo-therapy and in the prevention of tuberculosis is abundant and free ventilation. The dwelling, the bedroom, the workshop, the office, the church, the schoolroom, the theatre, the modern subway are one and all dangerous in proportion, as their atmosphere is composed of dead or rebreathed air. Not only is tuberculosis favored by unhygienic surroundings and vitiated atmosphere in particular, but no other agent, not excepting alcohol and bad food, so surely undermines the constitution and renders it unable to resist disease. Air that has once been breathed, ought not to be breathed again. Out of doors the danger is minimized; indoors we usually breathe and rebreathe the contained air again and again. To some extent, of course, this cannot be avoided, but we should endeavor to reduce it to a minimum. This subject has been recently investigated by Dr. Thomas R. Crowder, who studied by ingenious methods the effect of such factors as change of position, body motion, different types of breathing and different temperatures and, in addition, has determined the conditions that obtain on the sleeping porch and in the open air. Nasal breathing was the type examined, since in mouth breathing there is, under favorable circumstances, little reinspiration.[1]

The conclusions that may fairly be drawn from Crowder's work are that (1) a person remaining quiet and indoors will immediately rebreathe from 1 to 2 per cent of his own expired air; (2) when lying in bed the percentage is higher, rising to from 4 to 10 per cent, depending on the position assumed while sleeping. "Nor does sleeping in the open insure pure air for breathing. The same influences here produce the same relative results that they do inside. When one buries his head between pillow and bed clothes for the sake of warmth, reinspiration is inevitable, and it is not necessarily small in amount." In addition, it must be noted that at each inspiration we reinhale not only some of the air just exhaled, but also the air contained in the nose and larger bronchi—the so-called "dead-space" air. This may amount to one-third of the whole volume in quiet inspiration and not less than one-tenth in deep breathing.

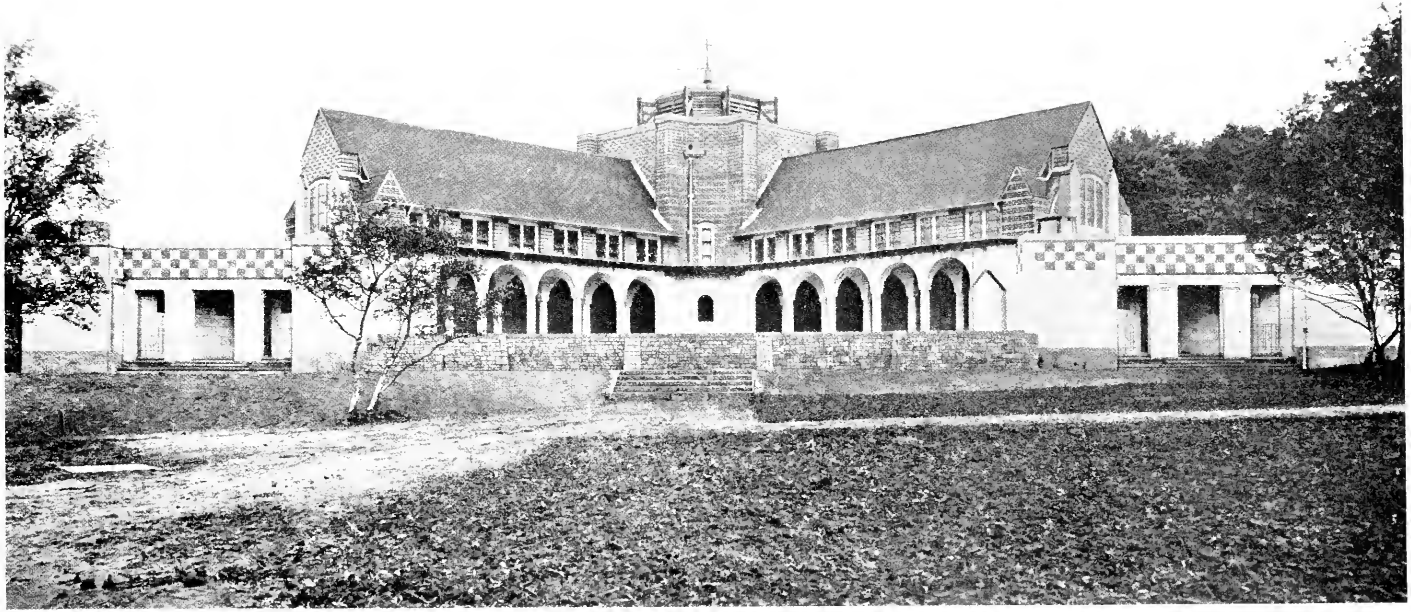
The significance of this study in connection with questions of ventilation is obvious. Since even under the most favorable conditions we cannot avoid drawing back into the lungs some of the air that has just passed out of them, not much importance can be attached to the slight variations in carbon dioxide content which occur in the air of rooms.

---

[1] The Reinspiration of Expired Air. Archives of Internal Medicine, Chicago, October, 1913, p. 1936. Journ. Amer. Med. Ass., Editorial, Nov. 29, 1913, p. 1986.

PORTABLE OPEN AIR SANATORIUM FOR CONSUMPTIVES ON THE GRABOWSEE, NEAR ORANIENBURG. DOECKER CONSTRUCTION

Courtesy of Christoph and Unmack



THE OPEN AIR CHAPEL, KING EDWARD VII SANATORIUM, MIDHURST, ENGLAND

OPEN AIR CHAPELS AND THEATRES

It is remarkable how inconsistent we all are in matters of hygiene. Medical men are often among the worst offenders. Their offices are commonly stuffy, their conventions and social gatherings are often held in inadequate halls in which vitiated air, sometimes reeking with smoke, is perfectly abominable.

> If to do were as easy as to know what 'twere well to do
> Then chapels had been churches and poor men's cottages princes'
> palaces.

We cannot go back to the time of the Druids or worship in groves after the manner of the Greeks, but it seems fitting here to call attention to one chapel that has been specially constructed for out-of-door worship and that is destined to be a model for many a sanatorium at least. This has been constructed for the famous King Edward VII Sanatorium near Midhurst, in Sussex, England. The accompanying illustration of this unique chapel marks a step in advance in sanatorium construction. It is in the Moorish style, shaped like a broad letter V. The double rows of columns of the cloister are on the southerly side, the pulpit and chancel are in the apex and the northerly sides forming the inner walls are provided with arched apertures so that the patients may sit absolutely in the open air but with sufficient protection from the weather at all seasons. In fair weather services are held under the sky in the open space in front of the building between its extended arms. The illustration shows this very beautifully.

Open air theatres were built by the Greeks and Romans and the remains of these structures are among the most interesting of ancient ruins. In Europe the Passion Play at Bayreuth is enacted wholly out of doors, but is entirely apart from our subject except so far as it demonstrates the possibilities of out-of-door representation. The low theatre and concert hall are invariably hot and stuffy and undoubtedly foster tuberculosis by inadequate ventilation. It would be better if we could have some theatres or assembly halls with perfectly free circulation of air.

The Groton School in Connecticut has lately undertaken to build an outdoor gymnasium, so that the boys shall have the advantage of exercise in the open air rather than in an enclosed building. This is the first school we know of to adopt this admirable plan.

VENTILATION OF DWELLINGS

Ordinary dwellings are terribly deficient as regards ventilation. The country dwellings of the poor are strangely defective in this respect. It has been said that the reason why the air in rural districts is so pure is that the poor country people have all the bad air shut up in their houses. There is a great deal of truth in this. Doctors are constantly struggling with the strange aversion that the rural population has regarding sufficient air in the bedrooms. As soon as night falls the windows and doors are tightly closed and the kerosene lamp adds to the pollution of the air. It is a common experience to find the doors and windows kept closely shut owing to the deeply rooted fear of catching cold. In European countries the windows of many of the older dwellings were originally intended for light and not for air, and are merely panes of glass built into the wall and not intended to be opened. Others are so badly constructed that the upper sash cannot be lowered and the lower sash is scarcely ever raised more than a few inches.

The children in many country cottages instead of being rosy and robust, as they should be with healthy surroundings, are frequently pale and bloodless on account of this bad air. This deficient ventilation of country houses and the bad food so common, where milk and eggs ought to be so plentiful and good, conspire to give to some country populations a bad start in the earlier years. No better example can be cited than that of the "poor whites" of the Southern United States. Indolence, ignorance, general helplessness and inertia are their characteristics. Their children are pale and gaunt, and their living quarters are horrible beyond description. It is a wonder the death rate among them is not greater than it is.[1]

It seems very strange, but it is a fact, that about seventy years ago a proposition was made to use the Mammoth Cave in Kentucky as a winter resort for invalids. Sixteen consumptives were sent there to gain the reputed benefit from the equable temperature and asserted purity of the air in that cavern. Five of these patients died and the others were injured as a result of the darkness and dampness combined. That such an irrational and cruel experiment should have been tried seems incomprehensible at the present day.[2]

---

[1] The death rate from pulmonary tuberculosis for Virginia during the year ending June 30, 1913, was for whites 98.4, and for colored 256 per 100,000. The state rate was estimated at 148.

[2] See Croghan: The Mammoth Cave as a Winter Resort for Invalids (Boston Medical and Surgical Journal, 1843, Vol. 28, p. 188).

Daniel Drake, M. D.: Western Journal of Medicine and Surgery, Louisville, Kentucky, 1843, Vol. 7, p. 78.

OPEN AIR DINING HALL. DR. WALTHER'S SANATORIUM, NORDRACH-COLONIE, BLACK FOREST, GERMANY

LAWN CUTTING. GRADUATED LABOR IN PULMONARY TUBERCULOSIS. SANATORIUM OF THE BROMPTON HOSPITAL, FRIMLEY, ENGLAND

ROYAL VICTORIA HOSPITAL FARM COLONY. PLANTING POTATOES. GRADUATED LABOR
Courtesy of Sir Robert Philip

CHAPTER VIII. EXERCISE IN TUBERCULOSIS; GRADUATED LABOR

The Nordrach system of treatment of pulmonary tuberculosis carried out by Dr. Walther and that of his predecessor, Dr. Brehmer, at Goebersdorf, in Silesia, involves much exercise in addition to fresh air and alimentation; the Dettweiler system enjoins rest in the open air with superalimentation. McLean's dictum is: "If the phthisical patient would live, he must work for it."[1] Probably this advice should not be taken too literally, at least by every tuberculous patient; but graduated physical exercise has a very important and useful place in the treatment of most patients. Brehmer advocated hill-climbing, while Walther advises graduated walking exercises, in some cases to the extent of walking twenty miles a day. Whether one practices walking, or hill-climbing or graduated labor, we cannot dissociate from these measures the effect of atmospheric air, in its various qualities, upon the lungs and the accompanying stimulation of the pulmonary and general circulation. Two recent papers by London practitioners are full of such suggestive thoughts on this subject that we call special attention to them. They are considered by some as marking an epoch in the treatment of pulmonary tuberculosis.

At a meeting of the Medical Society of London, January 13, 1908, Dr. Marcus S. Paterson, the Medical Superintendent of the Brompton Hospital Sanatorium, at Frimley, read a paper on "Graduated Labor in Pulmonary Tuberculosis" which was supplemented by another on the "Effect of Exercise on the Opsonic Index of Patients Suffering from Pulmonary Tuberculosis," by Dr. A. C. Inman, Superintendent of the Laboratories, Brompton Hospital.[2]

The patients for whom Paterson instituted graduated labor were selected cases sent from the Brompton Hospital in London to its Sanatorium at Frimley, at an elevation of 380 feet in the country.

He was induced to carry out this plan of treatment after seeing tuberculous patients who did well while working under unfavorable surroundings; but he believed that under careful regulation of labor and with very careful observation of the temperature records, he might safely proceed. The exercises adopted involved all the muscles of the trunk and extremities and this was thought to be better than walking exercises in which the lower limbs were chiefly employed. The use of the upper limbs seemed more likely to favor

---

[1] McLean: Personal Observation in Phthisis Pulmonalis (Journal Amer. Med. Ass., February, 1898).

[2] The Lancet, January 25, 1908.

the expansion of the lungs. It was not forgotten that the common objections to this plan of treatment are, (1) that the disease would become active again under the strain; and (2) that the exertion would tend to produce hemoptysis. Considerable tact and personal influence must have been exerted to get the patients to carry out a plan which involved increasing labor and measures that are generally considered positively harmful.

The first exercise ordered was walking, the distance being gradually increased up to ten miles a day. When a patient had reached this stage he was given a basket in which to carry mould for spreading on the lawns. No case of hemoptysis or of pyrexia occurred among these patients. When they had been on this grade with nothing but beneficial results for from three weeks to a month, they were given boys' spades with which to dig for five minutes followed by an interval of five minutes for a rest. After a few weeks, several of the patients on this work, who were doing well, were allowed to work as hard as possible with their small spades without any intervals for rest. As they had all improved on this labor larger shovels were obtained, and it was found that the patients were able to use them without the occurrence of hemoptysis or a rise of temperature. About this time many of the patients were feeling so well that it became necessary to restrain them from doing too much.

These results in a few cases creates a most favorable sentiment among the other patients so that the system was extended generally, with great care and minute supervision. Harder work was prescribed for patients who could be trusted even to the use of spades, shovels and five pound pick-axes. The patients all expressed the opinion that the work did them good and that the harder they worked the better they felt. Many patients have written to Dr. Paterson to say that they date their improvement from the commencement of the labor, and that they think the hardest work did them the most good. It certainly speaks well for the strict supervision of these patients that no accidents occurred of a serious nature, though several developed fever and, subsequently, pleurisy. One patient was laid up for two months and was much worse at the end of that time, though eventually he did well and returned to work, though the extent of his disease was increased through overexertion.

The suitability of cases for graduated labor rests on a very careful physical examination, importance being laid on the general muscular and physical development. Marked wasting and poor development is, naturally, a bar to this method of treatment. The resisting power

ROYAL VICTORIA HOSPITAL FOR CONSUMPTION, EDINBURGH. GRADUATED LABOR; ROAD MAKING BY THE PATIENTS ON HEAVY GRADE WORK. THERAPEUTIC AUTO-INOCULATION ARTIFICIALLY CONTROLLED BY MANUAL LABOR

Courtesy of Sir Robert Philip

THERAPEUTIC AUTO-INOCULATION ARTIFICIALLY CONTROLLED BY MANUAL LABOR. LOOMIS SANATORIUM, NEW YORK.
LIGHT GRADE WORK IN THE GARDENS

of a patient with a very limited lesion is an unknown quantity and has to be determined, whereas a patient with a lesion involving four lobes may remain at work for some time and exhibit a good initial resisting power.

Dr. Paterson lays very great stress on the temperature taken in the mouth. If this is or has been 99° F. or over during the week preceding admission to the sanatorium, the patient is put to bed after the journey. So long as the temperature remains at 99° F. in the case of men or 99.6° F. in the case of women, the patient is not allowed up for any purpose. So long as the temperature is unaffected by exertion the patient is gradually allowed up for longer and longer periods. Patients with apparently limited disease, but who are in poor general condition and without fever, are allowed to be up all day, but are not permitted to take further exercise than is entailed by walking to and from the dining hall for their meals. The remainder of the day is spent in resting. As their condition improves they are allowed to walk half a mile a day, and so on, until a distance of six miles a day is reached. The rate of increase in the amount of exercise depends upon such factors as the patient's disposition, weight and appetite.

The grades of work are briefly as follows:

(A 1) Walking from one-half to ten miles daily.
(1) Carrying baskets of mould or other material.
(2) Using a small shovel.
(3) Using a large shovel.
(4) Using a five-pound pick-axe.
(5) Using a pick-axe for six hours a day.

Patients in grades 1, 2, 3, and 4, work four hours a day.

The basket work in which about eight pounds of earth are carried is considered the most important and, as a rule, patients spend far more time in this work than in any other. It brings into use all the muscles.

Work has a wholesome effect on the mind. If the patient is at first sullen and apathetic, the improvement in physical condition quickly begets a lively and cheerful mental attitude, and one that seeks work rather than to shirk it.

During 1905 and 1906 the number of patients discharged from this sanatorium was 164, and they all returned to their previous occupations, whatever they happened to be, and not to light, outdoor work. They were fitted by the line of treatment which we have described for effective wage earning.

We have dwelt quite fully on this innovation in tuberculo-therapy because it gives promise of good, practical results and, further, because it is so radically different from the prevailing methods adopted in most sanatoria. But, the most interesting feature is the explanation which is offered to account for the benefits which has accrued. This explanation is set forth in an elaborate study made by A. C. Inman, M. B., the superintendent of the laboratories of the Brompton Hospital, on the "Effect of Exercise on the Opsonic Index of Patients Suffering from Pulmonary Tuberculosis."[1]

This study of Inman's was prompted and made possible by the brilliant work of Sir Almroth Wright. Wright showed in his Harveian Lecture in New York, that there are three great agencies by which immunizing responses can be evoked in the organism:

(1) By the inoculation of bacterial vaccines.
(2) By artificially induced auto-inoculations.
(3) By spontaneous auto-inoculations.

Wright had previously elucidated the subject of vaccine therapy by constructing curves from the opsonic indices of patients vaccinated against their infection and in this manner traced a definite train of events which follow upon a single inoculation. The successive phases were termed the negative phase, the positive phase and the phase of maintained high level. Freeman, working in Wright's laboratory, then took up the subject of massage in its effect on gonococcal joints showing that "*Auto-inoculations follow upon all active and passive movements which affect a focus of infection and upon all vascular changes which activate the lymph-stream in such a focus.*"

Wright's dictum was that "where in association with a bacterial invasion of the organism bacteria or bacterial products pass into the general lymph, and blood-stream, intoxication effects and immunizing responses, similar to those which follow upon the inoculation of bacterial vaccines, must inevitably supervene." It is a perfectly logical conclusion, then, that nature cures bacterial infections through such auto-inoculations. Inman set himself to find out what the body is doing of itself and what value extraneous circumstances, such as physical exercise, have in aiding these attempts on the part of the body. Inman's work was conducted on a carefully planned technique, controlled and checked at all points, using forty-three patients in the sanatorium treated by the System of Graduated Labor.

Inman found that in 41 out of 43 cases the opsonic index was at

---

[1] Read before the Medical Society of London, January 13, 1908.

THERAPEUTIC AUTO-INOCULATION ARTIFICIALLY CONTROLLED BY MANUAL LABOR. LOOMIS SANATORIUM, NEW YORK.
HEAVY GRADE WORK; ROAD MAKING

THERAPEUTIC AUTO-INOCULATION ARTIFICIALLY CONTROLLED BY MANUAL LABOR. LOOMIS SANATORIUM, NEW YORK.
HEAVY GRADE WORK; ROAD MAKING

some time of the day well above the normal, and what is of even more importance, in no case did the exercise, even though severe, lower the index below the normal line—that is, the auto-inoculation was never so great as to produce a negative phase and, therefore, never in excess.

> It was observed during these investigations that in some bloods examined, tuberculo-agglutinins appeared in association with the immune tuberculo-opsonins. This must be taken as another evidence of an immunizing response on the part of the organism. When the difficulties of such a method of treatment and the danger of the weapon employed are taken into consideration it will be readily understood that every now and then, in spite of the most careful supervision, an excessive auto-inoculation must take place. Such an over-dose is readily recognized clinically. A patient doing well on the grade of work prescribed for him and with no abnormality of temperature suddenly complains of feeling tired, of loss of appetite and of headache; and the temperature chart registers an elevation to 99° or 100° F. These are precisely the symptoms which are found during the negative phase after an excessive dose of bacterial vaccine.

Thus we have a new scientific test by which the effect of physical exercise on the blood of patients has been traced. As Inman says:

> The opsonic index has shown that the exercise has supplied the stimulus needed to induce artificial auto-inoculation, and that this systematic graduation has regulated this in point of time and amount. This co-operation with the natural efforts of the blood has enabled Dr. Paterson to send his patients back to their accustomed work, however hard it may be. But the investigation has done more than explain a successful mode of treatment. Dr. Paterson agrees with me that with the aid of the opsonic index he can regulate the stimulus with scientific accuracy and obtain his results more certainly and more rapidly. This, of course, involves work in the laboratory. But it also means a more rapid and a more certain discharge of the patient which is the main object of the sanatorium.

Fresh air, exercise, and proper food seem then to constitute the foundation of successful treatment of tuberculosis. The improvement of the general condition of the patient and life in the open air evidently needs to be supplemented by certain exercise so as to produce a series of auto-inoculations and probably the best method yet devised is by the system of graduated labor just described.

All sorts of exercises such as horseback riding, golfing, light dumb-bell exercises and other calisthenics have been practiced for many years in treating tuberculosis; walking exercises have been the feature of some of the German sanatoria referred to; patients sent to the western states and territories almost invariably practiced outdoor exercises, some with great harm and some with benefit. Neither physician nor patient in most instances regulated these exercises intelligently, but groped in the dark, never dreaming of the underlying principles as explained by laboratory studies of Sir Almroth Wright, Paterson, Inman, and others. We trust that further studies and the application of the same method in Europe and America will fix the value of exercise in tuberculosis.

A somewhat similar system of graduated labor has been adopted in the King Edward VII Sanatorium near Midhurst, England. Light work in the gardens and grounds is prescribed in lieu of some of the walking exercise and forms part of the regular treatment. Practical gardening in the grounds and flower beds is utilized. The lightest labor consists of weeding, hoeing and edging paths and borders, gathering seeds, plucking dead flowers, pruning, etc. Somewhat harder exercise consists in wheeling soil to the lawns and spreading it, clearing ground of stones and taking them away in barrows, and in leveling new ground after being broken up. The heaviest work is that of digging and trenching unbroken ground, moving, rolling, etc. Paths through the pine woods have also been constructed. In this particular work the breaking up of the ground with picks and clearing away the roots from neighboring trees was allotted to the first division of patients. The second division cleared away the broken ground and roughly leveled it. The third division finished the leveling of the paths with rakes and tidied up the edges.[1]

Free patients at the King's Sanatorium have made a cinder tennis court; they have cut down and sawed fire wood; they have an open air carpenter shop and an instructor in carpentry, who is himself a patient; they care for the poultry and make the runs for the fowls. In this way patients are constantly occupied.

Although the system of graduated exercises, or labor, adopted at the sanatoria referred to, has attracted wide notice and its principles were there first placed on a highly scientific basis, there were previous attempts to do this in an intelligent and rational manner. Sir Robert Philip, at Edinburgh, over twenty years ago, before the bacteriology of tuberculosis had been so well developed, prescribed practically the same thing as a therapeutic measure of definite dosage. He had had classes of selected patients who came at fixed hours to take regular training with regard to posture and healthy respiratory movement. More especially the young were taught the value of a healthy form of chest, the principles of nose-breathing and full diaphragmatic movement. "In addition to this, measured walks of varying amount and gradient were prescribed exactly

---

[1] Noel Dean Bardswell, Tuberculosis, Berlin, May, 1908.

as we prescribe medicines. Thus we had walks radiating from the dispensary round the meadows, walks over the Bruntsfield Links and walks in various directions on the slopes of Arthur's Seat. The patients reported, at successive visits, their experience in carrying out such instructions and notes were made of the effects produced." Here we see the germ of the class method so well developed and practiced by Pratt, of Boston, although he is an apostle of rest rather than labor.

The results in Philip's hands were eminently satisfactory. "The patients did remarkably well and no accident was traced to the adoption of active movement instead of rest. The experience led to a change in my outlook in relation to the meaning of treatment in tuberculosis." Philip came to the conclusion that by the establishment of hospitals or sanatoria for patients in the earlier stages of tuberculosis "we might hope to achieve permanent cures to a degree not dreamt of, by elaboration of the principle of regulated exercises and graded activity of all kinds." These conclusions were justified by the results obtained "in the home treatment undertaken for so many years at the Victoria Dispensary and in the systematized *régime* of work at the Royal Victoria Hospital and the recently opened Farm Colony."

Sir Robert Philip lays great stress on the well-known fact that there is a progressive intoxication in tuberculosis and the toxins produced by the tubercle bacillus appear to exert their vicious influence particularly on the neuromuscular apparatus. The toxin is especially a muscle poison.[1] There is a visible and palpable progressive wasting of the muscles, both of the trunk and the extremities, with advancing flaccidity and increased myotatic irritability. It is an expression of malnutrition, a muscular dystrophy dependent on intoxication. The obvious conclusion is that by the institution of natural movements the physiologic cure of "recreation" is assisted and health gradually returns.

Sir Robert's scheme of physical treatment at the Royal Victoria Hospital is worthy of mention. On admission each patient is placed at complete rest. During this stage, in addition to minute examination of every organ, the patients general condition is carefully observed. According to the estimate which is made the length of the resting period is fixed. Thereafter, in the absence of counter-indication, the patient is gradually advanced through the other stages.

---

[1] R. W. Philip, Trans. International Med. Congress, Washington, 1887, Vol. 1, p. 205.

The dose of exercise is increased or diminished as the temperature chart, pulse rate and other indications suggest. A colored badge is given to the patient to denote the stage he has reached.

I. Resting Stage, as noted above. (White Badge.)

II. Stage of Regulated Exercises. (Yellow Badge.) This includes (1) walking ¼ to 5 miles; (a) on the level; (b) on sloping ground. (2) Various respiratory exercises once or twice a day. (3) Other forms of movements to improve carriage of shoulders, head, chest, etc.

III. Stage of Regulated Work. (Pale Blue Badge.)

IIIA. Picking up papers, leaves and other light rubbish on the grounds; knitting; sewing; drawing.

IIIB. (Green Badge.) Emptying waste garden boxes and assisting to carry away rubbish. Carrying light baskets for various garden purposes. Light painting work, wiping shelters; setting tables and laying cloth in patients' dining room; cleaning silver, brasses, taps, etc.

IIIC. (Deep Blue Badge.) Raking, hoeing; mowing; sweeping leaves; light wheel-barrow; heavier painting work; sweeping shelters; scrubbing floors; cleaning knives; assisting in laundry; washing dishes.

IIID. (Red Badge.) Digging; sawing; carrying heavy baskets for various gardening purposes; wheeling and drawing full wheel-barrow and other heavy gardening work. Window cleaning and polishing floors; sweeping and cleaning court yard. Carpentering; joinering; engineering; attending boiler; errands.

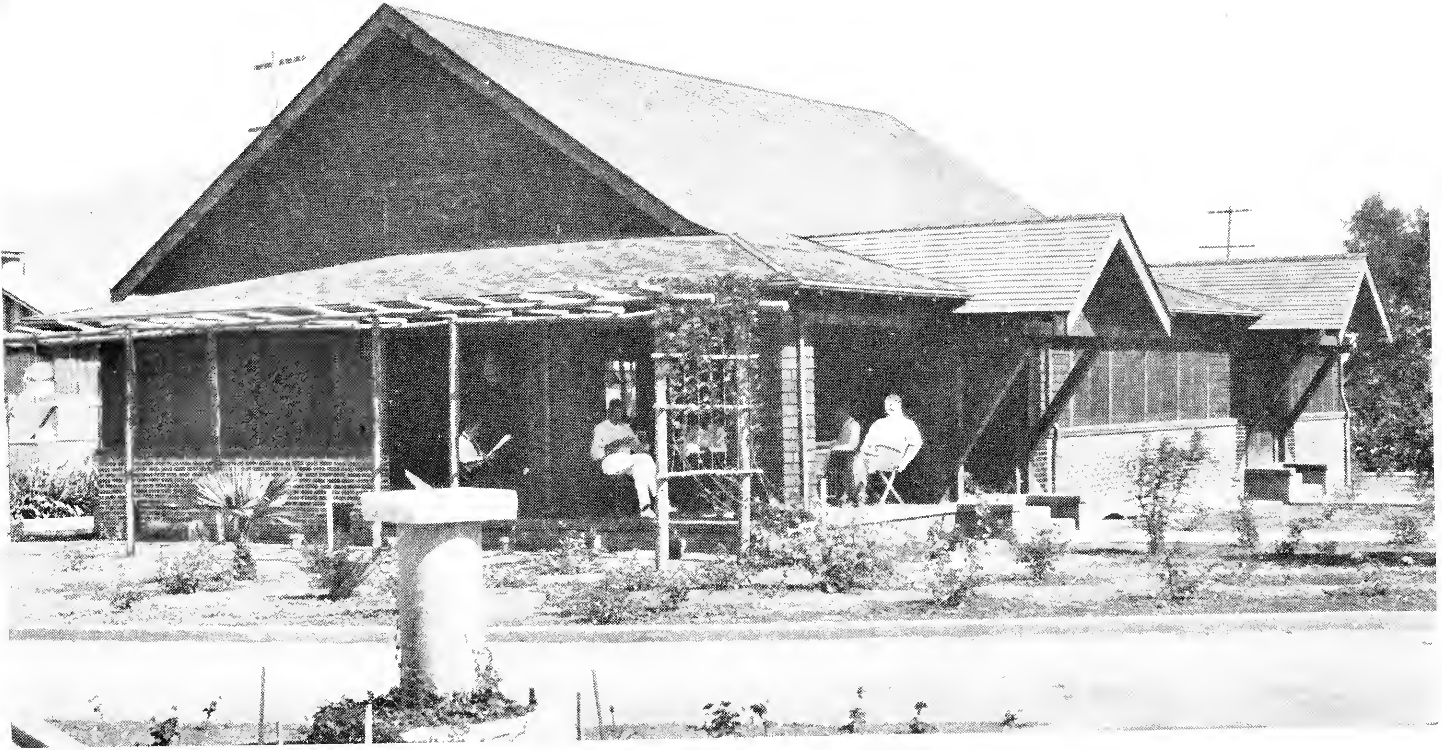
An institution providing diversified occupations has a great advantage over one whose patients are restricted to walking exercises and where the women are employed in kitchen work and the men as laboratory orderlies, assistants in the drug rooms, clerks and so on. It is well to vary the walking exercise with manual labor. Patients welcome it and take a great interest in the various occupations they are put to. They acquire confidence in themselves as they see their muscular tone improving and some prospect of resuming useful occupations.

With various modifications suggested by local conditions the system of graduated labor described above is now adopted at various institutions in America; in many cases, however, the economic aspect of the plan of treatment apparently overshadows the therapeutic features; probably the best examples of the method are at the Loomis Sanatorium, New York, Otisville State Sanatorium, New York, The Adirondack Cottage Sanitarium, New York, The North Reading State Sanatorium, Massachusetts, and The Barlow Sanatorium, Los Angeles, California. Dr. Barlow has kindly sent me the following description of the method he has carried out:

This institution is semi-charitable and receives cases in all stages.

You ask me to send you a statement of our use of graduated labor. I will give you the facts as we handle the matter, which is somewhat modified to

TENT HOUSES. BARLOW SANATORIUM, LOS ANGELES, CALIFORNIA



BARLOW SANATORIUM, LOS ANGELES, CALIFORNIA meet the needs of our institution. It seems to me that every institution must modify this according to the facilities at command. Our working plan is as follows:

All the patients without any fever are kept absolutely quiet for the first two or three weeks, except that they are allowed to go to the dining room for meals. If, during this time, there is no elevation of temperature, no marked acceleration of pulse, and no loss of weight, they are started on exercise, beginning with ten minutes' walking twice a day. If they continue to do well, gain weight, temperature remains normal, and progress of physical signs is favorable, then exercise is increased every two weeks. The amount of exercise is charted for each patient; one copy posted on the bulletin board, and one copy retained by the nurse in charge of the order, to check up the allowance for each patient. Patients who have more than ten minutes' exercise twice a day make their own beds and keep their rooms in order, except the heavy cleaning. After patients have reached an allowance of thirty minutes twice a day, they are assigned to more practical work about the place or grounds. In making these assignments, the patient's physical condition and progress, former, and probably future, occupation are considered. Most of these assignments are changed each month, the effort being to try to increase the work each month. The work done includes the setting of tables in the dining room, removing and washing dishes, work in the diet kitchen, looking after books and pamphlets in the library, cataloguing books, statistical work, stenography and typewriting, carrying mail, light repairs about buildings, care of paths and summer-houses, sprinkling during dry weather, and operating the incinerator. Many patients are assigned to flower beds of their own, or to doing light work in caring for the sanatorium grounds. In carrying out this exercise or labor, careful watch is kept over patients, and if any elevation of temperature, acceleration of pulse, or extension of physical signs are observed, they are put back to rest. The purposes that this exercise and labor seem to serve are, recreation, stimulating the appetite and digestion, building up healthy tissue, inducing healthy sleep, and testing the patients against relapses when they resume their normal way of living after being discharged. We find that patients who accept the occupation cheerfully make better progress mentally and physically than those who resent being assigned to duties.

For patients with an elevation of temperature 99° or over, acceleration of pulse, either loss or no gain in weight, or who do not show improvement in other ways, rest is continued, and exercise or assigned work is deferred.

At the present time (December 11, 1913), there are 43 patients in the sanatorium. Ten are in the infirmary; thirty-three in open-air cottages; of the latter twenty-seven are doing their own work, and twenty-five additional assigned work. Of the six in open air cottages not doing their own work, three are new patients who have been recently admitted and not under observation a sufficient time for report.

REFERENCES TO WORKS ON EXERCISE AND WORK

Sir Robert W. Philip: Rest and Movement in Tuberculosis (British Medical Journal, December 24, 1910).

Albert Robin: How Consumption is Cured by Work (Therapeutic Gazette, December, 1911, p. 854-865).

Lawrason Brown and F. H. Heise: Properly Regulated Rest and Exercise in Pulmonary Tuberculosis (Journal of the Out-Door Life, August, 1912).

J. W. Flinn: Rest and Repair in Pulmonary Tuberculosis (Journ. Amer. Med. Ass., Aug. 16, 1913, p. 466).

L. Teleky: Choice of Occupation with Regard to Tuberculosis (Wien. klin. Wochnschr., March 13, 1913; abstr., Journal Amer. Med. Ass., April 26, 1913, p. 1336).

S. R. C. Halcomb: Graduated Labor in Pulmonary Tuberculosis (Military Surgeon, February, 1913; abstr., Journ. Amer. Med. Ass., Oct. 26, 1912, p. 1564).

J. W. Allan: Graduated Labor at Bellefield Sanatorium (Glasgow Med. Journ., January, 1911; abstr., Journ. Amer. Med. Ass., Feb. 4, 1911, p. 384).

A. P. Francine: Rest, Exercise and Food in the Management of Tuberculosis (New York Med. Jour., Dec. 31, 1910; abstr., Journ. Amer. Med. Ass., Oct. 29, 1910).

M. Paterson: Treatment of Pulmonary Tuberculosis by Graduated Rest and Exercise (Practitioner, January, 1913).

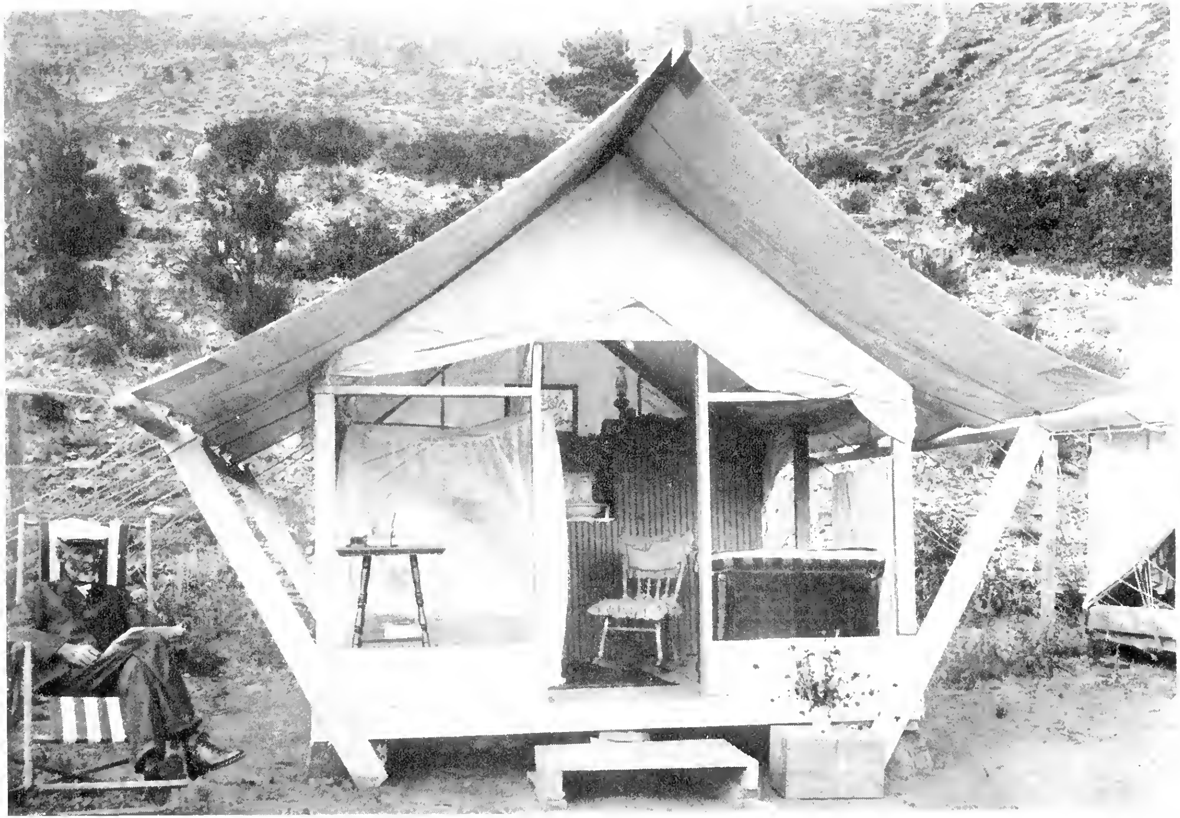
C. C. MacCorison and N. B. Burns: Method of Recording Exercise Data in Sanatorium for Consumptives (Boston Med. and Surg. Journ., May 9, 1912).

CHAPTER IX. ACCESSORIES FOR THE FRESH AIR TREATMENT OF TUBERCULOSIS

It would be impossible to carry out the fresh air treatment of tuberculosis without some special facilities or accessories. These vary somewhat in accordance with the plan of treatment, whether singly or collectively; or in cities, forests, or plains. Among these accessories we include: (1) Tents; pavilion tents. (2) Tent houses; shacks, "lean-tos." (3) Disused trolley cars. (4) Balconies or leigeterrasse for day use. (5) Day camps. (6) Sleeping porches or balconies. (7) Wooden pavilions. (8) Glass pavilions. (9) Hospital roof wards. (10) Detached Cottages. (11) Sleeping canopies.

Tents.—Tents have the advantage of low cost, portability, and the fact that they are adapted for almost any locality, whether in the city, the forest, or the plains. In the city a tent for the use of a tuberculous patient usually attracts too much notice and unfavorable comment unless placed in a rural district. It is possible, however, to erect tents in the heart of a great city, hundreds of feet above the ground where an abundance of pure air and sunlight are obtained. The modern hotel or office building can furnish a far better site, in these particulars, than many rural districts. The author is not aware of any extensive use of tall buildings for the treatment of pulmonary tuberculosis, but it would seem to be an entirely feasible proposition.

TENTS FOR TUBERCULOUS PATIENTS, SUNNYREST, WHITE HAVEN, PENNA.



ESTES PARK, COLORADO. CHEAP BUT COMFORTABLE TENT FOR SUMMER USE
Courtesy of Dr. S. G. Bonney

Anyone who will read the interesting story by Van Tassel Sutphen entitled "The Negative Pole,"[1] will find the history of an interesting case of pulmonary tuberculosis cured by residence of eighteen months on the top of a modern "skyscraper." The patient had been advised to remove to Arizona, but circumstances made this advice impossible to follow; as an alternative measure he isolated himself almost entirely from the world in the midst of a metropolis, and was rewarded by a complete cure. The imaginative author of this original story assigns to the patient a much more difficult rôle than need be assumed by anyone who may follow the general line of treatment and perhaps we may hear of many who may be encouraged to carry out the plan suggested.

In the forest during the warmer season tents are almost indispensable. A substantial tent properly erected, protected with a "fly" and with a surrounding trench to provide for excessive rainfall, can be made a comfortable and healthful habitation during a large part of the year.

The ventilation of tents, and their heating in cold weather, have received a great deal of study, and as they are perfected in these respects their suitability for a continuous residence throughout the year has been proved. Tents can be made storm proof and almost as comfortable in stormy weather as an ordinary building. On Blackwell's Island and on Ward's Island, New York City, tents are in constant use, with astonishing success for tuberculous patients.

At the Manhattan State Hospital East, for the insane, Ward's Island, New York City, the late Dr. A. E. Macdonald instituted, in 1901, a tent colony for the tuberculous patients.

This experiment resulted most favorably and led to the extension of the outdoor treatment to other classes of the insane besides the consumptives. For thirteen years the consumptive insane on Ward's Island have been treated in tents and pavilions. Tuberculous infection has been removed from the wards and 11.39 per cent of patients are reported to have had their tubercular disease arrested. They almost invariably gained flesh; one is reported to have gained 79.5 lbs. (Eighth Annual Report, Manhattan State Hosp., New York.) In the Eighth Annual Report the following comment is made: "In our experience the winter months have proven to be the most favorable for these patients, despite popular opinion to the contrary, and likewise it is seen that the summer month of July was in a decided manner proven to be the least favorable of the year."

---

[1] Harper's Magazine, July, 1908.

The accompanying illustrations show fully the initial stage of this experiment in a portion of New York City having many natural beauties. But in the course of time it was apparently realized that the same results might be obtained with other structures of a more permanent character and I am informed by Dr. William Mabon, the superintendent and medical director, that the tents have been replaced by wooden and glass camps. The reason for this change is that the tents were found to be very close and unsatisfactory in wet weather, whereas the wooden camps can be opened and ventilated under all conditions of weather.

Pavilion Tents.—On Blackwell's Island, New York, the Metropolitan Hospital makes use of twelve pavilion tents with a capacity for 142 patients. Steam pipes are arranged in a double circuit and in some cases stoves render these pavilion tents comfortable in winter and were preferred by the majority of the patients, in the coldest weather, to the ordinary quarters in the main building of the hospital. These pavilion tents were devised by Dr. A. M. Holmes, of Denver.

The tent devised by Dr. Charles Fox Gardiner, of Colorado Springs, is largely used in western sanatoria and has some notable advantages. It is of conical shape, like the Sibley army tent, with a ventilator at the apex of the cone which may be opened or shut. The board floor has an air space beneath and air inlets opening at the floor between the interior wainscoting and the tent wall supplying air at the height of three or four feet above the floor. This is an improvement over the method of allowing air to enter at the floor. These inlets are controlled by hinged lids. This tent avoids the use of a center pole, pegs, or guy-ropes, as it is supported by two-by-four-inch timbers reinforced by angle irons and plates. This tent costs from $90 to $100 and is thoroughly practical. It is not unlike the Nordrach tent. (See plate 55.)

The tent devised by Dr. H. L. Ulrich, of Minneapolis, is simpler and less expensive. It consists of a wall tent with ridge pole for the tent, and another 12 inches clear above it for the "fly." There are ventilating openings on either side of the tent ridge. The tent and "fly" are secured by guy-ropes and pegs and all four sides may be rolled up and lowered as required. A stove may be used in cold weather. A tent 10 by 12 feet costs $22.50.

Other excellent tents have been devised by Prof. Irving Fisher, of New Haven, Dr. Mary Lapham, of Highland, N. C.,[1] and Dr. James A. Hart, of Geneva, New York, and Colorado Springs.

---

[1] American Medicine, Phila., 1905, Vol. 9, 517.

UNITED STATES PUBLIC HEALTH SANATORIUM, FORT STANTON NEW MEXICO. SHOWING TENTS OCCUPIED BY CONSUMPTIVE EMPLOYEES

FIG. 1. MANHATTAN STATE HOSPITAL, EAST, WARD'S ISLAND, NEW YORK CITY. TENTS FOR THE TUBERCULOUS INSANE

FIG 2. MANHATTAN STATE HOSPITAL. EAST, WARD'S ISLAND, NEW YORK CITY. CAMP C, FOR DEMENTED AND UNCLEANLY TUBERCULOSIS INSANE PATIENTS

FIG. 1. MANHATTAN STATE HOSPITAL, EAST, WARD'S ISLAND, NEW YORK CITY. TENTS FOR THE TUBERCULOUS INSANE. SUMMER LOCATION

FIG. 2. MANHATTAN STATE HOSPITAL, EAST, WARD'S ISLAND, NEW YORK CITY. CAMP A, FOR THE TUBERCULOUS INSANE. SUMMER LOCATION

FIG. 1. TENT DEVISED BY DR. CHARLES F. GARDINER, COLORADO SPRINGS. SEE PAGE 122

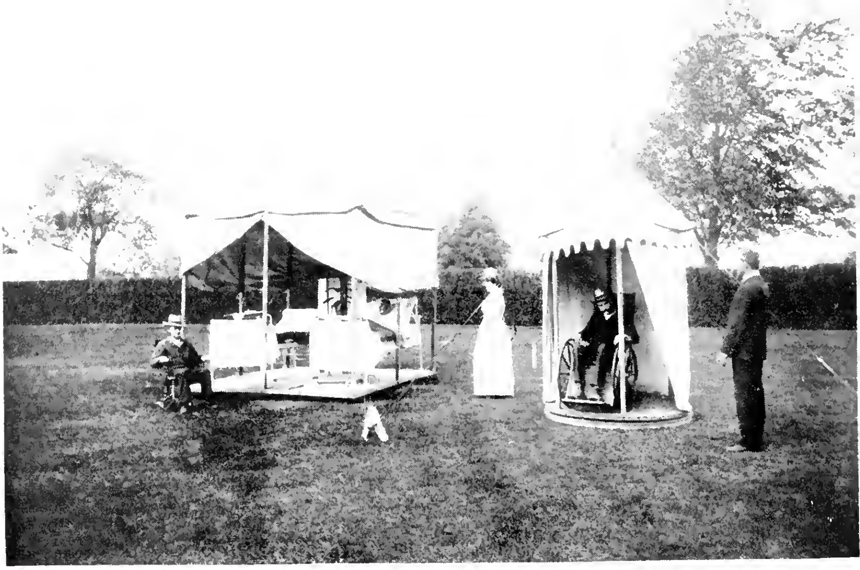
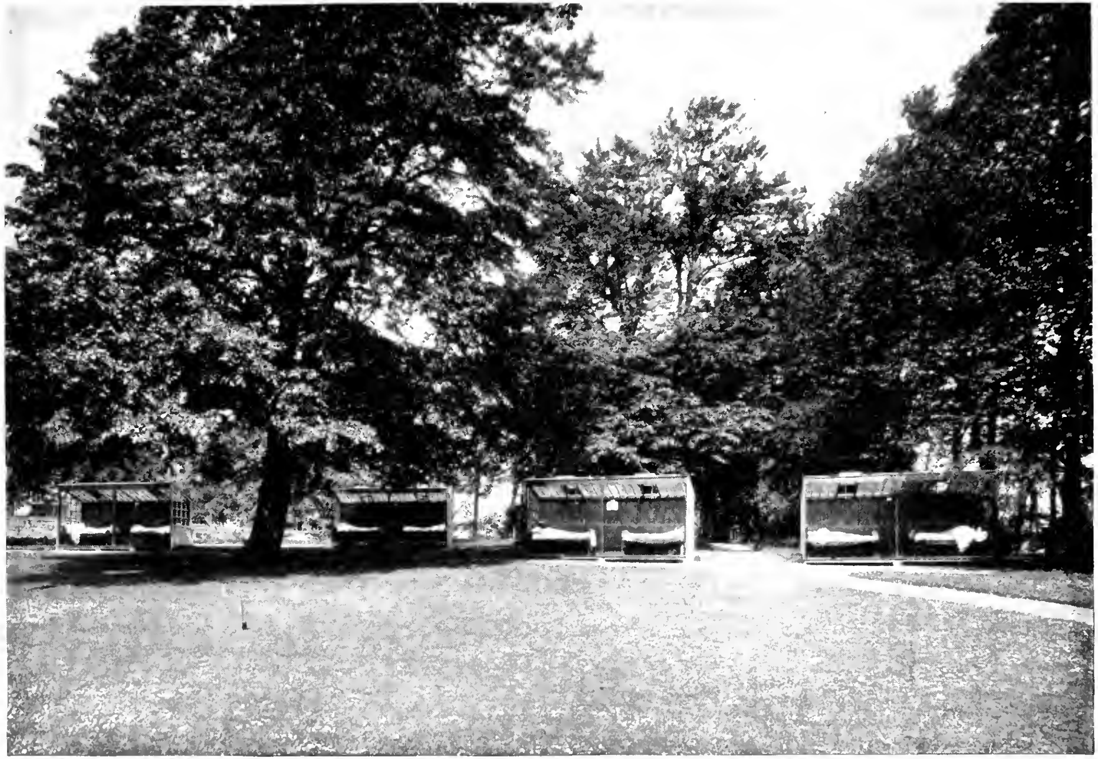


FIG. 2. MANHATTAN STATE HOSPITAL, EAST, CAMP A. INSANE TUBERCULOUS PATIENTS. REVOLVING TENT CONSTRUCTED SO AS TO BE EASILY TURNED IN ACCORDANCE WITH THE DIREC TION OF SUN AND WIND.

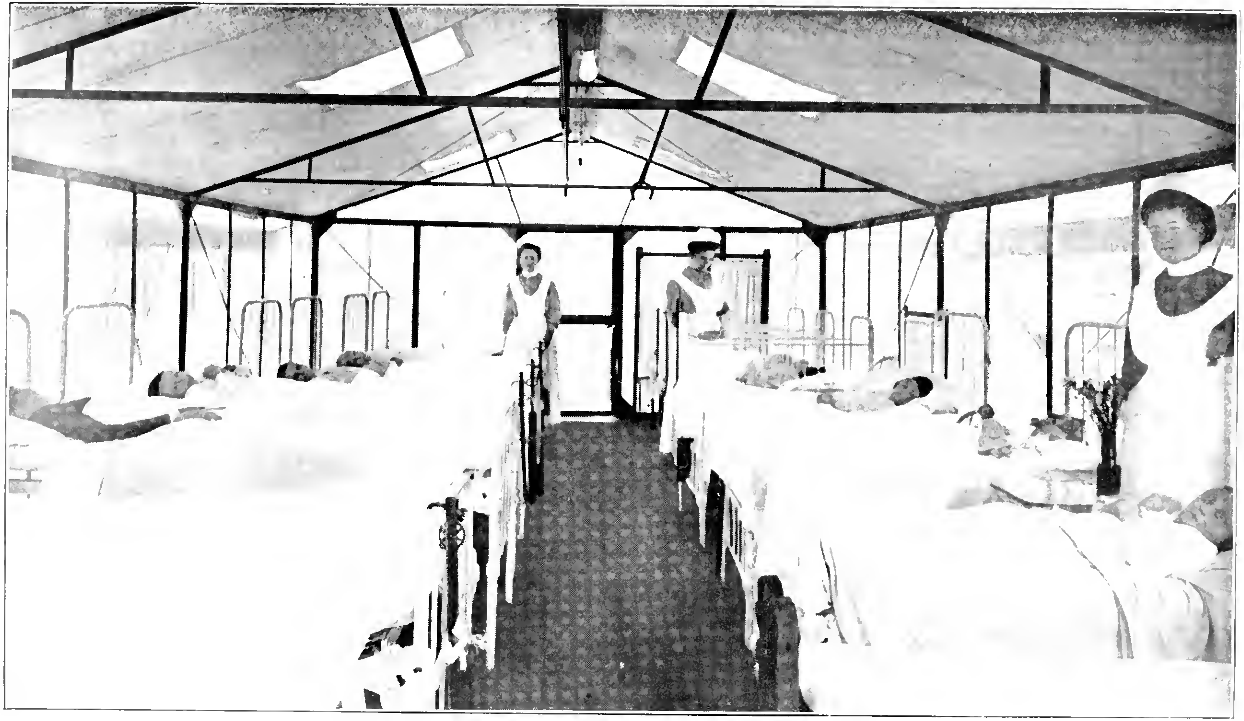


ROYAL VICTORIA HOSPITAL FOR CONSUMPTION, EDINBURGH. SHELTERS ARRANGED FOR NIGHT USE. THESE ARE USED ALL THE YEAR ROUND

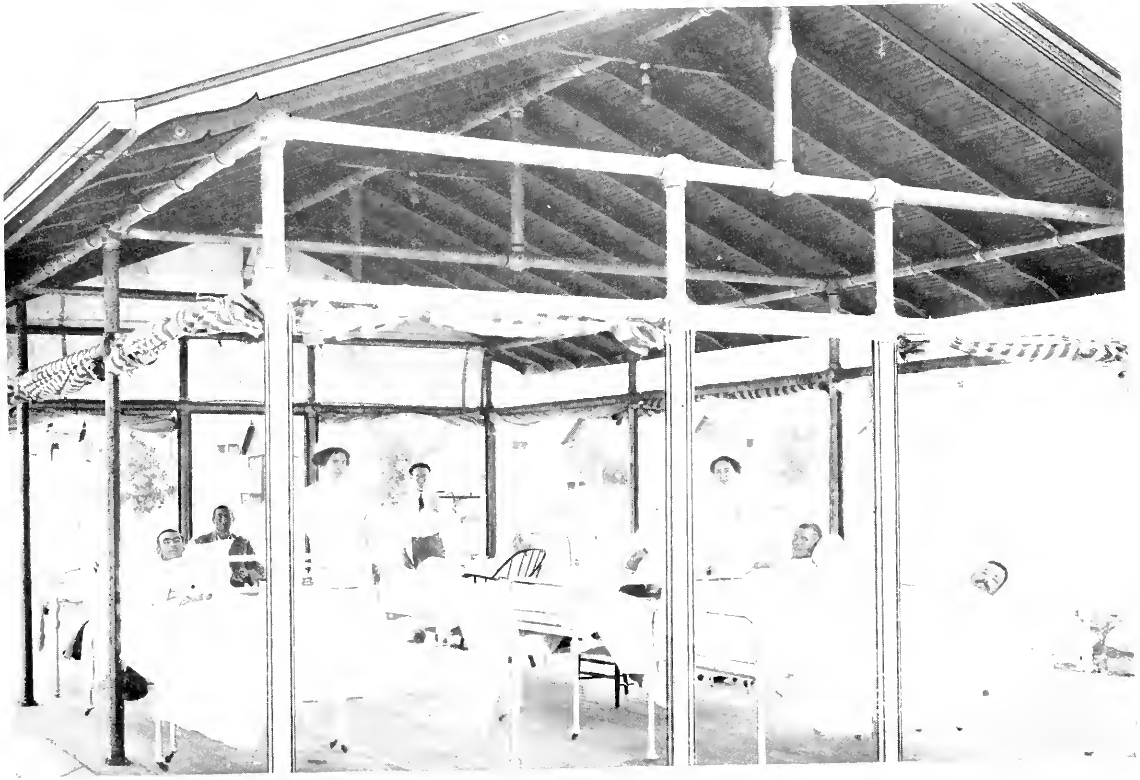
Courtesy of Sir Robert Philip

FIG. 1. MANHATTAN STATE HOSPITAL, EAST, WARD'S ISLAND, NEW YORK CITY. NEW OPEN SHELTER FOR THE TUBERCULOUS INSANE

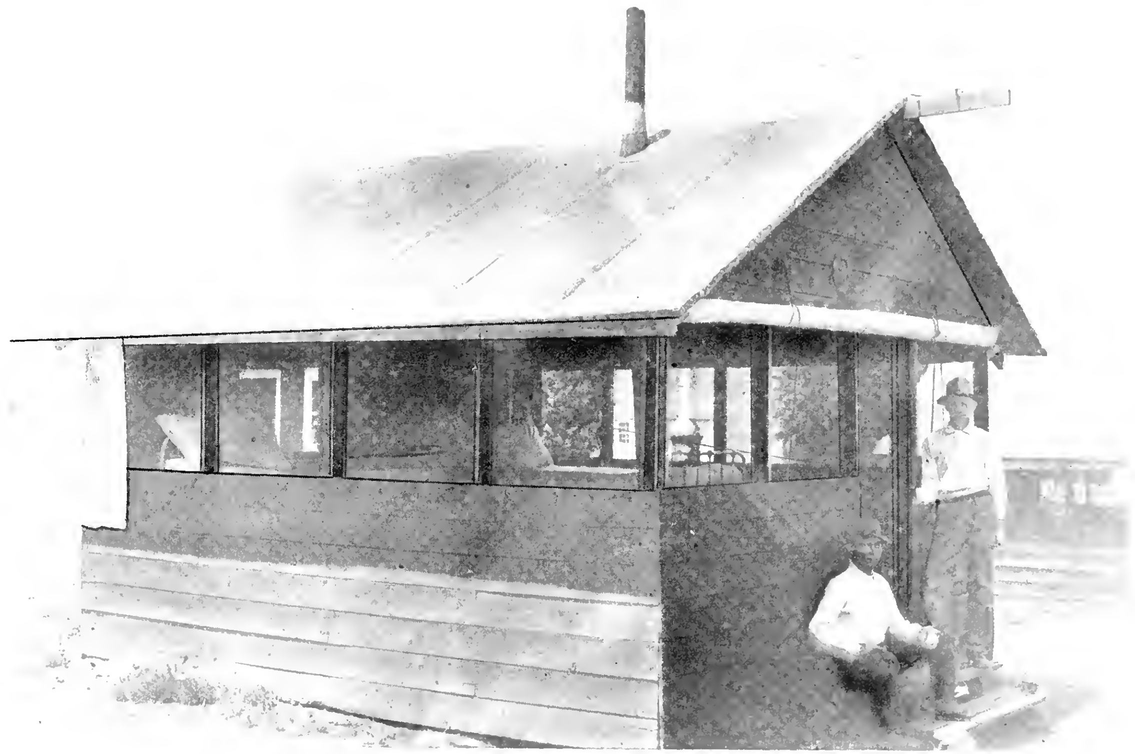
FIG. 2. LOOMIS SANATORIUM, SULLIVAN COUNTY, NEW YORK. SLEEPING GALLERY IN GUILD LEAN-TO



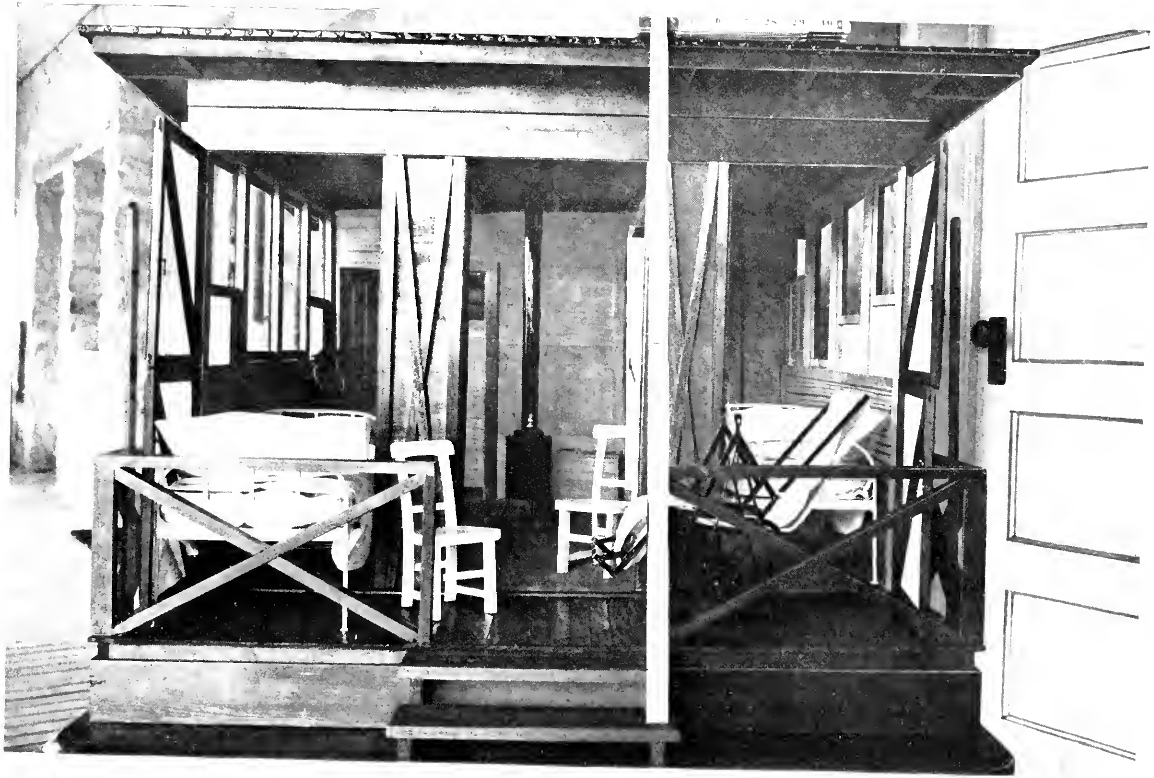
INTERIOR VIEW OF OPEN AIR COTTAGE USED BY STATE HOSPITAL FOR CRIPPLED AND DEFORMED CHILDREN, AT ST. PAUL, MINNESOTA
A PERFECT OPEN AIR TREATMENT. PATIENTS PROTECTED FROM SUN, FLIES AND MOSQUITOS
Courtesy of the Metal Screened Cottage Company, St. Paul



BED SHELTER, UNITED STATES PUBLIC HEALTH SERVICE SANATORIUM, FORT STANTON, NEW MEXICO, 1912

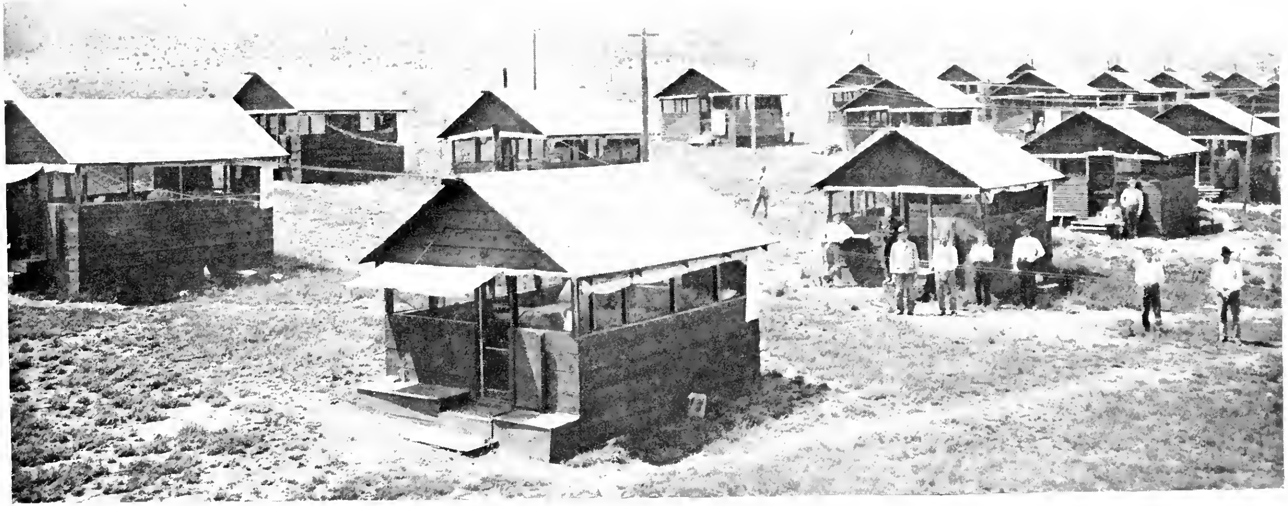


TENT HOUSE, TYPE B, UNITED STATES PUBLIC HEALTH SERVICE SANATORIUM, FORT STANTON, NEW MEXICO, 1912

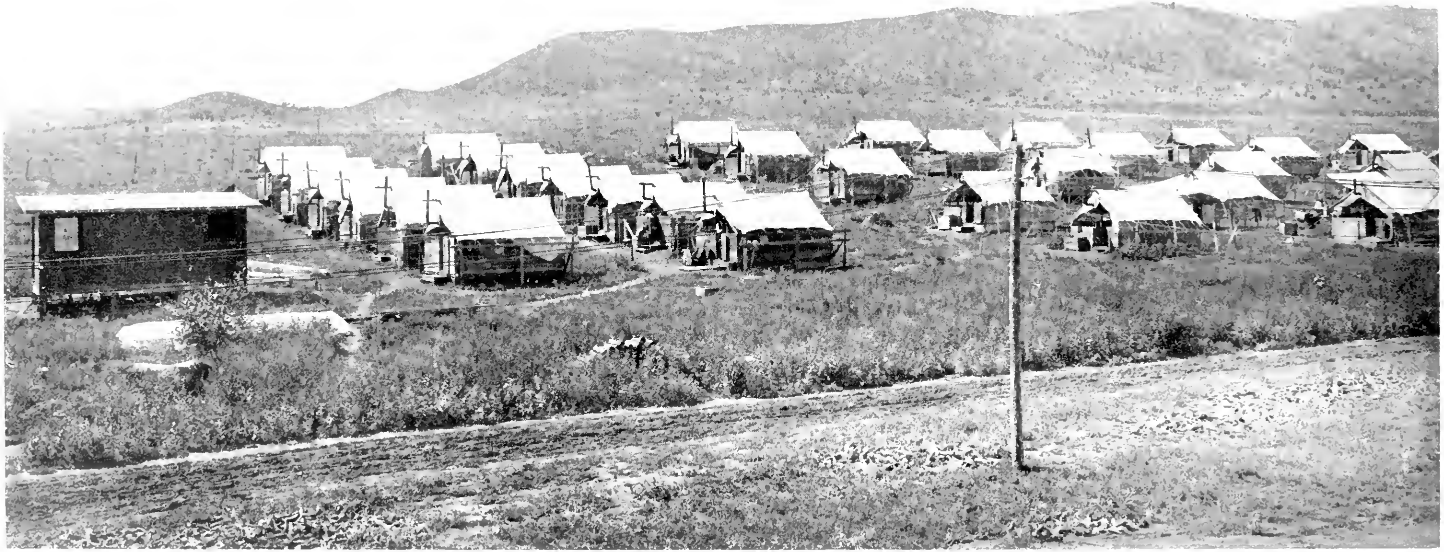


MODEL OF TENT HOUSE, TYPE A, USED AT THE UNITED STATES PUBLIC HEALTH SERVICE SANATORIUM, FORT STANTON, NEW MEXICO, 1912

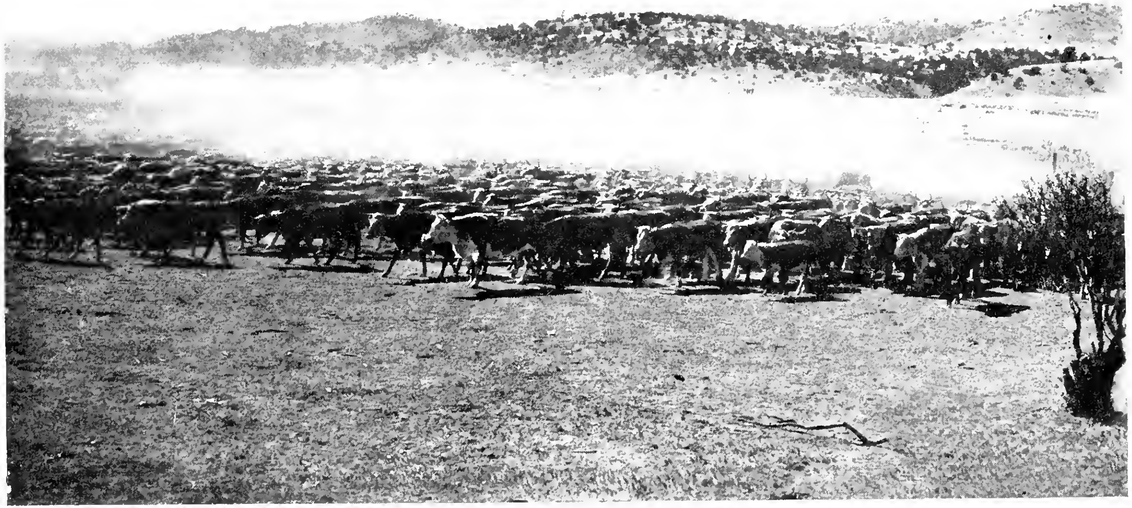
TENT HOUSES, TYPE A, UNITED STATES PUBLIC HEALTH SERVICE SANATORIUM, FORT STANTON, NEW MEXICO, FOR MASTERS, PILOTS AND ENGINEERS



TENT HOUSES, TYPE B, UNITED STATES PUBLIC HEALTH SERVICE SANATORIUM, FORT STANTON, NEW MEXICO



TUBERCULOSIS SANATORIUM OF THE UNITED STATES PUBLIC HEALTH SERVICE AT FORT STANTON, NEW MEXICO



SCENE IN NEW MEXICO, NEAR FORT STANTON. THIS HERD BELONGS TO THE SANATORIUM OF THE UNITED STATES PUBLIC HEALTH SERVICE

A "ROUND-UP" OF THE HERD BELONGING TO THE SANATORIUM FOR TUBERCULOSIS, UNITED STATES PUBLIC HEALTH SERVICE, FORT STANTON. A CHARACTERISTIC SCENE IN NORTHERN NEW MEXICO

DISUSED TROLLEY CARS WERE FIRST USED FOR CONSUMPTIVE PATIENTS BY DR. WILLIAM H. PETERS, OF PROVIDENCE, AT THE PINE RIDGE CAMP, RHODE ISLAND. THE CAMP CONSISTED OF SHACKS. PHOTOGRAPH SHOWS THE EFFORTS MADE TO PROVIDE THE OPEN AIR CURE BEFORE THE STATE SANATORIUM WAS BUILT

The evolution of the tent and open air shelter into the tent house, shack, and cottage, is an interesting feature of the open air treatment of tuberculosis.

"Lean-to."—The open air shelter and "lean-to" are somewhat alike. The latter has been long used by sportsmen and others in our northern forests, and has been greatly amplified for sanatorium purposes. The roof of the "lean-to" slopes directly back from its front or there may be a ridge placed close to the front or southerly side of the structure. The roof slopes well toward the back, but is short in front and allows free access of air and light. Canvass or screens are arranged to hang in front as a protection from wind or rain, and to insure privacy. For a full description of a "lean-to" the reader is referred to Dr. H. M. King's description with plans in "Some Methods of Housing," Charity Organization Society, New York.

Excellent "lean-tos" or open air shelters are in use all the year at the Royal Victoria Hospital, Edinburgh, Scotland, as seen in the illustration kindly supplied by Sir Robert Philip. (See plate 56.)

Pavilion tents are amplifications of the tent cottage, and are adapted for ten or twelve beds. As described by Mr. Homer Folks, they are sixteen by thirty-two feet long; the walls are eight feet high; the roof is fifteen feet high at the ridge and the floor of the tent is sixteen inches above the ground with free circulation of air underneath.

Tent Houses adapted for use in the New England and Middle States are naturally different from those in use in New Mexico and Arizona, where rain and snow are uncommon. The accompanying illustrations show a row of six tent houses and a single tent house at the U. S. Public Health Sanatorium at Fort Stanton, New Mexico, for consumptive sailors, under the care of the United States Public Health Service. The roof has a slight incline and the sides are arranged to give free ventilation as well as shelter when required.

Trolley Cars.—Superannuated and disused trolley cars were first used for tuberculosis patients by Dr. W. H. Peters, of Providence, Rhode Island, at the Pine Ridge Camp near that city. With slight alterations and at very little expense these cars may serve a useful purpose in connection with the outdoor treatment of tuberculosis at all seasons. Once located on a convenient site they have many advantages over the ordinary shack, affording a maximum of light and air and good protection against storms with their adjustable windows and doors. The author visited Pine Ridge Camp and can testify to their efficiency; the camp itself was discontinued after the erection of the fine State Sanatorium for tuberculosis at Wallum Lake. Trolley cars were also used at the Camp Auxiliary, Montefiore Home, Bedford, New York. (See plates 67 and 68.)

The Balcony, or Liege-terrasse as it is known in Germany, is a necessary adjunct of any sanatorium for tuberculosis. Plate 71 shows a covered or partly sheltered balcony in use at a large private sanatorium in St. Blasien in the Black Forest, Germany. Plate 89 shows an open or uncovered balcony at the Sharon Sanatorium, Massachusetts. In June, 1908, the author visited the latter sanatorium with the Medical Director, Dr. Vincent Y. Bowditch, and can bear witness to the excellent arrangements for the outdoor treatment of tuberculosis carried out at this institution.

The records, now extending over 22 years, show that about 50 per cent of all cases, and 72 per cent of all incipient cases have been arrested or cured.[1] Of the 160 arrested cases treated between 1891 and 1906, 133 or 83 per cent were still living and well in 1908, most of them house-keepers and wage earners; in addition, 3.7 per cent were doing well at last accounts, but were not recently heard from.

We have given the particulars of these cases treated at Sharon Sanatorium because the results are remarkably good being obtained at an elevation of 250 feet above sea level, about 15 miles from Massachusetts Bay, and about 20 miles from Boston. Sharon is near enough to the ocean to be affected by the sea breeze during the hot weather.

Day Camps; Walderholungstätten.—The daily care of consumptives at a day camp for the outpatients of a general hospital had its origin about the same time in both Boston and Berlin. It was proposed by Dr. A. K. Stone and Dr. E. P. Joslin in 1905 in Boston, and provision was made at the Mattapan Day Camps and at the House of the Good Samaritan for ambulatory patients. Plates 72-74 show how this is carried out. In July, 1908, fifty consumptives too ill to be benefited by treatment at the Massachusetts General Hospital were transferred to the new home of the Boston Consumptives' Hospital on the Conness estate, Mattapan, and entered on treatment which it was hoped would culminate in their improvement to an extent that should warrant their entrance into the state institution. They went to the camp in the morning and returned to their homes

---

[1] See V. Y. Bowditch, Boston Medical and Surg. Journ., June 22, 1899.
See V. Y. Bowditch, Journ. Amer. Med. Ass., Nov. 14, 1903.
See V. Y. Bowditch, Trans. Amer. Climatological Ass., 1907, p. 168.

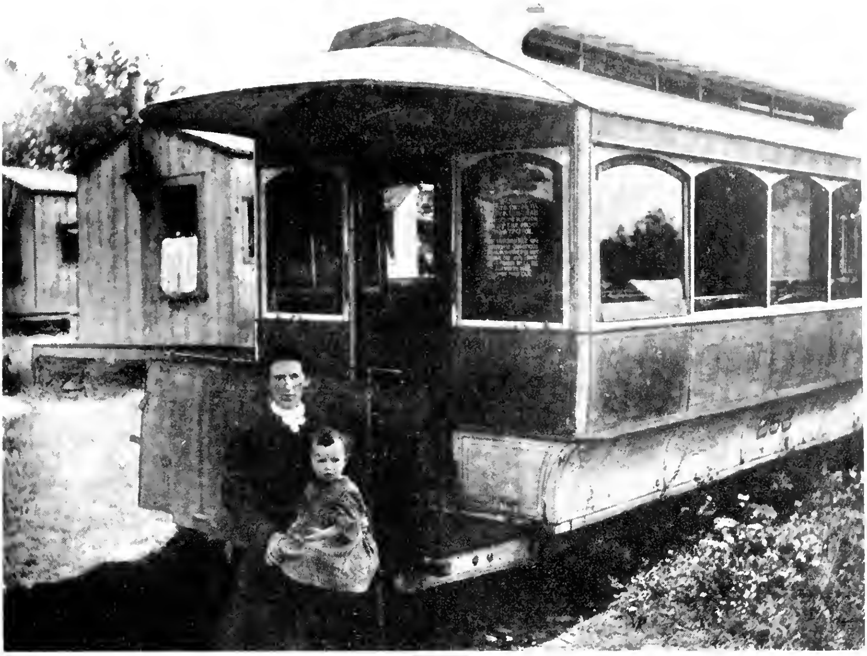


FIG. 1. OLD TROLLEY CAR THAT WAS USED BY MOTHER AND CHILD AT THE PINE RIDGE CAMP FOR CONSUMPTIVES, NEAR PROVIDENCE, RHODE ISLAND
Photograph by Courtesy of Dr. W. H Peters, Providence

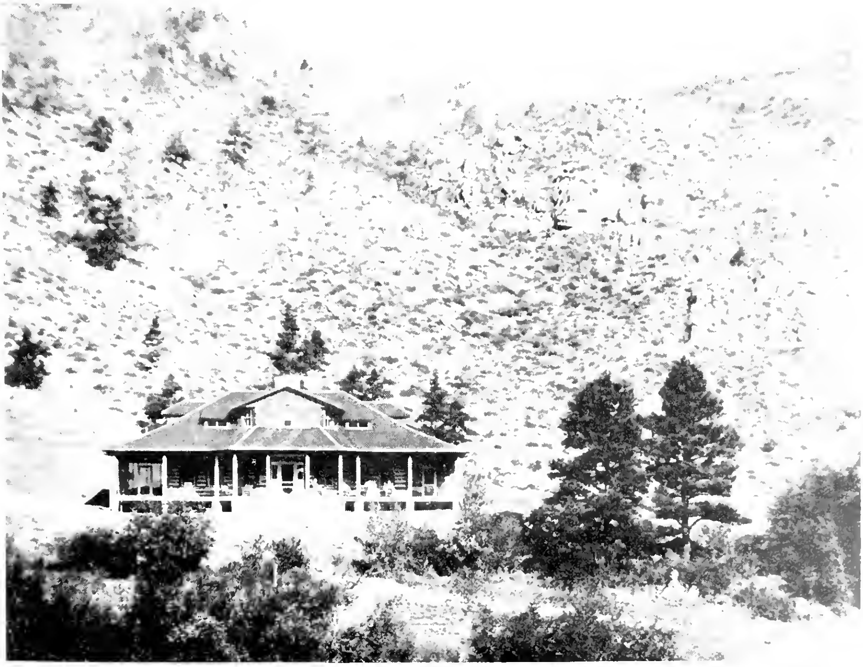


FIG. 2. ESTES PARK, COLORADO. IDEAL SUMMER RESIDENCE, WITH SPACIOUS PORCHES FOR PULMONARY INVALIDS. SLOPING GROUND, SANDY SOIL, MOUNTAINOUS BACK-GROUND AFFORDING PROTECTION FROM WIND AND DUST.
Courtesy of Dr. S. G. Bonney

SHARON SANATORIUM, MASSACHUSETTS. PATIENTS TAKING THE SUN BATH IN WINTER

Courtesy of Dr. Vincent Y. Bowditch

at night. Those given preference in treatment were patients whose dependents, circumstances, and health most demanded it. The new hospital and its location are picturesque as well as healthful, and patients are able to remain throughout the winter. The main building is 125 feet long and contains dining-room, kitchen, examination and rest rooms, and has a spacious veranda facing the south. It is designed to accommodate 150 patients, in the two pavilions, two cottages, and children's building. The Day Camp has proved to be a great success.

Day camps, when properly conducted, have an immense value on educational lines. In addition they remove for a time the sources of infection from the community and from the homes. These patients cannot always go to a sanatorium but in this way receive proper care during a large part of the day and may eventually avoid the necessity of going to a sanatorium; others who need sanatorium care are provided for, pending admission; and after discharge from the sanatorium the camp helps to complete the cure. Dr. Otis does not believe that these camps are destined to become a permanent therapeutic measure in conducting the cure.

The best location for day camps is in the forest. In Germany they are known as Walderholungstätte and there are over eighty of them scattered throughout the Empire. Those who are only slightly affected with tuberculosis, or are convalescent from it, pass the day in camp and return at night to their homes. The accompanying illustration (pl. 76) shows these camps for adults and children at Kuhfelde, Germany. These forest convalescent homes are greatly favored by the German insurance societies and sick lodges. Their benefits are extended to the children of patients.

Germany must be given credit for making the greatest discoveries and for instituting the most rational methods of treatment in connection with tuberculosis. The most thorough measures are adopted by the Imperial Government, the industrial insurance companies and by the medical profession of Germany.

According to the business report of the German Central Committee for the campaign against tuberculosis, there were in Germany in 1908 99 popular sanatoria for adults affected with disease of the lungs. These have 10,539 beds, 6,500 for men and 4,039 for women; in addition there are 36 private sanatoria with 2,175 beds, so that in all, 12,714 beds for adult tuberculosis patients are available. For children with pronounced tuberculosis there are 18 sanatoria with 875 beds; besides there are 73 institutions, with 6,348 beds, in which are received only "scrofulous" children and those who are threatened with tuberculosis. During the last five years these facilities have been greatly increased; 31,022 insured persons were treated in the sanatoria during a total of 2,312,850 days of care, at a cost of 11,483,033 marks ($2,755,928). On an average, each person treated received 75 days of care at a cost of 370.16 marks ($88.84) or 4.96 marks ($1.19) per person for each day of care.

Night Camps.—These afford open air conditions of sleeping, either for patients with arrested tuberculosis who pursue their occupation by day in the nearby city, or with disease still unarrested but who are able, or from necessity are compelled to work by day.[1]

Sleeping porches and balconies.—Sleeping out of doors requires special arrangements which are not usually found in cities. The ordinary dwelling, apartment house, or tenement has no provision for this innovation in tuberculo-therapy. Suburban and country houses or those in the less crowded cities are better adapted for the conversion of an upper porch or balcony into a sleeping apartment. In Denver, for instance, the practice is common enough to excite little comment. Detached houses are usually easily fitted with the necessary screened enclosures.[2]

Pavilions are more substantial and permanent than the forms of shelter previously referred to. Where large numbers of patients must be cared for at a minimum of expense the pavilion system has distinct advantages, especially for night use. At the Metropolitan Hospital, Blackwell's Island, New York City, about one-third of all consumptives under hospital care in New York are there provided for in the tent pavilions referred to on page 123; these tent pavilions cost about $12.00 per bed or $144.00 for a tent pavilion with a capacity of 12 beds.

At the Manhattan State Hospital for the Insane, Ward's Island. New York, more substantial and permanent pavilions have been constructed of wood and glass and have displaced the cloth tents. These pavilions are heated by steam, lighted by electricity, and have removable glass sides permitting a free circulation of air and light all the time. Their per capita cost is about $100.

In addition, there are camps for both the men and the women with a total capacity of 175 patients. In summer some canvas tents

---

[1] E. O. Otis: Institutions for the Prevention and Cure of Tuberculosis. Boston Med. and Surg. Journ., Aug. 1, 1912.

[2] See "Directions for Living and Sleeping in the Open Air," National Ass. Tuberculosis, 1910. See T. S. Carrington: Interstate Med. Journ., April, 1914.

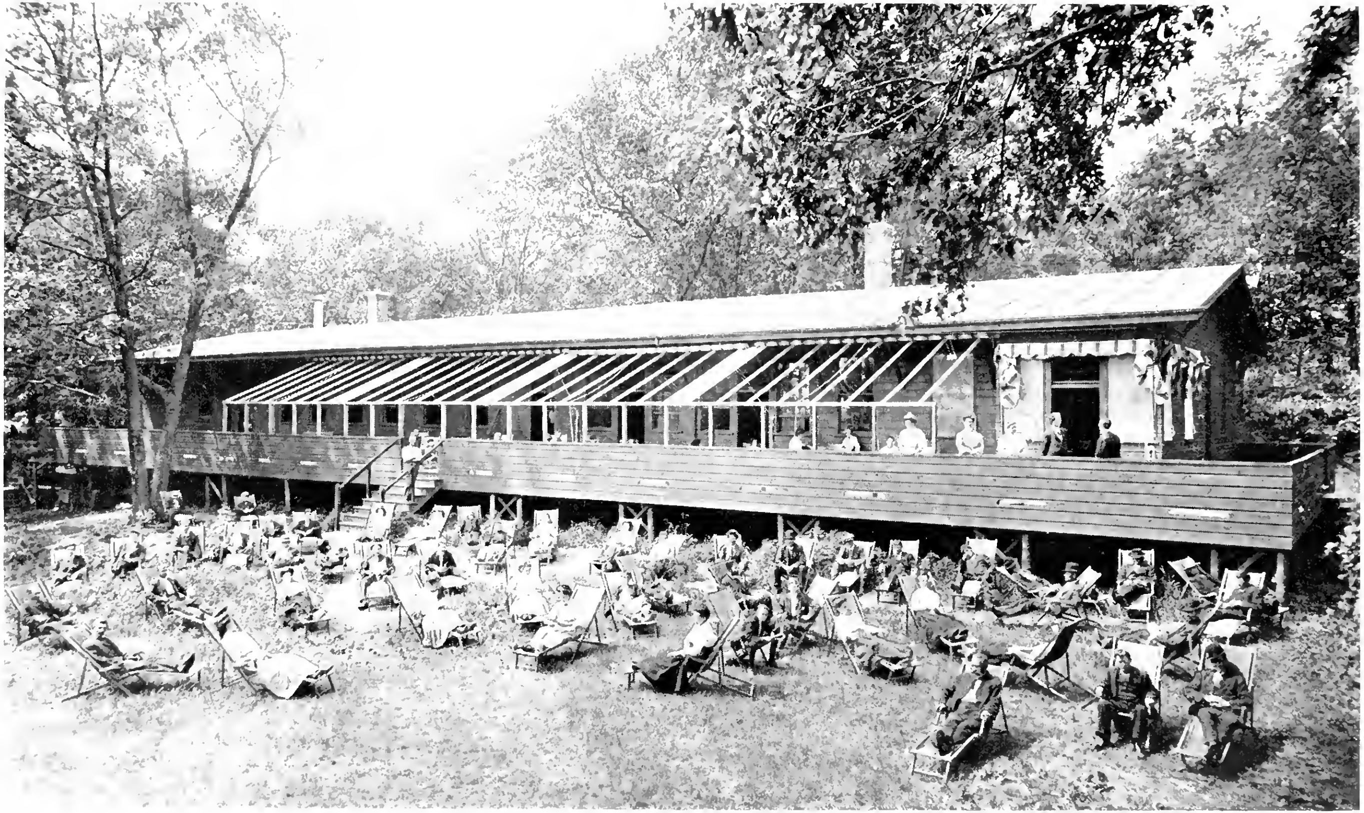
OPEN AIR LIFE AT THE ADIRONDACK COTTAGE SANITARIUM; WINTER

SANATORIUM ST. BLASIEN IN THE BADEN BLACK FOREST. THIS "REST HALL" IS CLOSE TO THE WOODS, HAS A PERMANENT ROOF AND FLOOR AND AWNINGS WHICH ARE ROLLED UP OUT OF SIGHT

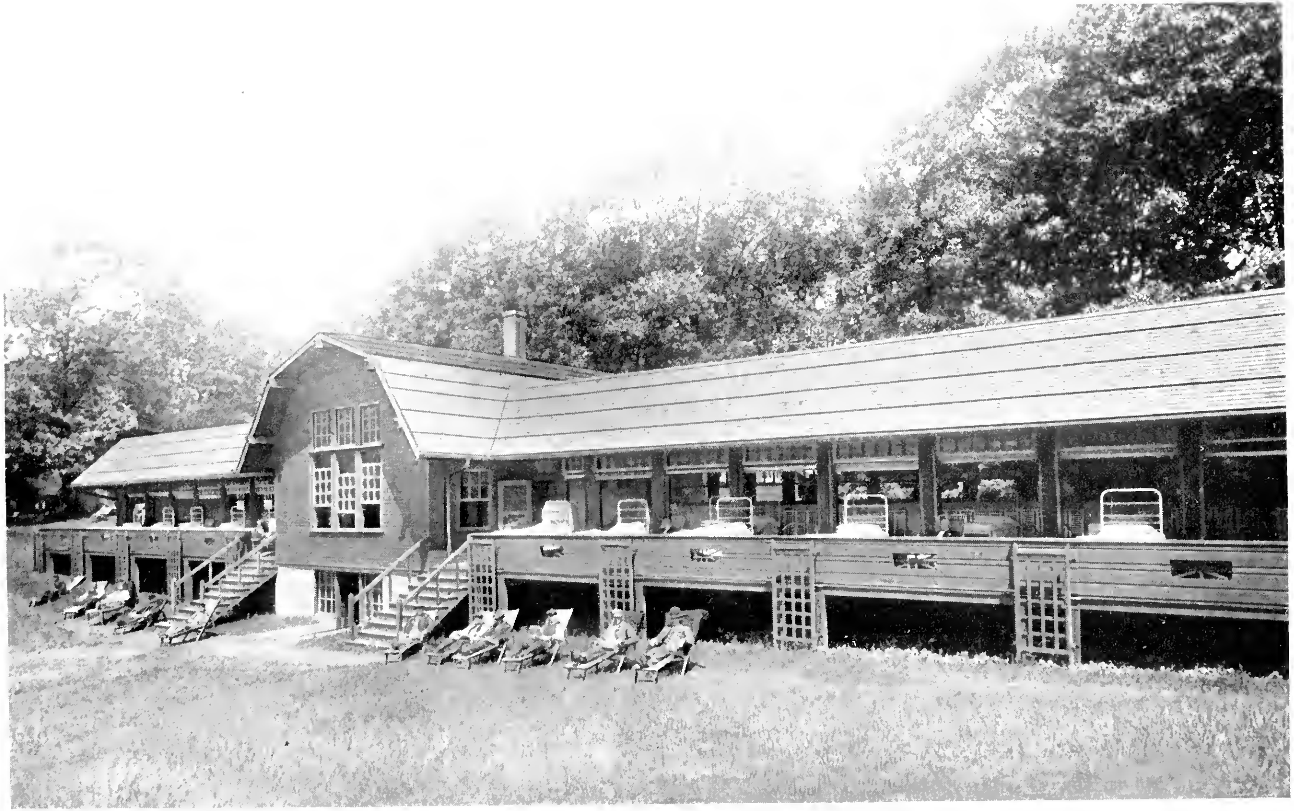
FIG. 1. DAY CAMP FOR TUBERCULOSIS PATIENTS, HOUSE OF THE GOOD SAMARITAN, BOSTON

FIG. 2. A DAY CAMP FOR TUBERCULOUS PATIENTS AT THE HOUSE OF THE GOOD SAMARITAN, BOSTON, NEAR THE HARVARD MEDICAL SCHOOL

DAY CAMP FOR TUBERCULOUS PATIENTS, HOLYOKE MASSACHUSETTS



BOSTON CONSUMPTIVES' HOSPITAL AT MATTAPAN. DAY CAMP. PATIENTS REPORT AT 9 A. M. AND RETURN HOME BETWEEN 5 AND 6 P. M



BOSTON CONSUMPTIVES' HOSPITAL AT MATTAPAN. COTTAGE WARD; LENGTH 150 FEET; CAPACITY 26 BEDS. IT AFFORDS CARE

DOECKER PORTABLE BARRACKS, USED AS A RECOVERY STATION, AT KUHFELDE IN THE ALTMARK, GERMANY

Courtesy of Christoph and Unmack

FIG. 1. DIET KITCHEN. DAY CAMP AT PARKER HILL, BOSTON, MASSACHUSETTS

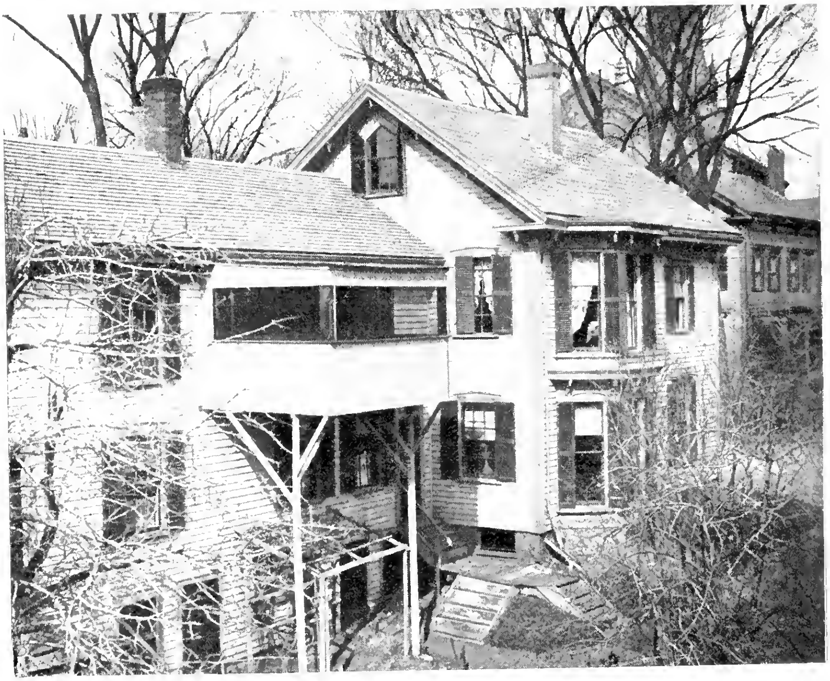
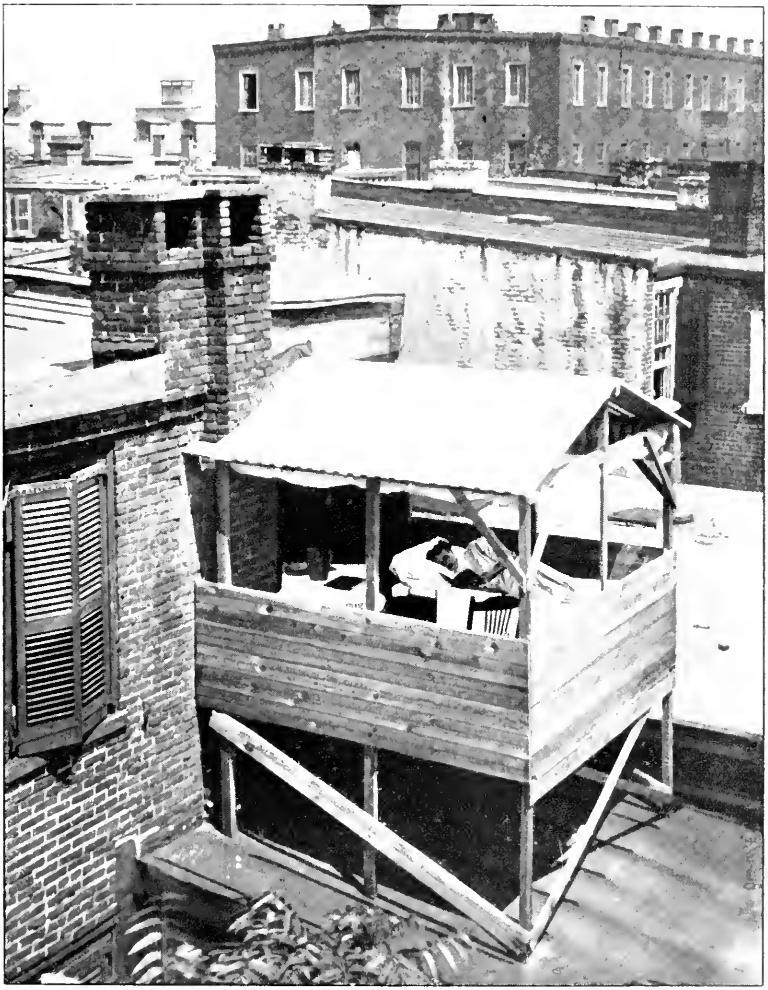


FIG. 2. SLEEPING BALCONY USED BY A PATIENT IN HAVERHILL, MASSACHUSETTS



SLEEPING PORCH IN A CROWDED DISTRICT OF PHILADELPHIA

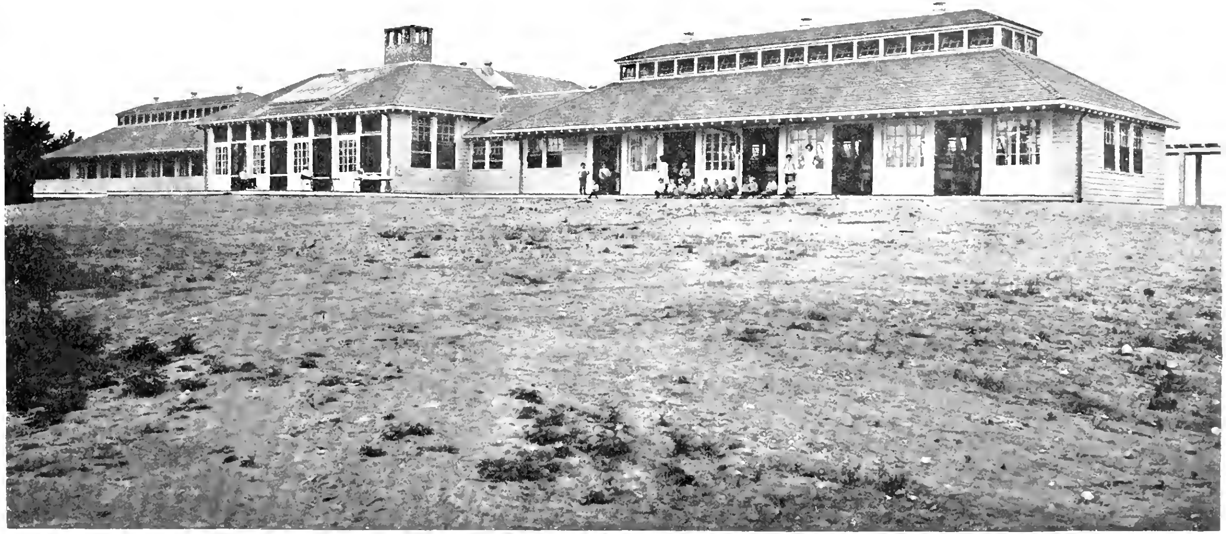
DOUBLE SLEEPING PORCH WITH EASTERN AND SOUTHERN EXPOSURES. THIS SUMMER RESIDENCE IN ESTES PARK, COLORADO, IS PROVIDED WITH PORCHES ON ALL SIDES SAVE THE NORTH, WHICH IS PROTECTED BY THE ROCKY FORMATION IN THE BACKGROUND. THE PORCH IS COVERED WITH A PERMANENT ROOF.

Courtesy of Dr. S. G. Bonney

CITY RESIDENCE WITH IDEAL UPPER DOUBLE SLEEPING PORCH CONNECTED WITH BEDROOM. SHEATHING AT THE BASE, WIRE SCREENING, AWNINGS, ELECTRIC LIGHT.

Courtesy of Dr. S. G. Bonney, Denver

PAVILIONS AT THE ROYAL VICTORIA HOSPITAL FOR CONSUMPTION, EDINBURGH, SCOTLAND
Courtesy of Sir Robert Philip



CANTON, MASSACHUSETTS, STATE HOSPITAL SCHOOL FOR CRIPPLED (TUBERCULOUS) CHILDREN, SHOWING UNIT

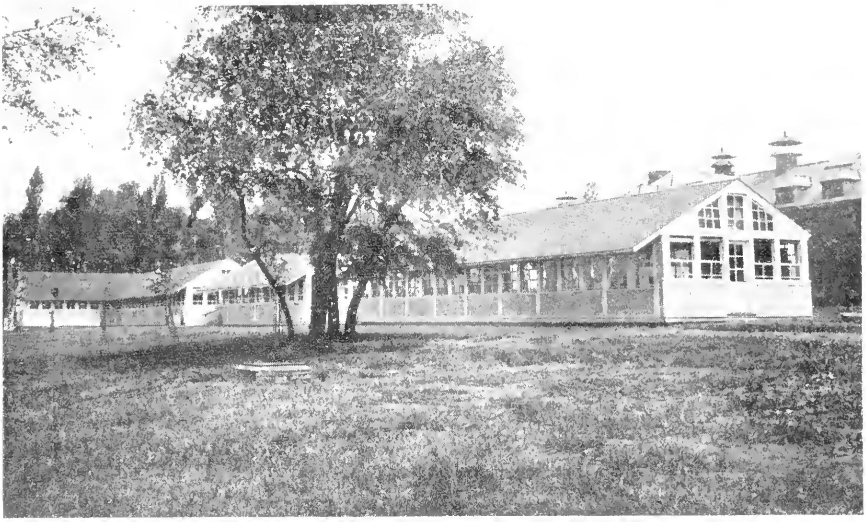


FIG. 1. MANHATTAN STATE HOSPITAL, EAST, WARD'S ISLAND, NEW YORK CITY. NEW PAVILIONS FOR THE TUBERCULOUS INSANE
Courtesy of Dr. William Mabon

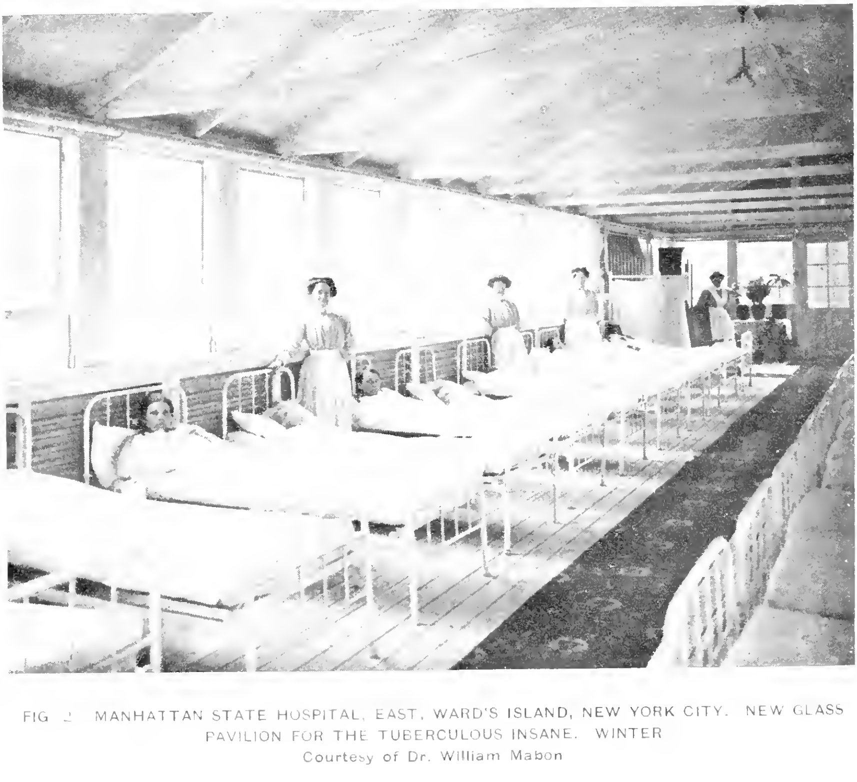


FIG. 2. MANHATTAN STATE HOSPITAL, EAST, WARD'S ISLAND, NEW YORK CITY. NEW GLASS PAVILION FOR THE TUBERCULOUS INSANE. WINTER
Courtesy of Dr. William Mabon

INTERIOR OF ONE OF THE PAVILIONS, ROYAL VICTORIA HOSPITAL, EDINBURGH

Courtesy of Sir Robert Philip

FIG. 1. KIOSK AND OPEN DECK ADJOINING WARDS FOR EARLY CASES OF TUBERCULOSIS, PHIPPS INSTITUTE, IN A VERY OLD AND CROWDED PART OF PHILADELPHIA

Courtesy of Dr. C. J. Hatfield, Director

FIG. 2. BELLEVUE HOSPITAL, NEW YORK CITY. ROOF WARD FOR CHILDREN

Courtesy of Dr. J. W. Brannan

are used. The accompanying photograph (pl. 83), kindly furnished by Dr. Wm. Mabon, the superintendent, shows the character of the pavilion.

In the Royal Victoria Hospital for Consumptives, Edinburgh, Scotland, still more substantial and expensive pavilions are in use as seen from the illustrations (pl. 84) kindly furnished by Dr. R. W. Philip.

Roof Gardens.—At the Philadelphia Hospital the first attempt to segregate tuberculous patients for the fresh air cure was by means of a roof garden ward. This was a vast improvement over the previous method of indoor confinement and was greatly appreciated by the patients. The roof garden ward was in use winter and summer, but later gave way to the six glass pavilions erected at an expense of over $112,000.

Each pavilion is intended to accommodate eighteen patients, usually in an advanced stage of tuberculosis. Each is separate in itself with walls and roof of glass and only sufficient metal work to give proper support. The floors are of cement so as to be as smooth and non-absorbent as possible. Including the porches, which are also enclosed in glass, each pavilion measures 39 by 70 feet. The glass is arranged in frames in both walls and porches and by means of automatic devices one side of the building or all three sides may be thrown open. Screens or shades are arranged to prevent too much access of the sun. The system of ventilation and heating is considered ample.

Detached Cottages.—At the Nordrach Ranch Sanatorium, three miles from Colorado Springs, independent cottages resembling tents are used. These are economical and insure privacy and sufficient protection. The system is adopted from that in use in Nordrach, Germany.

The highest development of housing for the tuberculous patient is undoubtedly the independent cottage. It is necessarily expensive, but the patient fortunate enough to be its inmate has a maximum of comfort and at the same time is in the enjoyment of the best atmospheric conditions night and day. At the Loomis Sanatorium where the snow lies on the ground more than four months in the year, and at Saranac Lake, in the Adirondack Mountains, where the winters are even longer and more severe, the independent cottage is a distinctive feature.

Sleeping Canopies.—Detachable windows may be applied to tents, pavilions, or ordinary dwellings, so as to allow patients to breathe by day and night the outer air uncontaminated by others occupying the same room or dwelling. Devices suitable for any window may be obtained. It is thus possible in a hospital ward to have half a dozen patients breathe the outer air while the ward is kept warm. The tent can come over the end of the regular hospital bed so that patients sleeping in wards where miscellaneous cases are received, may nevertheless have the full benefit of the outer air. By means of thick celluloid the patient may be readily seen. The celluloid window may be raised to give the patient drink and nourishment.

Plate 93 shows the Walsh Window Tent applied to the window of an ordinary dwelling.[1]

CHAPTER X. CONCLUSIONS.

There are some people, especially those of a skeptical or combative tendency, who refuse to admit that climate plays any important rôle in the cure of tuberculosis. One of these who was formerly in charge of a widely known institution for the study and treatment of tuberculosis has said: " I desire to go on record as believing that there is no therapeutic value in climate." This same physician probably owes his life to the fact that thirty-five years or more ago he left the city and removed to the mountains of Pennsylvania for the relief of a pulmonary disease and recovered. Such an attitude is a study for the psychologists and would hardly seem deserving of serious attention, except that we hear such statements as this: "If a case of consumption cannot be cured in its home climate it cannot be cured anywhere."

I think there is no doubt that if any of us were told that he is in the incipient stage of tuberculosis he would immediately take steps to familiarize himself with the line of treatment which would, before much time had elasped, involve leaving Boston, New York, Philadelphia, or Chicago, as the case might be, and so live as to enjoy what air and sunshine and other atmospheric features might afford.

One reason why home climates, if such a term may be permissible, have grown in favor is that it has been found necessary to establish a large number of State sanatoria, or at least to seek aid for private sanatoria from some of our State legislatures. It is a matter of expediency to have such sanatoria and legislators must be convinced that good results or, if necessary, the best results, can be obtained close at hand. We are all heartily in favor of such institu-

---

[1] For the history of this tent see Knopf and McLaughlin, N. Y. Med. Journ., 1905, Vol. 81, 425.

tions whether or not we should wish to stake our chances of recovery in any of them.

Of course we do not claim that there is any specific climate for tuberculosis and the long search for such climate, a search lasting for nearly two thousand years, is apparently at an end.

Now what is there left to us, and what do we understand by a climatic change?

We all know that the New England climate is changeable, that is, the meteorological conditions are constantly varying just as they also vary in the Mississippi Valley and along the Atlantic seaboard. But the New England climate is peculiarly unstable and, as Charles Dudley Warner has said, "New England is the battle-ground of the weather."

We have a change of climate when we leave the hot city in summer and go a few miles to the shore. We have floating hospitals so that this climatic change may stimulate a sick child to recovery. A so-called "home-climate" may work a cure or aid in a cure because we leave the climate of our homes, often too dry with furnace heat, too poorly ventilated, too damp from lack of sun, and remove to more hygienic dwellings in the same locality where sun and air and cleanliness abound.

But, to take up the principal question at issue, the first thing usually asked is whether one should go to the Adirondacks, Colorado, New Mexico, Arizona, California, or elsewhere, in order to get what is so frequently claimed to be the greatest climatic advantages. No one who has visited these localities can fail to be impressed with the living examples of recovery from tuberculosis. Denver, Colorado Springs, and innumerable towns in southern California abound in doctors who have practically recovered from this disease and are earning a living that is the envy of their eastern confrères.

Would they have recovered in their eastern homes? Almost to a man they answer "No." I have never heard of an exception. But the case is hard to prove from such *ex parte* evidence. However, it is interesting to note Dr. H. B. Dunham's conclusion. He stated in 1904, after visiting discharged Massachusetts State Sanatorium patients in the west, and after comparing Massachusetts Sanatorium statistics with those of the U. S. Army Sanatorium at Fort Bayard, New Mexico, that "the results corroborate our beliefs in the efficacy of residence in dry climates, but with a smaller margin in its favor than was anticipated." The proportion of people adapted for treatment in these extremes of climate must be more equal than thought possible by climatologists generally. That is to say, a small majority of the patients at Rutland, Mass., would probably do better at Fort Bayard, New Mexico, and a large minority might do better at Rutland. But no one can say positively, in any given case, what would have been the outcome had he chosen differently.

We need not discuss the bearing of what to do for the poor or what to do for the rich, or the question of food, or the physician's management; these are important and may govern the choice, but what we want is an answer to the abstract question of the influence of climate.

We believe that climate may be *utilized as an adjuvant* of great value for carrying out the hygienic, dietetic treatment of all forms of tuberculosis and of many other diseases. There are some elements of climate that have a more positive influence in hastening cure than others. The first place must be assigned to an abundance of air, which is as nearly as possible bacteriologically and chemically pure. It goes without saying that city air is polluted by smoke and dust and all dwellings, whether in the city or the country, are far below the standard of purity desirable. Only on the sea or at the highest elevations do we find air really pure, but we can approximate it by living out of doors. There is a climate of the city, a suburban climate, a climate of the country, woods, and plains, all differing as regards purity of air. We are all probably agreed on this point.

Next comes the subject of sunshine. We admit that good results are obtained in cloudy regions as, for instance, in the Adirondacks and at Rutland; but there is at least no objection to sunshine, and I believe that the moral effect of bright sunny days and plenty of them is very great. Invalids always welcome the sun. We can protect ourselves from too much sun if need be, and I, for one, believe that sunlight does a vast amount of good and sunny regions are much to be preferred, other things being equal. That is the great asset of our western plains and mountains; and it is a real asset that counts. Of course there are exceptions. Tastes differ. Dr. Solly used to relate the story of one of his countrymen who had been sojourning in Colorado and finally returned to England. As he landed in a fog and found himself home again, he exclaimed, "Thank God! I am out of that beastly sunshine." I do not suppose he intended to be irrational or ungrateful for the greatest of all natural gifts.

Now, what other climatic conditions besides pure air and abundant sunshine have we to help us? Is a cool climate or a warm climate the best? Is a dry or humid climate to be preferred? These quali-

FIG. 1. SHACK WITH SCREENED PORCH. ESTES PARK, COLORADO
Courtesy of Dr. S. G. Bonney

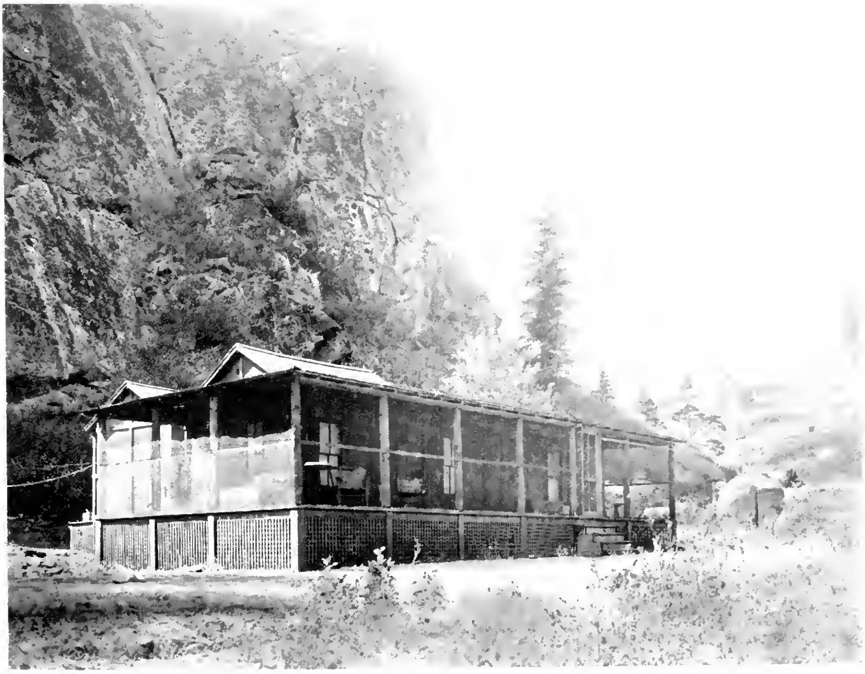
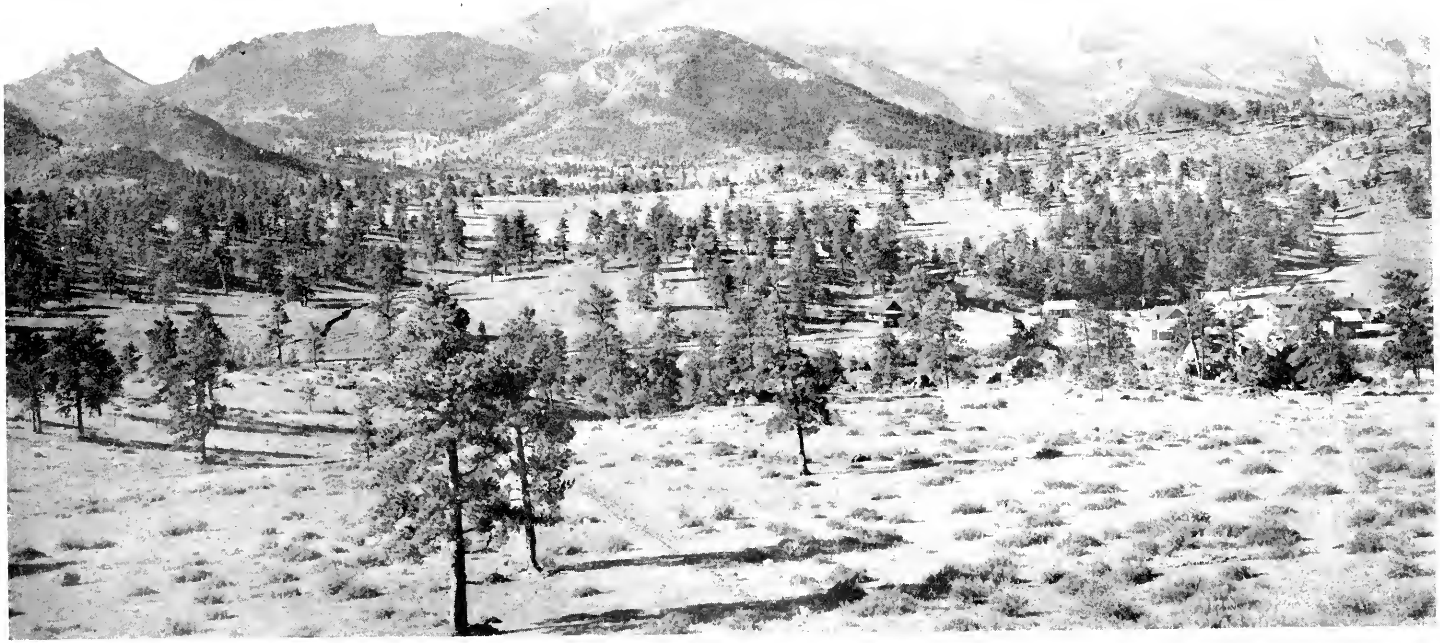


FIG. 2. WELCH'S RESORT, FIVE MILES FROM LYONS, COLORADO. SIX ROOM COTTAGE SOMEWHAT PRIMITIVE BUT WITH AMPLE SCREENED PORCH. SHELTERED FROM NORTH AND WEST WINDS.
Courtesy of Dr. S. G. Bonney



VIEW OF THE ROCKY MOUNTAIN RANGE FROM THE PORCHES OF SUMMER COTTAGES, ESTES PARK, COLORADO
Courtesy of Dr. S. G. Bonney

COTTAGE AT THE ADIRONDACK COTTAGE SANITARIUM NEW YORK

FIG. 1. ANNE M. LOOMIS MEMORIAL COTTAGE—(NEW INDEPENDENT UNIT) LOOMIS SANATORIUM SULLIVAN COUNTY, NEW YORK

FIG. 2. LOOMIS SANATORIUM, SULLIVAN COUNTY, NEW YORK. ONE OF THE EAST PORCHES OF THE MARY LEWIS RECEPTION HOSPITAL

ties of temperature and humidity may as well be considered together. Undoubtedly for the majority of cases in the first stage the climate should be dry and the temperature comfortable—not warm enough to be relaxing, but not so cold as to be repellent and restrict exercise or out-of-door life. It is true that in special localities better results are obtained during the cold months than during the summer. This is true of the Adirondack Cottage Sanitarium in the State of New York. One reason for this is that in winter the lakes and ponds are frozen and covered with dry snow; the air is drier. It is far enough north and at a sufficient altitude to escape the alternate freezing and thawing that is experienced in New York City, where unquestionably it is less favorable for the consumptive during the cold season than during the warm months. Take Florida and South Carolina: Undoubtedly the best season there is during the winter months, as the summers are oppressively warm and wet. The winter is the dry season and the temperature is comfortable. The interior of Florida forty or fifty miles from either coast is reasonably dry. As far as Arizona and New Mexico are concerned, the summers are too hot at all the lower elevations for any invalid, but at the higher elevations, 5,000 or 6,000 or 7,000 feet, the summer heat is not oppressive. Along the southern coast of California and at many of the resorts somewhat inland, as good results are obtained in summer as in winter, although the latter is the more fashionable season for eastern visitors. The southern California resorts which have been most frequented by consumptives vary greatly between themselves as regards the important question of humidity. That a place is frequented by consumptives does not prove that it is a desirable place for them. Many of them are misguided, wandering invalids, sent out from the east with little or no judgment as to their individual needs and with no proper knowledge on the part of their medical advisers as to the humidity or local character of the places to which they are destined. A man, for instance, will go to Los Angeles. It does not take him long to find out that while the air is fairly dry from 11 a. m. to 5 p. m., it is always damp at night. Six hours out of twenty-four are dry, the remaining eighteen are decidedly damp. The physicians of Los Angeles do not claim that their climate is a suitable one for cases of tuberculosis and usually send these cases to the interior stations, such as Redlands or Riverside, Monrovia or Altadena. Many are sent to Arizona. Experience shows that consumptives do better if they avoid the coast region. Or, if near the coast, as at Santa Barbara, they are better if they find a site at some elevation on the hillside or in the mountain valleys beyond the reach of the morning fog and the excessive humidity at the shore.[1] The records of the Weather Bureau show that these places on the coast or within reach of the fogs which penetrate inland have a greater humidity than Boston or New York, the mean annual absolute humidity for Santa Barbara, Los Angeles, and San Diego being given at 4.20, 4.42 and 4.34 grains, more than one-third more than that of New York and Boston, 3.19 grains and 2.84 grains. The mean annual relative humidity of all these places mentioned is from 72 to 73 per cent. But the advantage of places like Santa Barbara, San Diego, Redlands, and Riverside, lies in the fact that the mean annual humidity shows a remarkable variation during the twenty-four hours compared with places like Boston, New York, or Philadelphia, where the daily range is much less. At Redlands, fifty miles inland from the Pacific Ocean, one of the best known stations, the hygrometer has been known to indicate in fair weather 55 per cent at 4.30 p. m., and 80 per cent at 6.00 p. m. The relative humidity is sometimes as low as 30 per cent for a limited time during the day, and 70 to 80 per cent at night when the temperature is from 44° to 60° F.

It may as well be stated that the government records of humidity are quite misleading when we use them to judge of the climate of any given place. The observations are made at 8 a. m. and 8 p. m., but in the invalid's day, made up of the intervening hours, the relative humidity reaches a much lower mark than the records show. I often observe a relative humidity in Virginia of 25 or 30 per cent at 2 p. m., and 95 or 98 per cent at night or in the early morning, especially when dew falls after a bright, invigorating day. I think that people, whether sick or well, adjust themselves to these natural changes of humidity if properly clothed and constantly in the open air; but when subject to rapid changes in humidity, as in going back and forth from the excessively dry air of a house in winter to the damp air outside, the demands upon the mucous membranes are very great and such frequent and violent changes certainly do harm to susceptible people. Such rapid variations or alterations of the humidity of the inspired air I think are as bad as would be rapid alternations of altitude involving variations of several thousand feet.

Some patients, however, seem to do better with a humidity greater than that chosen for others. If we have a low relative humidity

---

[1] See W. Jarvis Barlow, M. D.: Climate in the Treatment of Pulmonary Tuberculosis (Journ. Amer. Medical Association, October 28, 1911).

and at the same time a moderately low temperature the general effect is tonic and it is beneficial in conditions of irritability of the respiratory mucous membrane; but if the temperature is very low this may be rather irritating. We find atmospheric conditions like this from Minnesota to the Rockies and through Manitoba and Alberta.

The combination of high relative humidity and low temperature certainly favors catarrh and we have such conditions all winter long in the region of the Great Lakes and in New York and New England. Probably the best combination is a low humidity and a moderately cool temperature; the average tuberculous patient makes his best gains after August first and in subsequent cold, dry weather when such conditions prevail. But of course there are exceptions and some do better with a high relative humidity and a warm temperature; these are not numerous and probably include more of the patients in later stages when expectoration is profuse and vitality is low.

The old idea about equability of temperature, at least between the temperature of midday and midnight, is not of great importance; all mountainous stations show great variations in this respect. Some variability tends to stimulate the vital activities, but in older people and those who are feeble great variability is a disadvantage.

As far as altitude is concerned it probably has not, *per se,* any great influence; certainly to my mind not so much as we used to think. However, altitude is incidentally associated with mountain life or life on the plains, with more sun, less moisture, and scattered population. We should not forget that surgical tuberculosis is always favorably influenced by a seashore residence suitably chosen.

I never shall forget the wonderful impression made on visiting the Sea Breeze Hospital for Tuberculous Children on Long Island, New York. Constant outdoor life in all weather works miraculous cures after the most formidable operations for bone tuberculosis and in many cases renders them wholly unnecessary in patients whose physical condition on admission was most unpromising. All the great French and Italian sanatoria for tuberculous children are located on the seashore.

Among the numberless histories of the climatic cure I will give only one and I think I may safely let it stand as a good example by which to let the argument rest. The history is that of a physician whom we all love and respect. It was published, together with twenty other carefully recorded histories, by that prince of clinicians, the late Dr. Alfred L. Loomis, in the Medical Record and formed a part of a paper read before the Medical Society of the State of New York in 1879, a paper which we commend to your attention. Dr. Loomis says:

> At the age of twenty-five this patient, being of good family history, began to lose his health in the winter of 1872. His symptoms were rapidly becoming urgent; he was examined by several physicians. Extensive consolidation at the left apex was found, extending posteriorly nearly to the angle of the scapula; on the right side nothing was discovered save slight pleuritic adhesions at the apex.
>
> He was ordered south, but returned in the spring in no way benefited. On the contrary, night-sweating had set in, and his fever was higher. In the latter part of May he started for the Adirondacks, the ride in the stage being accomplished on an improvised bed. His condition at this time was most unpromising; he had daily fever, night sweats, profuse and purulent expectoration, had lost his appetite and was obliged constantly to have recourse to stimulants. Weight about 134 pounds. He began to improve at once, his appetite returned, all his symptoms decreased in severity, and after a stay of more than three months he returned to New York weighing 146 pounds, with only slight morning cough, presenting the appearance of a man in good health. A few days after his arrival in New York he had a chill, all his old symptoms returned and he was advised to leave for St. Paul, Minnesota, where he spent the entire winter. He did badly there; was sick the greater portion of the winter. In the spring of 1873 he again went to the Adirondacks. At this time he was in a most debilitated state, was anemic, emaciated, had daily hectic fever, constant cough, and profuse purulent expectoration.
>
> The marked improvement did not commence at once as it did the previous summer, and the first of September found him in a wretched condition. I then examined him for the first time and found complete consolidation of the left lung over the scapula and suprascapular space, with pleuritic thickenings and adhesions over the infraclavicular space. On coughing, bronchial rales of large and small size were heard over the consolidated portion of the lung. Over the right infraclavicular region the respiratory murmur was feeble, and on full inspiration pleuritic friction sounds were heard. I advised him to remain at St. Regis Lake during the winter, and although he was repeatedly warned that such a step would prove fatal, he followed my advice.
>
> From this time he began slowly to improve. Since that time he has lived in this region. At the present time his weight is 158 pounds, gain of 22 pounds since he first went to the Adirondacks in 1873, and ten pounds more than was his weight in health. He has slight morning cough and expectoration, his pulse is from 72 to 85 and he presents the appearance of a person in good health. In his lungs evidences still remain of the disease he has so many years combated.
>
> Although he has made three attempts to live in New York, at intervals of two years, each time his removal from the mountains has been followed within ten days by a chill, and a return of pneumonic symptoms—symptoms so ominous that he has become convinced that it will be necessary for him to remain in the Adirondack region for some time to come.

FIG. 1. LOOMIS SANATORIUM, SULLIVAN COUNTY, NEW YORK

FIG. 2. LOOMIS SANATORIUM, SULLIVAN COUNTY, NEW YORK. PORCH OF OLD INFIRMARY

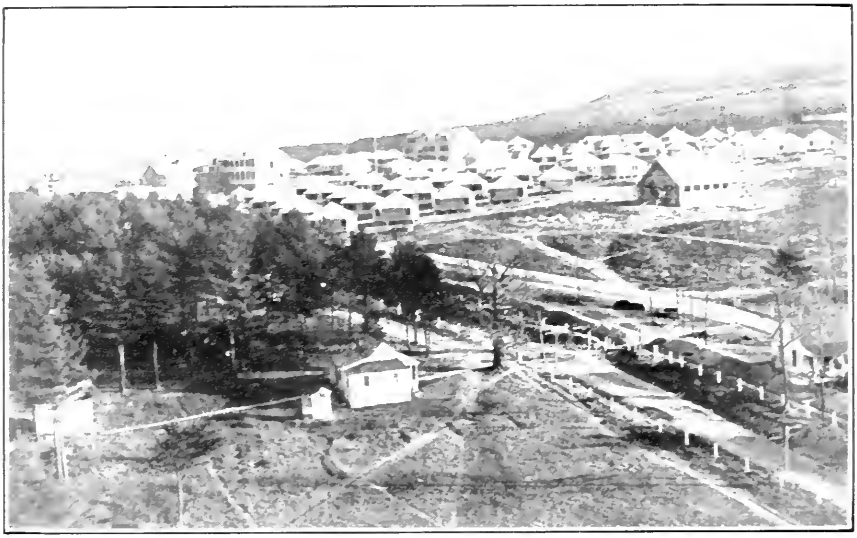


FIG. 1. PARTIAL VIEW OF PENNSYLVANIA'S STATE SANATORIUM FOR TUBERCULOSIS, NUMBER 1, MONT ALTO, FRANKLIN COUNTY

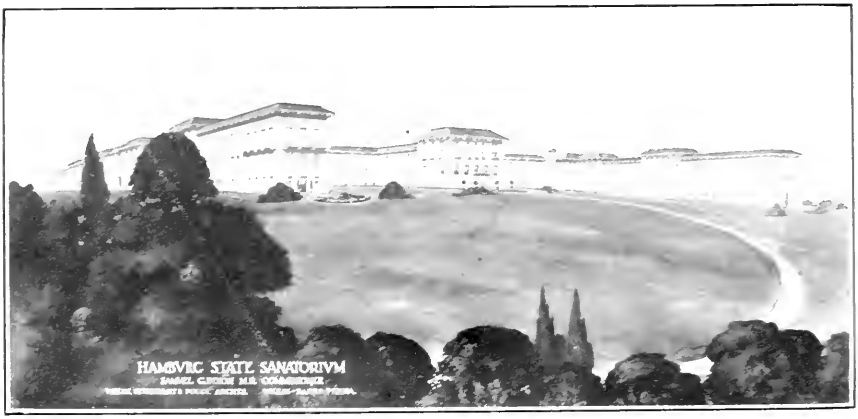


FIG. 2. PENNSYLVANIA'S STATE SANATORIUM FOR TUBERCULOSIS, NUMBER 3, HAMBURG, BERKS COUNTY

PARTIAL VIEW OF PENNSYLVANIA'S STATE SANATORIUM FOR TUBERCULOSIS, NUMBER 2, CRESSON, CAMBRIA COUNTY

This property, formerly a popular summer resort hotel, was presented to the State by Mr. Andrew Carnegie for sanatorium purposes

THE WALSH WINDOW TENT. ALTHOUGH LYING IN THE BEDROOM THE SLEEPER HAS FREE ACCESS TO THE OUTER AIR

We all know the after history of this patient. Thank God, he is still living, still working, and there are thousands living to-day who owe their lives to the example which he has set them. He seized the principles of climatic treatment and adapted it to the individual.

I recently sent the following question to the deans of medical colleges in Boston, Chicago, New Orleans, Los Angeles, and Montreal. I knew nothing of the views of these men on this subject except one; of course we all know that every one from California has decided views on climate. The question was:

What would you do for yourself climatically if you were told for the first time that you had incipient pulmonary tuberculosis?

Here are the answers:

I would strike for the wild pine woods of northern Michigan or Wisconsin and stay there.—A. R. Edwards, Chicago.

In answer to your question I may say that if I had incipient tuberculosis I should either go to Saranac or St. Agathe in Canada and employ the open air treatment.—F. J. Shepherd, McGill University, Montreal.

In answer to your question of December 26, I would say that I would treat myself as I do patients on whom I make the diagnosis of incipient pulmonary tuberculosis, that is, refer them to a local man who specializes in this disease, and ask him to look them over and refer them for climatic treatment in accordance with his knowledge of climatic conditions suitable to the individual case. Were I to start out to select a climate for myself, I would be much more influenced by the physician under whose care I would come in the new place than by the actual climate, and would probably select either Saranac Lake or Asheville, N. C., as I know and have confidence in physicians in each place. Were they to decide that I was better suited to some other climate, I would move on under their advice. If it were possible, I believe that I would undoubtedly leave Boston, had I incipient tuberculosis.

Very truly yours,

HENRY A. CHRISTIAN,

Boston.

If I had to answer your question categorically I would say that I would ask the advice of one or two men living in my own community as to what I should do for myself climatically if I were told for the first time that I had incipient pulmonary tuberculosis.

The practice among the profession in New Orleans is to send patients to St. Tammany Parish, in Louisiana, where the growth of piney woods is thick and ozone plentiful. When the particular case justifies, the patient is sent to the plains of Arizona or New Mexico, and, rarely, to El Paso, Texas. A few patients go to Colorado.—Isadore Dyer, Tulane University, New Orleans, La.

Perhaps I can best answer this personally by telling you what I did when I was told this very thing fifteen years ago. Having contracted tuberculosis in New York city I sought a better climate for an outdoor life, spending the first summer in the Adirondack Mountains and in November of that year going to California, where I lived for one year in the foothill region near the coast at an elevation of 1,000 feet, free from responsibility and work. After the first year I never had any return of my pulmonary tuberculosis.

I believe a change of climate is more a question of finances than anything else. If one has not the necessary means to have what is right in a different climate his chances for a cure are much better with home treatment, but when a better climate can conveniently be added to other measures of treatment for pulmonary tuberculosis it should be advised.—W. Jarvis Barlow, Univ. of Southern California, Los Angeles, Cal.

NOTE.—For the bibliography of tuberculosis in its various relations the reader is referred to the Index Catalogue of the Surgeon-General's Library, U. S. Army, Volume 18, Second Series, Washington, 1913. This bibliography embraces 412 pages in double columns, an invaluable contribution to the history and literature of this subject.

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 63, NUMBER 2

Notes on Some Specimens of a Species of Onychophore (Oroperipatus corradoi) New to the Fauna of Panama

BY

AUSTIN HOBART CLARK

(Publication 2261)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
FEBRUARY 21, 1914

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

NOTES ON SOME SPECIMENS OF A SPECIES OF ONYCHOPHORE (OROPERIPATUS CORRADOI) NEW TO THE FAUNA OF PANAMA

By AUSTIN HOBART CLARK

Through Professor T. D. A. Cockerell I have recently received four specimens of a species of Peripatus collected at Ancon, Canal Zone, by Mr. J. Zetek, which represent a genus, as well as a species, not previously definitely known as an inhabitant of the region.

These specimens are now in the collection of the United States National Museum.

OROPERIPATUS CORRADOI (Camerano)

Peripatus corradoi 1898. Camerano, Boll. Mus. Zool. ed Anat. comp. di Torino, vol. 13, No. 316, p. 2.—1898. Camerano, Atti R. Acc. Sci. di Torino (2), vol. 33, pp. 308-310, figs. A and B; p. 591.—1905. Bouvier, Ann. des. sci. nat. (9), vol. 2, p. 120, pl. 3, fig. 15; pl. 4, figs. 29, 30; text figs. 6, p. 15; 18, p. 20; 42, p. 38; 63, p. 124; 64 and 65, p. 125 (the complete synonymy is given).

Oroperipatus corradoi 1913. A. H. Clark, Proc. Biol. Soc. Washington, vol. 26, p. 16.

Locality.—Ancon, Panama Canal Zone.

Material.—Four specimens, two males and two females.

Notes.—One of the females is 34 mm. long and 4 mm. broad, and possesses twenty-seven pairs of ambulatory legs; the other is 34 mm. long and 3.5 mm. broad, with twenty-nine pairs of ambulatory legs.

Of the males one is 19 mm. long and 2.3 mm. broad, with twenty-four pairs of ambulatory legs, and the other is 19 mm. long and 2.5 mm. broad, with twenty-five pairs of ambulatory legs.

All the specimens are dorsally dark brown in color, with a narrow median line of darker, and ventrally light brown.

The dorsal folds in the two females are all of approximately the same width, but in the males there is a more or less distinct alternation of broader and narrower folds; there are no incomplete folds.

Some of the primary papillæ of the back are very much more developed than the others, and lighter in color, and these enlarged light colored papillæ show a more or less regular arrangement which, however, is very much less evident in the females than in the males.

There is a regular line of these papillæ on either side of the median dorsal dark line, which gradually becomes irregular and disappears somewhat before the middle of the body. There are two scalloped rows, one along each of the outer margins of the dorsal surface of the body, consisting of a series of arcs of which the convexity is above each of the ambulatory legs; beyond these in the males there are similar lines with the arcs alternating with those in the inner rows, their convexity being between the legs, and reaching down to the level of the leg bases. Between the median and lateral lines the enlarged papillæ are arranged in a sinuous and more or less irregular line, with scattered ones on either side of it; but toward the posterior part of the body they become less and less numerous, and more and more irregular in their position.

All of the legs are provided with feet.

The creeping pads consist each of four arcs of nearly equal width, of which the fourth is about as long as the second.

The urinary tubercle which, in reference to the short diameter of the third arc is approximately central in position, divides the third arc into two parts, of which the posterior is much smaller than the anterior, and is entirely separated from the tubercle, which is broadly united with the anterior portion. The conditions in these specimens is well represented in Bouvier's figure.

Remarks.—These individuals appear to agree with the specimens of *Oroperipatus corradoi* from Guayaquil as described by Bouvier.

Range.—*Oroperipatus corradoi* is now known from Quito, Balzar and Guayaquil, Ecuador, and from Ancon, Panama Canal Zone.

List of the Species of Onychophores Known from the Isthmus of Panamá

Oroperipatus corradoi (Camerano).
Oroperipatus eiseni (Wheeler)[1].
Macroperipatus geayi (Bouvier).
Epiperipatus brasiliensis (Bouvier).
Epiperipatus edwardsii (Blanchard).

---

[1] This species has not actually been taken on the isthmus, but as it ranges from Tepic, Mexico, south to the Rio Purus, Brazil, it probably occurs there.

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 63, NUMBER 3

A New Ceratopsian Dinosaur from the Upper Cretaceous of Montana, with Note on Hypacrosaurus

(With Two Plates)

BY

CHARLES W. GILMORE
Assistant Curator of Fossil Reptiles, U. S. National Museum

(Publication 2262)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
MARCH 21, 1914

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

A NEW CERATOPSIAN DINOSAUR FROM THE UPPER CRETACEOUS OF MONTANA, WITH NOTE ON HYPACROSAURUS[1]

By CHARLES W. GILMORE

ASSISTANT CURATOR OF FOSSIL REPTILES, U. S. NATIONAL MUSEUM.

(With Two Plates)

INTRODUCTION

The fossil remains upon which the present communication is based were collected by the writer during the summer of 1913 while working under the auspices of the U. S. Geological Survey on the Blackfeet Indian Reservation in northwestern Montana. The partial skeletons of five individuals were found and these supplement one another to such an extent that nearly all parts of the skeleton are represented. The skull presents some anatomical features not heretofore known in the Ceratopsia and the new genus and species *Brachyceratops montanensis* is here proposed.

This new form is the smallest known representative among the Ceratopsian dinosaurs and in several respects strikingly different from any of its allied contemporaries.

The present paper is preliminary. Upon the completion of the preparatory work now in progress a more detailed account of the skeletal anatomy and a discussion of its affinities will be given.

BRACHYCERATOPS MONTANENSIS, new genus and species

Type.—Cat. No. 7951 U. S. Nat. Mus. A considerable portion of a disarticulated skull (*i. e.*, nasals, prefrontals, postfrontals, postorbitals, premaxillaries, maxillaries, alisphenoid), with which is provisionally associated a fragmentary part of the frill and a right dentary and a predentary.

Type locality.—N. E. ¼ Sec. 16, T 37 N, R 8 W, Milk River, Blackfeet Indian Reservation, Teton County, Montana.

Paratypes.—Cat. No. 7952, U. S. Nat. Mus. Rostral and portions of the premaxillaries; Cat. No. 7953 U. S. Nat. Mus. Sacrum,

---

[1] Published by permission of the Director of the U. S. Geological Survey.

complete pelvis and articulated caudal series of 45 vertebræ continuing to the tip of the tail; Cat. No. 7957, U. S. Nat. Mus. Two tarsals of the distal row, four articulated metatarsals, a portion of the fifth, and eleven phalanges.

Localities.—Same as the type.

Horizon.—From the upper part of an Upper Cretaceous formation soon to be described by the U. S. Geological Survey, which includes the equivalent of the Judith River formation and some older beds. The fossiliferous horizon is also the equivalent of the upper part of the Belly River formation, as described in neighboring areas of Canada.

Generic and specific characters.—Typically of small size. Skull with facial portion much abbreviated, and deep vertically. Supraorbital horn cores small. Nasal horn core outgrowth from nasals, large, slightly recurved, laterally compressed, and divided longitudinally by median suture. Frill with comparatively sharp median crest, fenestræ apparently of small size, and entirely within the median element. Supratemporal fossæ opening widely behind. Border of frill scalloped, but without separate marginal ossifications. Dentition as compared with *Triceratops* greatly reduced.

Description of skull.—The description to follow is devoted entirely to a consideration of the skull, since it shows characters of sufficient importance to readily distinguish it from all the other known members of the Ceratopsian group, which in the greater number of instances have also been established upon cranial material.

When found, the skull was entirely disarticulated, but the excellent state of preservation of the bone and the absence of distortion by crushing rendered the assembling of the scattered elements a comparatively easy matter. This specimen is of the utmost importance in the evidence it gives for the proper interpretation of the cranial elements, and especially the positive information it affords relating to those parts of the Ceratopsian cranium now somewhat in controversy.

In the above diagnosis of the genus and species, it is stated to be typically of small size. While this statement is true so far as applied to the known specimens, it should also be stated that to some extent the small size of these specimens may be due to the immaturity of the individuals. The open sutures of the skull, sacrum, and vertebræ all testify to the youth of the animals.

Viewing the skull in profile (pl. 1), one is especially impressed by the great abbreviation of the facial portion, when compared with the

Ceratopsians of the Lance formation. It is to this shortening that the generic name refers. The narial opening, as in other known Judith River and Belly River forms, is situated well forward and under the nasal horn, whereas in the later and more highly specialized *Triceratops* this orifice is entirely posterior to that horn. The distance between the nasal and supraorbital horns, as seen in the upper outline, is exceedingly short, due largely to the shortened nasal bones and the great fore and aft development of the basal portion of the nasal horn and also to the forward position over the orbits of the small brow horns.

The exact pitch of the frill portion in relation to the anterior part of the skull cannot be positively determined, though in the drawing it has been placed in accordance with the evidence of articulated skulls.

This specimen brings to light an entirely new phase of nasal horn development and one which, so far as our previous knowledge goes, appears to be unique among dinosaurs. Reference is made here to the longitudinal separation of the horn core into two halves by the nasal suture. This also indicates the nasal horn to be an outgrowth from the nasal bones instead of having originated from a separate center of ossification, as is the case in the more specialized *Triceratops*. It appears quite probable there are some of the described Belly River species that will also show a similar mode of nasal horn development when juvenile specimens are found.

The nasals are especially deep and massive, due to the development on their superior surfaces of the nasal horn cores. Posteriorly they present a pointed process with a beveled underlapping surface for contact with the prefrontals (the frontals and lachrymals of authors). Laterally they send down a deep extension to meet the premaxillary, and anteriorly the arched ventral borders of the nasal bones form the upper half of the boundary of the narial orifice. Anteriorly they send out vertically flattened processes (see *p*, fig. 1) between which are received the ascending processes of the premaxillæ. This nasal process appears to end about 32 mm. in advance of the forward line of the horn core, so that the upper outline of the beak is formed largely by the premaxillaries. The horn has a broad fore and aft extent at its base, but tapers rapidly to a bluntly pointed horn of moderate height. Transversely it is much compressed at the base, though inclined to expand somewhat toward the summit. The horn as a whole is directed somewhat forward, but the curve of the posterior side is such as to give the impression that its upper part is slightly recurved. The surfaces of the upper half are roughened and grooved by vascular impressions.

On the tip of the left half of the nasal horn is a small, flattened oval bony ossicle, which rests in a shallow depression or pit on the apex of the horn as shown at *os*, figure 1. This ossicle is a distinct element from the underlying bone and may represent the incipient horn of later Ceratopsians where it is known to be developed from a center of ossification distinct from the nasal bones.

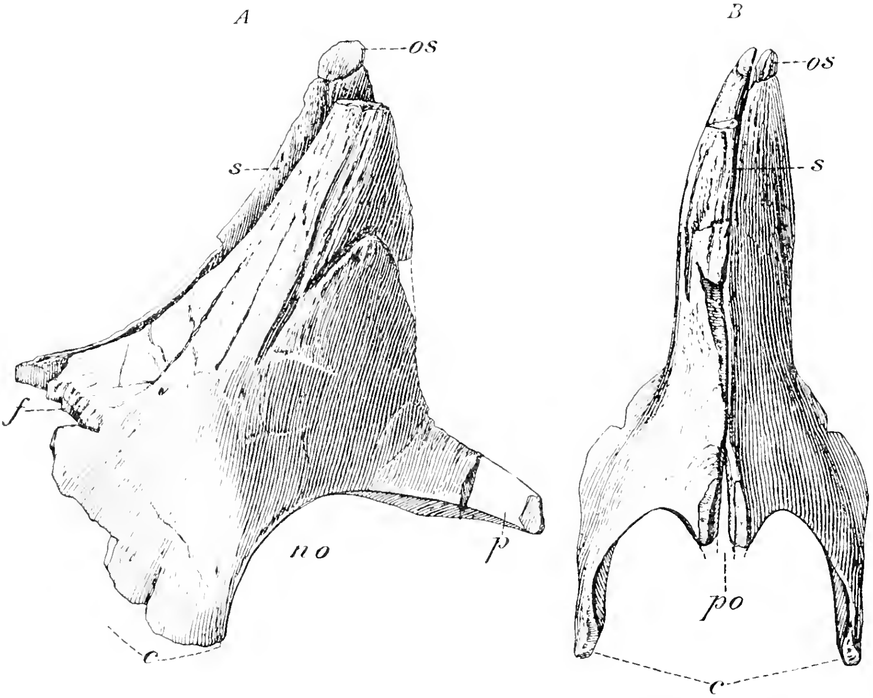


FIG. 1.—Nasals and nasal horn cores of *Brachyceratops montanensis*. Type: Cat. No. 7951 U. S. Nat. Mus., ½ Nat. size. A, side view; B, front view; *c*, surface for contact with the premaxillaries; *f*, surface for articulation of prefrontal; *no*, anterior nasal opening; *os*, ossicle on top of horn core; *p*, anterior process of nasal; *po*, orifice for superior processes of premaxillaries; *s*, suture separating two halves of nasal horn.

The maxillaries are of triangular outline with alveoli for twenty teeth in the functional row. As compared with *Triceratops* this is a greatly reduced number, *Triceratops* having forty alveoli in the maxillary. In this specimen all of the functional teeth have fallen out, but two or more germ teeth are still retained and these give some idea of their character.

The true extent of the postfrontals in the Ceratopsian skull is here correctly determined for the first time. Authorities have heretofore considered the postfrontal as extending from the median line outward and including all of that portion of the skull here designated as postfrontal and postorbital (see pl. 2). In this specimen a longitudinal suture just internal to the base of the supraorbital horn core separates it into two distinct elements. The inner portion all paleontologists agree in calling the postfrontal, the outer appears without question to represent the postorbital. Von Huene,[1] in 1912, in a skull of *Triceratops prorsus* regarded that portion forming the posterior boundary of the orbit as representing the whole of the postorbital, but the writer now questions the correctness of this determination in the genus *Triceratops*, in so far as regarding it as representing the entire postorbital.

In *Brachyceratops* the postfrontal is a somewhat irregularly triangular bone, longer than wide, which unites by suture on the median line with its fellow of the opposite side.

Anteriorly the combined postfrontals terminate in a pointed projection that is interposed between the deeply emarginate posterior borders of the prefrontals. Posteriorly and on either side of the postfrontal foramen these bones articulate by suture with the median element of the frill. A toothed external border unites with the postorbital. Beginning between the horn cores the median upper surfaces of the postfrontals are angularly depressed, gradually deepening and widening transversely as they approach the fontenelle much as in *Styracosaurus albertensis* Lambe, see B, plate II, The Ottawa Naturalist, Vol. 27, 1913.

The postorbital gives rise to the small supraorbital horn core and forms nearly one-half of the orbital border. Posterior to this horn which is situated on the extreme anterior end, the bone flares out into a wide expanded portion, much deflected externally, with a curved posterior border, the inner half of which forms a portion of the outer boundary of the supratemporal fossa, the outer half having an underlapping sutural edge for articulation with the squamosal. The straight inferior edge meets the jugal which is missing in this specimen.

The thickened anterior border shows a sutural edge for union with the missing supraorbital bone. On the median inferior surface is a shallow pit which receives the outer end of the alisphenoid, as it does in *Stegosaurus* and *Camptosaurus*.

---

[1] Neues Jahrbuch, 1912, fig. 3, p. 151.

Immediately above the orbit on the anterior part of the postorbital there rises a low horn core, the upper extremity being obtusely rounded from a lateral aspect, see *po.h* plate 1, but sharply pointed when viewed from the front. The external surface of this horn is plane, the internal strongly convex, with the antero-posterior diameter greatly exceeding the transverse, the total height of the horn above the orbit being 35 mm. These horn cores appear to be outgrowths from the postorbital bones unless they include a posterior supraorbital element such as has recently been found in the skull of *Stegosaurus*. However that may be, there is no trace of such a division in the postorbitals of this specimen. This again raises the question of the proper designation of these horns which have been called successively postfrontal and supraorbital horn cores. If an outgrowth from the postorbital bone, as the present specimen appears to indicate, the term postorbital horn core would be a more appropriate designation.

The prefrontals (the frontals and lachrymals of authors) are deeply emarginate anteriorly and receive between them the pointed posterior ends of the nasals.

The prefrontal is a quadrangular plate of bone diagonally placed filling the interspace between the postfrontal and nasal bones. Its thickened posterior end contributes to the inner part of the anterior boundary of the orbit. Near the posterior termination a narrow vertical sutural surface (*so,* pl. 2) on the external side was for the articulation of the small supraorbital bone that is missing. This element would have completed the thickened projecting orbital border immediately in front of the eye and which forms such a conspicuous feature of the Ceratopsian skull. On the upper posterior end of the prefrontal a pointed peg-like projection is received in a corresponding pit in the anterior border of the postfrontal, thus strengthening the union of these two bones. The prefrontal is just barely in contact with the postorbital at the base of the postorbital horn core.

The relationships of the pre- and postfrontals in *Brachyceratops* is an unusual one, for in most dinosaurian crania the frontal is interposed between them, and so far as the writer is aware the above condition is only found in *Stegosaurus* among the dinosauria and in some of the Permian reptilia. Von Huene has shown, and the writer believes correctly too, that the frontal in *Triceratops* has been entirely excluded from the dorsal surface of the skull.

The frill is represented by the median elements from two individuals. Both have portions missing, but the better preserved one is provisionally associated with the type as shown in plates 1 and 2. This association, however, is only provisional in so far as it applies to the recognition of the proper individual, for it can be said without question that all the bones found belong to the same kind of an animal.

The dermo-supraoccipital or interparietal, for surely it cannot be the parietal as Hay[1] and von Huene[2] have clearly shown, is united by suture with the anterior portion of the skull at the postfrontal foramen. The median part of the interparietal is sharply ridged, excepting the posterior extremity, where it flattens out into a thinner portion with an emarginate median border. Between the fenestræ the median bar, in cross section, is triangular. The superior surface of this ridge forward of its narrowest part between the fenestræ presents three low longitudinal swellings arranged one in front of the other. Proximally the median portion is greatly compressed transversely into a short neck, forward of which it again widens into a much depressed end that articulates laterally with the postfrontals and with them forms the upper boundaries of the postfrontal foramen, see *fo,* plate 2. Between these two lateral portions the median surface is deeply concave and slopes downward to a heavy truncated border that in all probability was suturally united with the parietals. In *Brachyceratops* at least, the parietal was entirely excluded from the dorsal aspect, and it is presumed that similar conditions obtained in *Triceratops,* although von Huene was inclined to regard a small portion of the median part of the frill posterior to the postfrontal foramen in that genus as being parietal.

The bone surrounding the frill fenestræ is very thin, but toward the lateral free edges and posteriorly it becomes thickened. Proximally it remains thin where it forms the floor of the supratemporal fossa but thickens toward the sutural border for the squamosal. The exact shape and extent of the frill fenestræ cannot be accurately determined from the available specimens, but it is readily apparent that they were of comparatively small size. The surfaces of the frill are relatively smooth and without the ramifying system of vascular grooves of the later Ceratopsians. There were no epoccipital bones on the margins of the frill, but on either side of the median emargination a series of prominences give to the periphery much the same peculiar scalloped effect found in the *Triceratops* frill with its separate ossifications.

---

[1] Proc. U. S. Nat. Mus. vol. 36, 1909, p. 97.

[2] Neues Jährbuch, 1912, pp. 150-156, figs. 3, 4, 5 and 6.

Laterally the median portion unites with the squamosal by a straight sutural edge that is directed forward and inward toward the center of the skull. A triangular outward projection with an upper striated surface at the anterior termination of the squamosal suture represents a surface that was overlapped by the articulated squamosals (*s.s.*, plate 1). A low, sharp, diagonally directed ridge apparently indicates the posterior extent of the overlap of the squamosal. The squamosals are missing, but those as in other primitive Ceratopsians appear to have been short and broad.

The rostral is missing from the type, but is present in a slightly smaller individual (Cat. No. 7952, U. S. Nat. Mus.). (See fig. 2.) In general aspect it resembles the rostral of *Triceratops*, but with a less curved anterior border. Externally the surfaces are pitted and grooved and in life were doubtless covered by a horny sheath.

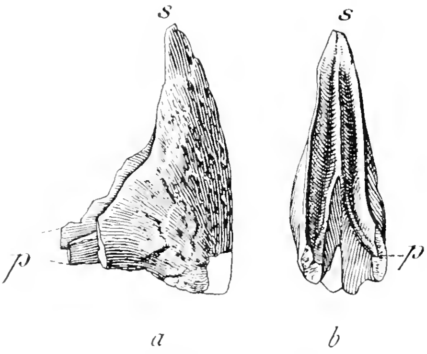


FIG. 2.—Rostral of *Brachyceratops montanensis*. Paratype: Cat. No. 7952 U. S. Nat. Mus., 1/2 nat. size. *a*, side view; *b*, posterior view; *s*, superior process; *p*, posterior processes.

The predentary except for its much smaller size is indistinguishable from that of *Triceratops*. It is to be distinguished from the predentary of *Monoclonius dawsoni* Lambe by the upward turned apex of the anterior end.

The dentary is stout, gradually narrowing vertically toward the front, the anterior end being especially depressed and unusually broad transversely, this end being nearly at right angles to the posterior portion. Near the posterior end on the external surface a stout coronoid process is developed, extending well above the dental border. It is compressed transversely but widens antero-posteriorly with a hooked forward process as in other primitive Ceratopsians. Beginning at the base of this process, a low, broad ridge extends forward at about mid-height along the outer side of the dentary. Above and below this ridge the outer surface retreats obliquely inward.

Viewed from above, the dental border is straight but is obliquely placed in relation to the lower portion, that is, it passes from the inner posterior margin to the outer anterior margin of the jaw. Beneath the coronoid process there is a deep mandibular fossa which extends forward about one-third the length of the dentary. On the inner side there is the usual row of foramina, leading into the dental chamber. The exact number of alveoli cannot be determined at this time, although the tooth series is relatively shorter than in either *Ceratops* or *Triceratops*.

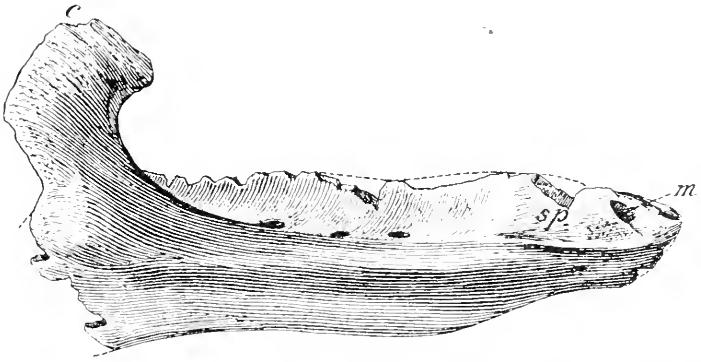


FIG. 3.—Dentary of *Brachyceratops montanensis*. Type: Cat. No. 7951 U. S. Nat. Mus., ½ nat. size. *c*, coronoid process; m, mental foramen; *sp*, surface for predentary.

At this time little can be said regarding the affinities of *Brachyceratops*, though it would appear most nearly allied to *Monoclonius*, as shown by its small size, the small brow horns of similar shape, large nasal horn and crenulated margin of the frill without separate marginal ossifications.

It is readily distinguished, however, from all known Ceratopsians by the longitudinal suture of the nasal horn, the small fenestræ wholly within the median frill element, and the greatly abbreviated facial portion of the skull. It is also apparent that there are other distinguishing features in the skeleton which is to be described later.

The striking resemblance of the fragment of a skull figured by Hatcher as *Monoclonius crassus*[1] to the homologous parts of the

---

[1] Monog. U. S. Geol. Survey, Vol. 49, 1907, p. 74, fig. 76.

present specimen leads the writer to suggest its possible identification with the present genus. Hatcher regarded it as belonging to a smaller and distinct individual from the type of that species and he also observes: "I describe and figure this element in this connection not out of regard for any certain additional characters it may furnish distinctive of the present genus and species [*Monoclonius crassus*] but rather for the information which it affords relative to the homologies of certain cranial elements in the Ceratopsia as a group." The great similarity of the horn-cores with those of *Brachyceratops* lends much color to the above suggestion.

MEASUREMENTS

	mm.
Greatest length of skull, about	565
Greatest breadth of skull, estimated	400
Expanse of frontal region at base of brow horn cores	90
Greatest width of nasals	58
Length of interparietal along median line	315
Height of nasal horn core above border of narial orifice	125
Greatest width of postfrontals	80
Greatest length of combined post- and prefrontals	126

NOTE ON HYPACROSAURUS

I wish to announce the discovery in northwestern Montana, in beds equivalent to the upper part of the Belly River formation, of the Trachodont reptile *Hypacrosaurus*.[1] A considerable portion of the skeleton (Cat. No. 7948, U. S. Nat. Mus.) of one individual was recovered, and at this time (the specimen not being entirely prepared) I am unable to distinguish it specifically from the type and only known species, *H. altispinus* Brown, from the Edmonton Cretaceous of Canada.

---

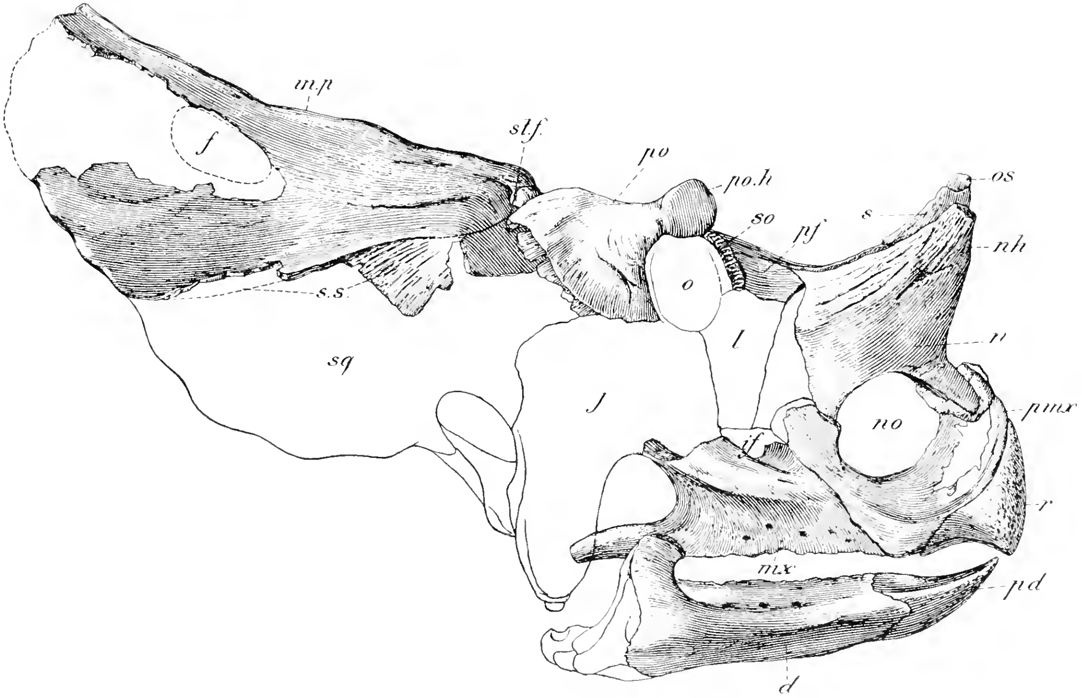
[1] Barnum Brown: A New Trachodont Dinosaur Hypacrosaurus, from the Edmonton Cretaceous of Alberta. (*Bull. Amer. Mus. Nat. Hist.*, Vol. 32, 1913, pp. 395-406.)

EXPLANATION OF PLATE 1

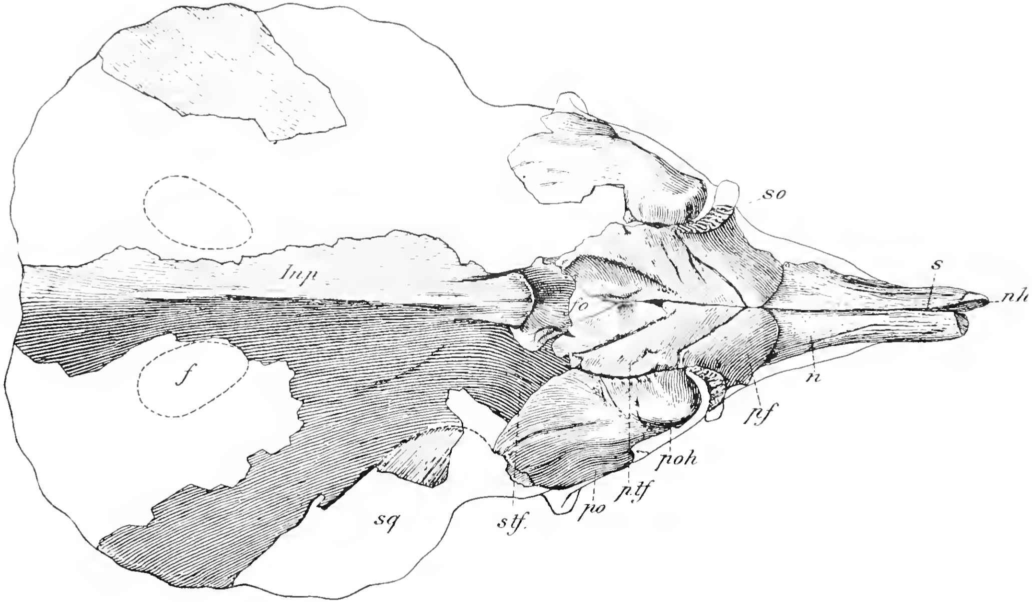
Lateral view of the skull of *Brachyceratops montanensis*. Type: Cat. No. 7951 U. S. Nat. Mus., ¼ nat. size. *d*, dentary; *f*, fenestra in frill; *if*, infraorbital foramen; *in.p*, interparietal; *j*, jugal; *l*, lachrymal; *mx*, maxillary; *n*, nasal; *nh*, nasal horn cores; *no*, anterior narial opening; *o*, orbit; *os*, ossicle on top of nasal horn core; *pd*, predentary; *pf*, prefrontal; *pmx*, premaxillary; *po*, postorbital; *po.h*, postorbital horn core; *r*, rostral; *s*, suture separating halves of nasal horn; *sq*, squamosal; *so*, sutural border on prefrontal for small supraorbital; *s.s*, sutural surfaces for squamosal; *st.f*, supratemporal fossa.

EXPLANATION OF PLATE 2

Superior view of the skull of *Brachyceratops montanensis*. Type: Cat. No. 7951 U. S. Nat. Mus., ¼ nat. size. *f*, fenestra in frill; *fo*, postfrontal foramen; *in.p*, interparietal; *n*, nasal; *nh*, nasal horn cores; *pf*, prefrontal; *po*, postorbital; *poh*, postorbital horn core; *p.tf*, postfrontal; *s*, suture representing halves of the nasal horn core; *so*, sutural border for missing supraorbital bone; *sq*, squamosal; *s.tf*, supratemporal fossa.



LATERAL VIEW OF SKULL OF BRACHYCERATOPS MONTANENSIS



SUPERIOR VIEW OF SKULL OF BRACHYCERATOPS MONTANENSIS

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 63, NUMBER 4

ON THE RELATIONSHIP OF THE GENUS AULACOCARPUS, WITH DESCRIPTION OF A NEW PANAMANIAN SPECIES

BY
H. PITTIER

(Publication 2264)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
MARCH 18, 1914

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

ON THE RELATIONSHIP OF THE GENUS AULACOCARPUS, WITH DESCRIPTION OF A NEW PANAMANIAN SPECIES

By H. PITTIER

The genus Aulacocarpus, as originally regarded[1] by its founder, Dr. O. Berg, included two species, *A. Sellowianus* Berg, from Brazil, and *A. crassifolius* (Benth.) Berg, from Colombia. The latter was first described as *Campomanesia crassifolia* Benth.,[2] upon material collected by the botanists of the *Sulphur* voyage on Gorgona Island, off the Pacific coast of Colombia, between Buenaventura and Tumaco. The Flora of the British West Indies by Grisebach contains[3] the description of a new species, *A. quadrangularis,* from Antigua and Guadeloupe Islands; and subsequently the same author added his *A. Wrightii,* originally collected in Eastern Cuba.[4]

Thus, in 1866 Aulacocarpus had been increased to four species,[5] but the flower of none of these had ever been described. Taking into consideration the general distribution of the Myrtaceae, it was but logical, in the absence of more complete information, to find a place for this genus among the Myrtoideae, which are widely dispersed in America. According to Berg, its affinities were with Campomanesia, a supposition which was strengthened by the original inclusion in this genus of one of the species of Aulacocarpus. On the other hand, Niedenzu, taking as a basis the embryonic characters, places it among the Eugeniinae.

During his exploration of the forests of Eastern Panama, in 1911, the writer had the good fortune to discover a new representative of Aulacocarpus in the shape of a medium-sized tree, from which herbarium specimens were obtained, the flowers being preserved in alcohol. The description of these shows that, contrary to every expectation, Aulacocarpus is not a true Myrtoid, but must be placed among

---

[1] Linnaea **27**: 345. 1856. Martius, Fl. Bras. **14**^{1}: 380. 1857.

[2] Bot. Voy. Sulphur 97. pl. 37. 1844.

[3] Page 239.

[4] Cat. Pl. Cub. 90. 1866.

[5] Niedenzu, however, ignores Grisebach's Antillean species (Engl. & Prantl, Pflanzenfam. **3**^{7}: 83. 1898).

the Leptospermoideae, also represented in South America by the Chilean genus Tepualia. This will be made clear by the following amended and completed description:

AULACOCARPUS Berg.

Receptacle forming a crater-like cup above the ovary. Sepals 5, short, obtuse or acute. Petals 5, unguiculate, apiculate. Stamens 10, inserted on the margin of the receptacle, 5 opposite to, 5 alternate with the sepals, curved outward beyond the corolla, the basifixed 2-celled anthers hanging around the receptacle; anther cells longitudinally dehiscent. Ovary 5-celled, each cell with 5 (or 4) ovules; style simple, truncate. Drupe depressed-globose, horny or sublignose, 5 to 1-celled, each cell with 1 seed. Seed albuminose, covered with a thick, suberose testa. Cotyledons plano-convex, thick; radicle basal, very short. Trees with very hard wood; leaves opposite, exstipulate, thick, obscurely veined; flowers single or few in a cluster, pseudo-axillary.

Species 5, Tropical American.

On account of its fundamental characters, viz.: exalbuminose seed, short basal radicle, ovate-depressed seeds, indehiscent woody drupe, 5-celled ovary, and 10 stamens, with basifixed anthers, Aulacocarpus would take perhaps an intermediary position between the Calothamninae and the Chamaelauciae. The genus does not naturally fit into any of the present divisions of the Leptospermoideae, although there can be no doubt as to its belonging to this subfamily.

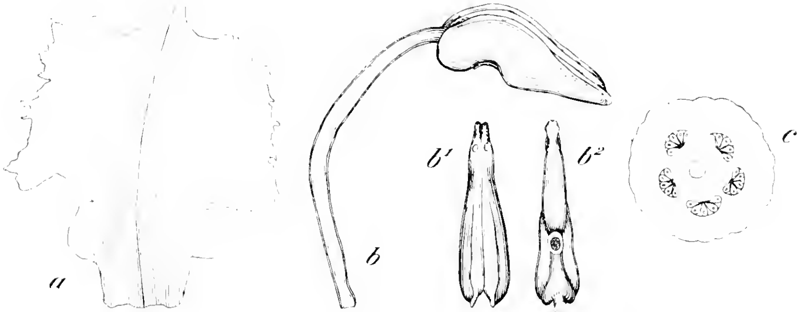
The collection and study of new materials of the 4 species of Aulacocarpus already described is highly desirable and it is not unlikely that a better knowledge of the genus will result in a reduction of the number of species. My own specimens do not agree with any existing description, and so I have presumed to describe them under a new name.

AULACOCARPUS COMPLETENS, sp. nov.

A tree up to about 18 meters high and 35 to 40 cm. in diameter at the base. Crown elongate; trunk continuous. Bark smooth, grayish. Entirely glabrous.

Leaves opposite, large, coriaceous, short-petiolate. Stipules none. Petioles thick, 4 to 5 mm. long. Leaf blades 14 to 25 cm. long, 5 to 11 cm. broad, ovate-elliptic (broader toward the base), cordate to truncate at the base, narrowly acuminate at tip, light green above, paler and sometimes brownish beneath. Costa impressed above, very prominent beneath; primary veins numerous, almost straight and parallel, slightly prominent above and underneath.

Flowers single or aggregate at nodes on old wood (never on the year's growth). Pedicels slender, 12 to 15 mm. long, bearing at the middle one pair of small bractlets, these clasping, ovate-acute, persistent, about 2 mm. long. Receptacle funnel-shaped or obconic, growing much above the ovary. Sepals 5, coriaceous, thick, ovate-triangular and acute at the tip, caducous, about 6 mm. long and 4 mm. broad at the base. Petals 5, reflexed, pink, irregularly and broadly ovate, apiculate, with a short, broad claw and a pair of rounded basal winglets; margin irregularly denticulate or sublacerate; length 11 mm., breadth 9 mm. Stamens 10, inserted on margin of receptacle and alternately opposite to sepals and petals; filaments about 10 mm. long, bending outwards; anthers 6 to 6.5 mm. long, golden yellow, basifixed, introrse, with a large ovate, glandular, porelike structure at about the middle of the ventral side, and four small glands near the tip; cells longitudinally dehiscent. Ovary 5-celled, each cell with 5 or 4 ovules; style glabrous, terete, truncate, about 7.5 mm. long.



Floral details of *Aulococarpus completens*: *a*, petal; *b*, stamen; *b*¹, anther, ventral side; *b*², anther, dorsal side; *c*, cross-section of ovary. Enlarged 4 times.

Fruit dry, 4 to 1-celled, globose-depressed in the first case, with the cells showing outside, globose and crowned with the cuplike receptacular overgrowth when 1-celled; pericarp thick, hard, greenish outside at maturity; cells 1-seeded. Seeds large, ovoid and slightly compressed laterally, their length 11 mm., the longest diameter 9 mm.

PANAMA: Hills back of Puerto Obaldia, San Blas Coast; flowers and fruit, August 30, 1911; *Pittier* 4310 (type, U. S. Nat. Herb. Nos. 479435-7).

This remarkable species differs from *A. crassifolius* (Benth.) Berg in its larger leaves, these almost always deeply emarginate at the base, and in having the lobes of the calyx long, acute, triangular, and caducous. Further, our species is a relatively large tree, while the latter, compared in its habit with *Calycolpus glaber,* is barely more than a shrub. The wood is very hard and known under the name "gasparillo."

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 63, NUMBER 5

DESCRIPTIONS OF FIVE NEW MAMMALS FROM PANAMA

BY
E. A. GOLDMAN

(PUBLICATION 2266)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
MARCH 14, 1914

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

DESCRIPTIONS OF FIVE NEW MAMMALS FROM PANAMA

By E. A. GOLDMAN

Additional determinations of mammals obtained by the writer, while assigned to the Smithsonian Biological Survey of the Panama Canal Zone, reveal five hitherto unrecognized forms which are described below.

For the loan of types and other material for comparison I am indebted to Dr. J. A. Allen of the American Museum of Natural History, New York City, and to Mr. Samuel Henshaw of the Museum of Comparative Zoology, Cambridge, Massachusetts.

CHIRONECTES PANAMENSIS, new species

Type from Cana (altitude 2,000 feet), eastern Panama. No. 179164, skin and skull, male, old adult, U. S. National Museum (Biological Survey Collection); collected by E. A. Goldman, March 23, 1912. Original number 21562.

General characters.—Similar to *C. minimus* of Guiana in size and color, but differing in cranial details, especially the longer braincase and much longer, evenly tapering, and posteriorly pointed nasals.

Color.—Color pattern about as in *C. minimus*, but light facial areas apparently less distinct; dark brown or black of forearms extending down over the thinly haired first phalanges of three median digits, the terminal phalanges white or light flesh color as in *minimus;* hairy base of tail dark all round.

Skull.—Similar to that of *C. minimus*, but braincase more elongated, the well-developed lambdoid crest projecting posteriorly over foramen magnum; nasals longer, encroaching farther on frontal platform, the ends pointed instead of truncate, and the sides not constricted near middle; ascending branches of premaxillae reaching farther posteriorly along sides of nasals; fronto-parietal suture convex posteriorly; inner sides of parietals longer; sagittal crest well developed.

Measurements.—Type: Total length, 651 mm.; tail vertebrae, 386; hind foot, 72. *Skull* (type): Greatest length, 74.2; condylobasal length, 72.3; zygomatic breadth, 43.8; length of nasals, 33;

greatest breadth of nasals, 11; interorbital breadth, 14.1; postorbital breadth, 8.5; palatal length, 45.6; upper molariform tooth row, 26.4; upper premolar series, 11.6.

Remarks.—While the water opossum of Middle America and Colombia is very similar in size and color to *C. minimus* of northeastern South America it differs in numerous cranial details from that animal as figured by Burmeister.[1] The nasals are conspicuously longer and very different in form. The sagittal crest develops in both sexes early in life. In a specimen from Rio Frio, Cauca River, Colombia, the tail is black to the tip.

Specimens examined.—Total number, 11, as follows:

Panama: Cana (type), 1.

Costa Rica: San Jose, 1; exact localities unknown, 3.

Nicaragua: Matagalpa, 1.

Colombia: Bagado, 1; Barbacoas, 1; Guanchito, 1; Porto Frio, Cauca River, 1; Palmira, 1.

LONCHOPHYLLA CONCAVA, new species

Type from Cana (altitude 2,000 feet), eastern Panama. No. 179621, skin and skull, male adult, U. S. National Museum (Biological Survey Collection), collected by E. A. Goldman, May 20, 1912. Original number 21701.

General characters.—Similar in size to *L. mordax,* but color darker; cranial and dental characters different, the second upper premolar notably narrower, and in the reduced development of the internal lobe more like that of the much larger species, *L. hesperia.*

Color.—About as in *Glossophaga soricina;* general color of upper parts near warm sepia (Ridgway, Color Standards and Nomenclature, 1912), the under parts and basal color of fur of upper parts somewhat paler.

Skull.—Broader and more massive than that of *L. mordax,* the braincase larger and more fully inflated; interpterygoid fossa broader; coronoid process lower, the upper outline more broadly rounded; angle of mandible longer; incisors slightly larger; second upper premolar much less extended transversely owing to reduction in size of inner lobe; molar crowns more quadrate, less triangular in outline. Compared with that of *L. hesperia* the skull is much smaller and relatively shorter and broader, the braincase relatively larger but flatter above; coronoid process with less broadly rounded

---

[1] Fauna Brasiliens, pp. 72-73, pl. 11, figs 3-4, 1856.

upper outline; dentition similar, but relatively heavier, the premolar series less widely spaced; third upper molar nearly as large as second (decidedly smaller in *hesperia*).

Measurements.—Type (measured in flesh): Total length, 68 mm.; tail vertebrae, 10; tibia, 12.7; hind foot, 11; forearm, 33.9. *Skull* (type): Greatest length, 23.4; condylobasal length, 22.4; interorbital breadth, 4.6; breadth of braincase, 9.3; mastoid breadth, 9.8; depth of braincase at middle, 6.9; palatal length, 12.3; length of mandible, 16.8; maxillary tooth row, 8.

Remarks.—In the general form of the skull this species is in all essential respects like *L. mordax* and *L. robusta* and unlike *L. hesperia* in which the skull is relatively much narrower and more elongated. The narrowness and *Chaeronycteris*-like appearance of the skull of *L. hesperia* has been pointed out by Mr. Gerrit S. Miller, Jr.[1] The greater relative as well as actual length of the rostrum in *hesperia* leaves the third upper molar implanted well in front of the maxillary processes of the zygoma as in the genus *Chaeronycteris* instead of in the same horizontal plane with these processes as in *mordax* and *robusta*. In the narrowness of the second upper premolar, however, *L. concava* approaches *hesperia*, the conspicuous inner lobe present in *mordax* and *robusta* being reduced to a slight swelling bearing a small cusp. The coronoid process in *concava* is somewhat intermediate in shape between the high angular form seen in *mordax* and the low, broadly rounded upper outline of *hesperia*.

A small bat, *Lionycteris spurrelli*, from northwestern Colombia, has recently been described by Mr. Oldfield Thomas and made the type of a new genus characterized by the narrowness of the upper premolars. *L. concava* may possibly require comparison with the Colombian species which is based on an immature individual. But, allowing for immaturity, the cranial dimensions given are so different (greatest length, 18.7 in *spurrelli*, 23.4 in *concava*) that the specific identity of the two seems very improbable.

Specimens examined.—One, the type.

LUTRA REPANDA, new species

Type from Cana (altitude 2,000 feet), eastern Panama. No. 179974, skin and skull, male adult, U. S. National Museum (Biological Survey Collection), collected by E. A. Goldman, May 30, 1912. Original number 21758.

---

[1] Proc. U. S. Nat. Mus., vol. 42, No. 1882, p. 24, March 6, 1912.

General characters.—A small form with low, flat skull closely allied to *L. colombiana,* but differing in dental and slight cranial characters, especially the lesser transverse extent of the large upper molariform teeth. Differing from *L. latidens* in much smaller size as well as cranial details.

Color.—Entire upper parts warm sepia or mars brown (Ridgway, 1912); under parts grayish brown, palest on throat, pectoral and inguinal regions; lips and inner sides of forelegs soiled whitish.

Skull.—Similar in size to that of *L. colombiana;* rostrum and interorbital space narrower; lachrymal eminence more prominent, projecting as a distant process on anterior border of orbit; jugal less extended vertically but bearing a postorbital process as in *colombiana;* palate reaching farther posteriorly beyond molars; upper carnassial narrower, with inner lobe less produced posteriorly, leaving a gap which is absent in *colombiana;* upper molar narrower, the postero-external cusp set inward, giving the crown a less evenly rectangular outline. Contrasted with that of *L. latidens* the skull is very much smaller, with flatter frontal region.

Measurements.—Type: Total length, 1085 mm.; tail vertebrae, 500; hind foot, 119. An adult female from Gatun, Canal Zone: 1095; 463; 111. *Skull* (type): Condylobasal length, 109.1; zygomatic breadth, 72; interorbital breadth, 23.1; postorbital breadth, 16.8; mastoid breadth, 69.9; palatal length, 49.8; maxillary tooth row, 36.1; alveolar length of upper carnassial, 12.4; alveolar breadth of upper carnassial, 10.

Remarks.—The otter of Panama, like other Middle American forms of *Lutra,* has the nose pad haired to near the upper border of the nostrils; the soles of the feet are entirely naked; the tufts of hair under the toes and the granular tubercles present on the soles of the hind feet in *L. canadensis* are absent. The frontal region is flatter in skulls of *L. repanda* than in the skull of the type of *L. colombiana,* but the more swollen condition of the latter may be due to the presence of the parasites that frequent the frontal sinuses in *Mustelidae.*

Specimens examined.—Two, from localities as follows:

Panama: Cana (type), 1.

Canal Zone: Gatun, 1.

FELIS PIRRENSIS, new species

Type from Cana (altitude 2,000 feet), eastern Panama, No. 179162, skin and skull, female adult, U. S. National Museum (Biological Survey Collection); collected by E. A. Goldman, March 22, 1912. Original number 21559.

General characters.—A large, long-tailed tiger-cat, probably a member of the *F. pardinoides* group. Pelage rather long and soft; fur of nape not reversed; skull large with narrowly spreading zygomata and fully inflated audital bullae.

Color.—Ground color of upper parts ochraceous tawny (Ridgway, 1912), nearly uniform from nape to base of tail, but becoming somewhat paler on head and paling through cinnamon buff to pinkish buff along lower part of sides; general upper surface heavily lined and spotted with black, the spots on sides more or less completely encircling tawny areas, or forming rosettes; back of neck with a narrow median black line and two broader parallel lines, one on each side; shoulders marked by heavy diagonal stripes extending from near a rounded solid black median spot downward and forward on each side; posterior part of back with two narrow central lines extending to near base of tail; under parts white, heavily spotted with black across abdomen, and with black bars, one across throat and one across neck; outer sides of forearms and hind legs cinnamon buffy, spotted with black; feet buffy grayish interrupted by small black markings; ears deep black, with white submarginal spots and buffy edges; tail with about 12 broad, irregular, but nearly complete black rings, the narrow interspaces buffy above and white below.

Skull.—Large and rather elongated, the vault of braincase highest near fronto-parietal suture; frontal region broad; zygomata slightly spreading posteriorly, the squamosal arms not strongly bowed outward; palate narrow; audital bullae large and much inflated anteriorly.

Measurements.—Type: Total length, 963 mm.; tail vertebrae, 440; hind foot, 131.5. *Skull* (type): Greatest length, 99.6; condylobasal length, 95.6; zygomatic breadth, 62.8; interorbital breadth, 18.5; length of nasals (median line), 17.6; greatest breadth of nasals, 13; intertemporal breadth of braincase, 34; breadth between tips of postorbital processes, 51.5; length of palate, 38.5; length of upper incisive tooth row, 12.2; alveolar length (outer side) of upper carnassial, 11.6.

Remarks.—This tiger cat is provisionally referred to the little known *F. pardinoides* group. In size it seems nearer to the *F. wiedii* group, but it lacks the reversed pelage of nape commonly ascribed to that group. Moreover, the skull is more elongated than in the available Mexican and Brazilian specimens used for comparison and assumed to represent the *F. wiedii* group. It may be similar to *F. pardinoides oncilla* Thomas, from Volcan de Irazu, Costa Rica, but the type of the latter without skull is described as a much smaller animal with clay colored under parts. No comparison with the forms of *Felis pajeros* seems necessary.

Specimens examined.—One, the type.

AOTUS ZONALIS, new species

Type from Gatun (altitude 100 feet), Canal Zone, Panama, No. 171231, skin and skull, female adult, U. S. National Museum (Biological Survey Collection); collected by E. A. Goldman, April 29, 1911. Original number 21101.

General characters.—Resembling *A. griseimembra,* but general color more buffy, less grayish; skull broader and differing in numerous details; dentition heavier.

Color.—General shade of upper parts, limbs and upper base of tail near wood brown (Ridgway, 1912) with a buffy suffusion, this color more or less heavily overlaid with russet and black along median line of back; head marked with narrow black lateral lines converging to a point on back of neck, and a black median frontal line extending from between eyes to crown; white spots above and below eyes; sides of neck grayish in some specimens; under parts light ochraceous-buff; feet blackish; proximal third of under side of tail usually stained with chestnut, the distal two-thirds black all round.

Skull.—Similar in general size to that of *A. griseimembra,* but broader, the greater breadth most noticeable in the braincase; interorbital region more depressed, materially altering the facial angle; frontals less extended posteriorly between parietals; parietals joined by a longer suture owing to lesser posterior development of frontals; supraoccipital reaching farther upward in a wedge-shaped extension between parietals; zygomatic portion of jugal heavier; audital bullae less inflated in front of meatus; mandible broader and heavier, the angle more everted; molariform teeth heavier.

Measurements.—Type: Total length, 683 mm.; tail vertebrae, 400; hind foot, 90. Average of two adult female topotypes: 637 (620-654); 357 (325-390); 85.5 (83-88). An adult male from Boca de Cupe: 670; 360; 90. *Skull* (type): Greatest length, 60.9; condylobasal length, 47.2; zygomatic breadth, 37.5; breadth between outer sides of orbits, 43.3; postorbital breadth, 31.5; mastoid breadth, 33.8; interorbital breadth, 5.2; palatal length, 17.5; maxillary tooth row, 18.3.

Remarks.—This species, the only known nocturnal monkey of Panama, closely resembles *A. griseimembra* of the Santa Marta region of Colombia in external appearance, the principal difference being a more general buffy suffusion of the body and limbs. The skull, however, differs in many important respects and the larger molariform teeth of the Panama animal would alone serve as a distinguishing character.

Specimens examined.—Total number, 10, from localities as follows:

Canal Zone: Gatun (type locality), 4.
Panama: Cana, 3; Boca de Cupe, 3.

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 63, NUMBER 6

SMITHSONIAN
PHYSICAL TABLES

SIXTH REVISED EDITION

PREPARED BY
FREDERICK E. FOWLE
AID, SMITHSONIAN ASTROPHYSICAL OBSERVATORY

(PUBLICATION 2269)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
1914

ADVERTISEMENT.

In connection with the system of meteorological observations established by the Smithsonian Institution about 1850, a series of meteorological tables was compiled by Dr. Arnold Guyot, at the request of Secretary Henry, and the first edition was published in 1852. Though primarily designed for meteorological observers reporting to the Smithsonian Institution, the tables were so widely used by physicists that it seemed desirable to recast the work entirely. It was decided to publish three sets of tables, each representative of the latest knowledge in its field, and independent of one another, but forming a homogeneous series. The first of the new series, Meteorological Tables, was published in 1893, the second, Geographical Tables, in 1894, and the third, Physical Tables, in 1896. In 1909 yet another volume was added, so that the series now comprises: Smithsonian Meteorological Tables, Smithsonian Geographical Tables, Smithsonian Physical Tables, and Smithsonian Mathematical Tables.

The fourteen years which had elapsed in 1910 since the publication of the first edition of the Physical Tables, prepared by Professor Thomas Gray, had brought such changes in the material upon which the tables must be based that it became necessary to make a radical revision for the 5th revised edition issued in 1910. That revision has been still further continued for the present sixth edition.

Charles D. Walcott,
Secretary of the Smithsonian Institution.

June, 1914.

PREFACE TO THE 5TH REVISED EDITION.

The present Smithsonian Physical Tables are the outcome of a radical revision of the set of tables compiled by Professor Thomas Gray in 1896. Recent data and many new tables have been added for which the references to the sources have been made more complete; and several mathematical tables have been added, — some of them especially computed for this work. The inclusion of these mathematical tables seems warranted by the demand for them. In order to preserve a uniform change of argument and to facilitate comparison, many of the numbers given in some tables have been obtained by interpolation in the data actually given in the papers quoted.

Our gratitude is expressed for many suggestions and for help in the improvement of the present edition: to the U. S. Bureau of Standards for the revision of the electrical, magnetic, and metrological tables and other suggestions; to the U. S. Coast and Geodetic Survey for the revision of the magnetic and geodetic tables; to the U. S. Geological Survey for various data; to Mr. Van Orstrand for several of the mathematical tables; to Mr. Wead for the data on the musical scales; to Mr. Sosman for the new physical-chemistry data; to Messrs. Abbot, Becker, Lanza, Rosa, and Wood; to the U. S. Bureau of Forestry and to others. We are also under obligation to the authors and publishers of Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen (1905) and B. O. Peirce's Mathematical Tables for the use of certain tables.

It is hardly possible that any series of tables involving so much transcribing, interpolation, and calculation should be entirely free from errors, and the Smithsonian Institution will be grateful, not only for notice of whatever errors may be found, but also for suggestions as to other changes which may seem advisable for later editions.

F. E. FOWLE.

ASTROPHYSICAL OBSERVATORY
OF THE SMITHSONIAN INSTITUTION,
June, 1910

PREFACE TO THE 6TH REVISED EDITION.

The revision commenced for the fifth edition has been continued; a large proportion of the tables have been rechecked, typographical errors corrected, later data inserted and many new tables are added, including among others a new set of wire tables from advance sheets courteously given by the Bureau of Standards, new mathematical tables computed by Mr. Van Orstrand and those on Röntgen rays and radioactivity. The number of tables has been increased from 335 to over 400. We express our gratitude to the Bureau of Standards, to the Geophysical Laboratory, the Geological Survey, and to those who have helped through suggested improvements, new data, or by calling our attention to errors in the earlier editions.

F. E. FOWLE.

ASTROPHYSICAL OBSERVATORY
OF THE SMITHSONIAN INSTITUTION,
October, 1913.

TABLE OF CONTENTS.

INTRODUCTION.

UNITS OF MEASUREMENT AND CONVERSION FORMULÆ.

Units. — The quantitative measure of anything is a number which expresses the ratio of the magnitude of the thing to the magnitude of some other thing of the same kind. In order that the number expressing the measure may be intelligible, the magnitude of the thing used for comparison must be known. This leads to the conventional choice of certain magnitudes as units of measurement, and any other magnitude is then simply expressed by a number which tells how many magnitudes equal to the unit of the same kind of magnitude it contains. For example, the distance between two places may be stated as a certain number of miles or of yards or of feet. In the first case, the mile is assumed as a known distance; in the second, the yard, and in the third, the foot. What is sought for in the statement is to convey an idea of the distance by describing it in terms of distances which are either familiar or easily referred to for comparison. Similarly quantities of matter are referred to as so many tons or pounds or grains and so forth, and intervals of time as a number of hours or minutes or seconds. Generally in ordinary affairs such statements appeal to experience; but, whether this be so or not, the statement must involve some magnitude as a fundamental quantity, and this must be of such a character that, if it is not known, it can be readily referred to. We become familiar with the length of a mile by walking over distances expressed in miles, with the length of a yard or a foot by examining a yard or a foot measure and comparing it with something easily referred to, — say our own height, the length of our foot or step, — and similarly for quantities of other kinds. This leads us to be able to form a mental picture of such magnitudes when the numbers expressing them are stated, and hence to follow intelligently descriptions of the results of scientific work. The possession of copies of the units enables us by proper comparisons to find the magnitude-numbers expressing physical quantities for ourselves. The numbers descriptive of any quantity must depend on the intrinsic magnitude of the unit in terms of which it is described. Thus a mile is 1760 yards, or 5280 feet, and hence when a mile is taken as the unit the magnitude-number for the distance is 1, when a yard is taken as the unit the magnitude-number is 1760, and when a foot is taken it is 5280. Thus, to obtain the magnitude-number for a quantity in terms of a new unit when it is already known in terms of another we have to multiply the old magnitude-number by the ratio of the intrinsic values of the old and new units; that is, by the number of the new units required to make one of the old.

Fundamental Units of Length and Mass. — It is desirable that as few different kinds of unit quantities as possible should be introduced into our measurements, and since it has been found possible and convenient to express a large number of physical quantities in terms of length or mass or time units and combinations of these, they have been very generally adopted as fundamental units. Two systems of such units are used in this country for scientific measurements, namely, the customary, and the French or metric, systems. Tables of conversion factors are given in the book for facilitating comparisons between quantities expressed in terms of one system with similar quantities expressed in the other. In the customary system the standard unit of length is the yard and is now defined as 3600/3937 meter. The unit of mass is the avoirdupois pound and is defined as 1/2.20462 kilogram.

The British yard is defined as the "straight line or distance (at 62° F.) between the transverse lines in the two gold plugs in the bronze bar deposited in the office of the exchequer." The British standard of mass is the pound avoirdupois and is the mass of a piece of platinum marked "P. S. 1844, 1 lb.," preserved in the exchequer office.

In the metric system the standard of length is the meter and is defined as the distance between two lines at 0° Centrigrade on a platinum iridium bar deposited at the International Bureau of Weights and Measures. This bar is known as the International Prototype Meter, and its length was derived from the "mètre des Archives," which was made by Borda. Copies of the International Prototype Meter are possessed by the various governments, and are called "National Prototypes."

Borda, Delambre, Laplace, and others, acting as a committee of the French Academy, recommended that the standard unit of length should be the ten millionth part of the length, from the equator to the pole, of the meridian passing through Paris. In 1795 the French Republic passed a decree making this the legal standard of length, and an arc of the meridian extending from Dunkirk to Barcelona was measured by Delambre and Mechain for the purpose of realizing the standard. From the results of that measurement the meter bar was made by Borda. The meter is not now defined in terms of the meridian length, and hence subsequent measurements of the length of the meridian have not affected the length of the meter.

The metric standard of mass is the kilogram and is defined as the mass of a piece of platinum-iridium deposited at the International Bureau of Weights and Measures. This standard is known as the International Prototype Kilogram. Its mass is equal to that of the older standard, the "kilogramme des Archives," made by Borda and intended to have the same mass as a cubic decimeter of distilled water at the temperature of 4° C. Copies of the International Prototype Kilogram are possessed by the various governments, and as in the case of the meter standards are called National Prototypes.

Comparisons of the French and customary standards are given in tabular form in Table 2; and similarly Table 3, differing slightly, compares the British and French systems. In the metric system the decimal subdivision is used, and thus we have the decimeter, the centimeter, and the millimeter as subdivisions, and the dekameter, hektometer, and kilometer as multiples. The centimeter is most commonly used in scientific work.

Time. — The unit of time in both the systems here referred to is the mean solar second, or the 86,400th part of the mean solar day. The unit of time is thus founded on the average time required for the earth to make one revolution on its axis relatively to the sun as a fixed point of reference.

Derived Units. — Units of quantities depending on powers greater than unity of the fundamental length, mass, and time units, or on combinations of different powers of these units, are called "derived units." Thus, the unit of area and of volume are respectively the area of a square whose side is the unit of length and the volume of a cube whose edge is the unit of length. Suppose that the area of a surface is expressed in terms of the foot as fundamental unit, and we wish to find the area-number when the yard is taken as fundamental unit. The yard is 3 times as long as the foot, and therefore the area of a square whose side is a yard is 3 × 3 times as great as that whose side is a foot. Thus, the surface will only make one ninth as many units of area when the yard is the unit of length as it will make when the foot is that unit. To transform, then, from the foot as old unit to the yard as new unit, we have to multiply the old area-number by 1/9, or by the ratio of the magnitude of the old to that of the new unit of area. This is the same rule as that given above, but it is usually more convenient to express the transformations in terms of the fundamental units directly. In the above case, since on the method of measurement here adopted an area-number is the product of a length-number by a length-number the ratio of two units is the square of the ratio of the intrinsic values of the two units of length. Hence, if l be the ratio of the magnitude of the old to that of the new unit of length, the ratio of the corresponding units of area is l^2. Similarly the ratio of two units of volume will be l^3, and so on for other quantities.

Dimensional Formulæ. — It is convenient to adopt symbols for the ratios of length units, mass units, and time units, and adhere to their use throughout: and in what follows, the small letters, l, m, t, will be used for these ratios. These letters will always represent simple numbers, but the magnitude of the number will depend on the relative magnitudes of the units the ratios of which they represent. When the values of the numbers represented by l, m, t are known, and the powers of l, m, and t involved in any particular unit are also known, the factor for transformation is at once obtained. Thus, in the above example, the value of l was 1/3 and the power of l involved in the expression for area is l^2; hence, the factor for transforming from square feet to square yards is 1/9. These factors have been called by Prof. James Thomson "change ratios," which seems an appropriate term. The term "conversion factor" is perhaps more generally known, and has been used throughout this book.

Conversion Factor. — In order to determine the symbolic expression for the conversion factor for any physical quantity, it is sufficient to determine the degree to which the quantities length, mass, and time are involved in the quantity. Thus, a velocity is expressed by the ratio of the number representing a length to that representing an interval of time, or L/T, an acceleration by a velocity-number divided by an interval of time-number, or L/T^2, and so on, and the corresponding ratios of units must therefore enter to precisely the same degree. The factors would thus be for the above cases, l/t and l/t^2. Equations of the form above given for velocity and acceleration which show the dimensions of the quantity in terms of the fundamental units are called "dimensional equations." Thus

$$E = ML^2T^{-2}$$

is the dimensional equation for energy, and ML^2T^{-2} is the dimensional formula for energy.

In general, if we have an equation for a physical quantity

$$Q = CL^aM^bT^c,$$

where C is a constant and LMT represents length, mass, and time in terms of one set of units, and we wish to transform to another set of units in terms of which the length, mass, and time are $L_\prime M_\prime T_\prime$, we have to find the value of $\frac{L_\prime}{L}, \frac{M_\prime}{M}, \frac{T_\prime}{T}$, which in accordance with the convention adopted above will be $l\ m\ t$, or the ratios of the magnitudes of the old to those of the new units.

Thus $L_\prime = Ll$, $M_\prime = Mm$, $T_\prime = Tt$, and if $Q_\prime$ be the new quantity-number

$$\begin{aligned} Q_\prime &= CL_\prime^{\,a}M_\prime^{\,b}T_\prime^{\,c} \\ &= CL^al^aM^bm^bT^ct^c = Ql^am^bt^c, \end{aligned}$$

or the conversion factor is $l^am^bt^c$, a quantity of precisely the same form as the dimension formula $L^aM^bT^c$.

We now proceed to form the dimensional and conversion factor formulæ for the more commonly occurring derived units.

1. **Area.** — The unit of area is the square the side of which is measured by the unit of length. The area of a surface is therefore expressed as

$$S = CL^2,$$

where C is a constant depending on the shape of the boundary of the surface and L a linear dimension. For example, if the surface be square and L be the length of a side C is unity. If the boundary be a circle and L be a diameter $C = \pi/4$, and so on. The dimensional formula is thus L^2, and the conversion factor l^2.

2. **Volume.** — The unit of volume is the volume of a cube the edge of which is measured by the unit of length. The volume of a body is therefore expressed as

$$V = CL^3,$$

where as before C is a constant depending on the shape of the boundary. The dimensional formula is L^3 and the conversion factor l^3.

3. **Density.** — The density of a substance is the quantity of matter in the unit of volume. The dimension formula is therefore M/V or ML^{-3}, and conversion factor ml^{-3}.

Example. — The density of a body is 150 in pounds per cubic foot: required the density in grains per cubic inch.

Here m is the number of grains in a pound $= 7000$, and l is the number of inches in a foot $= 12$; $\therefore ml^{-3} = 7000/12^3 = 4.051$. Hence the density is $150 \times 4.051 = 607.6$ in grains per cubic inch.

NOTE. — The specific gravity of a body is the ratio of its density to the density of a standard substance. The dimension formula and conversion factor are therefore both unity.

4. **Velocity.** — The velocity of a body at any instant is given by the equation $v = \frac{dL}{dT}$, or velocity is the ratio of a length-number to a time-number. The dimension formula is LT^{-1}, and the conversion factor lt^{-1}.

Example. — A train has a velocity of 60 miles an hour: what is its velocity in feet per second?

Here $l = 5280$ and $t = 3600$; $\therefore lt^{-1} = \frac{5280}{3600} = \frac{44}{30} = 1.467$. Hence the velocity $= 60 \times 1.467 = 88.0$ in feet per second.

5. **Angle.** — An angle is measured by the ratio of the length of an arc to the length of the radius of the arc. The dimension formula and the conversion factor are therefore both unity.

6. **Angular Velocity.** — Angular velocity is the ratio of the magnitude of the angle described in an interval of time to the length of the interval. The dimension formula is therefore T^{-1}, and the conversion factor is t^{-1}.

7. **Linear Acceleration.** — Acceleration is the rate of change of velocity or $a = \frac{dv}{dt}$. The dimension formula is therefore VT^{-1} or LT^{-2}, and the conversion factor is lt^{-2}.

Example. — A body acquires velocity at a uniform rate, and at the end of one minute is moving at the rate of 20 kilometers per hour: what is the acceleration in centimeters per second per second?

Since the velocity gained was 20 kilometers per hour in one minute, the acceleration was 1200 kilometers per hour per hour.

Here $l = 100\,000$ and $t = 3600$; $\therefore lt^{-2} = 100\,000/3600^2 = .00771$, and therefore acceleration $= .00771 \times 1200 = 9.26$ centimeters per second.

8. **Angular Acceleration.** — Angular acceleration is rate of change of angu-

lar velocity. The dimensional formula is thus $\frac{\text{angular velocity}}{\text{T}}$ or T^{-2}, and the conversion factor t^{-2}.

9. **Solid Angle.** — A solid angle is measured by the ratio of the surface of the portion of a sphere enclosed by the conical surface forming the angle to the square of radius of the spherical surface, the centre of the sphere being at the vertex of the cone. The dimensional formula is therefore $\frac{\text{area}}{L^2}$ or 1, and hence the conversion factor is also 1.

10. **Curvature.** — Curvature is measured by the rate of change of direction of the curve with reference to distance measured along the curve as independent variable. The dimension formula is therefore $\frac{\text{angle}}{\text{length}}$ or L^{-1}, and the conversion factor is l^{-1}.

11. **Tortuosity.** — Tortuosity is measured by the rate of rotation of the tangent plane round the tangent to the curve of reference when length along the curve is independent variable. The dimension formula is therefore $\frac{\text{angle}}{\text{length}}$ or L^{-1}, and the conversion factor is l^{-1}.

12. **Specific Curvature of a Surface.** — This was defined by Gauss to be, at any point of the surface, the ratio of the solid angle enclosed by a surface formed by moving a normal to the surface round the periphery of a small area containing the point, to the magnitude of the area. The dimensional formula is therefore $\frac{\text{solid angle}}{\text{surface}}$ or L^{-2}, and the conversion factor is thus l^{-2}.

13. **Momentum.** — This is quantity of motion in the Newtonian sense, and is, at any instant, measured by the product of the mass-number and the velocity-number for the body.

Thus the dimension formula is MV or MLT^{-1}, and the conversion factor mlt^{-1}.

Example. — A mass of 10 pounds is moving with a velocity of 30 feet per second: what is its momentum when the centimeter, the gram, and the second are fundamental units?

Here $m = 453.59$, $l = 30.48$, and $t = 1$; $\therefore mlt^{-1} = 453.59 \times 30.48 = 13825$. The momentum is thus $13825 \times 10 \times 30 = 4\,147\,500$.

14. **Moment of Momentum.** — The moment of momentum of a body with reference to a point is the product of its momentum-number and the number expressing the distance of its line of motion from the point. The dimensional formula is thus ML^2T^{-1}, and hence the conversion factor is ml^2t^{-1}.

15. **Moment of Inertia.** — The moment of inertia of a body round any axis is expressed by the formula Σmr^2, where m is the mass of any particle of the body

and r its distance from the axis. The dimension formula for the sum is clearly the same as for each element, and hence is ML^2. The conversion factor is therefore ml^2.

16. **Angular Momentum.** — The angular momentum of a body round any axis is the product of the numbers expressing the moment of inertia and the angular velocity of the body. The dimensional formula and the conversion factor are therefore the same as for moment of momentum given above.

17. **Force.** — A force is measured by the rate of change of momentum it is capable of producing. The dimension formulæ for force and "time rate of change of momentum" are therefore the same, and are expressed by the ratio of momentum-number to time-number or MLT^{-2}. The conversion factor is thus mlt^{-2}.

NOTE. — When mass is expressed in pounds, length in feet, and time in seconds, the unit force is called the poundal. When grams, centimeters, and seconds are the corresponding units the unit of force is called the dyne.

Example. Find the number of dynes in 25 poundals.

Here $m = 453.59$, $l = 30.48$, and $t = 1$; $\therefore\ mlt^{-2} = 453.59 \times 30.48 = 13825$ nearly. The number of dynes is thus $13825 \times 25 = 345625$ approximately.

18. **Moment of a Couple, Torque, or Twisting Motive.** — These are different names for a quantity which can be expressed as the product of two numbers representing a force and a length. The dimension formula is therefore FL or ML^2T^{-2}, and the conversion factor is ml^2t^{-2}.

19. **Intensity of a Stress.** — The intensity of a stress is the ratio of the number expressing the total stress to the number expressing the area over which the stress is distributed. The dimensional formula is thus FL^{-2} or $ML^{-1}T^{-2}$, and the conversion factor is $ml^{-1}t^{-2}$.

20. **Intensity of Attraction, or "Force at a Point."** — This is the force of attraction per unit mass on a body placed at the point, and the dimensional formula is therefore FM^{-1} or LT^{-2}, the same as acceleration. The conversion factors for acceleration therefore apply.

21. **Absolute Force of a Centre of Attraction, or "Strength of a Centre."** — This is the intensity of force at unit distance from the centre, and is therefore the force per unit mass at any point multiplied by the square of the distance from the centre. The dimensional formula thus becomes FL^2M^{-1} or L^3T^{-2}. The conversion factor is therefore l^3t^{-2}.

22. **Modulus of Elasticity.** — A modulus of elasticity is the ratio of stress intensity to percentage strain. The dimension of percentage strain is a length divided by a length, and is therefore unity. Hence, the dimensional formula of a modulus of elasticity is the same as that of stress intensity, or $ML^{-1}T^{-2}$, and the conversion factor is thus also $ml^{-1}t^{-2}$.

23. **Work and Energy.** — When the point of application of a force, acting on a body, moves in the direction of the force, work is done by the force, and the amount is measured by the product of the force and displacement numbers. The dimensional formula is therefore FL or ML^2T^{-2}.

The work done by the force either produces a change in the velocity of the body or a change of shape or configuration of the body, or both. In the first case it produces a change of kinetic energy, in the second a change of potential energy. The dimension formulæ of energy and work, representing quantities of the same kind, are identical, and the conversion factor for both is ml^2t^{-2}.

24. **Resilience.** — This is the work done per unit volume of a body in distorting it to the elastic limit or in producing rupture. The dimension formula is therefore $ML^2T^{-2}L^{-3}$ or $ML^{-1}T^{-2}$, and the conversion factor $ml^{-1}t^{-2}$.

25. **Power, or Activity.** — Power — or, as it is now very commonly called, activity — is defined as the time rate of doing work, or if W represent work and P power $P = \frac{dw}{dt}$. The dimensional formula is therefore WT^{-1} or ML^2T^{-3}, and the conversion factor ml^2t^{-3}, or for problems in gravitation units more conveniently flt^{-1}, where f stands for the force factor.

Examples. (*a*) Find the number of gram centimeters in one foot pound.

Here the units of force are the attraction of the earth on the pound * and the gram of matter, and the conversion factor is fl, where f is 453.59 and l is 30.48.

Hence the number is $453.59 \times 30.48 = 13825$.

(*b*) Find the number of foot poundals in 1 000 000 centimeter dynes.

Here $m = 1/453.59$, $l = 1/30.48$, and $t = 1$; $\therefore\ ml^2t^{-2} = 1/453.59 \times 30.48^2$, and $10^6ml^2t^{-2} = 10^6/453.59 \times 30.48^2 = 2.373$.

(*c*) If gravity produces an acceleration of 32.2 feet per second per second, how many watts are required to make one horse-power?

One horse-power is 550 foot pounds per second, or $550 \times 32.2 = 17710$ foot poundals per second. One watt is 10^7 ergs per second, that is, 10^7 dyne centimeters per second. The conversion factor is ml^2t^{-3}, where $m = 453.59$, $l = 30.48$, and $t = 1$, and the result has to be divided by 10^7, the number of dyne centimeters per second in the watt.

Hence, $17710\,ml^2t^{-3}/10^7 = 17710 \times 453.59 \times 30.48^2/10^7 = 746.3$.

(*d*) How many gram centimeters per second correspond to 33000 foot pounds per minute?

The conversion factor suitable for this case is flt^{-1}, where f is 453.59, l is 30.48, and t is 60.

Hence, $33000\,lt^{-1} = 33000 \times 453.59 \times 30.48/60 = 7\,604\,000$ nearly.

---

* It is important to remember that in problems like that here given the term "pound" or "gram" refers to force and not to mass.

HEAT UNITS.

1. If heat be measured in dynamical units its dimensions are the same as those of energy, namely ML^2T^{-2}. The most common measurements, however, are made in thermal units, that is, in terms of the amount of heat required to raise the temperature of unit mass of water one degree of temperature at some stated temperature. This method of measurement involves the unit of mass and some unit of temperature; and hence, if we denote temperature-numbers by Θ and their conversion factors by θ, the dimensional formula and conversion factor for quantity of heat will be $M\Theta$ and $m\theta$ respectively. The relative amount of heat compared with water as standard substance required to raise unit mass of different substances one degree in temperature is called their specific heat, and is a simple number.

Unit volume is sometimes used instead of unit mass in the measurement of heat, the units being then called thermometric units. The dimensional formula is in that case changed by the substitution of volume for mass, and becomes $L^3\Theta$, and hence the conversion factor is to be calculated from the formula $l^3\theta$.

For other physical quantities involving heat we have:—

2. **Coefficient of Expansion.**—The coefficient of expansion of a substance is equal to the ratio of the change of length per unit length (linear), or change of volume per unit volume (voluminal) to the change of temperature. These ratios are simple numbers, and the change of temperature is inversely as the magnitude of the unit of temperature. Hence the dimensional and conversion-factor formulæ are Θ^{-1} and θ^{-1}.

3. **Conductivity, or Specific Conductance.**—This is the quantity of heat transmitted per unit of time per unit of surface per unit of temperature gradient. The equation for conductivity is therefore, with H as quantity of heat,

$$K = \frac{H}{\frac{\Theta}{L} L^2 T}$$

and the dimensional formula $\frac{H}{\Theta LT} = \frac{M}{LT}$, which gives $ml^{-1}t^{-1}$ for conversion factor.

In thermometric units the formula becomes L^2T^{-1}, which properly represents diffusivity. In dynamical units H becomes ML^2T^{-2}, and the formula changes to $MLT^{-3}\Theta^{-1}$. The conversion factors obtained from these are l^2t^{-1} and $mlt^{-3}\theta^{-1}$ respectively.

4. Thermal Capacity. — This is the product of the number for mass and the specific heat, and hence the dimensional formula and conversion factor are simply M and *m*.

5. Latent Heat. — Latent heat is the ratio of the number representing the quantity of heat required to change the state of a body to the number representing the quantity of matter in the body. The dimensional formula is therefore $M\Theta/M$ or Θ, and hence the conversion factor is simply the ratio of the temperature units or θ. In dynamical units the factor is l^2t^{-2}.*

6. Joule's Equivalent. — Joule's dynamical equivalent is connected with quantity of heat by the equation

$$ML^2T^{-2} = JH \text{ or } JM\Theta.$$

This gives for the dimensional formula of J the expression $L^2T^{-2}\Theta^{-1}$. The conversion factor is thus represented by $l^2t^{-2}\theta^{-1}$. When heat is measured in dynamical units J is a simple number.

7. Entropy. — The entropy of a body is directly proportional to the quantity of heat it contains and inversely proportional to its temperature. The dimensional formula is thus $M\Theta/\Theta$ or M, and the conversion factor is *m*. When heat is measured in dynamical units the factor is $ml^2t^{-2}\theta^{-1}$.

Examples. (*a*) Find the relation between the British thermal unit, the calorie, and the therm.

Neglecting the variation of the specific heat of water with temperature, or defining all the units for the same temperature of the standard substance, we have the following definitions. The *British thermal unit* is the quantity of heat required to raise the temperature of one pound of water 1° F. The *calorie* is the quantity of heat required to raise the temperature of one kilogramme of water 1° C. The *therm* is the quantity of heat required to raise the temperature of one gramme of water 1° C. Hence: —

(1) To find the number of calories in one British thermal unit, we have $m = .45359$ and $\theta = \frac{5}{9}$; $\therefore m\theta = .45359 \times 5/9 = .25199$.

(2) To find the number of therms in one calorie, $m = 1000$ and $\theta = 1$; $\therefore m\theta = 1000$.

It follows at once that the number of therms in one British thermal unit is $1000 \times .25199 = 251.99$.

(*b*) What is the relation between the foot grain second Fahrenheit-degree and the centimetre gramme second Centigrade-degree units of conductivity?

The number of the latter units in one of the former is given by the for-

---

* It will be noticed that when Θ is given the dimension formula L^2T^{-2} the formulæ in thermal and dynamical units are always identical. The thermometric units practically suppress mass.

mula $ml^{-1}t^{-1}\theta^{\circ}$, where $m = .064799$, $l = 30.48$, and $t = 1$, and is therefore $=$ $.064\,799/30.48 = 2.126 \times 10^{-3}$.

(*c*) Find the relation between the units stated in (*b*) for emissivity.

In this case the conversion formula is $ml^{-2}t^{-1}$, where ml and t have the same value as before. Hence the number of the latter units in the former is $0.064\,799/30.48^2 = 6.975 \times 10^{-5}$.

(*d*) Find the number of centimeter gram second units in the inch grain hour unit of emissivity.

Here the formula is $ml^{-2}t^{-1}$, where $m = 0.064\,799$, $l = 2.54$, and $t = 3600$. Therefore the required number is $0.064\,799/2.54^2 \times 3600 = 2.790 \times 10^{-6}$.

(*e*) If Joule's equivalent be 776 foot pounds per pound of water per degree Fahrenheit, what will be its value in gravitation units when the metre, the kilogramme, and the degree Centigrade are units?

The conversion factor in this case is $\frac{l^2t^{-2}\theta^{-1}}{lt^{-2}}$ or $l\theta^{-1}$, where $l = .3048$ and $\theta^{-1} = 1.8$; $\therefore\ 776 \times .3048 \times 1.8 = 425.7$.

(*f*) If Joule's equivalent be 24832 foot poundals when the degree Fahrenheit is unit of temperature, what will be its value when kilogram meter second and degree-Centigrade units are used?

The conversion factor is $l^2t^{-2}\theta^{-1}$, where $l = .3048$, $t = 1$, and $\theta^{-1} = 1.8$; $\therefore\ 24832 \times l^2t^{-2}\theta^{-1} = 24832 \times .3048^2 \times 1.8 = 4152.5$.

In gravitation units this would give $4152.5/9.81 = 423.3$.

ELECTRIC AND MAGNETIC UNITS.

There are two systems of these units, the electrostatic and the electromagnetic systems, which differ from each other because of the different fundamental suppositions on which they are based. In the electrostatic system the repulsive force between two quantities of static electricity is made the basis. This connects force, quantity of electricity, and length by the equation $f = a\frac{qq_{\prime}}{l^2}$, where f is force, a a quantity depending on the units employed and on the nature of the medium, q and $q_{\prime}$ quantities of electricity, and l the distance between q and $q_{\prime}$. The magnitude of the force f for any particular values of q, $q_{\prime}$ and l depends on a property of the medium across which the force takes place called its inductive capacity. The inductive capacity of air has generally been assumed as unity, and the inductive capacity of other media expressed as a number representing the ratio of the inductive capacity of the medium to that of air. These numbers are known as the specific inductive capacities of the media. According to the ordinary assumption, then, of air as the standard medium, we obtain unit quantity of electricity when in the above equation $q = q_{\prime}$, and f, a, and l are each unity. A formal definition is given below.

In the electromagnetic system the repulsion between two magnetic poles or quantities of magnetism is taken as the basis. In this system the quantities force, quantity of magnetism, and length are connected by an equation of the form

$$f = a\frac{mm_{\prime}}{l^2},$$

where m and $m_{\prime}$ are in this case quantities of magnetism, and the other symbols have the same meaning as before. In this case it has been usual to assume the magnetic inductive capacity of air to be unity, and to express the magnetic inductive capacity of other media as a simple number representing the ratio of the inductive capacity of the medium to that of air. These numbers, by analogy with specific inductive capacity for electricity, might be called specific inductive capacities for magnetism. They are usually called permeabilities. (*Vide* Thomson, "Papers on Electrostatics and Magnetism," p. 484.) In this case, also, like that for electricity, the unit quantity of magnetism is obtained by making $m = m_{\prime}$, and f, a, and l each unity.

In both these cases the intrinsic inductive capacity of the standard medium is suppressed, and hence also that of all other media. Whether this be done or not, direct experiment has to be resorted to for the determination of the absolute values of the units and the relations of the units in the one system to those in the other. The character of this relation can be directly inferred from the dimensional formulæ of the different quantities, but these can give no information as to the relative absolute values of the units in the two systems. Prof. Rücker has suggested (Phil. Mag. vol. 27) the advisability of at least indicating the existence of the suppressed properties by putting symbols for them in the dimensional formulæ. This has the advantage of showing how the magnitudes of the different units would be affected by a change in the standard medium, or by making the standard medium different for the two systems. In accordance with this idea, the symbols K and P have been introduced into the formulæ given below to represent inductive capacity in the electrostatic and the electromagnetic systems respectively. In the conversion formulæ k and p are the ordinary specific inductive capacities and permeabilities of the media when air is taken as the standard, or generally those with reference to the first medium taken as standard. The ordinary formulæ may be obtained by putting K and P equal to unity.

ELECTROSTATIC UNITS.

1. **Quantity of Electricity.** — The unit quantity of electricity is defined as that quantity which if concentrated at a point and placed at unit distance from an equal and similarly concentrated quantity repels it, or is repelled by it, with unit force. The medium or dielectric is usually taken as air, and the other units in accordance with the centimeter gram second system.

In this case we have the force of repulsion proportional directly to the square of the quantity of electricity and inversely to the square of the distance between the quantities and to the inductive capacity. The dimensional formula is therefore the same as that for [force × length^2 × inductive capacity]$^{\frac{1}{2}}$ or $M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}$, and the conversion factor is $m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-1}k^{\frac{1}{2}}$.

2. **Electric Surface Density and Electric Displacement.** — The density of an electric distribution at any point on a surface is measured by the quantity per unit of area, and the electric displacement at any point in a dielectric is measured by the quantity displaced per unit of area. These quantities have therefore the same dimensional formula, namely, the ratio of the formulæ for quantity of electricity and for area or $M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}K^{\frac{1}{2}}$, and the conversion factor $m^{\frac{1}{2}}l^{-\frac{1}{2}}t^{-1}k^{\frac{1}{2}}$.

3. **Electric Force at a Point, or Intensity of Electric Field.** — This is measured by the ratio of the magnitude of the force on a quantity of electricity at a point to the magnitude of the quantity of electricity. The dimensional formula is therefore the ratio of the formulæ for force and electric quantity, or

$$\frac{MLT^{-2}}{M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}} = M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}K^{-\frac{1}{2}},$$

which gives the conversion factor $m^{\frac{1}{2}}l^{-\frac{1}{2}}t^{-1}k^{-\frac{1}{2}}$.

4. **Electric Potential and Electromotive Force.** — Change of potential is proportional to the work done per unit of electricity in producing the change. The dimensional formula is therefore the ratio of the formulæ for work and electric quantity, or

$$\frac{ML^2T^{-2}}{M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}} = M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}K^{-\frac{1}{2}},$$

which gives the conversion factor $m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-1}k^{-\frac{1}{2}}$.

5. **Capacity of a Conductor.** — The capacity of an insulated conductor is proportional to the ratio of the numbers representing the quantity of electricity in a charge and the potential of the charge. The dimensional formula is thus the ratio of the two formulæ for electric quantity and potential, or

$$\frac{M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}}{M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}K^{-\frac{1}{2}}} = LK,$$

which gives lk for conversion factor. When K is taken as unity, as in the ordinary units, the capacity of an insulated conductor is simply a length.

6. **Specific Inductive Capacity.** — This is the ratio of the inductive capacity of the substance to that of a standard substance, and hence the dimensional formula is K/K or 1.*

7. **Electric Current.** — Current is quantity flowing past a point per unit of time. The dimensional formula is thus the ratio of the formulæ for electric quantity and for time, or

$$\frac{M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}}{T} = M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}K^{\frac{1}{2}},$$

and the conversion factor $m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-2}k^{\frac{1}{2}}$.

---

* According to the ordinary definition referred to air as standard medium, the specific inductive capacity of a substance is K, or is identical in dimensions with what is here taken as inductive capacity. Hence in that case the conversion factor must be taken as 1 on the electrostatic and as $l^{-2}t^2$ on the electromagnetic system.

8. **Conductivity, or Specific * Conductance.** — This, like the corresponding term for heat, is quantity per unit area per unit potential gradient per unit of time. The dimensional formula is therefore

$$\frac{M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}}{L^2\dfrac{M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}K^{-\frac{1}{2}}}{L}T} = T^{-1}K, \text{ or } \frac{\text{electric quantity}}{\text{area} \times \text{potential gradient} \times \text{time}}.$$

The conversion factor is $t^{-1}k$.

9. **Specific * Resistance.** — This is the reciprocal of conductivity as above defined, and hence the dimensional formula and conversion factor are respectively TK^{-1} and tk^{-1}.

10. **Conductance.** — The conductance of any part of an electric circuit, not containing a source of electromotive force, is the ratio of the numbers representing the current flowing through it and the difference of potential between its ends. The dimensional formula is thus the ratio of the formulæ for current and potential, or

$$\frac{M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}K^{\frac{1}{2}}}{M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}K^{-\frac{1}{2}}} = LT^{-1}K,$$

from which we get the conversion factor $lt^{-1}k$.

11. **Resistance.**—This is the reciprocal of conductance, and therefore the dimensional formula and the conversion factor are respectively $L^{-1}TK^{-1}$ and $l^{-1}tk^{-1}$.

EXAMPLES OF CONVERSION IN ELECTROSTATIC UNITS.

(*a*) Find the factor for converting quantity of electricity expressed in foot grain second units to the same expressed in c. g. s. units.

By (1) the formula is $m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-1}k^{\frac{1}{2}}$, in which in this case $m = 0.0648$, $l = 30.48$, $t = 1$, and $k = 1$; ∴ the factor is $0.0648^{\frac{1}{2}} \times 30.48^{\frac{3}{2}} = 4.2836$.

(*b*) Find the factor required to convert electric potential from millimeter milligram second units to c. g. s. units.

By (4) the formula is $m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-1}k^{-\frac{1}{2}}$, and in this case $m = 0.001$, $l = 0.1$, $t = 1$, and $k = 1$; ∴ the factor $= 0.001^{\frac{1}{2}} \times 0.1^{\frac{1}{2}} = 0.01$.

(*c*) Find the factor required to convert from foot grain second and specific inductive capacity 6 units to c. g. s. units.

By (5) the formula is lk, and in this case $l = 30.48$ and $k = 6$; ∴ the factor $= 30.48 \times 6 = 182.88$.

---

* The term "specific," as used here and in 9, refers conductance and resistance to that between the ends of a bar of unit section and unit length, and hence is different from the same term in specific heat, specific inductivity, capacity, etc., which refer to a standard substance.

ELECTROMAGNETIC UNITS.

As stated above, these units bear the same relation to unit quantity of magnetism that the electric units do to quantity of electricity. Thus, when inductive capacity is suppressed, the dimensional formula for magnetic quantity on this system is the same as that for electric quantity on the electrostatic system. All quantities in this system which only differ from corresponding quantities defined above by the substitution of magnetic for electric quantity may have their dimensional formulæ derived from those of the corresponding quantity by substituting P for K.

1. **Magnetic Pole, or Quantity of Magnetism.** — Two unit quantities of magnetism concentrated at points unit distance apart repel each other with unit force. The dimensional formula is thus the same as for [force × length^2 × inductive capacity]$^{\frac{1}{2}}$ or $M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}P^{\frac{1}{2}}$, and the conversion factor is $m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-1}p^{\frac{1}{2}}$.

2. **Density of Surface Distribution of Magnetism.** — This is measured by quantity of magnetism per unit area, and the dimension formula is therefore the ratio of the expressions for magnetic quantity and for area, or $M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}P^{\frac{1}{2}}$, which gives the conversion factor $m^{\frac{1}{2}}l^{-\frac{1}{2}}t^{-1}p^{\frac{1}{2}}$.

3. **Magnetic Force at a Point, or Intensity of Magnetic Field.** — The number for this is the ratio of the numbers representing the magnitudes of the force on a magnetic pole placed at the point and the magnitude of the magnetic pole.

The dimensional formula is therefore the ratio of the expressions for force and magnetic quantity, or

$$\frac{MLT^{-2}}{M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}P^{\frac{1}{2}}} = M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}P^{-\frac{1}{2}},$$

and the conversion factor $m^{\frac{1}{2}}l^{-\frac{1}{2}}t^{-1}p^{-\frac{1}{2}}$.

4. **Magnetic Potential.** — The magnetic potential at a point is measured by the work which is required to bring unit quantity of positive magnetism from zero potential to the point. The dimensional formula is thus the ratio of the formula for work and magnetic quantity, or

$$\frac{ML^2T^{-2}}{M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}P^{\frac{1}{2}}} = M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}P^{-\frac{1}{2}},$$

which gives the conversion factor $m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-1}p^{-\frac{1}{2}}$.

5. **Magnetic Moment.** — This is the product of the numbers for pole strength and length of a magnet. The dimensional formula is therefore the product of the formulæ for magnetic quantity and length, or $M^{\frac{1}{2}}L^{\frac{5}{2}}T^{-1}P^{\frac{1}{2}}$, and the conversion factor $m^{\frac{1}{2}}l^{\frac{5}{2}}t^{-1}p^{\frac{1}{2}}$.

6. **Intensity of Magnetization.** — The intensity of magnetization of any portion of a magnetized body is the ratio of the numbers representing the magni-

tude of the magnetic moment of that portion and its volume. The dimensional formula is therefore the ratio of the formulæ for magnetic moment and volume, or

$$\frac{M^{\frac{1}{2}}L^{\frac{5}{2}}T^{-1}P^{\frac{1}{2}}}{L^3} = M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}P^{\frac{1}{2}}.$$

The conversion factor is therefore $m^{\frac{1}{2}}l^{-\frac{1}{2}}t^{-1}p^{\frac{1}{2}}$.

7. **Magnetic Permeability,* or Specific Magnetic Inductive Capacity.** — This is the analogue in magnetism to specific inductive capacity in electricity. It is the ratio of the magnetic induction in the substance to the magnetic induction in the field which produces the magnetization, and therefore its dimensional formula and conversion factor are unity.

8. **Magnetic Susceptibility.** — This is the ratio of the numbers which represent the values of the intensity of magnetization produced and the intensity of the magnetic field producing it. The dimensional formula is therefore the ratio of the formulæ for intensity of magnetization and magnetic field or

$$\frac{M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}P^{\frac{1}{2}}}{M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}P^{-\frac{1}{2}}} \text{ or } P.$$

The conversion factor is therefore p, and both the dimensional formula and conversion factor are unity in the ordinary system.

9. **Current Strength.** — A current of strength c flowing round a circle of radius r produces a magnetic field at the centre of intensity $2\pi c/r$. The dimensional formula is therefore the product of the formulæ for magnetic field intensity and length, or $M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}P^{-\frac{1}{2}}$, which gives the conversion factor $m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-1}p^{-\frac{1}{2}}$.

10. **Current Density, or Strength of Current at a Point.** — This is the ratio of the numbers for current strength and area. The dimensional formula and the conversion factor are therefore $M^{\frac{1}{2}}L^{-\frac{3}{2}}T^{-1}P^{-\frac{1}{2}}$ and $m^{\frac{1}{2}}l^{-\frac{3}{2}}t^{-1}p^{-\frac{1}{2}}$.

11. **Quantity of Electricity.** — This is the product of the numbers for current and time. The dimensional formula is therefore $M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}P^{-\frac{1}{2}} \times T = M^{\frac{1}{2}}L^{\frac{1}{2}}P^{-\frac{1}{2}}$, and the conversion factor $m^{\frac{1}{2}}l^{\frac{1}{2}}p^{-\frac{1}{2}}$.

12. **Electric Potential, or Electromotive Force.** — As in the electrostatic system, this is the ratio of the numbers for work and quantity of electricity. The dimensional formula is therefore

$$\frac{ML^2T^{-2}}{M^{\frac{1}{2}}L^{\frac{1}{2}}P^{-\frac{1}{2}}} = M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}P^{\frac{1}{2}},$$

and the conversion factor $m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-2}p^{\frac{1}{2}}$.

---

* Permeability, as ordinarily taken with the standard medium as unity, has the same dimension formula and conversion factor as that which is here taken as magnetic inductive capacity. Hence for ordinary transformations the conversion factor should be taken as 1 in the electromagnetic and $l^{-2}t^2$ in the electrostatic systems.

13. **Electrostatic Capacity.** — This is the ratio of the numbers for quantity of electricity and difference of potential. The dimensional formula is therefore

$$\frac{M^{\frac{1}{2}}L^{\frac{1}{2}}P^{-\frac{1}{2}}}{M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}P^{\frac{1}{2}}} = L^{-1}T^{2}P^{-1},$$

and the conversion factor $l^{-1}t^{2}p^{-1}$.

14. **Resistance of a Conductor.** — The resistance of a conductor or electrode is the ratio of the numbers for difference of potential between its ends and the constant current it is capable of producing. The dimensional formula is therefore the ratio of those for potential and current or

$$\frac{M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}P^{\frac{1}{2}}}{M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}P^{-\frac{1}{2}}} = LT^{-1}P.$$

The conversion factor thus becomes $lt^{-1}p$, and in the ordinary system resistance has the same conversion factor as velocity.

15. **Conductance.** — This is the reciprocal of resistance, and hence the dimensional formula and conversion factor are respectively $L^{-1}TP^{-1}$ and $l^{-1}tp^{-1}$.

16. **Conductivity, or Specific Conductance.** — This is quantity of electricity transmitted per unit of area per unit of potential gradient per unit of time. The dimensional formula is therefore derived from those of the quantities mentioned as follows: —

$$\frac{M^{\frac{1}{2}}L^{\frac{1}{2}}P^{-\frac{1}{2}}}{L^{2}\dfrac{M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}P^{\frac{1}{2}}}{L}T} = L^{-2}TP^{-1}.$$

The conversion factor is therefore $l^{-2}tp^{-1}$.

17. **Specific Resistance.** — This is the reciprocal of conductivity as defined in 16, and hence the dimensional formula and conversion factor are respectively $L^{2}T^{-1}P$ and $l^{2}t^{-1}p$.

18. **Coefficient of Self-Induction, or Inductance, or Electro-kinetic Inertia.** — These are for any circuit the electromotive force produced in it by unit rate of variation of the current through it. The dimensional formula is therefore the product of the formulæ for electromotive force and time divided by that for current or

$$\frac{M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}P^{\frac{1}{2}}}{M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}P^{-\frac{1}{2}}} \times T = LP.$$

The conversion factor is therefore lp, and in the ordinary system is the same as that for length.

19. **Coefficient of Mutual Induction.** — The mutual induction of two circuits is the electromotive force produced in one per unit rate of variation of the current in the other. The dimensional formula and the conversion factor are therefore the same as those for self-induction.

20. **Electro-kinetic Momentum.** — The number for this is the product of the numbers for current and for electro-kinetic inertia. The dimensional formula is therefore the product of the formulæ for these quantities, or $M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}P^{-\frac{1}{2}} \times LP = M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}P^{\frac{1}{2}}$, and the conversion factor is $m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-1}p^{\frac{1}{2}}$.

21. **Electromotive Force at a Point.** — The number for this quantity is the ratio of the numbers for electric potential or electromotive force as given in 12, and for length. The dimensional formula is therefore $M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-2}P^{\frac{1}{2}}$, and the conversion factor $m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-2}p^{\frac{1}{2}}$.

22. **Vector Potential.** — This is time integral of electromotive force at a point, or the electro-kinetic momentum at a point. The dimensional formula may therefore be derived from 21 by multiplying by T, or from 20 by dividing by L. It is therefore $M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}P^{\frac{1}{2}}$, and the conversion factor $m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-1}p^{\frac{1}{2}}$.

23. **Thermoelectric Height.** — This is measured by the ratio of the numbers for electromotive force and for temperature. The dimensional formula is therefore the ratio of the formulæ for these two quantities, or $M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}P^{\frac{1}{2}}\Theta^{-1}$, and the conversion factor $m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-2}p^{\frac{1}{2}}\theta^{-1}$.

24. **Specific Heat of Electricity.** — This quantity is measured in the same way as 23, and hence has the same formulæ.

25. **Coefficient of Peltier Effect.** — This is measured by the ratio of the numbers for quantity of heat and for quantity of electricity. The dimensional formula is therefore

$$\frac{M\Theta}{M^{\frac{1}{2}}L^{\frac{1}{2}}P^{-\frac{1}{2}}} = M^{\frac{1}{2}}L^{-\frac{1}{2}}P^{\frac{1}{2}}\Theta,$$

and the conversion factor $m^{\frac{1}{2}}l^{-\frac{1}{2}}p^{\frac{1}{2}}\theta$.

EXAMPLES OF CONVERSION IN ELECTROMAGNETIC UNITS.

(*a*) Find the factor required to convert intensity of magnetic field from foot grain minute units to c. g. s. units.

By (3) the formula is $m^{\frac{1}{2}}l^{-\frac{1}{2}}t^{-1}p^{-\frac{1}{2}}$, and in this case $m = 0.0648$, $l = 30.48$, $t = 60$, and $p = 1$; $\therefore$ the factors $= 0.0648^{\frac{1}{2}} \times 30.48^{-\frac{1}{2}} \times 60^{-1} = 0.00076847$.

Similarly to convert from foot grain second units to c. g. s. units the factor is $0.0648^{\frac{1}{2}} \times 30.48^{-\frac{1}{2}} = 0.046108$.

(*b*) How many c. g. s. units of magnetic moment make one foot grain second unit of the same quantity?

By (5) the formula is $m^{\frac{1}{2}}l^{\frac{5}{2}}t^{-1}p^{\frac{1}{2}}$, and the values for this problem are $m = 0.0648$, $l = 30.48$, $t = 1$, and $p = 1$; $\therefore$ the number $= 0.0648^{\frac{1}{2}} \times 30.48^{\frac{5}{2}} = 1305.6$.

(*c*) If the intensity of magnetization of a steel bar be 700 in c. g. s. units, what will it be in millimeter milligram second units?

By (6) the formula is $m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-1}p^{\frac{1}{2}}$, and in this case $m = 1000$, $l = 10$, $t = 1$, and $p = 1$; ∴ the intensity $= 700 \times 1000^{\frac{1}{2}} \times 10^{\frac{1}{2}} = 70000$.

(*d*) Find the factor required to convert current strength from c. g. s. units to earth quadrant 10^{-11} gram and second units.

By (9) the formula is $m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-1}p^{-\frac{1}{2}}$, and the values of these quantities are here $m = 10^{11}$, $l = 10^{-9}$, $t = 1$, and $p = 1$; ∴ the factor $= 10^{\frac{11}{2}} \times 10^{-\frac{9}{2}} = 10$.

(*e*) Find the factor required to convert resistance expressed in c. g. s. units into the same expressed in earth-quadrant 10^{-11} gram and second units.

By (14) the formula is $lt^{-1}p$, and for this case $l = 10^{-9}$, $t = 1$, and $p = 1$; ∴ the factor $= 10^{-9}$.

(*f*) Find the factor required to convert electromotive force from earth-quadrant 10^{-11} gram and second units to c. g. s. units.

By (12) the formula is $m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-2}p^{\frac{1}{2}}$, and for this case $m = 10^{-11}$, $l = 10^{9}$, $t = 1$, and $p = 1$; ∴ the factor $= 10^{8}$.

PRACTICAL UNITS.

In practical electrical measurements the units adopted are either multiples or submultiples of the units founded on the centimeter, the gram, and the second as fundamental units, and air is taken as the standard medium, for which K and P are assumed unity. The following, quoted from the report to the Honorable the Secretary of State, under date of November 6th, 1893, by the delegates representing the United States, gives the ordinary units with their names and values as defined by the International Congress at Chicago in 1893 : —

"*Resolved*, That the several governments represented by the delegates of this International Congress of Electricians be, and they are hereby, recommended to formally adopt as legal units of electrical measure the following : As a unit of resistance, the *international ohm*, which is based upon the ohm equal to 10^9 units of resistance of the C. G. S. system of electro-magnetic units, and is represented by the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice 14.4521 grams in mass, of a constant cross-sectional area and of the length of 106.3 centimeters.

"As a unit of current, the *international ampère*, which is one tenth of the unit of current of the C. G. S. system of electro-magnetic units, and which is represented sufficiently well for practical use by the unvarying current which, when passed through a solution of nitrate of silver in water, and in accordance with accompanying specifications,* deposits silver at the rate of 0.001118 of a gram per second.

---

* "In the following specification the term 'silver voltameter' means the arrangement of apparatus by means of which an electric current is passed through a solution of nitrate of silver in water. The silver voltameter measures the total electrical quantity which has passed during the time of the experiment, and by noting this time the time average of the current, or, if the current has been kept constant, the current itself can be deduced.

"In employing the silver voltameter to measure currents of about one ampère, the following arrangements should be adopted : —

"As a unit of electromotive force, the *international volt*, which is the electromotive force that, steadily applied to a conductor whose resistance is one international ohm, will produce a current of one international ampère, and which is represented sufficiently well for practical use by $\frac{1000}{1434}$ of the electromotive force between the poles or electrodes of the voltaic cell known as Clark's cell, at a temperature of 15° C., and prepared in the manner described in the accompanying specification.*

"As a unit of quantity, the *international coulomb*, which is the quantity of electricity transferred by a current of one international ampère in one second.

"As a unit of capacity, the *international farad*, which is the capacity of a condenser charged to a potential of one international volt by one international coulomb of electricity.†

"As a unit of work, the *joule*, which is equal to 10^7 units of work in the c. g. s. system, and which is represented sufficiently well for practical use by the energy expended in one second by an international ampère in an international ohm.

"As a unit of power, the *watt*, which is equal to 10^7 units of power in the c. g. s. system, and which is represented sufficiently well for practical use by the work done at the rate of one joule per second.

"As the unit of induction, the *henry*, which is the induction in a circuit when the electromotive force induced in this circuit is one international volt, while the inducing current varies at the rate of one ampère per second.

"The Chamber also voted that it was not wise to adopt or recommend a standard of light at the present time."

By an Act of Congress approved July 12th, 1894, the units recommended by the Chicago Congress were adopted in this country with only some unimportant verbal changes in the definitions.

By an Order in Council of date August 23d, 1894, the British Board of Trade adopted the ohm, the ampere, and the volt, substantially as recommended by the Chicago Congress. The other units were not legalized in Great Britain. They are, however, in general use in that country and all over the world.

"The kathode on which the silver is to be deposited should take the form of a platinum bowl not less than 10 centimeters in diameter and from 4 to 5 centimeters in depth.

"The anode should be a plate of pure silver some 30 square centimeters in area and 2 or 3 millimeters in thickness.

"This is supported horizontally in the liquid near the top of the solution by a platinum wire passed through holes in the plate at opposite corners. To prevent the disintegrated silver which is formed on the anode from falling on to the kathode, the anode should be wrapped round with pure filter paper, secured at the back with sealing wax.

"The liquid should consist of a neutral solution of pure silver nitrate, containing about 15 parts by weight of the nitrate to 85 parts of water.

"The resistance of the voltameter changes somewhat as the current passes. To prevent these changes having too great an effect on the current, some resistance besides that of the voltameter should be inserted in the circuit. The total metallic resistance of the circuit should not be less than 10 ohms."

* A committee, consisting of Messrs. Helmholtz, Ayrton, and Carhart, was appointed to prepare specifications for the Clark's cell, but no report was made, on account of Helmholtz's death.

† The one millionth part of the farad is more commonly used in practical measurements, and is called the microfarad.

PHYSICAL TABLES

TABLE 1.

FUNDAMENTAL AND DERIVED UNITS.

To change a quantity from one system of units to another: substitute in the corresponding conversion factor from the following table the ratio of the magnitudes of the *old* units to the *new* and multiply the old quantity by the resulting number. For example: to reduce velocity in miles per hour to feet per second, the conversion factor is $l\,t^{-1}$; $l=5280/1$, $t=3600/1$, therefore the factor$=5280/3600=1.467$.

(*a*) FUNDAMENTAL UNITS.

Name of Unit.	Symbol.	Conversion Factor.
Length.	L	l
Mass.	M	m
Time.	T	t
Temperature.	Θ	θ
Electric Inductive Capacity.	K	k
Magnetic Inductive Capacity.	P	p

(*b*) DERIVED UNITS.

I. Geometric and Dynamic Units.

Name of Unit.	Conversion Factor.
Area.	l^2
Volume.	l^3
Angle.	1
Solid Angle.	1
Curvature.	l^{-1}
Tortuosity.	l^{-1}
Specific curvature of a surface.	l^{-2}
Angular velocity.	t^{-1}
Angular acceleration.	t^{-2}
Linear velocity.	$l\,t^{-1}$
Linear acceleration.	$l\,t^{-2}$
Density.	$m\,l^{-3}$
Moment of inertia.	$m\,l^2$
Intensity of attraction, or "force at a point."	$l\,t^{-2}$
Absolute force of a centre of attraction, or "strength of a centre."	$l^3\,t^{-2}$
Momentum.	$m\,l\,t^{-1}$
Moment of momentum, or angular momentum.	$m\,l^2\,t^{-1}$
Force.	$m\,l\,t^{-2}$
Moment of a couple, or torque.	$m\,l^2\,t^{-2}$
Intensity of stress.	$m\,l^{-1}\,t^{-2}$
Modulus of elasticity.	$m\,l^{-1}\,t^{-2}$
Work and energy.	$m\,l^2\,t^{-2}$
Resilience.	$m\,l^{-1}\,t^{-2}$
Power or activity.	$m\,l^2\,t^{-3}$

FUNDAMENTAL AND DERIVED UNITS.

II. Heat Units.

Name of Unit.	Conversion Factor.
Quantity of heat (thermal units).	$m\,\theta$
" " (thermometric units).	$l^3\,\theta$
" " (dynamical units).	$m\,l^2\,t^{-2}$
Coefficient of thermal expansion.	θ^{-1}
Conductivity (thermal units).	$m\,l^{-1}\,t^{-1}$
" (thermometric units), or diffusivity.	$l^2\,t^{-1}$
" (dynamical units).	$m\,l\,t^{-3}\,\theta^{-1}$
Thermal capacity.	m
Latent heat (thermal units).	θ
" " (dynamical units).	$l^2\,t^{-2}$
Joule's equivalent.	$l^2\,t^{-2}\,\theta$
Entropy (heat measured in thermal units).	m
" (" " " dynamical units).	$m\,l^2\,t^{-2}\,\theta$

III. Magnetic and Electric Units.

Name of Unit.	Conversion factor for electrostatic system.	Conversion factor for electromagnetic system.
Magnetic pole, or quantity of magnetism.	$m^{\frac{1}{2}}\,l^{\frac{1}{2}}\,k^{-\frac{1}{2}}$	$m^{\frac{1}{2}}\,l^{\frac{3}{2}}\,t^{-1}\,p^{\frac{1}{2}}$
Density of surface distribution of magnetism.	$m^{\frac{1}{2}}\,l^{-\frac{3}{2}}\,k^{-\frac{1}{2}}$	$m^{\frac{1}{2}}\,l^{-\frac{1}{2}}\,t^{-1}\,p^{\frac{1}{2}}$
Intensity of magnetic field.	$m^{\frac{1}{2}}\,l^{\frac{1}{2}}\,t^{-2}\,k^{\frac{1}{2}}$	$m^{\frac{1}{2}}\,l^{-\frac{1}{2}}\,t^{-1}\,p^{-\frac{1}{2}}$
Magnetic potential.	$m^{\frac{1}{2}}\,l^{\frac{3}{2}}\,t^{-2}\,k^{\frac{1}{2}}$	$m^{\frac{1}{2}}\,l^{\frac{1}{2}}\,t^{-1}\,p^{-\frac{1}{2}}$
Magnetic moment.	$m^{\frac{1}{2}}\,l^{\frac{3}{2}}\,k^{-\frac{1}{2}}$	$m^{\frac{1}{2}}\,l^{\frac{5}{2}}\,t^{-1}\,p^{\frac{1}{2}}$
Intensity of magnetisation.	$m^{\frac{1}{2}}\,l^{-\frac{3}{2}}\,k^{-\frac{1}{2}}$	$m^{\frac{1}{2}}\,l^{-\frac{1}{2}}\,t^{-1}\,p^{\frac{1}{2}}$
Magnetic permeability.	I	I
Magnetic susceptibility and magnetic inductive capacity.	$l^{-2}\,t^2\,k^{-1}$	p
Quantity of electricity.	$m^{\frac{1}{2}}\,l^{\frac{3}{2}}\,t^{-1}\,k^{\frac{1}{2}}$	$m^{\frac{1}{2}}\,l^{\frac{1}{2}}\,p^{-\frac{1}{2}}$
Electric surface density and electric displacement.	$m^{\frac{1}{2}}\,l^{-\frac{1}{2}}\,t^{-1}\,k^{\frac{1}{2}}$	$m^{\frac{1}{2}}\,l^{-\frac{3}{2}}\,p^{-\frac{1}{2}}$
Intensity of electric field.	$m^{\frac{1}{2}}\,l^{-\frac{1}{2}}\,t^{-1}\,k^{-\frac{1}{2}}$	$m^{\frac{1}{2}}\,l^{\frac{1}{2}}\,t^{-2}\,p^{\frac{1}{2}}$
Electric potential and e. m. f.	$m^{\frac{1}{2}}\,l^{\frac{1}{2}}\,t^{-1}\,k^{-\frac{1}{2}}$	$m^{\frac{1}{2}}\,l^{\frac{3}{2}}\,t^{-2}\,p^{\frac{1}{2}}$
Capacity of a condenser.	$l\,k$	$l^{-1}\,t^2\,p^{-1}$
Inductive capacity.	k	$l^{-2}\,t^2\,p^{-1}$
Specific inductive capacity.	I	I
Electric current.	$m^{\frac{1}{2}}\,l^{\frac{3}{2}}\,t^{-2}\,k^{\frac{1}{2}}$	$m^{\frac{1}{2}}\,l^{\frac{1}{2}}\,t^{-1}\,p^{-\frac{1}{2}}$

TABLE 1.

FUNDAMENTAL AND DERIVED UNITS.

III. Magnetic and Electric Units.

Name of Unit.	Conversion factor for electrostatic system.	Conversion factor for electromagnetic system.
Conductivity.	$t^{-1}\,k$	$l^{-2}\,t\,p^{-1}$
Specific resistance.	$t\,k^{-1}$	$l^{2}\,t^{-1}\,p$
Conductance.	$l\,t^{-1}\,k$	$l^{-1}\,t\,p^{-1}$
Resistance.	$l^{-1}\,t\,k^{-1}$	$l\,t^{-1}\,p$
Coefficient of self induction and coefficient of mutual induction.	$l^{-1}\,t^{2}\,k^{-1}$	$l\,p$
Electrokinetic momentum.	$m^{\frac{1}{2}}\,l^{\frac{1}{2}}\,k^{-\frac{1}{2}}$	$m^{\frac{1}{2}}\,l^{\frac{3}{2}}\,t^{-1}\,p^{\frac{1}{2}}$
Electromotive force at a point.	$m^{\frac{1}{2}}\,l^{-\frac{1}{2}}\,t^{-1}\,k^{-\frac{1}{2}}$	$m^{\frac{1}{2}}\,l^{\frac{1}{2}}\,t^{-2}\,p^{\frac{1}{2}}$
Vector potential.	$m^{\frac{1}{2}}\,l^{-\frac{1}{2}}\,k^{-\frac{1}{2}}$	$m^{\frac{1}{2}}\,l^{\frac{1}{2}}\,t^{-1}\,p^{\frac{1}{2}}$
Thermoelectric height and specific heat of electricity.	$m^{\frac{1}{2}}\,l^{\frac{1}{2}}\,t^{-1}\,k^{-\frac{1}{2}}\,\theta^{-1}$	$m^{\frac{1}{2}}\,l^{\frac{3}{2}}\,t^{-2}\,p^{\frac{1}{2}}\,\theta^{-1}$
Coefficient of Peltier effect.	$m^{\frac{1}{2}}\,l^{-\frac{3}{2}}\,t\,k^{-\frac{1}{2}}\,\theta$	$m^{\frac{1}{2}}\,l^{-\frac{1}{2}}\,p^{\frac{1}{2}}\,\theta$

TABLE 2.

TABLES FOR CONVERTING U. S. WEIGHTS AND MEASURES.*

(1) CUSTOMARY TO METRIC.

LINEAR.

	Inches to millimeters.	Feet to meters.	Yards to meters.	Miles to kilometers.
1	25.4001	0.304801	0.914402	1.60935
2	50.8001	0.609601	1.828804	3.21869
3	76.2002	0.914402	2.743205	4.82804
4	101.6002	1.219202	3.657607	6.43739
5	127.0003	1.524003	4.572009	8.04674
6	152.4003	1.828804	5.486411	9.65608
7	177.8004	2.133604	6.400813	11.26543
8	203.2004	2.438405	7.315215	12.87478
9	228.6005	2.743205	8.229616	14.48412

CAPACITY.

	Fluid drams to milliliters or cubic centimeters.	Fluid ounces to milliliters.	Liquid quarts to liters.	Gallons to liters.
1	3.70	29.57	0.94633	3.78533
2	7.39	59.15	1.89267	7.57066
3	11.09	88.72	2.83900	11.35600
4	14.79	118.29	3.78533	15.14133
5	18.48	147.87	4.73167	18.92666
6	22.18	177.44	5.67800	22.71199
7	25.88	207.01	6.62433	26.49733
8	29.57	236.58	7.57066	30.28266
9	33.27	266.16	8.51700	34.06799

SQUARE.

	Square inches to square centimeters.	Square feet to square decimeters.	Square yards to square meters.	Acres to hectares.
1	6.452	9.290	0.836	0.4047
2	12.903	18.581	1.672	0.8094
3	19.355	27.871	2.508	1.2141
4	25.807	37.161	3.345	1.6187
5	32.258	46.452	4.181	2.0234
6	38.710	55.742	5.017	2.4281
7	45.161	65.032	5.853	2.8328
8	51.613	74.323	6.689	3.2375
9	58.065	83.613	7.525	3.6422

WEIGHT.

	Grains to milligrams.	Avoirdupois ounces to grams.	Avoirdupois pounds to kilograms.	Troy ounces to grams.
1	64.7989	28.3495	0.45359	31.10348
2	129.5978	56.6991	0.90718	62.20696
3	194.3968	85.0486	1.36078	93.31044
4	259.1957	113.3981	1.81437	124.41392
5	323.9946	141.7476	2.26796	155.51740
6	388.7935	170.0972	2.72155	186.62088
7	453.5924	198.4467	3.17515	217.72437
8	518.3913	226.7962	3.62874	248.82785
9	583.1903	255.1457	4.08233	279.93133

CUBIC.

	Cubic inches to cubic centimeters.	Cubic feet to cubic meters.	Cubic yards to cubic meters.	Bushels to hectoliters.
1	16.387	0.02832	0.765	0.35239
2	32.774	0.05663	1.529	0.70479
3	49.161	0.08495	2.294	1.05718
4	65.549	0.11327	3.058	1.40957
5	81.936	0.14159	3.823	1.76196
6	98.323	0.16990	4.587	2.11436
7	114.710	0.19822	5.352	2.46675
8	131.097	0.22654	6.116	2.81914
9	147.484	0.25485	6.881	3.17154

1 Gunter's chain = 20.1168 meters.
1 sq. statute mile = 259.000 hectares.
1 fathom = 1.829 meters.
1 nautical mile = 1853.25 meters.
1 foot = 0.304801 meter.
1 avoir. pound = 453.5924277 grams.
15432.35639 grains = 1.000 kilogram.

According to an executive order dated April 15, 1893, the United States yard is defined as 3600/3937 meter, and the avoirdupois pound as 1/2.20462 kilogram.

1 meter (international prototype) = 1553164.13 times the wave-length of the red Cd. line. Benoit, Fabry and Perot. C. R. 144, 1907 differs only in the decimal portion from the measure of Michelson and Benoit 14 years earlier.

The length of the nautical mile given above and adopted by the U. S. Coast and Geodetic Survey many years ago, is defined as that of a minute of arc of a great circle of a sphere whose surface equals that of the earth (Clarke's Spheroid of 1866).

* Quoted from sheets issued by the United States Bureau of Standards.

TABLE 2 (*continued*).

TABLES FOR CONVERTING U. S. WEIGHTS AND MEASURES.

(2) METRIC TO CUSTOMARY.

LINEAR.

	Meters to inches.	Meters to feet.	Meters to yards.	Kilometers to miles.
1	39.3700	3.28083	1.093611	0.62137
2	78.7400	6.56167	2.187222	1.24274
3	118.1100	9.84250	3.280833	1.86411
4	157.4800	13.12333	4.374444	2.48548
5	196.8500	16.40417	5.468056	3.10685
6	236.2200	19.68500	6.561667	3.72822
7	275.5900	22.96583	7.655278	4.34959
8	314.9600	26.24667	8.748889	4.97096
9	354.3300	29.52750	9.842500	5.59233

CAPACITY.

	Milliliters or cubic centimeters to fluid drams.	Centiliters to fluid ounces.	Liters to quarts.	Decaliters to gallons.	Hectoliters to bushels.
1	0.27	0.338	1.0567	2.6418	2.8378
2	0.54	0.676	2.1134	5.2836	5.6756
3	0.81	1.014	3.1701	7.9253	8.5135
4	1.08	1.353	4.2268	10.5671	11.3513
5	1.35	1.691	5.2836	13.2089	14.1891
6	1.62	2.029	6.3403	15.8507	17.0269
7	1.89	2.367	7.3970	18.4924	19.8647
8	2.16	2.705	8.4537	21.1342	22.7026
9	2.43	3.043	9.5104	23.7760	25.5404

SQUARE.

	Square centimeters to square inches.	Square meters to square feet.	Square meters to square yards.	Hectares to acres.
1	0.1550	10.764	1.196	2.471
2	0.3100	21.528	2.392	4.942
3	0.4650	32.292	3.588	7.413
4	0.6200	43.055	4.784	9.884
5	0.7750	53.819	5.980	12.355
6	0.9300	64.583	7.176	14.826
7	1.0850	75.347	8.372	17.297
8	1.2400	86.111	9.568	19.768
9	1.3950	96.875	10.764	22.239

WEIGHT.

	Milligrams to grains.	Kilograms to grains.	Hectograms to ounces avoirdupois.	Kilograms to pounds avoirdupois.
1	0.01543	15432.36	3.5274	2.20462
2	0.03086	30864.71	7.0548	4.40924
3	0.04630	46297.07	10.5822	6.61387
4	0.06173	61729.43	14.1096	8.81849
5	0.07716	77161.78	17.6370	11.02311
6	0.09259	92594.14	21.1644	13.22773
7	0.10803	108026.49	24.6918	15.43236
8	0.12346	123458.85	28.2192	17.63698
9	0.13889	138891.21	31.7466	19.84160

CUBIC.

	Cubic centimeters to cubic inches.	Cubic decimeters to cubic inches.	Cubic meters to cubic feet.	Cubic meters to cubic yards.
1	0.0610	61.023	35.314	1.308
2	0.1220	122.047	70.269	2.616
3	0.1831	183.070	105.943	3.924
4	0.2441	244.094	141.258	5.232
5	0.3051	305.117	176.572	6.540
6	0.3661	366.140	211.887	7.848
7	0.4272	427.164	247.201	9.156
8	0.4882	488.187	282.516	10.464
9	0.5492	549.210	317.830	11.771

WEIGHT.

	Quintals to pounds av.	Milliers or tonnes to pounds av.	Kilograms to ounces Troy.
1	220.46	2204.6	32.1507
2	440.92	4409.2	64.3015
3	661.39	6613.9	96.4522
4	881.85	8818.5	128.6030
5	1102.31	11023.1	160.7537
6	1322.77	13227.7	192.9045
7	1543.24	15432.4	225.0552
8	1763.70	17637.0	257.2059
9	1984.16	19841.6	289.3567

By the concurrent action of the principal governments of the world an International Bureau of Weights and Measures has been established near Paris. Under the direction of the International Committee, two ingots were cast of pure platinum-iridium in the proportion of 9 parts of the former to 1 of the latter metal. From one of these a certain number of kilograms were prepared, from the other a definite number of meter bars. These standards of weight and length were intercompared, without preference, and certain ones were selected as International prototype standards. The others were distributed by lot, in September, 1889, to the different governments, and are called National prototype standards. Those apportioned to the United States were received in 1890, and are kept at the Bureau of Standards in Washington, D. C.

The metric system was legalized in the United States in 1866.

The International Standard Meter is derived from the Mètre des Archives, and its length is defined by the distance between two lines at 0° Centigrade, on a platinum-iridium bar deposited at the International Bureau of Weights and Measures.

The International Standard Kilogram is a mass of platinum-iridium deposited at the same place, and its weight in vacuo is the same as that of the Kilogram des Archives.

The liter is equal to the quantity of pure water at 4° C, 760 mm. Hg. pressure which weighs 1 kilogram = 1.000027 cu. dm. (Trav. et Mem. Bureau Intern. des P. et M. 14, 1910, Benoit.)

TABLE 3.

EQUIVALENTS OF METRIC AND BRITISH IMPERIAL WEIGHTS AND MEASURES.*

(1) METRIC TO IMPERIAL.

LINEAR MEASURE.

1 millimeter (mm.) (.001 m.)	=	0.03937 in.
1 centimeter (.01 m.)	=	0.39370 “
1 decimeter (.1 m)	=	3.93701 “
1 METER (m.)	=	39.370113 “ 3.280843 ft. 1.09361425 yds.
1 dekameter (10 m.)	=	10.93614 “
1 hectometer (100 m.)	=	109.361425 “
1 kilometer (1,000 m.)	=	0.62137 mile.
1 myriameter (10,000 m.)	=	6.21372 miles.
1 micron	=	0.001 mm.

SQUARE MEASURE.

1 sq. centimeter	=	0.1550 sq. in.
1 sq. decimeter (100 sq. centm.)	=	15.500 sq. in.
1 sq. meter or centiare (100 sq. dcm.)	=	10.7639 sq. ft. 1.1960 sq. yds.
1 ARE (100 sq. m.)	=	119.60 sq. yds.
1 hectare (100 ares or 10,000 sq. m.)	=	2.4711 acres.

CUBIC MEASURE.

1 cub. centimeter (c.c.) (1,000 cubic millimeters)	=	0.0610 cub. in.
1 cub. decimeter (c.d.) (1,000 cubic centimeters)	=	61.024 “ “
1 CUB. METER or stere (1,000 c.d.)	=	35.3148 cub. ft. 1.307954 cub. yds.

MEASURE OF CAPACITY.

1 milliliter (ml.) (.001 liter)	=	0.0610 cub. in.
1 centiliter (.01 liter)	=	0.61024 “ “ 0.070 gill.
1 deciliter (.1 liter)	=	0.176 pint.
1 LITER (1,000 cub. centimeters or 1 cub. decimeter)	=	1.75980 pints.
1 dekaliter (10 liters)	=	2.200 gallons.
1 hectoliter (100 “)	=	2.75 bushels.
1 kiloliter (1,000 “)	=	3.437 quarters.

APOTHECARIES' MEASURE.

1 cubic centimeter (1 gram w't)	=	0.03520 fluid ounce. 0.28157 fluid drachm. 15.43236 grains weight.
1 cub. millimeter	=	0.01693 minim.

AVOIRDUPOIS WEIGHT.

1 milligram (mgr.)	=	0.01543 grain.
1 centigram (.01 gram.)	=	0.15432 “
1 decigram (.1 “)	=	1.54324 grains.
1 GRAM	=	15.43236 “
1 dekagram (10 gram.)	=	5.64383 drams.
1 hectogram (100 “)	=	3.52739 oz.
1 KILOGRAM (1,000 “)	=	2.2046223 lb. 15432.3564 grains.
1 myriagram (10 kilog.)	=	22.04622 lbs.
1 quintal (100 “)	=	1.96841 cwt.
1 millier or tonne (1,000 kilog.)	=	0.9842 ton.

TROY WEIGHT.

1 GRAM	=	0.03215 oz. Troy. 0.64301 pennyweight. 15.43236 grains.

APOTHECARIES' WEIGHT.

1 GRAM	=	0.25721 drachm. 0.77162 scruple. 15.43236 grains.

NOTE.—The METER is the length, at the temperature of 0° C., of the platinum-iridium bar deposited at the International Bureau of Weights and Measures at Sèvres, near Paris, France.

The present legal equivalent of the meter is 39.370113 inches, as above stated.

The KILOGRAM is the mass of a platinum-iridium weight deposited at the same place.

The LITER contains one kilogram weight of distilled water at its maximum density (4° C.), the barometer being at 760 millimeters.

---

*In accordance with the schedule adopted under the Weights and Measures (metric system) Act, 1897.

TABLE 3.

EQUIVALENTS OF METRIC AND BRITISH IMPERIAL WEIGHTS AND MEASURES.

(2) METRIC TO IMPERIAL.

LINEAR MEASURE.

	Millimeters to inches.	Meters to feet.	Meters to yards.	Kilometers to miles.
1	0.03937011	3.28084	1.09361	0.62137
2	0.07874023	6.56169	2.18723	1.24274
3	0.11811034	9.84253	3.28084	1.86412
4	0.15748045	13.12337	4.37446	2.48549
5	0.19685056	16.40421	5.46807	3.10686
6	0.23622068	19.68506	6.56169	3.72823
7	0.27559079	22.96590	7.65530	4.34960
8	0.31496090	26.24674	8.74891	4.97097
9	0.35433102	29.52758	9.84253	5.59235

MEASURE OF CAPACITY.

	Liters to pints.	Dekaliters to gallons	Hectoliters to bushels.	Kiloliters to quarters.
1	1.75980	2.19975	2.74969	3.43712
2	3.51961	4.39951	5.49938	6.87423
3	5.27941	6.59926	8.24908	10.31135
4	7.03921	8.79902	10.99877	13.74846
5	8.79902	10.99877	13.74846	17.18558
6	10.55882	13.19852	16.49815	20.62269
7	12.31862	15.39828	19.24785	24.05981
8	14.07842	17.59803	21.99754	27.49692
9	15.83823	19.79778	24.74723	30.93404

SQUARE MEASURE.

	Square centimeters to square inches.	Square meters to square feet.	Square meters to square yards.	Hectares to acres.
1	0.15500	10.76393	1.19599	2.4711
2	0.31000	21.52786	2.39198	4.9421
3	0.46500	32.29179	3.58798	7.4132
4	0.62000	43.05572	4.78397	9.8842
5	0.77500	53.81965	5.97996	12.3553
6	0.93000	64.58357	7.17595	14.8263
7	1.08500	75.34750	8.37194	17.2974
8	1.24000	86.11143	9.56794	19.7685
9	1.39501	96.87536	10.76393	22.2395

WEIGHT (Avoirdupois).

	Milligrams to grains.	Kilograms to grains.	Kilograms to pounds.	Quintals to hundredweights.
1	0.01543	15432.356	2.20462	1.96841
2	0.03086	30864.713	4.40924	3.93683
3	0.04630	46297.069	6.61387	5.90524
4	0.06173	61729.426	8.81849	7.87365
5	0.07716	77161.782	11.02311	9.84206
6	0.09259	92594.138	13.22773	11.81048
7	0.10803	108026.495	15.43236	13.77889
8	0.12346	123458.851	17.63698	15.74730
9	0.13889	138891.208	19.84160	17.71572

	CUBIC MEASURE.			Apothecaries' Measure.
	Cubic decimeters to cubic inches.	Cubic meters to cubic feet.	Cubic meters to cubic yards.	Cub. centimeters to fluid drachms.
1	61.02390	35.31476	1.30795	0.28157
2	122.04781	70.62952	2.61591	0.56314
3	183.07171	105.94428	3.92386	0.84471
4	244.09561	141.25904	5.23182	1.12627
5	305.11952	176.57379	6.53977	1.40784
6	366.14342	211.88855	7.84772	1.68941
7	427.16732	247.20331	9.15568	1.97098
8	488.19123	282.51807	10.46363	2.25255
9	549.21513	317.83283	11.77159	2.53412

	Avoirdupois (*cont.*)	Troy Weight.		Apothecaries' Weight.
	Milliers or tonnes to tons.	Grams to ounces Troy.	Grams to pennyweights.	Grams to scruples.
1	0.98421	0.03215	0.64301	0.77162
2	1.96841	0.06430	1.28603	1.54324
3	2.95262	0.09645	1.92904	2.31485
4	3.93683	0.12860	2.57206	3.08647
5	4.92103	0.16075	3.21507	3.85809
6	5.90524	0.19290	3.85809	4.62971
7	6.88944	0.22506	4.50110	5.40132
8	7.87365	0.25721	5.14412	6.17294
9	8.85786	0.28936	5.78713	6.94456

TABLE 3.

EQUIVALENTS OF BRITISH IMPERIAL AND METRIC WEIGHTS AND MEASURES.

(3) IMPERIAL TO METRIC.

LINEAR MEASURE.

1 inch . . . . . . = 25.400 millimeters.
1 foot (12 in.) . . = 0.30480 meter.
1 YARD (3 ft.) . . = 0.914399 "
1 pole ($5\frac{1}{2}$ yd.) . . = 5.0292 meters.
1 chain (22 yd. or 100 links) = 20.1168 "
1 furlong (220 yd.) = 201.168 "
1 mile (1,760 yd.) . = 1.6093 kilometers.

SQUARE MEASURE.

1 square inch . . = 6.4516 sq. centimeters.
1 sq. ft. (144 sq. in.) = 9.2903 sq. decimeters.
1 SQ. YARD (9 sq. ft.) = 0.836126 sq. meters.
1 perch ($30\frac{1}{4}$ sq. yd.) = 25.293 sq. meters.
1 rood (40 perches) = 10.117 ares.
1 ACRE (4840 sq. yd.) = 0.40468 hectare.
1 sq. mile (640 acres) = 259.00 hectares.

CUBIC MEASURE.

1 cub. inch = 16.387 cub. centimeters.
1 cub. foot (1728 cub. in.) = 0.028317 cub. meter, or 28.317 cub. decimeters.
1 CUB. YARD (27 cub. ft.) = 0.76455 cub. meter.

APOTHECARIES' MEASURE.

1 gallon (8 pints or 160 fluid ounces) = 4.5459631 liters.
1 fluid ounce, f ℥ (8 drachms) = 28.4123 cubic centimeters.
1 fluid drachm, f ʒ (60 minims) = 3.5515 cubic centimeters.
1 minim, ♏ (0.91146 grain weight) = 0.05919 cubic centimeters.

NOTE. — The Apothecaries' gallon is of the same capacity as the Imperial gallon.

MEASURE OF CAPACITY.

1 gill . . . . . . = 1.42 deciliters.
1 pint (4 gills) . . . = 0.568 liter.
1 quart (2 pints) . . = 1.136 liters.
1 GALLON (4 quarts) = 4.5459631 "
1 peck (2 galls.) . . = 9.092 "
1 bushel (8 galls.) . = 3.637 dekaliters.
1 quarter (8 bushels) = 2.909 hectoliters.

AVOIRDUPOIS WEIGHT.

1 grain . . . . . . = 64.8 milligrams.
1 dram . . . . . . = 1.772 grams.
1 ounce (16 dr.) . . = 28.350 "
1 POUND (16 oz. or 7,000 grains) = 0.45359243 kilogr.
1 stone (14 lb.) . . = 6.350 "
1 quarter (28 lb.) . = 12.70 "
1 hundredweight (112 lb.) = 50.80 "
 0.5080 quintal.
1 ton (20 cwt.) . = 1.0160 tonnes or 1016 kilograms.

TROY WEIGHT.

1 Troy OUNCE (480 grains avoir.) = 31.1035 grams.
1 pennyweight (24 grains) = 1.5552 "

NOTE. — The Troy grain is of the same weight as the Avoirdupois grain.

APOTHECARIES' WEIGHT.

1 ounce (8 drachms) = 31.1035 grams.
1 drachm, ʒ i (3 scruples) = 3.888 "
1 scruple, ℈ i (20 grains) = 1.296 "

NOTE. — The Apothecaries' ounce is of the same weight as the Troy ounce. The Apothecaries' grain is also of the same weight as the Avoirdupois grain.

NOTE. — The YARD is the length at 62° Fahr., marked on a bronze bar deposited with the Board of Trade.

The POUND is the weight of a piece of platinum weighed in vacuo at the temperature of 0° C., and which is also deposited with the Board of Trade.

The GALLON contains 10 lb. weight of distilled water at the temperature of 62° Fahr., the barometer being at 30 inches.

TABLE 3.

EQUIVALENTS OF BRITISH IMPERIAL AND METRIC WEIGHTS AND MEASURES.

(4) IMPERIAL TO METRIC.

	LINEAR MEASURE.			
	Inches to centimeters.	Feet to meters.	Yards to meters.	Miles to kilometers.
1	2.539998	0.30480	0.91440	1.60934
2	5.079996	0.60960	1.82880	3.21869
3	7.619993	0.91440	2.74320	4.82803
4	10.159991	1.21920	3.65760	6.43737
5	12.699989	1.52400	4.57200	8.04671
6	15.239987	1.82880	5.48640	9.65606
7	17.779984	2.13360	6.40080	11.26540
8	20.319982	2.43840	7.31519	12.87474
9	22.859980	2.74320	8.22959	14.48408

	MEASURE OF CAPACITY.			
	Quarts to liters.	Gallons to liters.	Bushels to dekaliters.	Quarters to hectoliters.
1	1.13649	4.54596	3.63677	2.90942
2	2.27298	9.09193	7.27354	5.81883
3	3.40947	13.63789	10.91031	8.72825
4	4.54596	18.18385	14.54708	11.63767
5	5.68245	22.72982	18.18385	14.54708
6	6.81894	27.27578	21.82062	17.45650
7	7.95544	31.82174	25.45739	20.36591
8	9.09193	36.36770	29.09416	23.27533
9	10.22842	40.91367	32.73093	26.18475

	SQUARE MEASURE.			
	Square inches to square centimeters.	Square feet to square decimeters.	Square yards to square meters.	Acres to hectares.
1	6.45159	9.29029	0.83613	0.40468
2	12.90318	18.58058	1.67225	0.80937
3	19.35477	27.87086	2.50838	1.21405
4	25.80636	37.16115	3.34450	1.61874
5	32.25794	46.45144	4.18063	2.02342
6	38.70953	55.74173	5.01676	2.42811
7	45.16112	65.03201	5.85288	2.83279
8	51.61271	74.32230	6.68901	3.23748
9	58.06430	83.61259	7.52513	3.64216

	WEIGHT (Avoirdupois).			
	Grains to milligrams.	Ounces to grams.	Pounds to kilograms.	Hundredweights to quintals.
1	64.79892	28.34953	0.45359	0.50802
2	129.59784	56.69905	0.90718	1.01605
3	194.39675	85.04858	1.36078	1.52407
4	259.19567	113.39811	1.81437	2.03209
5	323.99459	141.74763	2.26796	2.54012
6	388.79351	170.09716	2.72155	3.04814
7	453.59243	198.44669	3.17515	3.55616
8	518.39135	226.79621	3.62874	4.06419
9	583.19026	255.14574	4.08233	4.57221

	CUBIC MEASURE.			APOTHECARIES' MEASURE.
	Cubic inches to cubic centimeters.	Cubic feet to cubic meters.	Cubic yards to cubic meters.	Fluid drachms to cubic centimeters.
1	16.38702	0.02832	0.76455	3.55153
2	32.77404	0.05663	1.52911	7.10307
3	49.16106	0.08495	2.29366	10.65460
4	65.54808	0.11327	3.05821	14.20613
5	81.93511	0.14158	3.82276	17.75767
6	98.32213	0.16990	4.58732	21.30920
7	114.70915	0.19822	5.35187	24.86074
8	131.09617	0.22653	6.11642	28.41227
9	147.48319	0.25485	6.88098	31.96380

	AVOIRDUPOIS (*cont.*).	TROY WEIGHT.		APOTHECARIES' WEIGHT.
	Tons to milliers or tonnes.	Ounces to grams.	Pennyweights to grams.	Scruples to grams.
1	1.01605	31.10348	1.55517	1.29598
2	2.03209	62.20696	3.11035	2.59196
3	3.04814	93.31044	4.66552	3.88794
4	4.06419	124.41392	6.22070	5.18391
5	5.08024	155.51740	7.77587	6.47989
6	6.09628	186.62088	9.33104	7.77587
7	7.11233	217.72437	10.88622	9.07185
8	8.12838	248.82785	12.44139	10.36783
9	9.14442	279.93133	13.99657	11.66381

TABLE 4.

VOLUME OF A GLASS VESSEL FROM THE WEIGHT OF ITS EQUIVALENT VOLUME OF MERCURY OR WATER.

If a glass vessel contains at t° C, P grammes of mercury, weighted with brass weights in air at 760 mm. pressure, then its volume in c. cm.

at the same temperature, t, : $V = PR = P\frac{p}{d}$,

at another temperature, t_1, : $V = PR_1 = Pp/d\,\{1 + \gamma\,(t_1 - t)\}$

p = the weight, reduced to vacuum, of the mass of mercury or water which, weighed with brass weights, equals 1 gram;

d = the density of mercury or water at t° C,

and $\gamma = 0.000\,025$, is the cubical expansion coefficient of glass.

Temperature t	WATER.			MERCURY.		
	R.	R_1, $t_1 = 10^\circ$.	R_1, $t_1 = 20^\circ$.	R.	R_1, $t_1 = 10^\circ$.	R_1, $t_1 = 20^\circ$.
0°	1.001192	1.001443	1.001693	0.0735499	0.0735683	0.0735867
1	1133	1358	1609	5633	5798	5982
2	1092	1292	1542	5766	5914	6098
3	1068	1243	1493	5900	6029	6213
4	1060	1210	1460	6033	6144	6328
5	1068	1193	1443	6167	6259	6443
6	1.001092	1.001192	1.001442	0.0736301	0.0736374	0.0736558
7	1131	1206	1456	6434	6490	6674
8	1184	1234	1485	6568	6605	6789
9	1252	1277	1527	6702	6720	6904
10	1333	1333	1584	6835	6835	7020
11	1.001428	1.001403	1.001653	0.0736969	0.0736951	0.0737135
12	1536	1486	1736	7103	7066	7250
13	1657	1582	1832	7236	7181	7365
14	1790	1690	1940	7370	7297	7481
15	1935	1810	2060	7504	7412	7596
16	1.002092	1.001942	1.002193	0.0737637	0.0737527	0.0737711
17	2261	2086	2337	7771	7642	7826
18	2441	2241	2491	7905	7757	7941
19	2633	2407	2658	8039	7872	8057
20	2835	2584	2835	8172	7988	8172
21	1.003048	1.002772	1.003023	0.0738306	0.0738103	0.0738288
22	3271	2970	3220	8440	8218	8403
23	3504	3178	3429	8573	8333	8518
24	3748	3396	3647	8707	8449	8633
25	4001	3624	3875	8841	8564	8748
26	1.004264	1.003862	1.004113	0.0738974	0.0738679	0.0738864
27	4537	4110	4361	9108	8794	8979
28	4818	4366	4616	9242	8910	9094
29	5110	4632	4884	9376	9025	9210
30	5410	4908	5159	9510	9140	9325

Taken from Landolt, Börnstein, and Meyerhoffer's Physikalisch-Chemische Tabellen.

TABLE 5.

DERIVATIVES AND INTEGRALS.*

$d\,ax$	$= a\,dx$
$d\,u\,v$	$= \left(u\frac{dv}{dx}+v\frac{du}{dx}\right)dx$
$d\,\frac{u}{v}$	$= \left(\frac{v\frac{du}{dx}-u\frac{dv}{dx}}{v^2}\right)dx$
$d\,x^n$	$= nx^{n-1}\,dx$
$d\,f(u)$	$= d\,\frac{f(u)}{du}\cdot\frac{du}{dx}\cdot dx$
$d\,e^x$	$= e^x\,dx$
$d\,e^{ax}$	$= a\,e^{ax}\,dx$
$d\,\log_e x$	$= \frac{1}{x}\,dx$
$d\,x^x$	$= x^x\,(1+\log_e x)$
$d\,\sin x$	$= \cos x\,dx$
$d\,\cos x$	$= -\sin x\,dx$
$d\,\tan x$	$= \sec^2 x\,dx$
$d\,\cot x$	$= -\csc^2 x\,dx$
$d\,\sec x$	$= \tan x\sec x\,dx$
$d\,\csc x$	$= -\cot x\,.\,\mathrm{scs}\,x\,dx$
$d\,\sin^{-1} x$	$= (1-x^2)^{-\frac{1}{2}}\,dx$
$d\,\cos^{-1} x$	$= -(1-x^2)^{-\frac{1}{2}}\,dx$
$d\,\tan^{-1} x$	$= (1+x^2)^{-1}\,dx$
$d\,\cot^{-1} x$	$= -(1+x^2)^{-1}\,dx$
$d\,\sec^{-1} x$	$= x^{-1}\,(x^2-1)^{-\frac{1}{2}}\,dx$
$d\,\csc^{-1} x]$	$= -x^{-1}\,(x^2-1)^{-\frac{1}{2}}\,dx$
$d\,\sinh x$	$= \cosh x\,dx$
$d\,\cosh x$	$= \sinh x\,dx$
$d\,\tanh x$	$= \mathrm{sech}^2\,x\,dx$
$d\,\coth x$	$= -\mathrm{csch}^2\,x\,dx$
$d\,\mathrm{sech}\,x$	$= -\mathrm{sech}\,x\tanh dx$
$d\,\mathrm{csch}\,x$	$= -\mathrm{csch}\,x\,.\,\coth x\,dx$
$d\,\sinh^{-1} x$	$= (x^2+1)^{-\frac{1}{2}}\,dx$
$d\,\cosh^{-1} x$	$= (x^2-1)^{-\frac{1}{2}}\,dx$
$d\,\tanh^{-1} x$	$= (1-x^2)^{-1}\,dx$
$d\,\coth^{-1} x$	$= (1-x^2)^{-1}\,dx$
$d\,\mathrm{sech}^{-1}\,x$	$= -x^{-1}\,(1-x^2)^{-\frac{1}{2}}\,dx$
$d\,\mathrm{csch}^{-1}\,x$	$= -x^{-1}\,(x^2+1)^{-\frac{1}{2}}$

$\int x^n\,dx$	$=\frac{x^{n+1}}{n+1}$, unless $n=-1$
$\int\frac{dx}{x}$	$= \log x$
$\int e^x\,dx$	$= e^x$
$\int e^{ax}dx$	$=\frac{1}{a}\,e^{ax}$
$\int x\,e^{ax}\,dx$	$=\frac{e^{ax}}{a^2}\,(ax-1)$
$\int\log x\,dx$	$= x\log x-x$
$\int u\,dv$	$= u\,v-\int v\,du$
$\int(a+bx)^n\,dx$	$=\frac{(a+bx)^{n+1}}{(n+1)b}$
$\int(a^2+x^2)^{-1}\,dx$	$= \frac{1}{a}\tan^{-1}\frac{x}{a} = \frac{1}{a}\sin^{-1}\frac{x}{\sqrt{x^2+a^2}}$
$\int(a^2-x^2)^{-1}dx$	$= \frac{1}{2a}\log\frac{a+x}{a-x}$
$\int(a^2-x^2)^{-\frac{1}{2}}\,dx$	$= \sin^{-1}\frac{x}{a}$, or $-\cos^{-1}\frac{x}{a}$
$\int x(a^2\pm x^2)^{-\frac{1}{2}}\,dx$	$= \pm(a^2\pm x^2)^{\frac{1}{2}}$
$\int\sin^2 x\,dx$	$= -\frac{1}{2}\cos x\sin x+\frac{1}{2}x$
$\int\cos^2 x\,dx$	$= \frac{1}{2}\sin x\cos x+\frac{1}{2}x$
$\int\sin x\cos x\,dx$	$= \frac{1}{2}\sin^2 x$
$\int(\sin x\cos x)^{-1}\,dx$	$= \log\tan x$
$\int\tan x\,dx$	$= -\log\cos x$
$\int\tan^2 x\,dx$	$= \tan x-x$
$\int\cot x\,dx$	$= \log\sin x$
$\int\cot^2 x\,dx$	$= -\cot x-x$
$\int\csc x\,dx$	$= \log\tan\frac{1}{2}x$
$\int x\sin x\,dx$	$= \sin x-x\cos x$
$\int x\cos x\,dx$	$= \cos x+x\sin x$
$\int\tanh x\,dx$	$= \log\cosh x$
$\int\coth x\,dx$	$= \log\sinh x$
$\int\mathrm{sech}\,x\,dx$	$= 2\tan^{-1}c^x=\mathrm{gd}\,u$
$\int\mathrm{csch}\,x\,dx$	$= \log\tanh\frac{x}{2}$
$\int x\sinh x\,dx$	$= x\cosh x-\sinh x$
$\int x\cosh x\,dx$	$= x\sinh x-\cosh x$
$\int\sinh^2 x\,dx$	$= \frac{1}{2}(\sinh x\cosh x-x)$
$\int\cosh^2 x\,dx$	$= \frac{1}{2}(\sinh x\cosh x+x)$
$\int\sinh x\cosh x\,dx$	$=\frac{1}{4}\cosh(2\,x)$

---

* See also accompanying table of derivatives. For example : $\int$ cos. $x\,dx$ = sin. x + constant.

TABLE 6.

SERIES.

$$(x+y)^n = x^n + \frac{n}{1}\,x^{n-1}\,y + \frac{n\,(n-1)}{2\,!}\,x^{n-2}\,y^2 + \ldots$$

$$\frac{n(n-1)\ldots(n-m+1)}{m\,!}\,x^{n-m}\,y^m + \ldots \qquad (y^2<x^2)$$

$$(1 \pm x)^n = 1 \pm nx + \frac{n(n-1)x^2}{2\,!} \pm \frac{n(n-1)\;(n-2)x^2}{3\,!} + \ldots + \frac{(\pm 1)^k\, n\,!\; x^k}{(n-k)!\; k\,!} + \ldots \qquad (x^2<1)$$

$$(1 \pm x)^{-n} = 1 \mp nx + \frac{n\,(n+1)}{2\,!}x^2 \mp \frac{n(n+1)\,(n+2)\,x^3}{3\,!} + \ldots$$

$$(\mp 1)^k\,\frac{(n+k-1)\,x^k}{(n-1)\,!\;k\,!} + \ldots \qquad (x^2<1)$$

$$(1 \pm x)^{-1} = 1 \mp x + x^2 \mp x^3 + x^4 \mp x^5 + \ldots \qquad (x^2<1)$$

$$(1 \pm x)^{-2} = 1 \mp 2x + 3x^2 \mp 4x^3 + 5x^4 \mp 6x^5 + \ldots \qquad (x^2<1)$$

$$f(x+h) = f\,(x) + h\,f'\,(x) + \frac{h^2}{2!}\,f''\,(x) + \ldots + \frac{h^n}{n\,!}\,f^{(n)}\,(x) + \ldots \qquad \text{Taylor's series.}$$

$$f\,(x) = f\,(0) + \frac{x}{1}\,f'\,(0) + \frac{x^2}{2!}\,f''\,(0) + \ldots \frac{x^n}{n\,!}\,f^{(n)}\,(0) + \ldots \qquad \text{Maclaurin's series.}$$

$$e = \lim\left(1 + \frac{1}{n}\right)^n = 1 + \frac{1}{1\,!} + \frac{1}{2\,!} + \frac{1}{3\,!} + \frac{1}{4\,!} + \ldots \quad .$$

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \frac{x^4}{4!} + \ldots \qquad (x^2<\infty)$$

$$a^x = 1 + x\log a + \frac{(x\log a)^2}{2\,!} + \frac{(x\log a)^3}{3\,!} + \ldots. \qquad (x^2<\infty)$$

$$\log x = \frac{x-1}{x} + \frac{1}{2}\left(\frac{x-1}{x}\right)^2 + \frac{1}{3}\left(\frac{x-1}{x}\right)^3 + \ldots \qquad (x>\tfrac{1}{2})$$

$$= (x-1) - \tfrac{1}{2}\,(x-1)^2 + \tfrac{1}{3}\,(x-1)^3 - \ldots \qquad (2>x>0)$$

$$= 2\left[\frac{x-1}{x+1} + \frac{1}{3}\left(\frac{x-1}{x+1}\right)^3 + \frac{1}{5}\left(\frac{x-1}{x+1}\right)^5 + \ldots.\right] \qquad (x>0)$$

$$\log\,(1+x) = x - \tfrac{1}{2}\,x^2 + \tfrac{1}{3}\,x^3 - \tfrac{1}{4}\,x^4 + \ldots. \qquad (x^2<1)$$

$$\sin x = \frac{1}{2i}\,(e^{ix} - e^{-ix}) = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7\,!} + \ldots \qquad (x^2<\infty)$$

$$\cos x = \frac{1}{2}\,(e^{ix} + e^{-ix}) = 1 - \frac{x^2}{2\,!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \ldots = 1 - \text{versin}\,x \qquad (x^2<\infty)$$

$$\tan x = x + \frac{x^3}{3} + \frac{2x^5}{15} + \frac{17x^7}{315} + \frac{62}{2835}\,x^9 + \ldots \qquad \left(x^2<\frac{\pi^2}{4}\right)$$

$$\sin^{-1} x = \frac{\pi}{2} - \cos.^{-1} x = x + \frac{x^3}{6} + \frac{1}{2}\cdot\frac{3}{4}\cdot\frac{x^5}{5} + \frac{1}{2}\cdot\frac{3}{4}\cdot\frac{5}{6}\cdot\frac{x^7}{7} + \ldots \qquad (x^2<1)$$

$$\tan^{-1} x = \frac{\pi}{2} - \cot.^{-1} x = x - \frac{1}{3}\,x^3 + \frac{1}{5}\,x^5 - \frac{1}{7}\,x^7 + \ldots \qquad (x^2<1)$$

$$= \frac{\pi}{2} - \frac{1}{x} + \frac{1}{3x^3} - \frac{1}{5x^5} + \ldots \qquad (x^2>1)$$

$$\sinh x = \frac{1}{2}\,(e^x - e^{-x}) = x + \frac{x^3}{3!} + \frac{x^5}{5!} + \frac{x^7}{7\,!} + \ldots \qquad (x^2<\infty)$$

TABLE 6 (*continued*).

SERIES.

$$\cosh x = \frac{1}{2}(e^{x} + e^{-x}) = 1 + \frac{x^2}{2!} + \frac{x^4}{4!} + \frac{x^6}{6!} + \dots \qquad (x^2 < \infty)$$

$$\tanh x = x - \frac{1}{3}x^3 + \frac{2}{15}x^5 - \frac{17}{315}x^7 + \dots \qquad (x^2 < \tfrac{1}{4}\pi^2)$$

$$\sinh^{-1} x = x - \frac{1}{2}\frac{x^3}{3} + \frac{1}{2}\cdot\frac{3}{4}\cdot\frac{x^5}{5} - \frac{1}{2}\cdot\frac{3}{4}\cdot\frac{5}{6}\frac{x^7}{7} + \dots \qquad (x^2 < 1)$$

$$= \log 2x + \frac{1}{2}\frac{1}{2x^2} - \frac{1}{2}\frac{3}{4}\frac{1}{4x^4} + \frac{1}{2}\frac{3}{4}\frac{5}{6}\frac{1}{6x^6} - \dots \qquad (x^2 > 1)$$

$$\cosh^{-1} x = \log 2x - \frac{1}{2}\frac{1}{2x^2} - \frac{1}{2}\frac{3}{4}\frac{1}{4x^4} - \frac{1}{2}\frac{3}{4}\frac{5}{6}\frac{1}{6x^6} - \dots \qquad (x^2 > 1)$$

$$\tanh^{-1} x = x + \frac{1}{3}x^3 + \frac{1}{5}x^5 + \frac{1}{7}x^7 + \dots \qquad (x^2 < 1)$$

$$\mathrm{gd}\, x = \phi = x - \frac{1}{6}x^3 + \frac{1}{24}x^5 - \frac{61}{5040}x^7 + \dots \qquad (x \text{ small})$$

$$= \frac{\pi}{2} - \text{sech.}\, x - \frac{1}{2}\frac{\text{sech}^3 x}{3} - \frac{1}{2}\frac{3}{4}\frac{\text{sech}^5 x}{5} - \dots \qquad (x \text{ large})$$

$$x = \mathrm{gd}^{-1}\phi = \phi + \frac{1}{6}\phi^3 + \frac{1}{24}\phi^5 + \frac{61}{5040}\phi^7 + \dots \qquad \left(\phi < \frac{\pi}{2}\right)$$

$$f(x) = \frac{1}{2}b_0 + b_1 \cos\frac{\pi x}{c} + b_2 \cos\frac{2\pi x}{c} + \dots$$

$$+ a_1 \sin\frac{\pi x}{c} + a_2 \cos\frac{2\pi x}{c} + \dots \qquad (-c < x < c)$$

$$a_m = \frac{1}{c}\int_{-c}^{+c} f(x) \sin\frac{m\pi x}{c}\, dx$$

$$b_m = \frac{1}{c}\int_{-c}^{+c} f(x) \cos\frac{m\pi x}{c}\, dx$$

TABLE 7.—MATHEMATICAL CONSTANTS.

	Numbers.	Logarithms.
$e = 2.71828\ 18285$	$\pi = 3.14159\ 26536$	0.49714 98727
$e^{-1} = 0.36787\ 94412$	$\pi^2 = 9.86960\ 44011$	0.99429 97454
$M = \log_{10} e = 0.43429\ 44819$	$\frac{1}{\pi} = 0.31830\ 98862$	9.50285 01273
$(M)^{-1} = \log_e 10 = 2.30258\ 50930$	$\sqrt{\pi} = 1.77245\ 38509$	0.24857 49363
$\log_{10} \log_{10} e = 9.63778\ 43113$	$\frac{\sqrt{\pi}}{2} = 0.88622\ 69255$	9.94754 49407
$\log_{10} 2 = 0.30102\ 99957$	$\frac{1}{\sqrt{\pi}} = 0.56418\ 95835$	9.75142 50637
$\log_e 2 = 0.69314\ 71806$	$\frac{2}{\sqrt{\pi}} = 1.12837\ 91671$	0.05245 50593
$\log_{10} x = M.\log_e x$	$\sqrt{\frac{\pi}{2}} = 1.25331\ 41373$	0.09805 99385
$\log_B x = \log_e x.\ \log_B e$	$\sqrt{\frac{2}{\pi}} = 0.79788\ 45608$	9.90194 00615
$= \log_e x \div \log_e B$	$\frac{\pi}{4} = 0.78539\ 81634$	9.89508 98814
$\log_e \pi = 1.14472\ 98858$	$\frac{\sqrt{\pi}}{4} = 0.44311\ 34627$	9.64651 49450
$\rho = 0.47693\ 62762$	$\frac{4}{8}\pi = 4.18879\ 02048$	0.62208 86093
$\log \rho = 9.67846\ 03565$	$\frac{e}{\sqrt{2\pi}} = 1.08443\ 75514$	0.03520 45477

TABLE 8.

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$
10	100.000	100	1000	3.1623	**65**	15.3846	4225	274625	8.0623
11	90.9091	121	1331	3.3166	66	15.1515	4356	287496	8.1240
12	83.3333	144	1728	3.4641	67	14.9254	4489	300763	8.1854
13	76.9231	169	2197	3.6056	68	14.7059	4624	314432	8.2462
14	71.4286	196	2744	3.7417	69	14.4928	4761	328509	8.3066
15	66.6667	225	3375	3.8730	**70**	14.2857	4900	343000	8.3666
16	62.5000	256	4096	4.0000	71	14.0845	5041	357911	8.4261
17	58.8235	289	4913	4.1231	72	13.8889	5184	373248	8.4853
18	55.5556	324	5832	4.2426	73	13.6986	5329	389017	8.5440
19	52.6316	361	6859	4.3589	74	13.5135	5476	405224	8.6023
20	50.0000	400	8000	4.4721	**75**	13.3333	5625	421875	8.6603
21	47.6190	441	9261	4.5826	76	13.1579	5776	438976	8.7178
22	45.4545	484	10648	4.6904	77	12.9870	5929	456533	8.7750
23	43.4783	529	12167	4.7958	78	12.8205	6084	474552	8.8318
24	41.6667	576	13824	4.8990	79	12.6582	6241	493039	8.8882
25	40.0000	625	15625	5.0000	**80**	12.5000	6400	512000	8.9443
26	38.4615	676	17576	5.0990	81	12.3457	6561	531441	9.0000
27	37.0370	729	19683	5.1962	82	12.1951	6724	551368	9.0554
28	35.7143	784	21952	5.2915	83	12.0482	6889	571787	9.1104
29	34.4828	841	24389	5.3852	84	11.9048	7056	592704	9.1652
30	33.3333	900	27000	5.4772	**85**	11.7647	7225	614125	9.2195
31	32.2581	961	29791	5.5678	86	11.6279	7396	636056	9.2736
32	31.2500	1024	32768	5.6569	87	11.4943	7569	658503	9.3274
33	30.3030	1089	35937	5.7446	88	11.3636	7744	681472	9.3808
34	29.4118	1156	39304	5.8310	89	11.2360	7921	704969	9.4340
35	28.5714	1225	42875	5.9161	**90**	11.1111	8100	729000	9.4868
36	27.7778	1296	46656	6.0000	91	10.9890	8281	753571	9.5394
37	27.0270	1369	50653	6.0828	92	10.8696	8464	778688	9.5917
38	26.3158	1444	54872	6.1644	93	10.7527	8649	804357	9.6437
39	25.6410	1521	59319	6.2450	94	10.6383	8836	830584	9.6954
40	25.0000	1600	64000	6.3246	**95**	10.5263	9025	857375	9.7468
41	24.3902	1681	68921	6.4031	96	10.4167	9216	884736	9.7980
42	23.8095	1764	74088	6.4807	97	10.3093	9409	912673	9.8489
43	23.2558	1849	79507	6.5574	98	10.2041	9604	941192	9.8995
44	22.7273	1936	85184	6.6332	99	10.1010	9801	970299	9.9499
45	22.2222	2025	91125	6.7082	**100**	10.0000	10000	1000000	10.0000
46	21.7391	2116	97336	6.7823	101	9.90099	10201	1030301	10.0499
47	21.2766	2209	103823	6.8557	102	9.80392	10404	1061208	10.0995
48	20.8333	2304	110592	6.9282	103	9.70874	10609	1092727	10.1489
49	20.4082	2401	117649	7.0000	104	9.61538	10816	1124864	10.1980
50	20.0000	2500	125000	7.0711	**105**	9.52381	11025	1157625	10.2470
51	19.6078	2601	132651	7.1414	106	9.43396	11236	1191016	10.2956
52	19.2308	2704	140608	7.2111	107	9.34579	11449	1225043	10.3441
53	18.8679	2809	148877	7.2801	108	9.25926	11664	1259712	10.3923
54	18.5185	2916	157464	7.3485	109	9.17431	11881	1295029	10.4403
55	18.1818	3025	166375	7.4162	**110**	9.09091	12100	1331000	10.4881
56	17.8571	3136	175616	7.4833	111	9.00901	12321	1367631	10.5357
57	17.5439	3249	185193	7.5498	112	8.92857	12544	1404928	10.5830
58	17.2414	3364	195112	7.6158	113	8.84956	12769	1442897	10.6301
59	16.9492	3481	205379	7.6811	114	8.77193	12996	1481544	10.6771
60	16.6667	3600	216000	7.7460	**115**	8.69565	13225	1520875	10.7238
61	16.3934	3721	226981	7.8102	116	8.62069	13456	1560896	10.7703
62	16.1290	3844	238328	7.8740	117	8.54701	13689	1601613	10.8167
63	15.8730	3969	250047	7.9373	118	8.47458	13924	1643032	10.8628
64	15.6250	4096	262144	8.0000	119	8.40336	14161	1685159	10.9087

TABLE 8 *(continued)*.

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$
120	8.33333	14400	1728000	10.9545	**175**	5.71429	30625	5359375	13.2288
121	8.26446	14641	1771561	11.0000	176	5.68182	30976	5451776	13.2665
122	8.19672	14884	1815848	11.0454	177	5.64972	31329	5545233	13.3041
123	8.13008	15129	1860867	11.0905	178	5.61798	31684	5639752	13.3417
124	8.06452	15376	1906624	11.1355	179	5.58659	32041	5735339	13.3791
125	8.00000	15625	1953125	11.1803	**180**	5.55556	32400	5832000	13.4164
126	7.93651	15876	2000376	11.2250	181	5.52486	32761	5929741	13.4536
127	7.87402	16129	2048383	11.2694	182	5.49451	33124	6028568	13.4907
128	7.81250	16384	2097152	11.3137	183	5.46448	33489	6128487	13.5277
129	7.75194	16641	2146689	11.3578	184	5.43478	33856	6229504	13.5647
130	7.69231	16900	2197000	11.4018	**185**	5.40541	34225	6331625	13.6015
131	7.63359	17161	2248091	11.4455	186	5.37634	34596	6434856	13.6382
132	7.57576	17424	2299968	11.4891	187	5.34759	34969	6539203	13.6748
133	7.51880	17689	2352637	11.5326	188	5.31915	35344	6644672	13.7113
134	7.46269	17956	2406104	11.5758	189	5.29101	35721	6751269	13.7477
135	7.40741	18225	2460375	11.6190	**190**	5.26316	36100	6859000	13.7840
136	7.35294	18496	2515456	11.6619	191	5.23560	36481	6967871	13.8203
137	7.29927	18769	2571353	11.7047	192	5.20833	36864	7077888	13.8564
138	7.24638	19044	2628072	11.7473	193	5.18135	37249	7189057	13.8924
139	7.19424	19321	2685619	11.7898	194	5.15464	37636	7301384	13.9284
140	7.14286	19600	2744000	11.8322	**195**	5.12821	38025	7414875	13.9642
141	7.09220	19881	2803221	11.8743	196	5.10204	38416	7529536	14.0000
142	7.04225	20164	2863288	11.9164	197	5.07614	38809	7645373	14.0357
143	6.99301	20449	2924207	11.9583	198	5.05051	39204	7762392	14.0712
144	6.94444	20736	2985984	12.0000	199	5.02513	39601	7880599	14.1067
145	6.89655	21025	3048625	12.0416	**200**	5.00000	40000	8000000	14.1421
146	6.84932	21316	3112136	12.0830	201	4.97512	40401	8120601	14.1774
147	6.80272	21609	3176523	12.1244	202	4.95050	40804	8242408	14.2127
148	6.75676	21904	3241792	12.1655	203	4.92611	41209	8365427	14.2478
149	6.71141	22201	3307949	12.2066	204	4.90196	41616	8489664	14.2829
150	6.66667	22500	3375000	12.2474	**205**	4.87805	42025	8615125	14.3178
151	6.62252	22801	3442951	12.2882	206	4.85437	42436	8741816	14.3527
152	6.57895	23104	3511808	12.3288	207	4.83092	42849	8869743	14.3875
153	6.53595	23409	3581577	12.3693	208	4.80769	43264	8998912	14.4222
154	6.49351	23716	3652264	12.4097	209	4.78469	43681	9129329	14.4568
155	6.45161	24025	3723875	12.4499	**210**	4.76190	44100	9261000	14.4914
156	6.41026	24336	3796416	12.4900	211	4.73934	44521	9393931	14.5258
157	6.36943	24649	3869893	12.5300	212	4.71698	44944	9528128	14.5602
158	6.32911	24964	3944312	12.5698	213	4.69484	45369	9663597	14.5945
159	6.28931	25281	4019679	12.6095	214	4.67290	45796	9800344	14.6287
160	6.25000	25600	4096000	12.6491	**215**	4.65116	46225	9938375	14.6629
161	6.21118	25921	4173281	12.6886	216	4.62963	46656	10077696	14.6969
162	6.17284	26244	4251528	12.7279	217	4.60829	47089	10218313	14.7309
163	6.13497	26569	4330747	12.7671	218	4.58716	47524	10360232	14.7648
164	6.09756	26896	4410944	12.8062	219	4.56621	47961	10503459	14.7986
165	6.06061	27225	4492125	12.8452	**220**	4.54545	48400	10648000	14.8324
166	6.02410	27556	4574296	12.8841	221	4.52489	48841	10793861	14.8661
167	5.98802	27889	4657463	12.9228	222	4.50450	49284	10941048	14.8997
168	5.95238	28224	4741632	12.9615	223	4.48430	49729	11089567	14.9332
169	5.91716	28561	4826809	13.0000	224	4.46429	50176	11239424	14.9666
170	5.88235	28900	4913000	13.0384	**225**	4.44444	50625	11390625	15.0000
171	5.84795	29241	5000211	13.0767	226	4.42478	51076	11543176	15.0333
172	5.81395	29584	5088448	13.1149	227	4.40529	51529	11697083	15.0665
173	5.78035	29929	5177717	13.1529	228	4.38596	51984	11852352	15.0997
174	5.74713	30276	5268024	13.1909	229	4.36681	52441	12008989	15.1327

TABLE 8 (*continued*).

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS, OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$
230	4.34783	52900	12167000	15.1658	**285**	3.50877	81225	23149125	16.8819
231	4.32900	53361	12326391	15.1987	286	3.49650	81796	23393656	16.9115
232	4.31034	53824	12487168	15.2315	287	3.48432	82369	23639903	16.9411
233	4.29185	54289	12649337	15.2643	288	3.47222	82944	23887872	16.9706
234	4.27350	54756	12812904	15.2971	289	3.46021	83521	24137569	17.0000
235	4.25532	55225	12977875	15.3297	**290**	3.44828	84100	24389000	17.0294
236	4.23729	55696	13144256	15.3623	291	3.43643	84681	24642171	17.0587
237	4.21941	56169	13312053	15.3948	292	3.42466	85264	24897088	17.0880
238	4.20168	56644	13481272	15.4272	293	3.41297	85849	25153757	17.1172
239	4.18410	57121	13651919	15.4596	294	3.40136	86436	25412184	17.1464
240	4.16667	57600	13824000	15.4919	**295**	3.38983	87025	25672375	17.1756
241	4.14938	58081	13997521	15.5242	296	3.37838	87616	25934336	17.2047
242	4.13223	58564	14172488	15.5563	297	3.36700	88209	26198073	17.2337
243	4.11523	59049	14348907	15.5885	298	3.35570	88804	26463592	17.2627
244	4.09836	59536	14526784	15.6205	299	3.34448	89401	26730899	17.2916
245	4.08163	60025	14706125	15.6525	**300**	3.33333	90000	27000000	17.3205
246	4.06504	60516	14886936	15.6844	301	3.32226	90601	27270901	17.3494
247	4.04858	61009	15069223	15.7162	302	3.31126	91204	27543608	17.3781
248	4.03226	61504	15252992	15.7480	303	3.30033	91809	27818127	17.4069
249	4.01606	62001	15438249	15.7797	304	3.28947	92416	28094464	17.4356
250	4.00000	62500	15625000	15.8114	**305**	3.27869	93025	28372625	17.4642
251	3.98406	63001	15813251	15.8430	306	3.26797	93636	28652616	17.4929
252	3.96825	63504	16003008	15.8745	307	3.25733	94249	28934443	17.5214
253	3.95257	64009	16194277	15.9060	308	3.24675	94864	29218112	17.5499
254	3.93701	64516	16387064	15.9374	309	3.23625	95481	29503629	17.5784
255	3.92157	65025	16581375	15.9687	**310**	3.22581	96100	29791000	17.6068
256	3.90625	65536	16777216	16.0000	311	3.21543	96721	30080231	17.6352
257	3.89105	66049	16974593	16.0312	312	3.20513	97344	30371328	17.6635
258	3.87597	66564	17173512	16.0624	313	3.19489	97969	30664297	17.6918
259	3.86100	67081	17373979	16.0935	314	3.18471	98596	30959144	17.7200
260	3.84615	67600	17576000	16.1245	**315**	3.17460	99225	31255875	17.7482
261	3.83142	68121	17779581	16.1555	316	3.16456	99856	31554496	17.7764
262	3.81679	68644	17984728	16.1864	317	3.15457	100489	31855013	17.8045
263	3.80228	69169	18191447	16.2173	318	3.14465	101124	32157432	17.8326
264	3.78788	69696	18399744	16.2481	319	3.13480	101761	32461759	17.8606
265	3.77358	70225	18609625	16.2788	**320**	3.12500	102400	32768000	17.8885
266	3.75940	70756	18821096	16.3095	321	3.11526	103041	33076161	17.9165
267	3.74532	71289	19034163	16.3401	322	3.10559	103684	33386248	17.9444
268	3.73134	71824	19248832	16.3707	323	3.09598	104329	33698267	17.9722
269	3.71747	72361	19465109	16.4012	324	3.08642	104976	34012224	18.0000
270	3.70370	72900	19683000	16.4317	**325**	3.07692	105625	34328125	18.0278
271	3.69004	73441	19902511	16.4621	326	3.06748	106276	34645976	18.0555
272	3.67647	73984	20123648	16.4924	327	3.05810	106929	34965783	18.0831
273	3.66300	74529	20346417	16.5227	328	3.04878	107584	35287552	18.1108
274	3.64964	75076	20570824	16.5529	329	3.03951	108241	35611289	18.1384
275	3.63636	75625	20796875	16.5831	**330**	3.03030	108900	35937000	18.1659
276	3.62319	76176	21024576	16.6132	331	3.02115	109561	36264691	18.1934
277	3.61011	76729	21253933	16.6433	332	3.01205	110224	36594368	18.2209
278	3.59712	77284	21484952	16.6733	333	3.00300	110889	36926037	18.2483
279	3.58423	77841	21717639	16.7033	334	2.99401	111556	37259704	18.2757
280	3.57143	78400	21952000	16.7332	**335**	2.98507	112225	37595375	18.3030
281	3.55872	78961	22188041	16.7631	336	2.97619	112896	37933056	18.3303
282	3.54610	79524	22425768	16.7929	337	2.96736	113569	38272753	18.3576
283	3.53357	80089	22665187	16.8226	338	2.95858	114244	38614472	18.3848
284	3.52113	80656	22906304	16.8523	339	2.94985	114921	38958219	18.4120

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$
340	2.94118	115600	39304000	18.4391	**395**	2.53165	156025	61629875	19.8746
341	2.93255	116281	39651821	18.4662	396	2.52525	156816	62099136	19.8997
342	2.92398	116964	40001688	18.4932	397	2.51889	157609	62570773	19.9249
343	2.91545	117649	40353607	18.5203	398	2.51256	158404	63044792	19.9499
344	2.90698	118336	40707584	18.5472	399	2.50627	159201	63521199	19.9750
345	2.89855	119025	41063625	18.5742	**400**	2.50000	160000	64000000	20.0000
346	2.89017	119716	41421736	18.6011	401	2.49377	160801	64481201	20.0250
347	2.88184	120409	41781923	18.6279	402	2.48756	161604	64964808	20.0499
348	2.87356	121104	42144192	18.6548	403	2.48139	162409	65450827	20.0749
349	2.86533	121801	42508549	18.6815	404	2.47525	163216	65939264	20.0998
350	2.85714	122500	42875000	18.7083	**405**	2.46914	164025	66430125	20.1246
351	2.84900	123201	43243551	18.7350	406	2.46305	164836	66923416	20.1494
352	2.84091	123904	43614208	18.7617	407	2.45700	165649	67419143	20.1742
353	2.83286	124609	43986977	18.7883	408	2.45098	166464	67917312	20.1990
354	2.82486	125316	44361864	18.8149	409	2.44499	167281	68417929	20.2237
355	2.81690	126025	44738875	18.8414	**410**	2.43902	168100	68921000	20.2485
356	2.80899	126736	45118016	18.8680	411	2.43309	168921	69426531	20.2731
357	2.80112	127449	45499293	18.8944	412	2.42718	169744	69934528	20.2978
358	2.79330	128164	45882712	18.9209	413	2.42131	170569	70444997	20.3224
359	2.78552	128881	46268279	18.9473	414	2.41546	171396	70957944	20.3470
360	2.77778	129600	46656000	18.9737	**415**	2.40964	172225	71473375	20.3715
361	2.77008	130321	47045881	19.0000	416	2.40385	173056	71991296	20.3961
362	2.76243	131044	47437928	19.0263	417	2.39808	173889	72511713	20.4206
363	2.75482	131769	47832147	19.0526	418	2.39234	174724	73034632	20.4450
364	2.74725	132496	48228544	19.0788	419	2.38663	175561	73560059	20.4695
365	2.73973	133225	48627125	19.1050	**420**	2.38095	176400	74088000	20.4939
366	2.73224	133956	49027896	19.1311	421	2.37530	177241	74618461	20.5183
367	2.72480	134689	49430863	19.1572	422	2.36967	178084	75151448	20.5426
368	2.71739	135424	49836032	19.1833	423	2.36407	178929	75686967	20.5670
369	2.71003	136161	50243409	19.2094	424	2.35849	179776	76225024	20.5913
370	2.70270	136900	50653000	19.2354	**425**	2.35294	180625	76765625	20.6155
371	2.69542	137641	51064811	19.2614	426	2.34742	181476	77308776	20.6398
372	2.68817	138384	51478848	19.2873	427	2.34192	182329	77854483	20.6640
373	2.68097	139129	51895117	19.3132	428	2.33645	183184	78402752	20.6882
374	2.67380	139876	52313624	19.3391	429	2.33100	184041	78953589	20.7123
375	2.66667	140625	52734375	19.3649	**430**	2.32558	184900	79507000	20.7364
376	2.65957	141376	53157376	19.3907	431	2.32019	185761	80062991	20.7605
377	2.65252	142129	53582633	19.4165	432	2.31481	186624	80621568	20.7846
378	2.64550	142884	54010152	19.4422	433	2.30947	187489	81182737	20.8087
379	2.63852	143641	54439939	19.4679	434	2.30415	188356	81746504	20.8327
380	2.63158	144400	54872000	19.4936	**435**	2.29885	189225	82312875	20.8567
381	2.62467	145161	55306341	19.5192	436	2.29358	190096	82881856	20.8806
382	2.61780	145924	55742968	19.5448	437	2.28833	190969	83453453	20.9045
383	2.61097	146689	56181887	19.5704	438	2.28311	191844	84027672	20.9284
384	2.60417	147456	56623104	19.5959	439	2.27790	192721	84604519	20.9523
385	2.59740	148225	57066625	19.6214	**440**	2.27273	193600	85184000	20.9762
386	2.59067	148996	57512456	19.6469	441	2.26757	194481	85766121	21.0000
387	2.58398	149769	57960603	19.6723	442	2.26244	195364	86350888	21.0238
388	2.57732	150544	58411072	19.6977	443	2.25734	196249	86938307	21.0476
389	2.57069	151321	58863869	19.7231	444	2.25225	197136	87528384	21.0713
390	2.56410	152100	59319000	19.7484	**445**	2.24719	198025	88121125	21.0950
391	2.55754	152881	59776471	19.7737	446	2.24215	198916	88716536	21.1187
392	2.55102	153664	60236288	19.7990	447	2.23714	199809	89314623	21.1424
393	2.54453	154449	60698457	19.8242	448	2.23214	200704	89915392	21.1660
394	2.53807	155236	61162984	19.8494	449	2.22717	201601	90518849	21.1896

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS.

n	$1000 \cdot \frac{1}{n}$	n^2	n^3	$\sqrt{n}$	n	$1000 \cdot \frac{1}{n}$	n^2	n^3	$\sqrt{n}$
450	2.22222	202500	91125000	21.2132	**505**	1.98020	255025	128787625	22.4722
451	2.21729	203401	91733851	21.2368	506	1.97628	256036	129554216	22.4944
452	2.21239	204304	92345408	21.2603	507	1.97239	257049	130323843	22.5167
453	2.20751	205209	92959677	21.2838	508	1.96850	258064	131096512	22.5389
454	2.20264	206116	93576664	21.3073	509	1.96464	259081	131872229	22.5610
455	2.19780	207025	94196375	21.3307	**510**	1.96078	260100	132651000	22.5832
456	2.19298	207936	94818816	21.3542	511	1.95695	261121	133432831	22.6053
457	2.18818	208849	95443993	21.3776	512	1.95312	262144	134217728	22.6274
458	2.18341	209764	96071912	21.4009	513	1.94932	263169	135005697	22.6495
459	2.17865	210681	96702579	21.4243	514	1.94553	264196	135796744	22.6716
460	2.17391	211600	97336000	21.4476	**515**	1.94175	265225	136590875	22.6936
461	2.16920	212521	97972181	21.4709	516	1.93798	266256	137388096	22.7156
462	2.16450	213444	98611128	21.4942	517	1.93424	267289	138188413	22.7376
463	2.15983	214369	99252847	21.5174	518	1.93050	268324	138991832	22.7596
464	2.15517	215296	99897344	21.5407	519	1.92678	269361	139798359	22.7816
465	2.15054	216225	100544625	21.5639	**520**	1.92308	270400	140608000	22.8035
466	2.14592	217156	101194696	21.5870	521	1.91939	271441	141420761	22.8254
467	2.14133	218089	101847563	21.6102	522	1.91571	272484	142236648	22.8473
468	2.13675	219024	102503232	21.6333	523	1.91205	273529	143055667	22.8692
469	2.13220	219961	103161709	21.6564	524	1.90840	274576	143877824	22.8910
470	2.12766	220900	103823000	21.6795	**525**	1.90476	275625	144703125	22.9129
471	2.12314	221841	104487111	21.7025	526	1.90114	276676	145531576	22.9347
472	2.11864	222784	105154048	21.7256	527	1.89753	277729	146363183	22.9565
473	2.11416	223729	105823817	21.7486	528	1.89394	278784	147197952	22.9783
474	2.10970	224676	106496424	21.7715	529	1.89036	279841	148035889	23.0000
475	2.10526	225625	107171875	21.7945	**530**	1.88679	280900	148877000	23.0217
476	2.10084	226576	107850176	21.8174	531	1.88324	281961	149721291	23.0434
477	2.09644	227529	108531333	21.8403	532	1.87970	283024	150568768	23.0651
478	2.09205	228484	109215352	21.8632	533	1.87617	284089	151419437	23.0868
479	2.08768	229441	109902239	21.8861	534	1.87266	285156	152273304	23.1084
480	2.08333	230400	110592000	21.9089	**535**	1.86916	286225	153130375	23.1301
481	2.07900	231361	111284641	21.9317	536	1.86567	287296	153990656	23.1517
482	2.07469	232324	111980168	21.9545	537	1.86220	288369	154854153	23.1733
483	2.07039	233289	112678587	21.9773	538	1.85874	289444	155720872	23.1948
484	2.06612	234256	113379904	22.0000	539	1.85529	290521	156590819	23.2164
485	2.06186	235225	114084125	22.0227	**540**	1.85185	291600	157464000	23.2379
486	2.05761	236196	114791256	22.0454	541	1.84843	292681	158340421	23.2594
487	2.05339	237169	115501303	22.0681	542	1.84502	293764	159220088	23.2809
488	2.04918	238144	116214272	22.0907	543	1.84162	294849	160103007	23.3024
489	2.04499	239121	116930169	22.1133	544	1.83824	295936	160989184	23.3238
490	2.04082	240100	117649000	22.1359	**545**	1.83486	297025	161878625	23.3452
491	2.03666	241081	118370771	22.1585	546	1.83150	298116	162771336	23.3666
492	2.03252	242064	119095488	22.1811	547	1.82815	299209	163667323	23.3880
493	2.02840	243049	119823157	22.2036	548	1.82482	300304	164566592	23.4094
494	2.02429	244036	120553784	22.2261	549	1.82149	301401	165469149	23.4307
495	2.02020	245025	121287375	22.2486	**550**	1.81818	302500	166375000	23.4521
496	2.01613	246016	122023936	22.2711	551	1.81488	303601	167284151	23.4734
497	2.01207	247009	122763473	22.2935	552	1.81159	304704	168196608	23.4947
498	2.00803	248004	123505992	22.3159	553	1.80832	305809	169112377	23.5160
499	2.00401	249001	124251499	22.3383	554	1.80505	306916	170031464	23.5372
500	2.00000	250000	125000000	22.3607	**555**	1.80180	308025	170953875	23.5584
501	1.99601	251001	125751501	22.3830	556	1.79856	309136	171879616	23.5797
502	1.99203	252004	126506008	22.4054	557	1.79533	310249	172808693	23.6008
503	1.98807	253009	127263527	22.4277	558	1.79211	311364	173741112	23.6220
504	1.98413	254016	128024064	22.4499	559	1.78891	312481	174676879	23.6432

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS.

n	1000.$\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	n	1000.$\frac{1}{n}$	n^2	n^3	$\sqrt{n}$
560	1.78571	313600	175616000	23.6643	**615**	1.62602	378225	232608375	24.7992
561	1.78253	314721	176558481	23.6854	616	1.62338	379456	233744896	24.8193
562	1.77936	315844	177504328	23.7065	617	1.62075	380689	234885113	24.8395
563	1.77620	316969	178453547	23.7276	618	1.61812	381924	236029032	24.8596
564	1.77305	318096	179406144	23.7487	619	1.61551	383161	237176659	24.8797
565	1.76991	319225	180362125	23.7697	**620**	1.61290	384400	238328000	24.8998
566	1.76678	320356	181321496	23.7908	621	1.61031	385641	239483061	24.9199
567	1.76367	321489	182284263	23.8118	622	1.60772	386884	240641848	24.9399
568	1.76056	322624	183250432	23.8328	623	1.60514	388129	241804367	24.9600
569	1.75747	323761	184220009	23.8537	624	1.60256	389376	242970624	24.9800
570	1.75439	324900	185193000	23.8747	**625**	1.60000	390625	244140625	25.0000
571	1.75131	326041	186169411	23.8956	626	1.59744	391876	245314376	25.0200
572	1.74825	327184	187149248	23.9165	627	1.59490	393129	246491883	25.0400
573	1.74520	328329	188132517	23.9374	628	1.59236	394384	247673152	25.0599
574	1.74216	329476	189119224	23.9583	629	1.58983	395641	248858189	25.0799
575	1.73913	330625	190109375	23.9792	**630**	1.58730	396900	250047000	25.0998
576	1.73611	331776	191102976	24.0000	631	1.58479	398161	251239591	25.1197
577	1.73310	332929	192100033	24.0208	632	1.58228	399424	252435968	25.1396
578	1.73010	334084	193100552	24.0416	633	1.57978	400689	253636137	25.1595
579	1.72712	335241	194104539	24.0624	634	1.57729	401956	254840104	25.1794
580	1.72414	336400	195112000	24.0832	**635**	1.57480	403225	256047875	25.1992
581	1.72117	337561	196122941	24.1039	636	1.57233	404496	257259456	25.2190
582	1.71821	338724	197137368	24.1247	637	1.56986	405769	258474853	25.2389
583	1.71527	339889	198155287	24.1454	638	1.56740	407044	259694072	25.2587
584	1.71233	341056	199176704	24.1661	639	1.56495	408321	260917119	25.2784
585	1.70940	342225	200201625	24.1868	**640**	1.56250	409600	262144000	25.2982
586	1.70648	343396	201230056	24.2074	641	1.56006	410881	263374721	25.3180
587	1.70358	344569	202262003	24.2281	642	1.55763	412164	264609288	25.3377
588	1.70068	345744	203297472	24.2487	643	1.55521	413449	265847707	25.3574
589	1.69779	346921	204336469	24.2693	644	1.55280	414736	267089984	25.3772
590	1.69492	348100	205379000	24.2899	**645**	1.55039	416025	268336125	25.3969
591	1.69205	349281	206425071	24.3105	646	1.54799	417316	269586136	25.4165
592	1.68919	350464	207474688	24.3311	647	1.54560	418609	270840023	25.4362
593	1.68634	351649	208527857	24.3516	648	1.54321	419904	272097792	25.4558
594	1.68350	352836	209584584	24.3721	649	1.54083	421201	273359449	25.4755
595	1.68067	354025	210644875	24.3926	**650**	1.53846	422500	274625000	25.4951
596	1.67785	355216	211708736	24.4131	651	1.53610	423801	275894451	25.5147
597	1.67504	356409	212776173	24.4336	652	1.53374	425104	277167808	25.5343
598	1.67224	357604	213847192	24.4540	653	1.53139	426409	278445077	25.5539
599	1.66945	358801	214921799	24.4745	654	1.52905	427716	279726264	25.5734
600	1.66667	360000	216000000	24.4949	**655**	1.52672	429025	281011375	25.5930
601	1.66389	361201	217081801	24.5153	656	1.52439	430336	282300416	25.6125
602	1.66113	362404	218167208	24.5357	657	1.52207	431649	283593393	25.6320
603	1.65837	363609	219256227	24.5561	658	1.51976	432964	284890312	25.6515
604	1.65563	364816	220348864	24.5764	659	1.51745	434281	286191179	25.6710
605	1.65289	366025	221445125	24.5967	**660**	1.51515	435600	287496000	25.6905
606	1.65017	367236	222545016	24.6171	661	1.51286	436921	288804781	25.7099
607	1.64745	368449	223648543	24.6374	662	1.51057	438244	290117528	25.7294
608	1.64474	369664	224755712	24.6577	663	1.50830	439569	291434247	25.7488
609	1.64204	370881	225866529	24.6779	664	1.50602	440896	292754944	25.7682
610	1.63934	372100	226981000	24.6982	**665**	1.50376	442225	294079625	25.7876
611	1.63666	373321	228099131	24.7184	666	1.50150	443556	295408296	25.8070
612	1.63399	374544	229220928	24.7386	667	1.49925	444889	296740963	25.8263
613	1.63132	375769	230346397	24.7588	668	1.49701	446224	298077632	25.8457
614	1.62866	376996	231475544	24.7790	669	1.49477	447561	299418309	25.8650

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$
670	1.49254	448900	300763000	25.8844	**725**	1.37931	525625	381078125	26.9258
671	1.49031	450241	302111711	25.9037	726	1.37741	527076	382657176	26.9444
672	1.48810	451584	303464448	25.9230	727	1.37552	528529	384240583	26.9629
673	1.48588	452929	304821217	25.9422	728	1.37363	529984	385828352	26.9815
674	1.48368	454276	306182024	25.9615	729	1.37174	531441	387420489	27.0000
675	1.48148	455625	307546875	25.9808	**730**	1.36986	532900	389017000	27.0185
676	1.47929	456976	308915776	26.0000	731	1.36799	534361	390617891	27.0370
677	1.47710	458329	310288733	26.0192	732	1.36612	535824	392223168	27.0555
678	1.47493	459684	311665752	26.0384	733	1.36426	537289	393832837	27.0740
679	1.47275	461041	313046839	26.0576	734	1.36240	538756	395446904	27.0924
680	1.47059	462400	314432000	26.0768	**735**	1.36054	540225	397065375	27.1109
681	1.46843	463761	315821241	26.0960	736	1.35870	541696	398688256	27.1293
682	1.46628	465124	317214568	26.1151	737	1.35685	543169	400315553	27.1477
683	1.46413	466489	318611987	26.1343	738	1.35501	544644	401947272	27.1662
684	1.46199	467856	320013504	26.1534	739	1.35318	546121	403583419	27.1846
685	1.45985	469225	321419125	26.1725	**740**	1.35135	547600	405224000	27.2029
686	1.45773	470596	322828856	26.1916	741	1.34953	549081	406869021	27.2213
687	1.45560	471969	324242703	26.2107	742	1.34771	550564	408518488	27.2397
688	1.45349	473344	325660672	26.2298	743	1.34590	552049	410172407	27.2580
689	1.45138	474721	327082769	26.2488	744	1.34409	553536	411830784	27.2764
690	1.44928	476100	328509000	26.2679	**745**	1.34228	555025	413493625	27.2947
691	1.44718	477481	329939371	26.2869	746	1.34048	556516	415160936	27.3130
692	1.44509	478864	331373888	26.3059	747	1.33869	558009	416832723	27.3313
693	1.44300	480249	332812557	26.3249	748	1.33690	559504	418508992	27.3496
694	1.44092	481636	334255384	26.3439	749	1.33511	561001	420189749	27.3679
695	1.43885	483025	335702375	26.3629	**750**	1.33333	562500	421875000	27.3861
696	1.43678	484416	337153536	26.3818	751	1.33156	564001	423564751	27.4044
697	1.43472	485809	338608873	26.4008	752	1.32979	565504	425259008	27.4226
698	1.43266	487204	340068392	26.4197	753	1.32802	567009	426957777	27.4408
699	1.43062	488601	341532099	26.4386	754	1.32626	568516	428661064	27.4591
700	1.42857	490000	343000000	26.4575	**755**	1.32450	570025	430368875	27.4773
701	1.42653	491401	344472101	26.4764	756	1.32275	571536	432081216	27.4955
702	1.42450	492804	345948408	26.4953	757	1.32100	573049	433798093	27.5136
703	1.42248	494209	347428927	26.5141	758	1.31926	574564	435519512	27.5318
704	1.42045	495616	348913664	26.5330	759	1.31752	576081	437245479	27.5500
705	1.41844	497025	350402625	26.5518	**760**	1.31579	577600	438976000	27.5681
706	1.41643	498436	351895816	26.5707	761	1.31406	579121	440711081	27.5862
707	1.41443	499849	353393243	26.5895	762	1.31234	580644	442450728	27.6043
708	1.41243	501264	354894912	26.6083	763	1.31062	582169	444194947	27.6225
709	1.41044	502681	356400829	26.6271	764	1.30890	583696	445943744	27.6405
710	1.40845	504100	357911000	26.6458	**765**	1.30719	585225	447697125	27.6586
711	1.40647	505521	359425431	26.6646	766	1.30548	586756	449455096	27.6767
712	1.40449	506944	360944128	26.6833	767	1.30378	588289	451217663	27.6948
713	1.40252	508369	362467097	26.7021	768	1.30208	589824	452984832	27.7128
714	1.40056	509796	363994344	26.7208	769	1.30039	591361	454756609	27.7308
715	1.39860	511225	365525875	26.7395	**770**	1.29870	592900	456533000	27.7489
716	1.39665	512656	367061696	26.7582	771	1.29702	594441	458314011	27.7669
717	1.39470	514089	368601813	26.7769	772	1.29534	595984	460099648	27.7849
718	1.39276	515524	370146232	26.7955	773	1.29366	597529	461889917	27.8029
719	1.39082	516961	371694959	26.8142	774	1.29199	599076	463684824	27.8209
720	1.38889	518400	373248000	26.8328	**775**	1.29032	600625	465484375	27.8388
721	1.38696	519841	374805361	26.8514	776	1.28866	602176	467288576	27.8568
722	1.38504	521284	376367048	26.8701	777	1.28700	603729	469097433	27.8747
723	1.38313	522729	377933067	26.8887	778	1.28535	605284	470910952	27.8927
724	1.38122	524176	379503424	26.9072	779	1.28370	606841	472729139	27.9106

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$
780	1.28205	608400	474552000	27.9285	**835**	1.19760	697225	582182875	28.8964
781	1.28041	609961	476379541	27.9464	836	1.19617	698896	584277056	28.9137
782	1.27877	611524	478211768	27.9643	837	1.19474	700569	586376253	28.9310
783	1.27714	613089	480048687	27.9821	838	1.19332	702244	588480472	28.9482
784	1.27551	614656	481890304	28.0000	839	1.19190	703921	590589719	28.9655
785	1.27389	616225	483736625	28.0179	**840**	1.19048	705600	592704000	28.9828
786	1.27226	617796	485587656	28.0357	841	1.18906	707281	594823321	29.0000
787	1.27065	619369	487443403	28.0535	842	1.18765	708964	596947688	29.0172
788	1.26904	620944	489303872	28.0713	843	1.18624	710649	599077107	29.0345
789	1.26743	622521	491169069	28.0891	844	1.18483	712336	601211584	29.0517
790	1.26582	624100	493039000	28.1069	**845**	1.18343	714025	603351125	29.0689
791	1.26422	625681	494913671	28.1247	846	1.18203	715716	605495736	29.0861
792	1.26263	627264	496793088	28.1425	847	1.18064	717409	607645423	29.1033
793	1.26103	628849	498677257	28.1603	848	1.17925	719104	609800192	29.1204
794	1.25945	630436	500566184	28.1780	849	1.17786	720801	611960049	29.1376
795	1.25786	632025	502459875	28.1957	**850**	1.17647	722500	614125000	29.1548
796	1.25628	633616	504358336	28.2135	851	1.17509	724201	616295051	29.1719
797	1.25471	635209	506261573	28.2312	852	1.17371	725904	618470208	29.1890
798	1.25313	636804	508169592	28.2489	853	1.17233	727609	620650477	29.2062
799	1.25156	638401	510082399	28.2666	854	1.17096	729316	622835864	29.2233
800	1.25000	640000	512000000	28.2843	**855**	1.16959	731025	625026375	29.2404
801	1.24844	641601	513922401	28.3019	856	1.16822	732736	627222016	29.2575
802	1.24688	643204	515849608	28.3196	857	1.16686	734449	629422793	29.2746
803	1.24533	644809	517781627	28.3373	858	1.16550	736164	631628712	29.2916
804	1.24378	646416	519718464	28.3549	859	1.16414	737881	633839779	29.3087
805	1.24224	648025	521660125	28.3725	**860**	1.16279	739600	636056000	29.3258
806	1.24069	649636	523606616	28.3901	861	1.16144	741321	638277381	29.3428
807	1.23916	651249	525557943	28.4077	862	1.16009	743044	640503928	29.3598
808	1.23762	652864	527514112	28.4253	863	1.15875	744769	642735647	29.3769
809	1.23609	654481	529475129	28.4429	864	1.15741	746496	644972544	29.3939
810	1.23457	656100	531441000	28.4605	**865**	1.15607	748225	647214625	29.4109
811	1.23305	657721	533411731	28.4781	866	1.15473	749956	649461896	29.4279
812	1.23153	659344	535387328	28.4956	867	1.15340	751689	651714363	29.4449
813	1.23001	660969	537367797	28.5132	868	1.15207	753424	653972032	29.4618
814	1.22850	662596	539353144	28.5307	869	1.15075	755161	656234909	29.4788
815	1.22699	664225	541343375	28.5482	**870**	1.14943	756900	658503000	29.4958
816	1.22549	665856	543338496	28.5657	871	1.14811	758641	660776311	29.5127
817	1.22399	667489	545338513	28.5832	872	1.14679	760384	663054848	29.5296
818	1.22249	669124	547343432	28.6007	873	1.14548	762129	665338617	29.5466
819	1.22100	670761	549353259	28.6182	874	1.14416	763876	667627624	29.5635
820	1.21951	672400	551368000	28.6356	**875**	1.14286	765625	669921875	29.5804
821	1.21803	674041	553387661	28.6531	876	1.14155	767376	672221376	29.5973
822	1.21655	675684	555412248	28.6705	877	1.14025	769129	674526133	29.6142
823	1.21507	677329	557441767	28.6880	878	1.13895	770884	676836152	29.6311
824	1.21359	678976	559476224	28.7054	879	1.13766	772641	679151439	29.6479
825	1.21212	680625	561515625	28.7228	**880**	1.13636	774400	681472000	29.6648
826	1.21065	682276	563559976	28.7402	881	1.13507	776161	683797841	29.6816
827	1.20919	683929	565609283	28.7576	882	1.13379	777924	686128968	29.6985
828	1.20773	685584	567663552	28.7750	883	1.13250	779689	688465387	29.7153
829	1.20627	687241	569722789	28.7924	884	1.13122	781456	690807104	29.7321
830	1.20482	688900	571787000	28.8097	**885**	1.12994	783225	693154125	29.7489
831	1.20337	690561	573856191	28.8271	886	1.12867	784996	695506456	29.7658
832	1.20192	692224	575930368	28.8444	887	1.12740	786769	697864103	29.7825
833	1.20048	693889	578009537	28.8617	888	1.12613	788544	700227072	29.7993
834	1.19904	695556	580093704	28.8791	889	1.12486	790321	702595369	29.8161

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS.

n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	n	$1000.\frac{1}{n}$	n^2	n^3	$\sqrt{n}$
890	1.12360	792100	704969000	29.8329	**945**	1.05820	893025	843908625	30.7409
891	1.12233	793881	707347971	29.8496	946	1.05708	894916	846590536	30.7571
892	1.12108	795664	709732288	29.8664	947	1.05597	896809	849278123	30.7734
893	1.11982	797449	712121957	29.8831	948	1.05485	898704	851971392	30.7896
894	1.11857	799236	714516984	29.8998	949	1.05374	900601	854670349	30.8058
895	1.11732	801025	716917375	29.9166	**950**	1.05263	902500	857375000	30.8221
896	1.11607	802816	719323136	29.9333	951	1.05152	904401	860085351	30.8383
897	1.11483	804609	721734273	29.9500	952	1.05042	906304	862801408	30.8545
898	1.11359	806404	724150792	29.9666	953	1.04932	908209	865523177	30.8707
899	1.11235	808201	726572699	29.9833	954	1.04822	910116	868250664	30.8869
900	1.11111	810000	729000000	30.0000	**955**	1.04712	912025	870983875	30.9031
901	1.10988	811801	731432701	30.0167	956	1.04603	913936	873722816	30.9192
902	1.10865	813604	733870808	30.0333	957	1.04493	915849	876467493	30.9354
903	1.10742	815409	736314327	30.0500	958	1.04384	917764	879217912	30.9516
904	1.10619	817216	738763264	30.0666	959	1.04275	919681	881974079	30.9677
905	1.10497	819025	741217625	30.0832	**960**	1.04167	921600	884736000	30.9839
906	1.10375	820836	743677416	30.0998	961	1.04058	923521	887503681	31.0000
907	1.10254	822649	746142643	30.1164	962	1.03950	925444	890277128	31.0161
908	1.10132	824464	748613312	30.1330	963	1.03842	927369	893056347	31.0322
909	1.10011	826281	751089429	30.1496	964	1.03734	929296	895841344	31.0483
910	1.09890	828100	753571000	30.1662	**965**	1.03627	931225	898632125	31.0644
911	1.09769	829921	756058031	30.1828	966	1.03520	933156	901428696	31.0805
912	1.09649	831744	758550528	30.1993	967	1.03413	935089	904231063	31.0966
913	1.09529	833569	761048497	30.2159	968	1.03306	937024	907039232	31.1127
914	1.09409	835396	763551944	30.2324	969	1.03199	938961	909853209	31.1288
915	1.09290	837225	766060875	30.2490	**970**	1.03093	940900	912673000	31.1448
916	1.09170	839056	768575296	30.2655	971	1.02987	942841	915498611	31.1609
917	1.09051	840889	771095213	30.2820	972	1.02881	944784	918330048	31.1769
918	1.08932	842724	773620632	30.2985	973	1.02775	946729	921167317	31.1929
919	1.08814	844561	776151559	30.3150	974	1.02669	948676	924010424	31.2090
920	1.08696	846400	778688000	30.3315	**975**	1.02564	950625	926859375	31.2250
921	1.08578	848241	781229961	30.3480	976	1.02459	952576	929714176	31.2410
922	1.08460	850084	783777448	30.3645	977	1.02354	954529	932574833	31.2570
923	1.08342	851929	786330467	30.3809	978	1.02249	956484	935441352	31.2730
924	1.08225	853776	788889024	30.3974	979	1.02145	958441	938313739	31.2890
925	1.08108	855625	791453125	30.4138	**980**	1.02041	960400	941192000	31.3050
926	1.07991	857476	794022776	30.4302	981	1.01937	962361	944076141	31.3209
927	1.07875	859329	796597983	30.4467	982	1.01833	964324	946966168	31.3369
928	1.07759	861184	799178752	30.4631	983	1.01729	966289	949862087	31.3528
929	1.07643	863041	801765089	30.4795	984	1.01626	968256	952763904	31.3688
930	1.07527	864900	804357000	30.4959	**985**	1.01523	970225	955671625	31.3847
931	1.07411	866761	806954491	30.5123	986	1.01420	972196	958585256	31.4006
932	1.07296	868624	809557568	30.5287	987	1.01317	974169	961504803	31.4166
933	1.07181	870489	812166237	30.5450	988	1.01215	976144	964430272	31.4325
934	1.07066	872356	814780504	30.5614	989	1.01112	978121	967361669	31.4484
935	1.06952	874225	817400375	30.5778	**990**	1.01010	980100	970299000	31.4643
936	1.06838	876096	820025856	30.5941	991	1.00908	982081	973242271	31.4802
937	1.06724	877969	822656953	30.6105	992	1.00806	984064	976191488	31.4960
938	1.06610	879844	825293672	30.6268	993	1.00705	986049	979146657	31.5119
939	1.06496	881721	827936019	30.6431	994	1.00604	988036	982107784	31.5278
940	1.06383	883600	830584000	30.6594	**995**	1.00503	990025	985074875	31.5436
941	1.06270	885481	833237621	30.6757	996	1.00402	992016	988047936	31.5595
942	1.06157	887364	835896888	30.6920	997	1.00301	994009	991026973	31.5753
943	1.06045	889249	838561807	30.7083	998	1.00200	996004	994011992	31.5911
944	1.05932	891136	841232384	30.7246	999	1.00100	998001	997002999	31.6070

TABLE 9.

LOGARITHMS.

N.	0	1	2	3	4	5	6	7	8	9	10
100	0000	0004	0009	0013	0017	0022	0026	0030	0035	0039	0043
101	0043	0048	0052	0056	0060	0065	0069	0073	0077	0082	0086
102	0086	0090	0095	0099	0103	0107	0111	0116	0120	0124	0128
103	0128	0133	0137	0141	0145	0149	0154	0158	0162	0166	0170
104	0170	0175	0179	0183	0187	0191	0195	0199	0204	0208	0212
105	0212	0216	0220	0224	0228	0233	0237	0241	0245	0249	0253
106	0253	0257	0261	0265	0269	0273	0278	0282	0286	0290	0294
107	0294	0298	0302	0306	0310	0314	0318	0322	0326	0330	0334
108	0334	0338	0342	0346	0350	0354	0358	0362	0366	0370	0374
109	0374	0378	0382	0386	0390	0394	0398	0402	0406	0410	0414
110	0414	0418	0422	0426	0430	0434	0438	0441	0445	0449	0453
111	0453	0457	0461	0465	0469	0473	0477	0481	0484	0488	0492
112	0492	0496	0500	0504	0508	0512	0515	0519	0523	0527	0531
113	0531	0535	0538	0542	0546	0550	0554	0558	0561	0565	0569
114	0569	0573	0577	0580	0584	0588	0592	0596	0599	0603	0607
115	0607	0611	0615	0618	0622	0626	0630	0633	0637	0641	0645
116	0645	0648	0652	0656	0660	0663	0667	0671	0674	0678	0682
117	0682	0686	0689	0693	0697	0700	0704	0708	0711	0715	0719
118	0719	0722	0726	0730	0734	0737	0741	0745	0748	0752	0755
119	0755	0759	0763	0766	0770	0774	0777	0781	0785	0788	0792
120	0792	0795	0799	0803	0806	0810	0813	0817	0821	0824	0828
121	0828	0831	0835	0839	0842	0846	0849	0853	0856	0860	0864
122	0864	0867	0871	0874	0878	0881	0885	0888	0892	0896	0899
123	0899	0903	0906	0910	0913	0917	0920	0924	0927	0931	0934
124	0934	0938	0941	0945	0948	0952	0955	0959	0962	0966	0969
125	0969	0973	0976	0980	0983	0986	0990	0993	0997	1000	1004
126	1004	1007	1011	1014	1017	1021	1024	1028	1031	1035	1038
127	1038	1041	1045	1048	1052	1055	1059	1062	1065	1069	1072
128	1072	1075	1079	1082	1086	1089	1092	1096	1099	1103	1106
129	1106	1109	1113	1116	1119	1123	1126	1129	1133	1136	1139
130	1139	1143	1146	1149	1153	1156	1159	1163	1166	1169	1173
131	1173	1176	1179	1183	1186	1189	1193	1196	1199	1202	1206
132	1206	1209	1212	1216	1219	1222	1225	1229	1232	1235	1239
133	1239	1242	1245	1248	1252	1255	1258	1261	1265	1268	1271
134	1271	1274	1278	1281	1284	1287	1290	1294	1297	1300	1303
135	1303	1307	1310	1313	1316	1319	1323	1326	1329	1332	1335
136	1335	1339	1342	1345	1348	1351	1355	1358	1361	1364	1367
137	1367	1370	1374	1377	1380	1383	1386	1389	1392	1396	1399
138	1399	1402	1405	1408	1411	1414	1418	1421	1424	1427	1430
139	1430	1433	1436	1440	1443	1446	1449	1452	1455	1458	1461
140	1461	1464	1467	1471	1474	1477	1480	1483	1486	1489	1492
141	1492	1495	1498	1501	1504	1508	1511	1514	1517	1520	1523
142	1523	1526	1529	1532	1535	1538	1541	1544	1547	1550	1553
143	1553	1556	1559	1562	1565	1569	1572	1575	1578	1581	1584
144	1584	1587	1590	1593	1596	1599	1602	1605	1608	1611	1614
145	1614	1617	1620	1623	1626	1629	1632	1635	1638	1641	1644
146	1644	1647	1649	1652	1655	1658	1661	1664	1667	1670	1673
147	1673	1676	1679	1682	1685	1688	1691	1694	1697	1700	1703
148	1703	1706	1708	1711	1714	1717	1720	1723	1726	1729	1732
149	1732	1735	1738	1741	1744	1746	1749	1752	1755	1758	1761

TABLE 9 (*continued*).

LOGARITHMS.

N.	0	1	2	3	4	5	6	7	8	9	10
150	1761	1764	1767	1770	1772	1775	1778	1781	1784	1787	1790
151	1790	1793	1796	1798	1801	1804	1807	1810	1813	1816	1818
152	1818	1821	1824	1827	1830	1833	1836	1838	1841	1844	1847
153	1847	1850	1853	1855	1858	1861	1864	1867	1870	1872	1875
154	1875	1878	1881	1884	1886	1889	1892	1895	1898	1901	1903
155	1903	1906	1909	1912	1915	1917	1920	1923	1926	1928	1931
156	1931	1934	1937	1940	1942	1945	1948	1951	1953	1956	1959
157	1959	1962	1965	1967	1970	1973	1976	1978	1981	1984	1987
158	1987	1989	1992	1995	1998	2000	2003	2006	2009	2011	2014
159	2014	2017	2019	2022	2025	2028	2030	2033	2036	2038	2041
160	2041	2044	2047	2049	2052	2055	2057	2060	2063	2066	2068
161	2068	2071	2074	2076	2079	2082	2084	2087	2090	2092	2095
162	2095	2098	2101	2103	2106	2109	2111	2114	2117	2119	2122
163	2122	2125	2127	2130	2133	2135	2138	2140	2143	2146	2148
164	2148	2151	2154	2156	2159	2162	2164	2167	2170	2172	2175
165	2175	2177	2180	2183	2185	2188	2191	2193	2196	2198	2201
166	2201	2204	2206	2209	2212	2214	2217	2219	2222	2225	2227
167	2227	2230	2232	2235	2238	2240	2243	2245	2248	2251	2253
168	2253	2256	2258	2261	2263	2266	2269	2271	2274	2276	2279
169	2279	2281	2284	2287	2289	2292	2294	2297	2299	2302	2304
170	2304	2307	2310	2312	2315	2317	2320	2322	2325	2327	2330
171	2330	2333	2335	2338	2340	2343	2345	2348	2350	2353	2355
172	2355	2358	2360	2363	2365	2368	2370	2373	2375	2378	2380
173	2380	2383	2385	2388	2390	2393	2395	2398	2400	2403	2405
174	2405	2408	2410	2413	2415	2418	2420	2423	2425	2428	2430
175	2430	2433	2435	2438	2440	2443	2445	2448	2450	2453	2455
176	2455	2458	2460	2463	2465	2467	2470	2472	2475	2477	2480
177	2480	2482	2485	2487	2490	2492	2494	2497	2499	2502	2504
178	2504	2507	2509	2512	2514	2516	2519	2521	2524	2526	2529
179	2529	2531	2533	2536	2538	2541	2543	2545	2548	2550	2553
180	2553	2555	2558	2560	2562	2565	2567	2570	2572	2574	2577
181	2577	2579	2582	2584	2586	2589	2591	2594	2596	2598	2601
182	2601	2603	2605	2608	2610	2613	2615	2617	2620	2622	2625
183	2625	2627	2629	2632	2634	2636	2639	2641	2643	2646	2648
184	2648	2651	2653	2655	2658	2660	2662	2665	2667	2669	2672
185	2672	2674	2676	2679	2681	2683	2686	2688	2690	2693	2695
186	2695	2697	2700	2702	2704	2707	2709	2711	2714	2716	2718
187	2718	2721	2723	2725	2728	2730	2732	2735	2737	2739	2742
188	2742	2744	2746	2749	2751	2753	2755	2758	2760	2762	2765
189	2765	2767	2769	2772	2774	2776	2778	2781	2783	2785	2788
190	2788	2790	2792	2794	2797	2799	2801	2804	2806	2808	2810
191	2810	2813	2815	2817	2819	2822	2824	2826	2828	2831	2833
192	2833	2835	2838	2840	2842	2844	2847	2849	2851	2853	2856
193	2856	2858	2860	2862	2865	2867	2869	2871	2874	2876	2878
194	2878	2880	2882	2885	2887	2889	2891	2894	2896	2898	2900
195	2900	2903	2905	2907	2909	2911	2914	2916	2918	2920	2923
196	2923	2925	2927	2929	2931	2934	2936	2938	2940	2942	2945
197	2945	2947	2949	2951	2953	2956	2958	2960	2962	2964	2967
198	2967	2969	2971	2973	2975	2978	2980	2982	2984	2986	2989
199	2989	2991	2993	2995	2997	2999	3002	3004	3006	3008	3010

TABLE 10.

LOGARITHMS.

N	0	1	2	3	4	5	6	7	8	9	P. P.				
											1	2	3	4	5
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	5	7	9
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	6
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4

TABLE 10 *(continued)*.

LOGARITHMS.

N.	0	1	2	3	4	5	6	7	8	9	P. P. 1	2	3	4	5
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	3	3
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2

TABLE 11.

ANTILOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	P. P.				
											1	2	3	4	5
.00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1
.01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1
.02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1
.03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1
.04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1
.05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1
.06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1
.07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1
.08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1
.09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1
.10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1
.11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2
.12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2
.13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2
.14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2
.15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2
.16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2
.17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2
.18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2
.19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2
.20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2
.21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2
.22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2
.23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2
.24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2
.25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2
.26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2
.27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2
.28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2
.29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2
.30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2
.31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2
.32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2
.33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2
.34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3
.35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3
.36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3
.37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3
.38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3
.39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3
.40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3
.41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3
.42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3
.43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3
.44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3
.45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3
.46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3
.47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3
.48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4
.49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4

ANTILOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	P. P.				
											1	2	3	4	5
.50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4
.51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4
.52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4
.53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4
.54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4
.55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4
.56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4
.57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4
.58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4
.59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5
.60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5
.61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5
.62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5
.63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5
.64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5
.65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5
.66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5
.67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5
.68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6
.69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6
.70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6
.71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6
.72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6
.73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6
.74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6
.75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7
.76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7
.77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7
.78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7
.79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7
.80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7
.81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8
.82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8
.83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8
.84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8
.85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8
.86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8
.87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9
.88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9
.89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9
.90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9
.91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9
.92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10
.93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10
.94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10
.95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10
.96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11
.97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11
.98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11
.99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11

Table 12.

ANTILOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	10
.900	7943	7945	7947	7949	7951	7952	7954	7956	7958	7960	7962
.901	7962	7963	7965	7967	7969	7971	7973	7974	7976	7978	7980
.902	7980	7982	7984	7985	7987	7989	7991	7993	7995	7997	7998
.903	7998	8000	8002	8004	8006	8008	8009	8011	8013	8015	8017
.904	8017	8019	8020	8022	8024	8026	8028	8030	8032	8033	8035
.905	8035	8037	8039	8041	8043	8045	8046	8048	8050	8052	8054
.906	8054	8056	8057	8059	8061	8063	8065	8067	8069	8070	8072
.907	8072	8074	8076	8078	8080	8082	8084	8085	8087	8089	8091
.908	8091	8093	8095	8097	8098	8100	8102	8104	8106	8108	8110
.909	8110	8111	8113	8115	8117	8119	8121	8123	8125	8126	8128
.910	8128	8130	8132	8134	8136	8138	8140	8141	8143	8145	8147
.911	8147	8149	8151	8153	8155	8156	8158	8160	8162	8164	8166
.912	8166	8168	8170	8171	8173	8175	8177	8179	8181	8183	8185
.913	8185	8187	8188	8190	8192	8194	8196	8198	8200	8202	8204
.914	8204	8205	8207	8209	8211	8213	8215	8217	8219	8221	8222
.915	8222	8224	8226	8228	8230	8232	8234	8236	8238	8239	8241
.916	8241	8243	8245	8247	8249	8251	8253	8255	8257	8258	8260
.917	8260	8262	8264	8266	8268	8270	8272	8274	8276	8278	8279
.918	8279	8281	8283	8285	8287	8289	8291	8293	8295	8297	8299
.919	8299	8300	8302	8304	8306	8308	8310	8312	8314	8316	8318
.920	8318	8320	8321	8323	8325	8327	8329	8331	8333	8335	8337
.921	8337	8339	8341	8343	8344	8346	8348	8350	8352	8354	8356
.922	8356	8358	8360	8362	8364	8366	8368	8370	8371	8373	8375
.923	8375	8377	8379	8381	8383	8385	8387	8389	8391	8393	8395
.924	8395	8397	8398	8400	8402	8404	8406	8408	8410	8412	8414
.925	8414	8416	8418	8420	8422	8424	8426	8428	8429	8431	8433
.926	8433	8435	8437	8439	8441	8443	8445	8447	8449	8451	8453
.927	8453	8455	8457	8459	8461	8463	8464	8466	8468	8470	8472
.928	8472	8474	8476	8478	8480	8482	8484	8486	8488	8490	8492
.929	8492	8494	8496	8498	8500	8502	8504	8506	8507	8509	8511
.930	8511	8513	8515	8517	8519	8521	8523	8525	8527	8529	8531
.931	8531	8533	8535	8537	8539	8541	8543	8545	8547	8549	8551
.932	8551	8553	8555	8557	8559	8561	8562	8564	8566	8568	8570
.933	8570	8572	8574	8576	8578	8580	8582	8584	8586	8588	8590
.934	8590	8592	8594	8596	8598	8600	8602	8604	8606	8608	8610
.935	8610	8612	8614	8616	8618	8620	8622	8624	8626	8628	8630
.936	8630	8632	8634	8636	8638	8640	8642	8644	8646	8648	8650
.937	8650	8652	8654	8656	8658	8660	8662	8664	8666	8668	8670
.938	8670	8672	8674	8676	8678	8680	8682	8684	8686	8688	8690
.939	8690	8692	8694	8696	8698	8700	8702	8704	8706	8708	8710
.940	8710	8712	8714	8716	8718	8720	8722	8724	8726	8728	8730
.941	8730	8732	8734	8736	8738	8740	8742	8744	8746	8748	8750
.942	8750	8752	8754	8756	8758	8760	8762	8764	8766	8768	8770
.943	8770	8772	8774	8776	8778	8780	8782	8784	8786	8788	8790
.944	8790	8792	8794	8796	8798	8800	8802	8804	8806	8808	8810
.945	8810	8813	8815	8817	8819	8821	8823	8825	8827	8829	8831
.946	8831	8833	8835	8837	8839	8841	8843	8845	8847	8849	8851
.947	8851	8853	8855	8857	8859	8861	8863	8865	8867	8870	8872
.948	8872	8874	8876	8878	8880	8882	8884	8886	8888	8890	8892
.949	8892	8894	8896	8898	8900	8902	8904	8906	8908	8910	8913

TABLE 12 (*continued*).

ANTILOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	10
.950	8913	8915	8917	8919	8921	8923	8925	8927	8929	8931	8933
.951	8933	8935	8937	8939	8941	8943	8945	8947	8950	8952	8954
.952	8954	8956	8958	8960	8962	8964	8966	8968	8970	8972	8974
.953	8974	8976	8978	8980	8983	8985	8987	8989	8991	8993	8995
.954	8995	8997	8999	9001	9003	9005	9007	9009	9012	9014	9016
.955	9016	9018	9020	9022	9024	9026	9028	9030	9032	9034	9036
.956	9036	9039	9041	9043	9045	9047	9049	9051	9053	9055	9057
.957	9057	9059	9061	9064	9066	9068	9070	9072	9074	9076	9078
.958	9078	9080	9082	9084	9087	9089	9091	9093	9095	9097	9099
.959	9099	9101	9103	9105	9108	9110	9112	9114	9116	9118	9120
.960	9120	9122	9124	9126	9129	9131	9133	9135	9137	9139	9141
.961	9141	9143	9145	9147	9150	9152	9154	9156	9158	9160	9162
.962	9162	9164	9166	9169	9171	9173	9175	9177	9179	9181	9183
.963	9183	9185	9188	9190	9192	9194	9196	9198	9200	9202	9204
.964	9204	9207	9209	9211	9213	9215	9217	9219	9221	9224	9226
.965	9226	9228	9230	9232	9234	9236	9238	9241	9243	9245	9247
.966	9247	9249	9251	9253	9256	9258	9260	9262	9264	9266	9268
.967	9268	9270	9273	9275	9277	9279	9281	9283	9285	9288	9290
.968	9290	9292	9294	9296	9298	9300	9303	9305	9307	9309	9311
.969	9311	9313	9315	9318	9320	9322	9324	9326	9328	9330	9333
.970	9333	9335	9337	9339	9341	9343	9345	9348	9350	9352	9354
.971	9354	9356	9358	9361	9363	9365	9367	9369	9371	9373	9376
.972	9376	9378	9380	9382	9384	9386	9389	9391	9393	9395	9397
.973	9397	9399	9402	9404	9406	9408	9410	9412	9415	9417	9419
.974	9419	9421	9423	9425	9428	9430	9432	9434	9436	9438	9441
.975	9441	9443	9445	9447	9449	9451	9454	9456	9458	9460	9462
.976	9462	9465	9467	9469	9471	9473	9475	9478	9480	9482	9484
.977	9484	9486	9489	9491	9493	9495	9497	9499	9502	9504	9506
.978	9506	9508	9510	9513	9515	9517	9519	9521	9524	9526	9528
.979	9528	9530	9532	9535	9537	9539	9541	9543	9546	9548	9550
980	9550	9552	9554	9557	9559	9561	9563	9565	9568	9570	9572
.981	9572	9574	9576	9579	9581	9583	9585	9587	9590	9592	9594
.982	9594	9596	9598	9601	9603	9605	9607	9609	9612	9614	9616
.983	9616	9618	9621	9623	9625	9627	9629	9632	9634	9636	9638
.984	9638	9641	9643	9645	9647	9649	9652	9654	9656	9658	9661
.985	9661	9663	9665	9667	9669	9672	9674	9676	9678	9681	9683
.986	9683	9685	9687	9689	9692	9694	9696	9698	9701	9703	9705
.987	9705	9707	9710	9712	9714	9716	9719	9721	9723	9725	9727
.988	9727	9730	9732	9734	9736	9739	9741	9743	9745	9748	9750
.989	9750	9752	9754	9757	9759	9761	9763	9766	9768	9770	9772
.990	9772	9775	9777	9779	9781	9784	9786	9788	9790	9793	9795
.991	9795	9797	9799	9802	9804	9806	9808	9811	9813	9815	9817
.992	9817	9820	9822	9824	9827	9829	9831	9833	9836	9838	9840
.993	9840	9842	9845	9847	9849	9851	9854	9856	9858	9861	9863
.994	9863	9865	9867	9870	9872	9874	9876	9879	9881	9883	9886
.995	9886	9888	9890	9892	9895	9897	9899	9901	9904	9906	9908
.996	9908	9911	9913	9915	9917	9920	9922	9924	9927	9929	9931
.997	9931	9933	9936	9938	9940	9943	9945	9947	9949	9952	9954
.998	9954	9956	9959	9961	9963	9966	9968	9970	9972	9975	9977
.999	9977	9979	9982	9984	9986	9988	9991	9993	9995	9998	0000

TABLE 13.

CIRCULAR (TRIGONOMETRIC) FUNCTIONS.

(Taken from B. O. Peirce's "Short Table of Integrals," Ginn & Co.)

RADIANS.	DEGREES.	SINES.		COSINES.		TANGENTS.		COTANGENTS.			
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.		
0.0000	0°00′	.0000	∞	1.0000	0.0000	.0000	∞	∞	∞	90°00′	1.5708
0.0029	10	.0029	7.4637	1.0000	.0000	.0029	7.4637	343.77	2.5363	50	1.5679
0.0058	20	.0058	.7648	1.0000	.0000	.0058	.7648	171.89	.2352	40	1.5650
0.0087	30	.0087	.9408	1.0000	.0000	.0087	.9409	114.59	.0591	30	1.5621
0.0116	40	.0116	8.0658	.9999	.0000	.0116	8.0658	85.940	1.9342	20	1.5592
0.0145	50	.0145	.1627	.9999	.0000	.0145	.1627	68.750	.8373	10	1.5563
0.0175	1°00′	.0175	8.2419	.9998	9.9999	.0175	8.2419	57.290	1.7581	89°00′	1.5533
0.0204	10	.0204	.3088	.9998	.9999	.0204	.3089	49.104	.6911	50	1.5504
0.0233	20	.0233	.3668	.9997	.9999	.0233	.3669	42.964	.6331	40	1.5475
0.0262	30	.0262	.4179	.9997	.9999	.0262	.4181	38.188	.5819	30	1.5446
0.0291	40	.0291	.4637	.9996	.9998	.0291	.4638	34.368	.5362	20	1.5417
0.0320	50	.0320	.5050	.9995	.9998	.0320	.5053	31.242	.4947	10	1.5388
0.0349	2°00′	.0349	8.5428	.9994	9.9997	.0349	8.5431	28.636	1.4569	88°00′	1.5359
0.0378	10	.0378	.5776	.9993	.9997	.0378	.5779	26.432	.4221	50	1.5330
0.0407	20	.0407	.6097	.9992	.9996	.0407	.6101	24.542	.3899	40	1.5301
0.0436	30	.0436	.6397	.9990	.9996	.0437	.6401	22.904	.3599	30	1.5272
0.0465	40	.0465	.6677	.9989	.9995	.0466	.6682	21.470	.3318	20	1.5243
0.0495	50	.0494	.6940	.9988	.9995	.0495	.6945	20.206	.3055	10	1.5213
0.0524	3°00′	.0523	8.7188	.9986	9 9994	.0524	8.7194	19.081	1.2806	87°00′	1.5184
0.0553	10	.0552	.7423	.9985	.9993	.0553	.7429	18.075	.2571	50	1.5155
0.0582	20	.0581	.7645	.9983	.9993	.0582	.7652	17.169	.2348	40	1.5126
0.0611	30	.0610	.7857	.9981	.9992	.0612	.7865	16.350	.2135	30	1.5097
0.0640	40	.0640	.8059	.9980	.9991	.0641	.8067	15.605	.1933	20	1.5068
0.0669	50	.0669	.8251	.9978	.9990	.0670	.8261	14.924	.1739	10	1.5039
0.0698	4°00′	.0698	8.8436	.9976	9.9989	.0699	8.8446	14.301	1.1554	86°00′	1.5010
0.0727	10	.0727	.8613	.9974	.9989	.0729	.8624	13.727	.1376	50	1.4981
0.0756	20	.0756	.8783	.9971	.9988	.0758	.8795	13.197	.1205	40	1.4952
0.0785	30	.0785	.8946	.9969	.9987	.0787	.8960	12.706	.1040	30	1.4923
0.0814	40	.0814	.9104	.9967	.9986	.0816	.9118	12.251	.0882	20	1.4893
0.0844	50	.0843	.9256	.9964	.9985	.0846	.9272	11.826	.0728	10	1.4864
0.0873	5°00′	.0872	8.9403	.9962	9.9983	.0875	8.9420	11.430	1.0580	85°00′	1.4835
0.0902	10	.0901	.9545	.9959	.9982	.0904	.9563	11.059	.0437	50	1.4806
0.0931	20	.0929	.9682	.9957	.9981	.0934	.9701	10.712	.0299	40	1.4777
0.0960	30	.0958	.9816	.9954	.9980	.0963	.9836	10.385	.0164	30	1.4748
0.0989	40	.0987	.9945	.9951	.9979	.0992	.9966	10.078	.0034	20	1.4719
0.1018	50	.1016	9.0070	.9948	.9977	.1022	9.0093	9.7882	0.9907	10	1.4690
0.1047	6°00	.1045	9.0192	.9945	9.9976	.1051	9.0216	9.5144	0.9784	84°00′	1.4661
0.1076	10	.1074	.0311	.9942	.9975	.1080	.0336	9.2553	.9664	50	1.4632
0.1105	20	.1103	.0426	.9939	.9973	.1110	.0453	9.0098	.9547	40	1.4603
0.1134	30	.1132	.0539	.9936	.9972	.1139	.0567	8.7769	.9433	30	1.4574
0.1164	40	.1161	.0648	.9932	.9971	.1169	.0678	8.5555	.9322	20	1.4544
0.1193	50	.1190	.0755	.9929	.9969	.1198	.0786	8.3450	.9214	10	1.4515
0.1222	7°00′	.1219	9.0859	.9925	9.9968	.1228	9.0891	8.1443	0.9109	83°00′	1.4486
0.1251	10	.1248	.0961	.9922	.9966	.1257	.0995	7.9530	.9005	50	1.4457
0.1280	20	.1276	.1060	.9918	.9964	.1287	.1096	7.7704	.8904	40	1.4428
0.1309	30	.1305	.1157	.9914	.9963	.1317	.1194	7.5958	.8806	30	1.4399
0.1338	40	.1334	.1252	.9911	.9961	.1346	.1291	7.4287	.8709	20	1.4370
0.1367	50	.1363	.1345	.9907	.9959	.1376	.1385	7.2687	.8615	10	1.4341
0.1396	8°00′	.1392	9.1436	.9903	9.9958	.1405	9.1478	7.1154	0.8522	82°00′	1.4312
0.1425	10	.1421	.1525	.9899	.9956	.1435	.1569	6.9682	.8431	50	1.4283
0.1454	20	.1449	.1612	.9894	.9954	.1465	.1658	6.8269	.8342	40	1.4254
0.1484	30	.1478	.1697	.9890	.9952	.1495	.1745	6.6912	.8255	30	1.4224
0.1513	40	.1507	.1781	.9886	.9950	.1524	.1831	6.5606	.8169	20	1.4195
0.1542	50	.1536	.1863	.9881	.9948	.1554	.1915	6.4348	.8085	10	1.4166
0.1571	9°00′	.1564	9.1943	.9877	9.9946	.1584	9.1997	6.3138	0.8003	81°00′	1.4137
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	DEGREES.	RADIANS.
		COSINES.		SINES.		COTANGENTS.		TANGENTS.			

TABLE 13 (*continued*).

CIRCULAR (TRIGONOMETRIC) FUNCTIONS.

RADIANS.	DEGREES.	SINES.		COSINES.		TANGENTS.		COTANGENTS.			
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.		
0.1571	9°00′	.1564	9.1943	.9877	9.9946	.1584	9.1997	6.3138	0.8003	81°00′	1.4137
0.1600	10	.1593	.2022	.9872	.9944	.1614	.2078	6.1970	.7922	50	1.4108
0.1629	20	.1622	.2100	.9868	.9942	.1644	.2158	6.0844	.7842	40	1.4079
0.1658	30	.1650	.2176	.9863	.9940	.1673	.2236	5.9758	.7764	30	1.4050
0.1687	40	.1679	.2251	.9858	.9938	.1703	.2313	5.8708	.7687	20	1.4021
0.1716	50	.1708	.2324	.9853	.9936	.1733	.2389	5.7694	.7611	10	1.3992
0.1745	10°00′	.1736	9.2397	.9848	9.9934	.1763	9.2463	5.6713	0.7537	80°00′	1.3963
0.1774	10	.1765	.2468	.9843	.9931	.1793	.2536	5.5764	.7464	50	1.3934
0.1804	20	.1794	.2538	.9838	.9929	.1823	.2609	5.4845	.7391	40	1.3904
0.1833	30	.1822	.2606	.9833	.9927	.1853	.2680	5.3955	.7320	30	1.3875
0.1862	40	.1851	.2674	.9827	.9924	.1883	.2750	5.3093	.7250	20	1.3846
0.1891	50	.1880	.2740	.9822	.9922	.1914	.2819	5.2257	.7181	10	1.3817
0.1920	11°00′	.1908	9.2806	.9816	9.9919	.1944	9.2887	5.1446	0.7113	79°00′	1.3788
0.1949	10	.1937	.2870	.9811	.9917	.1974	.2953	5.0658	.7047	50	1.3759
0.1978	20	.1965	.2934	.9805	.9914	.2004	.3020	4.9894	.6980	40	1.3730
0.2007	30	.1994	.2997	.9799	.9912	.2035	.3085	4.9152	.6915	30	1.3701
0.2036	40	.2022	.3058	.9793	.9909	.2065	.3149	4.8430	.6851	20	1.3672
0.2065	50	.2051	.3119	.9787	.9907	.2095	.3212	4.7729	.6788	10	1.3643
0.2094	12°00′	.2079	9.3179	.9781	9.9904	.2126	9.3275	4.7046	0.6725	78°00′	1.3614
0.2123	10	.2108	.3238	.9775	.9901	.2156	.3336	4.6382	.6664	50	1.3584
0.2153	20	.2136	.3296	.9769	.9899	.2186	.3397	4.5736	.6603	40	1.3555
0.2182	30	.2164	.3353	.9763	.9896	.2217	.3458	4.5107	.6542	30	1.3526
0.2211	40	.2193	.3410	.9757	.9893	.2247	.3517	4.4494	.6483	20	1.3497
0.2240	50	.2221	.3466	.9750	.9890	.2278	.3576	4.3897	.6424	10	1.3468
0.2269	13°00′	.2250	9.3521	.9744	9.9887	.2309	9.3634	4.3315	0.6366	77°00′	1.3439
0.2298	10	.2278	.3575	.9737	.9884	.2339	.3691	4.2747	.6309	50	1.3410
0.2327	20	.2306	.3629	.9730	.9881	.2370	.3748	4.2193	.6252	40	1.3381
0.2356	30	.2334	.3682	.9724	.9878	.2401	.3804	4.1653	.6196	30	1.3352
0.2385	40	.2363	.3734	.9717	.9875	.2432	.3859	4.1126	.6141	20	1.3323
0.2414	50	.2391	.3786	.9710	.9872	.2462	.3914	4.0611	.6086	10	1.3294
0.2443	14°00′	.2419	9.3837	.9703	9.9869	.2493	9.3968	4.0108	0.6032	76°00′	1.3265
0.2473	10	.2447	.3887	.9696	.9866	.2524	.4021	3.9617	.5979	50	1.3235
0.2502	20	.2476	.3937	.9689	.9863	.2555	.4074	3.9136	.5926	40	1.3206
0.2531	30	.2504	.3986	.9681	.9859	.2586	.4127	3.8667	.5873	30	1.3177
0.2560	40	.2532	.4035	.9674	.9856	.2617	.4178	3.8208	.5822	20	1.3148
0.2589	50	.2560	.4083	.9667	.9853	.2648	.4230	3.7760	.5770	10	1.3119
0.2618	15°00′	.2588	9.4130	.9659	9.9849	.2679	9.4281	3.7321	0.5719	75°00′	1.3090
0.2647	10	.2616	.4177	.9652	.9846	.2711	.4331	3.6891	.5669	50	1.3061
0.2676	20	.2644	.4223	.9644	.9843	.2742	.4381	3.6470	.5619	40	1.3032
0.2705	30	.2672	.4269	.9636	.9839	.2773	.4430	3.6059	.5570	30	1.3003
0.2734	40	.2700	.4314	.9628	.9836	.2805	.4479	3.5656	.5521	20	1.2974
0.2763	50	.2728	.4359	.9621	.9832	.2836	.4527	3.5261	.5473	10	1.2945
0.2793	16°00′	.2756	9.4403	.9613	9.9828	.2867	9.4575	3.4874	0.5425	74°00′	1.2915
0.2822	10	.2784	.4447	.9605	.9825	.2899	.4622	3.4495	.5378	50	1.2886
0.2851	20	.2812	.4491	.9596	.9821	.2931	.4669	3.4124	.5331	40	1.2857
0.2880	30	.2840	.4533	.9588	.9817	.2962	.4716	3.3759	.5284	30	1.2828
0.2909	40	.2868	.4576	.9580	.9814	.2994	.4762	3.3402	.5238	20	1.2799
0.2938	50	.2896	.4618	.9572	.9810	.3026	.4808	3.3052	.5192	10	1.2770
0.2967	17°00′	.2924	9.4659	.9563	9.9806	.3057	9.4853	3.2709	0.5147	73°00′	1.2741
0.2996	10	.2952	.4700	.9555	.9802	.3089	.4898	3.2371	.5102	50	1.2712
0.3025	20	.2979	.4741	.9546	.9798	.3121	.4943	3.2041	.5057	40	1.2683
0.3054	30	.3007	.4781	.9537	.9794	.3153	.4987	3.1716	.5013	30	1.2654
0.3083	40	.3035	.4821	.9528	.9790	.3185	.5031	3.1397	.4969	20	1.2625
0.3113	50	.3062	.4861	.9520	.9786	.3217	.5075	3.1084	.4925	10	1.2595
0.3142	18°00′	.3090	9.4900	.9511	9.9782	.3249	9.5118	3.0777	0.4882	72°00′	1.2566
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	DEGREES.	RADIANS.
		COSINES		SINES.		COTANGENTS.		TANGENTS			

CIRCULAR (TRIGONOMETRIC) FUNCTIONS.

RADIANS.	DEGREES.	SINES.		COSINES.		TANGENTS.		COTANGENTS.			
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.		
0.3142	18°00′	.3090	9.4900	.9511	9.9782	.3249	9.5118	3.0777	0.4882	72°00′	1.2566
0.3171	10	.3118	.4939	.9502	.9778	.3281	.5161	3.0475	.4839	50	1.2537
0.3200	20	.3145	.4977	.9492	.9774	.3314	.5203	3.0178	.4797	40	1.2508
0.3229	30	.3173	.5015	.9483	.9770	.3346	.5245	2.9887	.4755	30	1.2479
0.3258	40	.3201	.5052	.9474	.9765	.3378	.5287	2.9600	.4713	20	1.2450
0.3287	50	.3228	.5090	.9465	.9761	.3411	.5329	2.9319	.4671	10	1.2421
0.3316	19°00′	.3256	9.5126	.9455	9.9757	.3443	9.5370	2.9042	0.4630	71°00′	1.2392
0.3345	10	.3283	.5163	.9446	.9752	.3476	.5411	2.8770	.4589	50	1.2363
0.3374	20	.3311	.5199	.9436	.9748	.3508	.5451	2.8502	.4549	40	1.2334
0.3403	30	.3338	.5235	.9426	.9743	.3541	.5491	2.8239	.4509	30	1.2305
0.3432	40	.3365	.5270	.9417	.9739	.3574	.5531	2.7980	.4469	20	1.2275
0.3462	50	.3393	.5306	.9407	.9734	.3607	.5571	2.7725	.4429	10	1.2246
0.3491	20°00′	.3420	9.5341	.9397	9.9730	.3640	9.5611	2.7475	0.4389	70°00′	1.2217
0.3520	10	.3448	.5375	.9387	.9725	.3673	.5650	2.7228	.4350	50	1.2188
0.3549	20	.3475	.5409	.9377	.9721	.3706	.5689	2.6985	.4311	40	1.2159
0.3578	30	.3502	.5443	.9367	.9716	.3739	.5727	2.6746	.4273	30	1.2130
0.3607	40	.3529	.5477	.9356	.9711	.3772	.5766	2.6511	.4234	20	1.2101
0.3636	50	.3557	.5510	.9346	.9706	.3805	.5804	2.6279	.4196	10	1.2072
0.3665	21°00′	.3584	9.5543	.9336	9.9702	.3839	9.5842	2.6051	0.4158	69°00′	1.2043
0.3694	10	.3611	.5576	.9325	.9697	.3872	.5879	2.5826	.4121	50	1.2014
0.3723	20	.3638	.5609	.9315	.9692	.3906	.5917	2.5605	.4083	40	1.1985
0.3752	30	.3665	.5641	.9304	.9687	.3939	.5954	2.5386	.4046	30	1.1956
0.3782	40	.3692	.5673	.9293	.9682	.3973	.5991	2.5172	.4009	20	1.1926
0.3811	50	.3719	.5704	.9283	.9677	.4006	.6028	2.4960	.3972	10	1.1897
0.3840	22°00′	.3746	9.5736	.9272	9.9672	.4040	9.6064	2.4751	0.3936	68°00′	1.1868
0.3869	10	.3773	.5767	.9261	.9667	.4074	.6100	2.4545	.3900	50	1.1839
0.3898	20	.3800	.5798	.9250	.9661	.4108	.6136	2.4342	.3864	40	1.1810
0.3927	30	.3827	.5828	.9239	.9656	.4142	.6172	2.4142	.3828	30	1.1781
0.3956	40	.3854	.5859	.9228	.9651	.4176	.6208	2.3945	.3792	20	1.1752
0.3985	50	.3881	.5889	.9216	.9646	.4210	.6243	2.3750	.3757	10	1.1723
0.4014	23°00′	.3907	9.5919	.9205	9.9640	.4245	9.6279	2.3559	0.3721	67°00′	1.1694
0.4043	10	.3934	.5948	.9194	.9635	.4279	.6314	2.3369	.3686	50	1.1665
0.4072	20	.3961	.5978	.9182	.9629	.4314	.6348	2.3183	.3652	40	1.1636
0.4102	30	.3987	.6007	.9171	.9624	.4348	.6383	2.2998	.3617	30	1.1606
0.4131	40	.4014	.6036	.9159	.9618	.4383	.6417	2.2817	.3583	20	1.1577
0.4160	50	.4041	.6065	.9147	.9613	.4417	.6452	2.2637	.3548	10	1.1548
0.4189	24°00′	.4067	9.6093	.9135	9.9607	.4452	9.6486	2.2460	0.3514	66°00′	1.1519
0.4218	10	.4094	.6121	.9124	.9602	.4487	.6520	2.2286	.3480	50	1.1490
0.4247	20	.4120	.6149	.9112	.9596	.4522	.6553	2.2113	.3447	40	1.1461
0.4276	30	.4147	.6177	.9100	.9590	.4557	.6587	2.1943	.3413	30	1.1432
0.4305	40	.4173	.6205	.9088	.9584	.4592	.6620	2.1775	.3380	20	1.1403
0.4334	50	.4200	.6232	.9075	.9579	.4628	.6654	2.1609	.3346	10	1.1374
0.4363	25°00′	.4226	9.6259	.9063	9.9573	.4663	9.6687	2.1445	0.3313	65°00′	1.1345
0.4392	10	.4253	.6286	.9051	.9567	.4699	.6720	2.1283	.3280	50	1.1316
0.4422	20	.4279	.6313	.9038	.9561	.4734	.6752	2.1123	.3248	40	1.1286
0.4451	30	.4305	.6340	.9026	.9555	.4770	.6785	2.0965	.3215	30	1.1257
0.4480	40	.4331	.6366	.9013	.9549	.4806	.6817	2.0809	.3183	20	1.1228
0.4509	50	.4358	.6392	.9001	.9543	.4841	.6850	2.0655	.3150	10	1.1199
0.4538	26°00′	.4384	9.6418	.8988	9.9537	.4877	9.6882	2.0503	0.3118	64°00′	1.1170
0.4567	10	.4410	.6444	.8975	.9530	.4913	.6914	2.0353	.3086	50	1.1141
0.4596	20	.4436	.6470	.8962	.9524	.4950	.6946	2.0204	.3054	40	1.1112
0.4625	30	.4462	.6495	.8949	.9518	.4986	.6977	2.0057	.3023	30	1.1083
0.4654	40	.4488	.6521	.8936	.9512	.5022	.7009	1.9912	.2991	20	1.1054
0.4683	50	.4514	.6546	.8923	.9505	.5059	.7040	1.9768	.2960	10	1.1025
0.4712	27°00′	.4540	9.6570	.8910	9.9499	.5095	9.7072	1.9626	0.2928	63°00′	1.0996
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	DEGREES.	RADIANS.
		COSINES.		SINES.		COTANGENTS.		TANGENTS.			

CIRCULAR (TRIGONOMETRIC) FUNCTIONS.

RADIANS.	DEGREES.	SINES.		COSINES.		TANGENTS.		COTANGENTS.			
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.		
0.4712	27°00′	.4540	9.6570	.8910	9.9499	.5095	9.7072	1.9626	0.2928	63°00′	1.0996
0.4741	10	.4566	.6595	.8897	.9492	.5132	.7103	1.9486	.2897	50	1.0966
0.4771	20	.4592	.6620	.8884	.9486	.5169	.7134	1.9347	.2866	40	1.0937
0.4800	30	.4617	.6644	.8870	.9479	.5206	.7165	1.9210	.2835	30	1.0908
0.4829	40	.4643	.6668	.8857	.9473	.5243	.7196	1.9074	.2804	20	1.0879
0.4858	50	.4669	.6692	.8843	.9466	.5280	.7226	1.8940	.2774	10	1.0850
0.4887	28°00′	.4695	9.6716	.8829	9.9459	.5317	9.7257	1.8807	0.2743	62°00′	1.0821
0.4916	10	.4720	.6740	.8816	.9453	.5354	.7287	1.8676	.2713	50	1.0792
0.4945	20	.4746	.6763	.8802	.9446	.5392	.7317	1.8546	.2683	40	1.0763
0.4974	30	.4772	.6787	.8788	.9439	.5430	.7348	1.8418	.2652	30	1.0734
0.5003	40	.4797	.6810	.8774	.9432	.5467	.7378	1.8291	.2622	20	1.0705
0.5032	50	.4823	.6833	.8760	.9425	.5505	.7408	1.8165	.2592	10	1.0676
0.5061	29°00′	.4848	9.6856	.8746	9.9418	.5543	9.7438	1.8040	0.2562	61°00′	1.0647
0.5091	10	.4874	.6878	.8732	.9411	.5581	.7467	1.7917	.2533	50	1.0617
0.5120	20	.4899	.6901	.8718	.9404	.5619	.7497	1.7796	.2503	40	1.0588
0.5149	30	.4924	.6923	.8704	.9397	.5658	.7526	1.7675	.2474	30	1.0559
0.5178	40	.4950	.6946	.8689	.9390	.5696	.7556	1.7556	.2444	20	1.0530
0.5207	50	.4975	.6968	.8675	.9383	.5735	.7585	1.7437	.2415	10	1.0501
0.5236	30°00′	.5000	9.6990	.8660	9.9375	.5774	9.7614	1.7321	0.2386	60°00′	1.0472
0.5265	10	.5025	.7012	.8646	.9368	.5812	.7644	1.7205	.2356	50	1.0443
0.5294	20	.5050	.7033	.8631	.9361	.5851	.7673	1.7090	.2327	40	1.0414
0.5323	30	.5075	.7055	.8616	.9353	.5890	.7701	1.6977	.2299	30	1.0385
0.5352	40	.5100	.7076	.8601	.9346	.5930	.7730	1.6864	.2270	20	1.0356
0.5381	50	.5125	.7097	.8587	.9338	.5969	.7759	1.6753	.2241	10	1.0327
0.5411	31°00′	.5150	9.7118	.8572	9.9331	.6009	9.7788	1.6643	0.2212	59°00′	1.0297
0.5440	10	.5175	.7139	.8557	.9323	.6048	.7816	1.6534	.2184	50	1.0268
0.5469	20	.5200	.7160	.8542	.9315	.6088	.7845	1.6426	.2155	40	1.0239
0.5498	30	.5225	.7181	.8526	.9308	.6128	.7873	1.6319	.2127	30	1.0210
0.5527	40	.5250	.7201	.8511	.9300	.6168	.7902	1.6212	.2098	20	1.0181
0.5556	50	.5275	.7222	.8496	.9292	.6208	.7930	1.6107	.2070	10	1.0152
0.5585	32°00′	.5299	9.7242	.8480	9.9284	.6249	9.7958	1.6003	0.2042	58°00′	1.0123
0.5614	10	.5324	.7262	.8465	.9276	.6289	.7986	1.5900	.2014	50	1.0094
0.5643	20	.5348	.7282	.8450	.9268	.6330	.8014	1.5798	.1986	40	1.0065
0.5672	30	.5373	.7302	.8434	.9260	.6371	.8042	1.5697	.1958	30	1.0036
0.5701	40	.5398	.7322	.8418	.9252	.6412	.8070	1.5597	.1930	20	1.0007
0.5730	50	.5422	.7342	.8403	.9244	.6453	.8097	1.5497	.1903	10	0.9977
0.5760	33°00′	.5446	9.7361	.8387	9.9236	.6494	9.8125	1.5399	0.1875	57°00′	0.9948
0.5789	10	.5471	.7380	.8371	.9228	.6536	.8153	1.5301	.1847	50	0.9919
0.5818	20	.5495	.7400	.8355	.9219	.6577	.8180	1.5204	.1820	40	0.9890
0.5847	30	.5519	.7419	.8339	.9211	.6619	.8208	1.5108	.1792	30	0.9861
0.5876	40	.5544	.7438	.8323	.9203	.6661	.8235	1.5013	.1765	20	0.9832
0.5905	50	.5568	.7457	.8307	.9194	.6703	.8263	1.4919	.1737	10	0.9803
0.5934	34°00′	.5592	9.7476	.8290	9.9186	.6745	9.8290	1.4826	0.1710	56°00′	0.9774
0.5963	10	.5616	.7494	.8274	.9177	.6787	.8317	1.4733	.1683	50	0.9745
0.5992	20	.5640	.7513	.8258	.9169	.6830	.8344	1.4641	.1656	40	0.9716
0.6021	30	.5664	.7531	.8241	.9160	.6873	.8371	1.4550	.1629	30	0.9687
0.6050	40	.5688	.7550	.8225	.9151	.6916	.8398	1.4460	.1602	20	0.9657
0.6080	50	.5712	.7568	.8208	.9142	.6959	.8425	1.4370	.1575	10	0.9628
0.6109	35°00′	.5736	9.7586	.8192	9.9134	.7002	9.8452	1.4281	0.1548	55°00′	0.9599
0.6138	10	.5760	.7604	.8175	.9125	.7046	.8479	1.4193	.1521	50	0.9570
0.6167	20	.5783	.7622	.8158	.9116	.7089	.8506	1.4106	.1494	40	0.9541
0.6196	30	.5807	.7640	.8141	.9107	.7133	.8533	1.4019	.1467	30	0.9512
0.6225	40	.5831	.7657	.8124	.9098	.7177	.8559	1.3934	.1441	20	0.9483
0.6254	50	.5854	.7675	.8107	.9089	.7221	.8586	1.3848	.1414	10	0.9454
0.6283	36°00′	.5878	9.7692	.8090	9.9080	.7265	9.8613	1.3764	0.1387	54°00′	0.9425
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	DEGREES.	RADIANS.
		COSINES.		SINES.		COTANGENTS.		TANGENTS.			

Table 13 (*continued*).

CIRCULAR (TRIGONOMETRIC) FUNCTIONS.

RADIANS.	DEGREES.	SINES.		COSINES.		TANGENTS.		COTANGENTS.			
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.		
0.6283	36°00′	.5878	9.7692	.8090	9.9080	.7265	9.8613	1.3764	0.1387	54°00′	0.9425
0.6312	10	.5901	.7710	.8073	.9070	.7310	.8639	1.3680	.1361	50	0.9396
0.6341	20	.5925	.7727	.8056	.9061	.7355	.8666	1.3597	.1334	40	0.9367
0.6370	30	.5948	.7744	.8039	.9052	.7400	.8692	1.3514	.1308	30	0.9338
0.6400	40	.5972	.7761	.8021	.9042	.7445	.8718	1.3432	.1282	20	0.9308
0.6429	50	.5995	.7778	.8004	.9033	.7490	.8745	1.3351	.1255	10	0.9279
0.6458	37°00′	.6018	9.7795	.7986	9.9023	.7536	9.8771	1.3270	0.1229	53°00′	0.9250
0.6487	10	.6041	.7811	.7969	.9014	.7581	.8797	1.3190	.1203	50	0.9221
0.6516	20	.6065	.7828	.7951	.9004	.7627	.8824	1.3111	.1176	40	0.9192
0.6545	30	.6088	.7844	.7934	.8995	.7673	.8850	1.3032	.1150	30	0.9163
0.6574	40	.6111	.7861	.7916	.8985	.7720	.8876	1.2954	.1124	20	0.9134
0.6603	50	.6134	.7877	.7898	.8975	.7766	.8902	1.2876	.1098	10	0.9105
0.6632	38°00′	.6157	9.7893	.7880	9.8965	.7813	9.8928	1.2799	0.1072	52°00′	0.9076
0.6661	10	.6180	.7910	.7862	.8955	.7860	.8954	1.2723	.1046	50	0.9047
0.6690	20	.6202	.7926	.7844	.8945	.7907	.8980	1.2647	.1020	40	0.9018
0.6720	30	.6225	.7941	.7826	.8935	.7954	.9006	1.2572	.0994	30	0.8988
0.6749	40	.6248	.7957	.7808	.8925	.8002	.9032	1.2497	.0968	20	0.8959
0.6778	50	.6271	.7973	.7790	.8915	.8050	.9058	1.2423	.0942	10	0.8930
0.6807	39°00′	.6293	9.7989	.7771	9.8905	.8098	9.9084	1.2349	0.0916	51°00′	0.8901
0.6836	10	.6316	.8004	.7753	.8895	.8146	.9110	1.2276	.0890	50	0.8872
0.6865	20	.6338	.8020	.7735	.8884	.8195	.9135	1.2203	.0865	40	0.8843
0.6894	30	.6361	.8035	.7716	.8874	.8243	.9161	1.2131	.0839	30	0.8814
0.6923	40	.6383	.8050	.7698	.8864	.8292	.9187	1.2059	.0813	20	0.8785
0.6952	50	.6406	.8066	.7679	.8853	.8342	.9212	1.1988	.0788	10	0.8756
0.6981	40°00′	.6428	9.8081	.7660	9.8843	.8391	9.9238	1.1918	0.0762	50°00′	0.8727
0.7010	10	.6450	.8096	.7642	.8832	.8441	.9264	1.1847	.0736	50	0.8698
0.7039	20	.6472	.8111	.7623	.8821	.8491	.9289	1.1778	.0711	40	0.8668
0.7069	30	.6494	.8125	.7604	.8810	.8541	.9315	1.1708	.0685	30	0.8639
0.7098	40	.6517	.8140	.7585	.8800	.8591	.9341	1.1640	.0659	20	0.8610
0.7127	50	.6539	.8155	.7566	.8789	.8642	.9366	1.1571	.0634	10	0.8581
0.7156	41°00′	.6561	9.8169	.7547	9.8778	.8693	9.9392	1.1504	0.0608	49°00′	0.8552
0.7185	10	.6583	.8184	.7528	.8767	.8744	.9417	1.1436	.0583	50	0.8523
0.7214	20	.6604	.8198	.7509	.8756	.8796	.9443	1.1369	.0557	40	0.8494
0.7243	30	.6626	.8213	.7490	.8745	.8847	.9468	1.1303	.0532	30	0.8465
0.7272	40	.6648	.8227	.7470	.8733	.8899	.9494	1.1237	.0506	20	0.8436
0.7301	50	.6670	.8241	.7451	.8722	.8952	.9519	1.1171	.0481	10	0.8407
0.7330	42°00′	.6691	9.8255	.7431	9.8711	.9004	9.9544	1.1106	0.0456	48°00′	0.8378
0.7359	10	.6713	.8269	.7412	.8699	.9057	.9570	1.1041	.0430	50	0.8348
0.7389	20	.6734	.8283	.7392	.8688	.9110	.9595	1.0977	.0405	40	0.8319
0.7418	30	.6756	.8297	.7373	.8676	.9163	.9621	1.0913	.0379	30	0.8290
0.7447	40	.6777	.8311	.7353	.8665	.9217	.9646	1.0850	.0354	20	0.8261
0.7476	50	.6799	.8324	.7333	.8653	.9271	.9671	1.0786	.0329	10	0.8232
0.7505	43°00′	.6820	9.8338	.7314	9.8641	.9325	9.9697	1.0724	0.0303	47°00′	0.8203
0.7534	10	.6841	.8351	.7294	.8629	.9380	.9722	1.0661	.0278	50	0.8174
0.7563	20	.6862	.8365	.7274	.8618	.9435	.9747	1.0599	.0253	40	0.8145
0.7592	30	.6884	.8378	.7254	.8606	.9490	.9772	1.0538	.0228	30	0.8116
0.7621	40	.6905	.8391	.7234	.8594	.9545	.9798	1.0477	.0202	20	0.8087
0.7650	50	.6926	.8405	.7214	.8582	.9601	.9823	1.0416	.0177	10	0.8058
0.7679	44°00′	.6947	9.8418	.7193	9.8569	.9657	9.9848	1.0355	0.0152	46°00′	0.8029
0.7709	10	.6967	.8431	.7173	.8557	.9713	.9874	1.0295	.0126	50	0.7999
0.7738	20	.6988	.8444	.7153	.8545	.9770	.9899	1.0235	.0101	40	0.7970
0.7767	30	.7009	.8457	.7133	.8532	.9827	.9924	1.0176	.0076	30	0.7941
0.7796	40	.7030	.8469	.7112	.8520	.9884	.9949	1.0117	.0051	20	0.7912
0.7825	50	.7050	.8482	.7092	.8507	.9942	.9975	1.0058	.0025	10	0.7883
0.7854	45°00′	.7071	9.8495	.7071	9.8495	1.0000	0.0000	1.0000	0.0000	45°00′	0.7854
		Nat.	Log.	Nat	Log.	Nat.	Log.	Nat.	Log.	DEGREES.	RADIANS.
		COSINES.		SINES.		COTANGENTS.		TANGENTS.			

Smithsonian Tables.

TABLE 14.

CIRCULAR (TRIGONOMETRIC) FUNCTIONS.

RADIANS.	SINES.		COSINES.		TANGENTS		COTANGENTS.		DEGREES
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
0.00	0.00000	— ∞	1.00000	0.00000	— ∞	— ∞	∞	∞	00°00′
.01	.01000	7.99999	0.99995	9.99998	0.01000	8.00001	99.997	1.99999	00 34
.02	.02000	8.30100	.99980	.99991	.02000	.30109	49.993	.69891	01 09
.03	.03000	.47706	.99955	.99980	.03001	.47725	33.323	.52275	01 43
.04	.03999	.60194	.99920	.99965	.04002	.60229	24.987	.39771	02 18
0.05	0.04998	8.69879	0.99875	9.99946	0.05004	8.69933	19.983	1.30067	02°52′
.06	.05996	.77789	.99820	.99922	.06007	.77867	16.647	.22133	03 26
.07	.06994	.84474	.99755	.99894	.07011	.84581	14.262	.15419	04 01
.08	.07991	.90263	.99680	.99861	.08017	.90402	12.473	.09598	04 35
.09	.08988	.95366	.99595	.99824	.09024	.95542	11.081	.04458	05 09
0.10	0.09983	8.99928	0.99500	9.99782	0.10033	9.00145	9.9666	0.99855	05°44′
.11	.10978	9.04052	.99396	.99737	.11045	.04315	9.0542	.95685	06 18
.12	.11971	.07814	.99281	.99687	.12058	.08127	8.2933	.91873	06 53
.13	.12963	.11272	.99156	.99632	.13074	.11640	7.6489	.88360	07 27
.14	.13954	.14471	.99022	.99573	.14092	.14898	7.0961	.85102	08 01
0.15	0.14944	9.17446	0.98877	9.99510	0.15114	9.17937	6.6166	0.82063	08°36′
.16	.15932	.20227	.98723	.99442	.16138	.20785	6.1966	.79215	09 10
.17	.16918	.22836	.98558	.99369	.17166	.23466	5.8256	.76534	09 44
.18	.17903	.25292	.98384	.99293	.18197	.26000	5.4954	.74000	10 19
.19	.18886	.27614	.98200	.99211	.19232	.28402	5.1997	.71598	10 53
0.20	0.19867	9.29813	0.98007	9.99126	0.20271	9.30688	4.9332	0.69312	11°28′
.21	.20846	.31902	.97803	.99035	.21314	.32867	4.6917	.67133	12 02
.22	.21823	.33891	.97590	.98940	.22362	.34951	4.4719	.65049	12 36
.23	.22798	.35789	.97367	.98841	.23414	.36948	4.2709	.63052	13 11
.24	.23770	.37603	.97134	.98737	.24472	.38866	4.0864	.61134	13 45
0.25	0.24740	9.39341	0.96891	9.98628	0.25534	9.40712	3.9163	0.59288	14°19′
.26	.25708	.41007	.96639	.98515	.26602	.42491	3.7592	.57509	14 54
.27	.26673	.42607	.96377	.98397	.27676	.44210	3.6133	.55790	15 28
.28	.27636	.44147	.96106	.98275	.28755	.45872	3.4776	.54128	16 03
.29	.28595	.45629	.95824	.98148	.29841	.47482	3.3511	.52518	16 37
0.30	0.29552	9.47059	0.95534	9.98016	0.30934	9.49043	3.2327	0.50957	17°11′
.31	.30506	.48438	.95233	.97879	.32033	.50559	3.1218	.49441	17 46
.32	.31457	.49771	.94924	.97737	.33139	.52034	3.0176	.47966	18 20
.33	.32404	.51060	.94604	.97591	.34252	.53469	2.9195	.46531	18 54
.34	.33349	.52308	.94275	.97440	.35374	.54868	2.8270	.45132	19 29
0.35	0.34290	9.53516	0.93937	9.97284	0.36503	9.56233	2.7395	0.43767	20°03′
.36	.35227	.54688	.93590	.97123	.37640	.57565	2.6567	.42435	20 38
.37	.36162	.55825	.93233	.96957	.38786	.58868	2.5782	.41132	21 12
.38	.37092	.56928	.92866	.96786	.39941	.60142	2.5037	.39858	21 46
.39	.38019	.58000	.92491	.96610	.41105	.61390	2.4328	.38610	22 21
0.40	0.38942	9.59042	0.92106	9.96429	0.42279	9.62613	2.3652	0.37387	22°55′
.41	.39861	.60055	.91712	.96243	.43463	.63812	2.3008	.36188	23 29
.42	.40776	.61041	.91309	.96051	.44657	.64989	2.2393	.35011	24 04
.43	.41687	.62000	.90897	.95855	.45862	.66145	2.1804	.33855	24 38
.44	.42594	.62935	.90475	.95653	.47078	.67282	2.1241	.32718	25 13
0.45	0.43497	9.63845	0.90045	9.95446	0.48306	9.68400	2.0702	0.31600	25°47′
.46	.44395	.64733	.89605	.95233	.49545	.69500	2.0184	.30500	26 21
.47	.45289	.65599	.89157	.95015	.50797	.70583	1.9686	.29417	26 56
.48	.46178	.66443	.88699	.94792	.52061	.71651	1.9208	.28349	27 30
.49	.47063	.67268	.88233	.94563	.53339	.72704	1.8748	.27296	28 04
0 50	0.47943	9.68072	0.87758	9.94329	0.54630	9.73743	1.8305	0.26257	28°39′

CIRCULAR (TRIGONOMETRIC) FUNCTIONS.

RADIANS.	SINES.		COSINES.		TANGENTS.		COTANGENTS.		DEGREES.
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
0.50	0.47943	9.68072	0.87758	9.94329	0.54630	9.73743	1.8305	0.26257	28°39′
.51	.48818	.68858	.87274	.94089	.55936	.74769	.7878	.25231	29 13
.52	.49688	.69625	.86782	.93843	.57256	.75782	.7465	.24218	29 48
.53	.50553	.70375	.86281	.93591	.58592	.76784	.7067	.23216	30 22
.54	.51414	.71108	.85771	.93334	.59943	.77774	.6683	.22226	30 56
0.55	0.52269	9.71824	0.85252	9.93071	0.61311	9.78754	1.6310	0.21246	31°31′
.56	.53119	.72525	.84726	.92801	.62695	.79723	.5950	.20277	32 05
.57	.53963	.73210	.84190	.92526	.64097	.80684	.5601	.19316	32 40
.58	.54802	.73880	.83646	.92245	.65517	.81635	.5263	.18365	33 14
.59	.55636	.74536	.83094	.91957	.66956	.82579	.4935	.17421	33 48
0.60	0.56464	9.75177	0.82534	9.91663	0.68414	9.83514	1.4617	0.16486	34°23′
.61	.57287	.75805	.81965	.91363	.69892	.84443	.4308	.15557	34 57
.62	.58104	.76420	.81388	.91056	.71391	.85364	.4007	.14636	35 31
.63	.58914	.77022	.80803	.90743	.72911	.86280	.3715	.13720	36 06
.64	.59720	.77612	.80210	.90423	.74454	.87189	.3431	.12811	36 40
0.65	0.60519	9.78189	0.79608	9.90096	0.76020	9.88093	1.3154	0.11907	37°15′
.66	.61312	.78754	.78999	.89762	.77610	.88992	.2885	.11008	37 49
.67	.62099	.79308	.78382	.89422	.79225	.89886	.2622	.10114	38 23
.68	.62879	.79851	.77757	.89074	.80866	.90777	.2366	.09223	38 58
.69	.63654	.80382	.77125	.88719	.82534	.91663	.2116	.08337	39 32
0.70	0.64422	9.80903	0.76484	9.88357	0.84229	9.92546	1.1872	0.07454	40°06′
.71	.65183	.81414	.75836	.87988	.85953	.93426	.1634	.06574	40 41
.72	.65938	.81914	.75181	.87611	.87707	.94303	.1402	.05697	41 15
.73	.66687	.82404	.74517	.87226	.89492	.95178	.1174	.04822	41 50
.74	.67429	.82885	.73847	.86833	.91309	.96051	.0952	.03949	42 24
0.75	0.68164	9.83355	0.73169	9.86433	0.93160	9.96923	1.0734	0.03077	42°58′
.76	.68892	.83817	.72484	.86024	.95045	.97793	.0521	.02207	43 33
.77	.69614	.84269	.71791	.85607	.96967	.98662	.0313	.01338	44 07
.78	.70328	.84713	.71091	.85182	.98926	9.99531	1.0109	.00469	44 41
.79	.71035	.85147	.70385	.84748	1.0092	0.00400	0.99084	9.99600	45 16
0.80	0.71736	9.85573	0.69671	9.84305	1.0296	0.01268	0.97121	9.98732	45°50′
.81	.72429	.85991	.68950	.83853	.0505	.02138	.95197	.97862	46 25
.82	.73115	.86400	.68222	.83393	.0717	.03008	.93309	.96992	46 59
.83	.73793	.86802	.67488	.82922	.0934	.03879	.91455	.96121	47 33
.84	.74464	.87195	.66746	.82443	.1156	.04752	.89635	.95248	48 08
0.85	0.75128	9.87580	0.65998	9.81953	1.1383	0.05627	0.87848	9.94373	48°42′
.86	.75784	.87958	.65244	.81454	.1616	.06504	.86091	.93496	49 16
.87	.76433	.88328	.64483	.80944	.1853	.07384	.84365	.92616	49 51
.88	.77074	.88691	.63715	.80424	.2097	.08266	.82668	.91734	50 25
.89	.77707	.89046	.62941	.79894	.2346	.09153	.80998	.90847	51 00
0.90	0.78333	9.89394	0.62161	9.79352	1.2602	0.10043	0.79355	9.89957	51°34′
.91	.78950	.89735	.61375	.78799	.2864	.10937	.77738	.89063	52 08
.92	.79560	.90070	.60582	.78234	.3133	.11835	.76146	.88165	52 43
.93	.80162	.90397	.59783	.77658	.3409	.12739	.74578	.87261	53 17
.94	.80756	.90717	.58979	.77070	.3692	.13648	.73034	.86352	53 51
0.95	0.81342	9.91031	0.58168	9.76469	1.3984	0.14563	0.71511	9.85437	54°26′
.96	.81919	.91339	.57352	.75855	.4284	.15484	.70010	.84516	55 00
.97	.82489	.91639	.56530	.75228	.4592	.16412	.68531	.83588	55 35
.98	.83050	.91934	.55702	.74587	.4910	.17347	.67071	.82653	56 09
.99	.83603	.92222	.54869	.73933	.5237	.18289	.65631	.81711	56 43
1.00	0.84147	9.92504	0.54030	9.73264	1.5574	0.19240	0.64209	9.80760	57°18′

CIRCULAR (TRIGONOMETRIC) FUNCTIONS.

RADIANS.	SINES.		COSINES.		TANGENTS.		COTANGENTS.		DEGREES.
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
1.00	0.84147	9.92504	0.54030	9.73264	1.5574	0.19240	0.64209	9.80760	57°18′
.01	.84683	.92780	.53186	.72580	.5922	.20200	.62806	.79800	57 52
.02	.85211	.93049	.52337	.71881	.6281	.21169	.61420	.78831	58 27
.03	.85730	.93313	.51482	.71165	.6652	.22148	.60051	.77852	59 01
.04	.86240	.93571	.50622	.70434	.7036	.23137	.58699	.76863	59 35
1.05	0.86742	9.93823	0.49757	9.69686	1.7433	0.24138	0.57362	9.75862	60°10′
.06	.87236	.94069	.48887	.68920	.7844	.25150	.56040	.74850	60 44
.07	.87720	.94310	.48012	.68135	.8270	.26175	.54734	.73825	61 18
.08	.88196	.94545	.47133	.67332	.8712	.27212	.53441	.72788	61 53
.09	.88663	.94774	.46249	.66510	.9171	.28264	.52162	.71736	62 27
1.10	0.89121	9.94998	0.45360	9.65667	1.9648	0.29331	0.50897	9.70669	63°02′
.11	.89570	.95216	.44466	.64803	2.0143	.30413	.49644	.69587	63 36
.12	.90010	.95429	.43568	.63917	.0660	.31512	.48404	.68488	64 10
.13	.90441	.95637	.42666	.63008	.1198	.32628	.47175	.67372	64 45
.14	.90863	.95839	.41759	.62075	.1759	.33763	.45959	.66237	65 19
1.15	0.91276	9.96036	0.40849	9.61118	2.2345	0.34918	0.44753	9.65082	65°53′
.16	.91680	.96228	.39934	.60134	.2958	.36093	.43558	.63907	66 28
.17	.92075	.96414	.39015	.59123	.3600	.37291	.42373	.62709	67 02
.18	.92461	.96596	.38092	.58084	.4273	.38512	.41199	.61488	67 37
.19	.92837	.96772	.37166	.57015	.4979	.39757	.40034	.60243	68 11
1.20	0.93204	9.96943	0.36236	9.55914	2.5722	0.41030	0.38878	9.58970	68°45′
.21	.93562	.97110	.35302	.54780	.6503	.42330	.37731	.57670	69 20
.22	.93910	.97271	.34365	.53611	.7328	.43660	.36593	.56340	69 54
.23	.94249	.97428	.33424	.52406	.8198	.45022	.35463	.54978	70 28
.24	.94578	.97579	.32480	.51161	.9119	.46418	.34341	.53582	71 03
1.25	0.94898	9.97726	0.31532	9.49875	3.0096	0.47850	0.33227	9.52150	71°37′
.26	.95209	.97868	.30582	.48546	.1133	.49322	.32121	.50678	72 12
.27	.95510	.98005	.29628	.47170	.2236	.50835	.31021	.49165	72 46
.28	.95802	.98137	.28672	.45745	.3413	.52392	.29928	.47608	73 20
.29	.96084	.98265	.27712	.44267	.4672	.53998	.28842	.46002	73 55
1.30	0.96356	9.98388	0.26750	9.42732	3.6021	0.55656	0.27762	9.44344	74°29′
.31	.96618	.98506	.25785	.41137	.7471	.57369	.26687	.42631	75 03
.32	.96872	.98620	.24818	.39476	.9033	.59144	.25619	.40856	75 38
.33	.97115	.98729	.23848	.37744	4.0723	.60984	.24556	.39016	76 12
.34	.97348	.98833	.22875	.35937	.2556	.62896	.23498	.37104	76 47
1.35	0.97572	9.98933	0.21901	9.34046	4.4552	0.64887	0.22446	9.35113	77°21′
.36	.97786	.99028	.20924	.32064	.6734	.66964	.21398	.33036	77 55
.37	.97991	.99119	.19945	.29983	.9131	.69135	.20354	.30865	78 30
.38	.98185	.99205	.18964	.27793	5.1774	.71411	.19315	.28589	79 04
.39	.98370	.99286	.17981	.25482	.4707	.73804	.18279	.26196	79 38
1.40	0.98545	9.99363	0.16997	9.23036	5.7979	0.76327	0.17248	9.23673	80°13′
.41	.98710	.99436	.16010	.20440	6.1654	.78996	.16220	.21004	80 47
.42	.98865	.99504	.15023	.17674	6.5811	.81830	.15195	.18170	81 22
.43	.99010	.99568	.14033	.14716	7.0555	.84853	.14173	.15147	81 56
.44	.99146	.99627	.13042	.11536	7.6018	.88092	.13155	.11908	82 30
1.45	0.99271	9.99682	0.12050	9.08100	8.2381	0.91583	0.12139	9.08417	83°05′
.46	.99387	.99733	.11057	.04364	8.9886	.95369	.11125	.04631	83 39
.47	.99492	.99779	.10063	.00271	9.8874	.99508	.10114	.00492	84 13
.48	.99588	.99821	.09067	8.95747	10.983	1.04074	.09105	8.95926	84 48
.49	.99674	.99858	.08071	.90692	12.350	.09166	.08097	.90834	85 22
1.50	0.99749	9.99891	0.07074	8.84965	14.101	1.14926	0.07091	8.85074	85°57′

CIRCULAR FUNCTIONS AND FACTORIALS.

TABLE 14 (*continued*). — Circular (Trigonometric) Functions.

RADIANS.	SINES.		COSINES.		TANGENTS.		COTANGENTS.		DEGREES.
	Nat.	Log	Nat.	Log	Nat.	Log.	Nat.	Log.	
1.50	0.99749	9.99891	0.07074	8.84965	14.101	1.14926	0.07091	8.85074	85°57′
.51	.99815	.99920	.06076	.78361	16.428	.21559	.06087	.78441	86 31
.52	.99871	.99944	.05077	.70565	19.670	.29379	.05084	.70621	87 05
.53	.99917	.99964	.04079	.61050	24.498	.38914	.04082	.61086	87 40
.54	.99953	.99979	.03079	.48843	32.461	.51136	.03081	.48864	88 14
1.55	0.99978	9.99991	0.02079	8.31796	48.078	1.68195	0.02080	8.31805	88°49′
.56	0.99994	9.99997	.01080	8.03327	92.621	1.96671	.01080	8.03329	89 23
.57	1.00000	0.00000	.00080	6.90109	1255.8	3.09891	.00080	6.90109	89 57
.58	0.99996	9.99998	−.00920	7.96396n	108.65	2.03603	−.00920	7.96397n	90 32
.59	0.99982	9.99992	−.01920	8.28336n	52.067	1.71656	−.01921	8.28344n	91 06
1.60	0.99957	9.99981	−0.02920	8.46538n	34.233	1.53444	−0.02921	8.46556n	91°40′

90° = 1.570 7963 radians.

TABLE 15. — Logarithmic Factorials.

Logarithms of the products 1.2.3. …… *n*, *n* from 1 to 100.

See Table 17 for Factorials 1 to 20.

See Table 31 for log. Γ (*n* + 1), values of *n* between 1 and 2.

n.	log (*n!*)	*n*.	log (*n!*)	*n*.	log (*n!*)	*n*.	log (*n!*)
1	0.000000	**26**	26.605619	**51**	66.190645	**76**	111.275425
2	0.301030	27	28.036983	52	67.906648	77	113.161916
3	0.778151	28	29.484141	53	69.630924	78	115.054011
4	1.380211	29	30.946539	54	71.363318	79	116.951638
5	2.079181	30	32.423660	55	73.103681	80	118.854728
6	2.857332	**31**	33.915022	**56**	74.851869	**81**	120.763213
7	3.702431	32	35.420172	57	76.607744	82	122.677027
8	4.605521	33	36.938686	58	78.371172	83	124.596105
9	5.559763	34	38.470165	59	80.142024	84	126.520384
10	6.559763	35	40.014233	60	81.920175	85	128.449803
11	7.601156	**36**	41.570535	**61**	83.705505	**86**	130.384301
12	8.680337	37	43.138737	62	85.497896	87	132.323821
13	9.794280	38	44.718520	63	87.297237	88	134.268303
14	10.940408	39	46.309585	64	89.103417	89	136.217693
15	12.116500	40	47.911645	65	90.916330	90	138.171936
16	13.320620	**41**	49.524429	**66**	92.735874	**91**	140.130977
17	14.551069	42	51.147678	67	94.561949	92	142.094765
18	15.806341	43	52.781147	68	96.394458	93	144.063248
19	17.085095	44	54.424599	69	98.233307	94	146.036376
20	18.386125	45	56.077812	70	100.078405	95	148.014099
21	19.708344	**46**	57.740570	**71**	101.929663	**96**	149.996371
22	21.050767	47	59.412668	72	103.786996	97	151.983142
23	22.412494	48	61.093909	73	105.650319	98	153.974368
24	23.792706	49	62.784105	74	107.519550	99	155.970004
25	25.190646	50	64.483075	75	109.394612	100	157.970004

Table 16.

HYPERBOLIC FUNCTIONS.

u	sinh. u		cosh. u		tanh. u		coth. u		gd u
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
0.00	0.00000	— ∞	1.00000	0.00000	0.00000	— ∞	∞	∞	00°00′
.01	.01000	8.00001	.00005	.00002	.01000	7.99999	100.003	2.00001	0 34
.02	.02000	.30106	.00020	.00009	.02000	8.30097	50.007	1.69903	1 09
.03	.03000	.47719	.00045	.00020	.02999	.47699	33.343	1.52301	1 43
.04	.04001	.60218	.00080	.00035	.03998	.60183	25.013	1.39817	2 17
0.05	0.05002	8.69915	1.00125	0.00054	0.04996	8.69861	20.017	1.30139	2 52
.06	.06004	.77841	.00180	.00078	.05993	.77763	16.687	.22237	3 26
.07	.07006	.84545	.00245	.00106	.06989	.84439	14.309	.15561	4 00
.08	.08009	.90355	.00320	.00139	.07983	.90216	12.527	.09784	4 35
.09	.09012	.95483	.00405	.00176	.08976	.95307	11.141	.04693	5 09
0.10	0.10017	9.00072	1.00500	0.00217	0.09967	8.99856	10.0333	1.00144	5 43
.11	.11022	.04227	.00606	.00262	.10956	9.03965	9.1275	0.96035	6 17
.12	.12029	.08022	.00721	.00312	.11943	.07710	8.3733	.92290	6 52
.13	.13037	.11517	.00846	.00366	.12927	.11151	7.7356	.88849	7 26
.14	.14046	.14755	.00982	.00424	.13909	.14330	7.1895	.85670	8 00
0.15	0.15056	9.17772	1.01127	0.00487	0.14889	9.17285	6.7166	0.82715	8 34
.16	.16068	.20597	.01283	.00554	.15865	.20044	6.3032	.79956	9 08
.17	.17082	.23254	.01448	.00625	.16838	.22629	5.9389	.77371	9 42
.18	.18097	.25762	.01624	.00700	.17808	.25062	5.6154	.74938	10 15
.19	.19115	.28136	.01810	.00779	.18775	.27357	5.3263	.72643	10 49
0.20	0.20134	9.30392	1.02007	0.00863	0.19738	9.29529	5.0665	0.70471	11 23
.21	.21155	.32541	.02213	.00951	.20697	.31590	4.8317	.68410	11 57
.22	.22178	.34592	.02430	.01043	.21652	.33549	4.6186	.66451	12 30
.23	.23203	.36555	.02657	.01139	.22603	.35416	4.4242	.64584	13 04
.24	.24231	.38437	.02894	.01239	.23550	.37198	4.2464	.62802	13 37
0.25	0.25261	9.40245	1.03141	0.01343	0.24492	9.38902	4.0830	0.61098	14 11
.26	.26294	.41986	.03399	.01452	.25430	.40534	3.9324	.59466	14 44
.27	.27329	.43663	.03667	.01564	.26362	.42099	3.7933	.57901	15 17
.28	.28367	.45282	.03946	.01681	.27291	.43601	3.6643	.56399	15 50
.29	.29408	.46847	.04235	.01801	.28213	.45046	3.5444	.54954	16 23
0.30	0.30452	9.48362	1.04534	0.01926	0.29131	9.46436	3.4327	0.53564	16 56
.31	.31499	.49830	.04844	.02054	.30044	.47775	.3285	.52225	17 29
.32	.32549	.51254	.05164	.02187	.30951	.49067	.2309	.50933	18 02
.33	.33602	.52637	.05495	.02323	.31852	.50314	.1395	.49686	18 34
.34	.34659	.53981	.05836	.02463	.32748	.51518	.0536	.48482	19 07
0.35	0.35719	9.55290	1.06188	0.02607	0.33638	9.52682	2.9729	0.47318	19 39
.36	.36783	.56564	.06550	.02755	.34521	.53809	.8968	.46191	20 12
.37	.37850	.57807	.06923	.02907	.35399	.54899	.8249	.45101	20 44
.38	.38921	.59019	.07307	.03063	.36271	.55956	.7570	.44044	21 16
.39	.39996	.60202	.07702	.03222	.37136	.56980	.6928	.43020	21 48
0.40	0.41075	9.61358	1.08107	0.03385	0.37995	9.57973	2.6319	0.42027	22 20
.41	.42158	.62488	.08523	.03552	.38847	.58936	.5742	.41064	22 52
.42	.43246	.63594	.08950	.03723	.39693	.59871	.5193	.40129	23 23
.43	.44337	.64677	.09388	.03897	.40532	.60780	.4672	.39220	23 55
.44	.45434	.65738	.09837	.04075	.41364	.61663	.4175	.38337	24 26
0.45	0.46534	9.66777	1.102970	.04256	0.42190	9.62521	2.3702	0.37479	24 57
.46	.47640	.67797	.10768	.04441	.43008	.63355	.3251	.36645	25 28
.47	.48750	.68797	.11250	.04630	.43820	.64167	.2821	.35833	25 59
.48	.49865	.69779	.11743	.04822	.44624	.64957	.2409	.35043	26 30
.49	.50984	.70744	.12247	.05018	.45422	.65726	.2016	.34274	27 01
0.50	0.52110	9.71692	1.12763	0.05217	0.46212	9.66475	2.1640	0.33525	27 31

Table 16 *(continued).*

HYBERBOLIC FUNCTIONS.

u	sinh. u		cosh. u		tanh. u		coth. u		gd u
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
0.50	0.52110	9.71692	1.12763	0.05217	0.46212	9.66475	2.1640	0.33525	27°31′
.51	.53240	.72624	.13289	.05419	.46995	.67205	.1279	.32795	28 02
.52	.54375	.73540	.13827	.05625	.47770	.67916	.0934	.32084	28 32
.53	.55516	.74442	.14377	.05834	.48538	.68608	.0602	.31392	29 02
.54	.56663	.75330	.14938	.06046	.49299	.69284	.0284	.30716	29 32
0.55	0.57815	9.76204	1.15510	0.06262	0.50052	9.69942	1.9979	0.30058	30 02
.56	.58973	.77065	.16094	.06481	.50798	.70584	.9686	.29416	30 32
.57	.60137	.77914	.16690	.06703	.51536	.71211	.9404	.28789	31 01
.58	.61307	.78751	.17297	.06929	.52267	.71822	.9133	.28178	31 31
.59	.62483	.79576	.17916	.07157	.52990	.72419	.8872	.27581	32 00
0.60	0.63665	9.80390	1.18547	0.07389	0.53705	9.73001	1.8620	0.26999	32 29
.61	.64854	.81194	.19189	.07624	.54413	.73570	.8378	.26430	32 58
.62	.66049	.81987	.19844	.07861	.55113	.74125	.8145	.25875	33 27
63	.67251	.82770	.20510	.08102	.55805	.74667	.7919	.25333	33 55
.64	.68459	.83543	.21189	.08346	.56490	.75197	.7702	.24803	34 24
0.65	0.69675	9.84308	1.21879	0.08593	0.57167	9.75715	1.7493	0.24285	34 52
.66	.70897	.85063	.22582	.08843	.57836	.76220	.7290	.23780	35 20
.67	.72126	.85809	.23297	.09095	.58498	.76714	.7095	.23286	35 48
.68	.73363	.86548	.24025	.09351	.59152	.77197	.6906	.22803	36 16
.69	.74607	.87278	.24765	.09609	.59798	.77669	.6723	.22331	36 44
0 70	0.75858	9.88000	1.25517	0.09870	0.60437	9.78130	1.6546	0.21870	37 11
.71	.77117	.88715	.26282	.10134	.61068	.78581	.6375	.21419	37 38
.72	.78384	.89423	.27059	.10401	.61691	.79022	.6210	.20978	38 05
.73	.79659	.90123	.27849	.10670	.62307	.79453	.6050	.20547	38 32
.74	.80941	.90817	.28652	.10942	.62915	.79875	.5895	.20125	38 59
0.75	0.82232	9.91504	1.29468	0.11216	0.63515	9.80288	1.5744	0.19712	39 26
.76	.83530	.92185	.30297	.11493	.64108	.80691	.5599	.19309	39 52
.77	.84838	.92859	.31139	.11773	.64693	.81086	.5458	.18914	40 19
.78	.86153	.93527	.31994	.12055	.65271	.81472	.5321	.18528	40 45
.79	.87478	.94190	.32862	.12340	.65841	.81850	.5188	.18150	41 11
0.80	0.88811	9.94846	1.33743	0.12627	0.66404	9.82219	1.5059	0.17781	41 37
.81	.90152	.95498	.34638	.12917	.66959	.82581	.4935	.17419	42 02
.82	.91503	.96144	.35547	.13209	.67507	.82935	.4813	.17065	42 28
.83	.92863	.96784	.36468	.13503	.68048	.83281	.4696	.16719	42 53
.84	.94233	.97420	.37404	.13800	.68581	.83620	.4581	.16380	43 18
0.85	0.95612	9.98051	1.38353	0.14099	0.69107	9.83952	1.4470	0.16048	43 43
.86	.97000	.98677	.39316	.14400	.69626	.84277	.4362	.15723	44 08
.87	.98398	.99299	.40293	.14704	.70137	.84595	.4258	.15405	44 32
.88	.99806	.99916	.41284	.15009	.70642	.84906	.4156	.15094	44 57
.89	1.01224	0.00528	.42289	.15317	.71139	.85211	.4057	.14789	45 21
0.90	1.02652	0.01137	1.43309	0.15627	0.71630	9.85509	1.3961	0.14491	45 45
.91	.04090	.01741	.44342	.15939	.72113	.85801	.3867	.14199	46 09
.92	.05539	.02341	.45390	.16254	.72590	.86088	.3776	.13912	46 33
.93	.06998	.02937	.46453	.16570	.73059	.86368	.3687	.13632	46 56
.94	.08468	.03530	.47530	.16888	.73522	.86642	.3601	.13358	47 20
0.95	1.09948	0.04119	1.48623	0.17208	0.73978	9.86910	1.3517	0.13090	47 43
.96	.11440	.04704	.49729	.17531	.74428	.87173	.3436	.12827	48 06
.97	.12943	.05286	.50851	.17855	.74870	.87431	.3356	.12569	48 29
.98	.14457	.05864	.51988	.18181	.75307	.87683	.3279	.12317	48 51
.99	.15983	.06439	.53141	.18509	.75736	.87930	.3204	.12070	49 14
1.00	1.17520	0.07011	1.54308	0.18839	0.76159	9.88172	1.3130	0.11828	49 36

TABLE 16 (*continued*).

HYPERBOLIC FUNCTIONS.

u	sinh. u		cosh. u		tanh. u		coth u		gd u
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
1.00	1.17520	0.07011	1.54308	0.18839	0.76159	9.88172	1.3130	0.11828	49°36′
.01	.19069	.07580	.55491	.19171	.76576	.88409	.3059	.11591	49 58
.02	.20630	.08146	.56689	.19504	.76987	.88642	.2989	.11358	50 21
.03	.22203	.08708	.57904	.19839	.77391	.88869	.2921	.11131	50 42
.04	.23788	.09268	.59134	.20176	.77789	.89092	.2855	.10908	51 04
1.05	1.25386	0.09825	1.60379	0.20515	0.78181	9.89310	1.2791	0.10690	51 26
.06	.26996	.10379	.61641	.20855	.78566	.89524	.2728	.10476	51 47
.07	.28619	.10930	.62919	.21197	.78946	.89733	.2667	.10267	52 08
.08	.30254	.11479	.64214	.21541	.79320	.89938	.2607	.10062	52 29
.09	.31903	.12025	.65525	.21886	.79688	.90139	.2549	.09861	52 50
1.10	1.33565	0.12569	1.66852	0.22233	0.80050	9.90336	1.2492	0.09664	53 11
.11	.35240	.13111	.68196	.22582	.80406	.90529	.2437	.09471	53 31
.12	.36929	.13649	.69557	.22931	.80757	.90718	.2383	.09282	53 52
.13	.38631	.14186	.70934	.23283	.81102	.90903	.2330	.09097	54 12
.14	.40347	.14720	.72329	.23636	.81441	.91085	.2279	.08915	54 32
1.15	1.42078	0.15253	1.73741	0.23990	0.81775	9.91262	1.2229	0.08738	54 52
.16	.43822	.15783	.75171	.24346	.82104	.91436	.2180	.08564	55 11
.17	.45581	.16311	.76618	.24703	.82427	.91607	.2132	.08393	55 31
.18	.47355	.16836	.78083	.25062	.82745	.91774	.2085	.08226	55 50
.19	.49143	.17360	.79565	.25422	.83058	.91938	.2040	.08062	56 09
1.20	1.50946	0.17882	1.81066	0.25784	0.83365	9.92099	1.1995	0.07901	56 29
.21	.52764	.18402	.82584	.26146	.83668	.92256	.1952	.07744	56 47
.22	.54598	.18920	.84121	.26510	.83965	.92410	.1910	.07590	57 06
.23	.56447	.19437	.85676	.26876	.84258	.92561	.1868	.07439	57 25
.24	.58311	.19951	.87250	.27242	.84546	.92709	.1828	.07291	57 43
1.25	1.60192	0.20464	1.88842	0.27610	0.84828	9.92854	1.1789	0.07146	58 02
.26	.62088	.20975	.90454	.27979	.85106	.92996	.1750	.07004	58 20
.27	.64001	.21485	.92084	.28349	.85380	.93135	.1712	.06865	58 38
.28	.65930	.21993	.93734	.28721	.85648	.93272	.1676	.06728	58 55
.29	.67876	.22499	.95403	.29093	.85913	.93406	.1640	.06594	59 13
1.30	1.69838	0.23004	1.97091	0.29467	0.86172	9.93537	1.1605	0.06463	59 31
.31	.71818	.23507	.98800	.29842	.86428	.93665	.1570	.06335	59 48
.32	.73814	.24009	2.00528	.30217	.86678	.93791	.1537	.06209	60 05
.33	.75828	.24509	.02276	.30594	.86925	.93914	.1504	.06086	60 22
.34	.77860	.25008	.04044	.30972	.87167	.94035	.1472	.05965	60 39
1.35	1.79909	0.25505	2.05833	0.31352	0.87405	9.94154	1.1441	0.05846	60 56
.36	.81977	.26002	.07643	.31732	.87639	.94270	.1410	.05730	61 13
.37	.84062	.26496	.09473	.32113	.87869	.94384	.1381	.05616	61 29
.38	.86166	.26990	.11324	.32495	.88095	.94495	.1351	.05505	61 45
.39	.88289	.27482	.13196	.32878	.88317	.94604	.1323	.05396	62 02
1.40	1.90430	0.27974	2.15090	0.33262	0.88535	9.94712	1.1295	0.05288	62 18
.41	.92591	.28464	.17005	.33647	.88749	.94817	.1268	.05183	62 34
.42	.94770	.28952	.18942	.34033	.88960	.94919	.1241	.05081	62 49
.43	.96970	.29440	.20900	.34420	.89167	.95020	.1215	.04980	63 05
.44	.99188	.29926	.22881	.34807	.89370	.95119	.1189	.04881	63 20
1.45	2.01427	0.30412	2.24884	0.35196	0.89569	9.95216	1.1165	0.04784	63 36
.46	.03686	.30896	.26910	.35585	.89765	.95311	.1140	.04689	63 51
.47	.05965	.31379	.28958	.35976	.89958	.95404	.1116	.04596	64 06
.48	.08265	.31862	.31029	.36367	.90147	.95495	.1093	.04505	64 21
.49	.10586	.32343	.33123	.36759	.90332	.95584	.1070	.04416	64 36
1.50	2.12928	0.32823	2.35241	0.37151	0.90515	9.95672	1.1048	0.04328	64 51

TABLE 16 (*continued*).

HYPERBOLIC FUNCTIONS.

u	sinh. u		cosh. u		tanh. u		coth. u		gd. u
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
1.50	2.12928	0.32823	2.35241	0.37151	0.90515	9.95672	1.1048	0.04328	64° 51′
.51	.15291	.33303	.37382	.37545	.90694	.95758	.1026	.04242	65 05
.52	.17676	.33781	.39547	.37939	.90870	.95842	.1005	.04158	65 20
.53	.20082	.34258	.41736	.38334	.91042	.95924	.0984	.04076	65 34
.54	.22510	.34735	.43949	.38730	.91212	.96005	.0963	.03995	65 48
1.55	2.24961	0.35211	2.46186	0.39126	0.91379	9 96084	1.0943	0.03916	66 02
.56	.27434	.35686	.48448	.39524	.91542	.96162	.0924	.03838	66 16
.57	.29930	.36160	.50735	.39921	.91703	.96238	.0905	.03762	66 30
.58	.32449	.36633	.53047	.40320	.91860	.96313	.0886	.03687	66 43
.59	.34991	.37105	.55384	.40719	.92015	.96386	.0868	.03614	66 57
1.60	2.37557	0.37577	2.57746	0.41119	0.92167	9.96457	1.0850	0.03543	67 10
.61	40146	.38048	.60135	.41520	.92316	.96528	.0832	.03472	67 24
.62	.42760	.38518	.62549	.41921	.92462	.96597	.0815	.03403	67 37
.63	.45397	.38987	.64990	.42323	.92606	.96664	.0798	.03336	67 50
.64	.48059	.39456	.67457	.42725	.92747	.96730	.0782	.03270	68 03
1.65	2.50746	0.39923	2.69951	0.43129	0.92886	9.96795	1.0766	0.03205	68 15
.66	.53459	.40391	.72472	.43532	.93022	.96858	.0750	.03142	68 28
.67	.56196	.40857	.75021	.43937	.93155	.96921	.0735	.03079	68 41
.68	.58959	.41323	.77596	.44341	.93286	.96982	.0720	.03018	68 53
.69	.61748	.41788	.80200	.44747	.93415	.97042	.0705	.02958	69 05
1.70	2.64563	0.42253	2.82832	0.45153	0.93541	9.97100	1.0691	0.02900	69 18
.71	.67405	.42717	.85491	.45559	.93665	.97158	.0676	.02842	69 30
.72	.70273	.43180	.88180	.45966	.93786	.97214	.0663	.02786	69 42
.73	.73168	.43643	.90897	.46374	.93906	.97269	.0649	.02731	69 54
.74	.76091	.44105	.93643	.46782	.94023	.97323	.0636	.02677	70 05
1.75	2.79041	0.44567	2.96419	0.47191	0.94138	9.97376	1.0623	0.02624	70 17
.76	.82020	.45028	.99224	.47600	.94250	.97428	.0610	.02572	70 29
.77	.85026	.45488	3.02059	.48009	.94361	.97479	.0598	.02521	70 40
.78	.88061	.45948	.04925	.48419	.94470	.97529	.0585	.02471	70 51
.79	.91125	.46408	.07821	.48830	.94576	.97578	.0574	.02422	71 03
1.80	2.94217	0.46867	3.10747	0.49241	0.94681	9.97626	1.0562	0.02374	71 14
.81	.97340	.47325	.13705	.49652	.94783	.97673	.0550	.02327	71 25
.82	3.00492	.47783	.16694	.50064	.94884	.97719	.0539	.02281	71 36
.83	.03674	.48241	.19715	.50476	.94983	.97764	.0528	.02236	71 46
.84	.06886	.48698	.22768	.50889	.95080	.97809	.0518	.02191	71 57
1.85	3.10129	0.49154	3.25853	0.51302	0.95175	9.97852	1.0507	0.02148	72 08
.86	.13403	.49610	.28970	.51716	.95268	.97895	.0497	.02105	72 18
.87	.16709	.50066	.32121	.52130	.95359	.97936	.0487	.02064	72 29
.88	.20046	.50521	.35305	.52544	.95449	.97977	.0477	.02023	72 39
.89	.23415	.50976	.38522	.52959	.95537	.98017	.0467	.01983	72 49
1.90	3.26816	0.51430	3.41773	0.53374	0.95624	9.98057	1.0458	0.01943	72 59
.91	.30250	.51884	.45058	.53789	.95709	.98095	.0448	.01905	73 09
.92	.33718	.52338	.48378	.54205	.95792	.98133	.0439	.01867	73 19
.93	.37218	.52791	.51733	.54621	.95873	.98170	.0430	.01830	73 29
.94	.40752	.53244	.55123	.55038	.95953	.98206	.0422	.01794	73 39
1.95	3.44321	0.53696	3.58548	0.55455	0.96032	9.98242	1.0413	0.01758	73 48
.96	.47923	.54148	.62009	.55872	.96109	.98276	.0405	.01724	73 58
.97	.51561	.54600	.65507	.56290	.96185	.98311	.0397	.01689	74 07
.98	.55234	.55051	.69041	.56707	.96259	.98344	.0389	.01656	74 17
.99	.58942	.55502	.72611	.57126	.96331	.98377	.0381	.01623	74 26
2.00	3.62686	0.55953	3.76220	0.57544	0.96403	9.98409	1.0373	0.01591	74 35

HYPERBOLIC FUNCTIONS.

u	sinh. u		cosh. u		tanh. u		coth. u.		gd. u
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
2.00	3.62686	0.55953	3.76220	0.57544	0.96403	9.98409	1.0373	0.01591	74°35′
.01	.66466	.56403	.79865	.57963	.96473	.98440	.0366	.01560	74 44
.02	.70283	.56853	.83549	.58382	.96541	.98471	.0358	.01529	74 53
.03	.74138	.57303	.87271	.58802	.96609	.98502	.0351	.01498	75 02
.04	.78029	.57753	.91032	.59221	.96675	.98531	.0344	.01469	75 11
2.05	3.81958	0.58202	3.94832	0.59641	0.96740	9.98560	1.0337	0.01440	75 20
.06	.85926	.58650	.98671	.60061	.96803	.98589	.0330	.01411	75 28
.07	.89932	.59099	4.02550	.60482	.96865	.98617	.0324	.01383	75 37
.08	.93977	.59547	.06470	.60903	.96926	.98644	.0317	.01356	75 45
.09	.98061	.59995	.10430	.61324	.96986	.98671	.0311	.01329	75 54
2.10	4.02186	0.60443	4.14431	0.61745	0.97045	9.98697	1.0304	0.01303	76 02
.11	.06350	.60890	.18474	.62167	.97103	.98723	.0298	.01277	76 10
.12	.10555	.61337	.22558	.62589	.97159	.98748	.0292	.01252	76 19
.13	.14801	.61784	.26685	.63011	.97215	.98773	.0286	.01227	76 27
.14	.19089	.62231	.30855	.63433	.97269	.98798	.0281	.01202	76 35
2.15	4.23419	0.62677	4.35067	0.63856	0.97323	9.98821	1.0275	0.01179	76 43
.16	.27791	.63123	.39323	.64278	.97375	.98845	.0270	.01155	76 51
	.32205	.63569	.43623	.64701	.97426	.98868	.0264	.01132	76 58
.18	.36663	.64015	.47967	.65125	.97477	.98890	.0259	.01110	77 06
.19	.41165	.64460	.52356	.65548	.97526	.98912	.0254	.01088	77 14
2.20	4.45711	0.64905	4.56791	0.65972	0.97574	9.98934	1.0249	0.01066	77 21
.21	.50301	.65350	.61271	.66396	.97622	.98955	.0244	.01045	77 29
.22	.54936	.65795	.65797	.66820	.97668	.98975	.0239	.01025	77 36
.23	.59617	.66240	.70370	.67244	.97714	.98996	.0234	.01004	77 44
.24	.64344	.66684	.74989	.67668	.97759	.99016	.0229	.00984	77 51
2.25	4.69117	0.67128	4.79657	0.68093	0.97803	9.99035	1.0225	0.00965	77 58
.26	.73937	.67572	.84372	.68518	.97846	.99054	.0220	.00946	78 05
.27	.78804	.68016	.89136	.68943	.97888	.99073	.0216	.00927	78 12
.28	.83720	.68459	.93948	.69368	.97929	.99091	.0211	.00909	78 19
.29	.88684	.68903	.98810	.69794	.97970	.99109	.0207	.00891	78 26
2.30	4.93696	0.69346	5.03722	0.70219	0.98010	9.99127	1.0203	0.00873	78 33
.31	.98758	.69789	.08684	.70645	.98049	.99144	.0199	.00856	78 40
.32	5.03870	.70232	.13697	.71071	.98087	.99161	.0195	.00839	78 46
.33	.09032	.70675	.18762	.71497	.98124	.99178	.0191	.00822	78 53
.34	.14245	.71117	.23878	.71923	.98161	.99194	.0187	.00806	79 00
2.35	5.19510	0.71559	5.29047	0.72349	0.98197	9.99210	1.0184	0.00790	79 06
.36	.24827	.72002	.34269	.72776	.98233	.99226	.0180	.00774	79 13
.37	.30196	.72444	.39544	.73203	.98267	.99241	.0176	.00759	79 19
.38	.35618	.72885	.44873	.73630	.98301	.99256	.0173	.00744	79 25
.39	.41093	.73327	.50256	.74056	.98335	.99271	.0169	.00729	79 32
2.40	5.46623	0.73769	5.55695	0.74484	0.98367	9.99285	1.0166	0.00715	79 38
.41	.52207	.74210	.61189	.74911	.98400	.99299	.0163	.00701	79 44
.42	.57847	.74652	.66739	.75338	.98431	.99313	.0159	.00687	79 50
.43	.63542	.75093	.72346	.75766	.98462	.99327	.0156	.00673	79 56
.44	.69294	.75534	.78010	.76194	.98492	.99340	.0153	.00660	80 02
2.45	5.75103	0.75975	5.83732	0.76621	0.98522	9.99353	1.0150	0.00647	80 08
.46	.80969	.76415	.89512	.77049	.98551	.99366	.0147	.00634	80 14
.47	.86893	.76856	.95352	.77477	.98579	.99379	.0144	.00621	80 20
.48	.92876	.77296	6.01250	.77906	.98607	.99391	.0141	.00609	80 26
.49	.98918	.77737	.07209	.78334	.98635	.99403	.0138	.00597	80 31
2.50	6.05020	0.78177	6.13229	0.78762	0.98661	9.99415	1.0136	0.00585	80 37

TABLE 16 (*continued*).

HYPERBOLIC FUNCTIONS.

u	sinh. u		cosh. u		tanh. u		coth. u		gd. u
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
2.50	6.05020	0.78177	6.13229	0.78762	0.98661	9.99415	1.0136	0.00585	80° 37′
.51	.11183	.78617	.19310	.79191	.98688	.99426	.0133	.00574	80 42
.52	.17407	.79057	.25453	.79619	.98714	.99438	.0130	.00562	80 48
.53	.23692	.79497	.31658	.80048	.98739	.99449	.0128	.00551	80 53
.54	.30040	.79937	.37927	.80477	.98764	.99460	.0125	.00540	80 59
2.55	6.36451	0.80377	6.44259	0.80906	0.98788	9.99470	1.0123	0.00530	81 04
.56	.42926	.80816	.50656	.81335	.98812	.99481	.0120	.00519	81 10
.57	.49464	.81256	.57118	.81764	.98835	.99491	.0118	.00509	81 15
.58	.56068	.81695	.63646	.82194	.98858	.99501	.0115	.00499	81 20
.59	.62738	.82134	.70240	.82623	.98881	.99511	.0113	.00489	81 25
2.60	6.69473	0.82573	6.76901	0.83052	0.98903	9.99521	1.0111	0.00479	81 30
.61	.76276	.83012	.83629	.83482	.98924	.99530	.0109	.00470	81 35
.62	.83146	.83451	.90426	.83912	.98946	.99540	.0107	.00460	81 40
.63	.90085	.83890	.97292	.84341	.98966	.99549	.0104	.00451	81 45
.64	.97092	.84329	7.04228	.84771	.98987	.99558	.0102	.00442	81 50
2.65	7.04169	0.84768	7.11234	0.85201	0.99007	9.99566	1.0100	0.00434	81 55
.66	.11317	.85206	.18312	.85631	.99026	.99575	.0098	.00425	82 00
.67	.18536	.85645	.25461	.86061	.99045	.99583	.0096	.00417	82 05
.68	.25827	.86083	.32683	.86492	.99064	.99592	.0094	.00408	82 09
.69	.33190	.86522	.39978	.86922	.99083	.99600	.0093	.00400	82 14
2.70	7.40626	0.86960	7.47347	0.87352	0.99101	9.99608	1.0091	0.00392	82 19
.71	.48137	.87398	.54791	.87783	.99118	.99615	.0089	.00385	82 23
.72	.55722	.87836	.62310	.88213	.99136	.99623	.0087	.00377	82 28
.73	.63383	.88274	.69905	.88644	.99153	.99631	.0085	.00369	82 32
.74	.71121	.88712	.77578	.89074	.99170	.99638	.0084	.00362	82 37
2.75	7.78935	0.89150	7.85328	0.89505	0.99186	9.99645	1.0082	0.00355	82 41
.76	.86828	.89588	.93157	.89936	.99202	.99652	.0080	.00348	82 45
.77	.94799	.90026	8.01065	.90367	.99218	.99659	.0079	.00341	82 50
.78	8.02849	.90463	.09053	.90798	.99233	.99666	.0077	.00334	82 54
.79	.10980	.90901	.17122	.91229	.99248	.99672	.0076	.00328	82 58
2.80	8.19192	0.91339	8.25273	0.91660	0.99263	9.99679	1.0074	0.00321	83 02
.81	.27486	.91776	.33506	.92091	.99278	.99685	.0073	.00315	83 07
.82	.35862	.92213	.41823	.92522	.99292	.99691	.0071	.00309	83 11
.83	.44322	.92651	.50224	.92953	.99306	.99698	.0070	.00302	83 15
.84	.52867	.93088	.58710	.93385	.99320	.99704	.0069	.00296	83 19
2.85	8.61497	0.93525	8.67281	0.93816	0.99333	9.99709	1.0067	0.00291	83 23
.86	.70213	.93963	.75940	.94247	.99346	.99715	.0066	.00285	83 27
.87	.79016	.94400	.84686	.94679	.99359	.99721	.0065	.00279	83 31
.88	.87907	.94837	.93520	.95110	.99372	.99726	.0063	.00274	83 34
.89	.96887	.95274	9.02444	.95542	.99384	.99732	.0062	.00268	83 38
2.90	9.05956	0.95711	9.11458	0.95974	0.99396	9.99737	1.0061	0.00263	83 42
.91	.15116	.96148	.20564	.96405	.99408	.99742	.0060	.00258	83 46
.92	.24368	.96584	.29761	.96837	.99420	.99747	.0058	.00253	83 50
.93	.33712	.97021	.39051	.97269	.99531	.99752	.0057	.00248	83 53
.94	.43149	.97458	.48436	.97701	.99443	.99757	.0056	.00243	83 57
2.95	9.52681	0.97895	9.57915	0.98133	0.99454	9.99762	1.0055	0.00238	84 00
.96	.62308	.98331	.67490	.98565	.99464	.99767	.0054	.00233	84 04
.97	.72031	.98768	.77161	.98997	.99475	.99771	.0053	.00229	84 08
.98	.81851	.99205	.86930	.99429	.99485	.99776	.0052	.00224	84 11
.99	.91770	.99641	.96798	.99861	.99496	.99780	.0051	.00220	84 15
3.00	10.01787	1.00078	10.06766	1.00293	0.99505	9.99785	1.0050	0.00215	84 18

TABLE 16 (*continued*).

HYPERBOLIC FUNCTIONS.

u	sinh. u		cosh. u		tanh. u		coth. u		gd. u
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
3.0	10.0179	1.00078	10.0677	1.00293	0.99505	9.99785	1.0050	0.00215	84°18′
.1	11.0765	.04440	11.1215	.04616	.99595	.99824	.0041	.00176	84 50
.2	12.2459	.08799	12.2866	.08943	.99668	.99856	.0033	.00144	85 20
.3	13.5379	.13155	13.5748	.13273	.99728	.99882	.0027	.00118	85 47
.4	14.9654	.17509	14.9987	.17605	.99777	.99903	.0022	.00097	86 11
3.5	16.5426	1.21860	16.5728	1.21940	0.99818	9.99921	1.0018	0.00079	86 32
.6	18.2855	.26211	18.3128	.26275	.99851	.99935	.0015	.00065	86 52
.7	20.2113	.30559	20.2360	.30612	.99878	.99947	.0012	.00053	87 10
.8	22.3394	.34907	22.3618	.34951	.99900	.99957	.0010	.00043	87 26
.9	24.6911	.39254	24.7113	.39290	.99918	.99964	.0008	.00036	87 41
4.0	27.2899	1.43600	27.3082	1.43629	0.99933	9.99971	1.0007	0.00029	87 54
.1	30.1619	.47946	30.1784	.47970	.99945	.99976	.0005	.00024	88 06
.2	33.3357	.52291	33.3507	.52310	.99955	.99980	.0004	.00020	88 17
.3	36.8431	.56636	36.8567	.56652	.99963	.99984	.0004	.00016	88 27
.4	40.7193	.60980	40.7316	.60993	.99970	.99987	.0003	.00013	88 36
4.5	45.0030	1.65324	45.0141	1.65335	0.99975	9.99989	1.0002	0.00011	88 44
.6	49.7371	.69668	49.7472	.69677	.99980	.99991	.0002	.00009	88 51
.7	54.9690	.74012	54.9781	.74019	.99983	.99993	.0002	.00007	88 57
.8	60.7511	.78355	60.7593	.78361	.99986	.99994	.0001	.00006	89 03
.9	67.1412	.82699	67.1486	.82704	.99989	.99995	.0001	.00005	89 09
5.0	74.2032	1.87042	74.2099	1.87046	0.99991	9.99996	1.0001	0.00004	89 14

Table 17. Factorials.

See table 15 for logarithms of the products 1.2.3. . . . *n* from 1 to 100.
See table 31 for log. $(n+1)$ for values of *n* between 1.000 and 2.000.

n	$\frac{1}{n:}$	*n*: = 1. 2. 3. 4 . . . *n*	*n*
1	1.	1	1
2	0.5	2	2
3	.16666 66666 66666 66666 66667	6	3
4	.04166 66666 66666 66666 66667	24	4
5	.00833 33333 33333 33333 33333	120	5
6	0.00138 88888 88888 88888 88889	720	6
7	.00019 84126 98412 69841 26984	5040	7
8	.00002 48015 87301 58730 15873	40320	8
9	.00000 27557 31922 39858 90653	3 62880	9
10	.00000 02755 73192 23985 89065	36 28800	10
11	0.00000 00250 52108 38544 17188	399 16800	11
12	.00000 00020 87675 69878 68099	4790 01600	12
13	.00000 00001 60590 43836 82161	62270 20800	13
14	.00000 00000 11470 74559 77297	8 71782 91200	14
15	.00000 00000 00764 71637 31820	130 76743 68000	15
16	0.00000 00000 00047 79477 33239	2092 27898 88000	16
17	.00000 00000 00002 81145 72543	35568 74280 96000	17
18	.00000 00000 00000 15619 20697	6 40237 37057 28000	18
19	.00000 00000 00000 00822 06352	121 64510 04088 32000	19
20	.00000 00000 00000 00041 10318	2432 90200 81766 40000	20

Table 18.

EXPONENTIAL FUNCTION.

x	$\log_{10}(e^x)$	e^x	e^{-x}	x	$\log_{10}(e^x)$	e^x	e^{-x}
0.00	0.00000	1.0000	1.000000	0.50	0.21715	1.6487	0.606531
.01	.00434	.0101	0.990050	.51	.22149	.6653	.600496
.02	.00869	.0202	.980199	.52	.22583	.6820	.594521
.03	.01303	.0305	.970446	.53	.23018	.6989	.588605
.04	.01737	.0408	.960789	.54	.23452	.7160	.582748
0.05	0.02171	1.0513	0.951229	0.55	0.23886	1.7333	0.576950
.06	.02606	.0618	.941765	.56	.24320	.7507	.571209
.07	.03040	.0725	.932394	.57	.24755	.7683	.565525
.08	.03474	.0833	.923116	.58	.25189	.7860	.559898
.09	.03909	.0942	.913931	.59	.25623	.8040	.554327
0.10	0.04343	1.1052	0.904837	0.60	0.26058	1.8221	0.548812
.11	.04777	.1163	.895834	.61	.26492	.8404	.543351
.12	.05212	.1275	.886920	.62	.26926	.8589	.537944
.13	.05646	.1388	.878095	.63	.27361	.8776	.532592
.14	.06080	.1503	.869358	.64	.27795	.8965	.527292
0.15	0.06514	1.1618	0.860708	0.65	0.28229	1.9155	0.522046
.16	.06949	.1735	.852144	.66	.28663	.9348	.516851
.17	.07383	.1853	.843665	.67	.29098	.9542	.511709
.18	.07817	.1972	.835270	.68	.29532	.9739	.506617
.19	.08252	.2092	.826959	.69	.29966	.9937	.501576
0.20	0.08686	1.2214	0.818731	0.70	0.30401	2.0138	0.496585
.21	.09120	.2337	.810584	.71	.30835	.0340	.491644
.22	.09554	.2461	.802519	.72	.31269	.0544	.486752
.23	.09989	.2586	.794534	.73	.31703	.0751	.481909
.24	.10423	.2712	.786628	.74	.32138	.0959	.477114
0.25	0.10857	1.2840	0.778801	0.75	0.32572	2.1170	0.472367
.26	.11292	.2969	.771052	.76	.33006	.1383	.467666
.27	.11726	.3100	.763379	.77	.33441	.1598	.463013
.28	.12160	.3231	.755784	.78	.33875	.1815	.458406
.29	.12595	.3364	.748264	.79	.34309	.2034	.453845
0.30	0.13029	1.3499	0.740818	0.80	0.34744	2.2255	0.449329
.31	.13463	.3634	.733447	.81	.35178	.2479	.444858
.32	.13897	.3771	.726149	.82	.35612	.2705	.440432
.33	.14332	.3910	.718924	.83	.36046	.2933	.436049
.34	.14766	.4049	.711770	.84	.36481	.3164	.431711
0.35	0.15200	1.4191	0.704688	0.85	0.36915	2.3396	0.427415
.36	.15635	.4333	.697676	.86	.37349	.3632	.423162
.37	.16069	.4477	.690734	.87	.37784	.3869	.418952
.38	.16503	.4623	.683861	.88	.38218	.4109	.414783
.39	.16937	.4770	.677057	.89	.38652	.4351	.410656
0.40	0.17372	1.4918	0.670320	0.90	0.39087	2.4596	0.406570
.41	.17806	.5068	.663650	.91	.39521	.4843	.402524
.42	.18240	.5220	.657047	.92	.39955	.5093	.398519
.43	.18675	.5373	.650509	.93	.40389	.5345	.394554
.44	.19109	.5527	.644036	.94	.40824	.5600	.390628
0.45	0.19543	1.5683	0.637628	0.95	0.41258	2.5857	0.386741
.46	.19978	.5841	.631284	.96	.41692	.6117	.382893
.47	.20412	.6000	.625002	.97	.42127	.6379	.379083
.48	.20846	.6161	.618783	.98	.42561	.6645	.375311
.49	.21280	.6323	.612626	.99	.42995	.6912	.371577
0.50	0.21715	1.6487	0.606531	1.00	0.43429	2.7183	0.367879

TABLE 18 (*continued*).

EXPONENTIAL FUNCTION.

x	$\log_{10}(e^x)$	e^x	e^{-x}	x	$\log_{10}(e^x)$	e^x	e^{-x}
1.00	0.43429	2.7183	0.367879	1.50	0.65144	4.4817	0.223130
.01	.43864	.7456	.364219	.51	.65578	.5267	.220910
.02	.44298	.7732	.360595	.52	.66013	.5722	.218712
.03	.44732	.8011	.357007	.53	.66447	.6182	.216536
.04	.45167	.8292	.353455	.54	.66881	.6646	.214381
1.05	0.45601	2.8577	0.349938	1.55	0.67316	4.7115	0.212248
.06	.46035	.8864	.346456	.56	.67750	.7588	.210136
.07	.46470	.9154	.343009	.57	.68184	.8066	.208045
.08	.46904	.9447	.339596	.58	.68619	.8550	.205975
.09	.47338	.9743	.336216	.59	.69053	.9037	.203926
1.10	0.47772	3.0042	0.332871	1.60	0.69487	4.9530	0.201897
.11	.48207	.0344	.329559	.61	.69921	5.0028	.199888
.12	.48641	.0649	.326280	.62	.70356	.0531	.197899
.13	.49075	.0957	.323033	.63	.70790	.1039	.195930
.14	.49510	.1268	.319819	.64	.71224	.1552	.193980
1.15	0.49944	3.1582	0.316637	1.65	0.71659	5.2070	0.192050
.16	.50378	.1899	.313486	.66	.72093	.2593	.190139
.17	.50812	.2220	.310367	.67	.72527	.3122	.188247
.18	.51247	.2544	.307279	.68	.72961	.3656	.186374
.19	.51681	.2871	.304221	.69	.73396	.4195	.184520
1.20	0.52115	3.3201	0.301194	1.70	0.73830	5.4739	0.182684
.21	.52550	.3535	.298197	.71	.74264	.5290	.180866
.22	.52984	.3872	.295230	.72	.74699	.5845	.179066
.23	.53418	.4212	.292293	.73	.75133	.6407	.177284
.24	.53853	.4556	.289384	.74	.75567	.6973	.175520
1.25	0.54287	3.4903	0.286505	1.75	0.76002	5.7546	0.173774
.26	.54721	.5254	.283654	.76	.76436	.8124	.172045
.27	.55155	.5609	.280832	.77	.76870	.8709	.170333
.28	.55590	.5966	.278037	.78	.77304	.9299	.168638
.29	.56024	.6328	.275271	.79	.77739	.9895	.166960
1.30	0.56458	3.6693	0.272532	1.80	0.78173	6.0496	0.165299
.31	.56893	.7062	.269820	.81	.78607	.1104	.163654
.32	.57327	.7434	.267135	.82	.79042	.1719	.162026
.33	.57761	.7810	.264477	.83	.79476	.2339	.160414
.34	.58195	.8190	.261846	.84	.79910	.2965	.158817
1.35	0.58630	3.8574	0.259240	1.85	0.80344	6.3598	0.157237
.36	.59064	.8962	.256661	.86	.80779	.4237	.155673
.37	.59498	.9354	.254107	.87	.81213	.4883	.154124
.38	.59933	.9749	.251579	.88	.81647	.5535	.152590
.39	.60367	4.0149	.249075	.89	.82082	.6194	.151072
1.40	0.60801	4.0552	0.246597	1.90	0.82516	6.6859	0.149569
.41	.61236	.0960	.244143	.91	.82950	.7531	.148080
.42	.61670	.1371	.241714	.92	.83385	.8210	.146607
.43	.62104	.1787	.239309	.93	.83819	.8895	.145148
.44	.62538	.2207	.236928	.94	.84253	.9588	.143704
1.45	0.62973	4.2631	0.234570	1.95	0.84687	7.0287	0.142274
.46	.63407	.3060	.232236	.96	.85122	.0993	.140858
.47	.63841	.3492	.229925	.97	.85556	.1707	.139457
.48	.64276	.3929	.227638	.98	.85990	.2427	.138069
.49	.64710	.4371	.225373	.99	.86425	.3155	.136695
1.50	0.65144	4.4817	0.223130	2.00	0.86859	7.3891	0.135335

TABLE 18 (*continued*).

EXPONENTIAL FUNCTION.

x	$\log_{10}(e^x)$	e^x	e^{-x}	x	$\log_{10}(e^x)$	e^x	e^{-x}
2.00	0.86859	7.3891	0.135335	2.50	1.08574	12.182	0.082085
.01	.87293	.4633	.133989	.51	.09008	.305	.081268
.02	.87727	.5383	.132655	.52	.09442	.429	.080460
.03	.88162	.6141	.131336	.53	.09877	.554	.079659
.04	.88596	.6906	.130029	.54	.10311	.680	.078866
2.05	0.89030	7.7679	0.128735	2.55	1.10745	12.807	0.078082
.06	.89465	.8460	.127454	.56	.11179	.936	.077305
.07	.89899	.9248	.126186	.57	.11614	13.066	.076536
.08	.90333	8.0045	.124930	.58	.12048	.197	.075774
.09	.90768	.0849	.123687	.59	.12482	.330	.075020
2.10	0.91202	8.1662	0.122456	2.60	1.12917	13.464	0.074274
.11	.91636	.2482	.121238	.61	.13351	.599	.073535
.12	.92070	.3311	.120032	.62	.13785	.736	.072803
.13	.92505	.4149	.118837	.63	.14219	.874	.072078
.14	.92939	.4994	.117655	.64	.14654	14.013	.071361
2.15	0.93373	8.5849	0.116484	2.65	1.15088	14.154	0.070651
.16	.93808	.6711	.115325	.66	.15522	.296	.069948
.17	.94242	.7583	.114178	.67	.15957	.440	.069252
.18	.94676	.8463	.113042	.68	.16391	.585	.068563
.19	.95110	.9352	.111917	.69	.16825	.732	.067881
2.20	0.95545	9.0250	0.110803	2.70	1.17260	14.880	0.067206
.21	.95979	.1157	.109701	.71	.17694	15.029	.066537
.22	.96413	.2073	.108609	.72	.18128	.180	.065875
.23	.96848	.2999	.107528	.73	.18562	.333	.065219
.24	.97282	.3933	.106459	.74	.18997	.487	.064570
2.25	0.97716	9.4877	0.105399	2.75	1.19431	15.643	0.063928
.26	.98151	.5831	.104350	.76	.19865	.800	.063292
.27	.98585	.6794	.103312	.77	.20300	.959	.062662
.28	.99019	.7767	.102284	.78	.20734	16.119	.062039
.29	.99453	.8749	.101266	.79	.21168	.281	.061421
2.30	0.99888	9.9742	0.100259	2.80	1.21602	16.445	0.060810
.31	1.00322	10.074	.099261	.81	.22037	.610	.060205
.32	.00756	.176	.098274	.82	.22471	.777	.059606
.33	.01191	.278	.097296	.83	.22905	.945	.059013
.34	.01625	.381	.096328	.84	.23340	17.116	.058426
2.35	1.02059	10.486	0.095369	2.85	1.23774	17.288	0.057844
.36	.02493	.591	.094420	.86	.24208	.462	.057269
.37	.02928	.697	.093481	.87	.24643	.637	.056699
.38	.03362	.805	.092551	.88	.25077	.814	.056135
.39	.03796	.913	.091630	.89	.25511	.993	.055576
2.40	1.04231	11.023	0.090718	2.90	1.25945	18.174	0.055023
.41	.04665	.134	.089815	.91	.26380	.357	.054476
.42	.05099	.246	.088922	.92	.26814	.541	.053934
.43	.05534	.359	.088037	.93	.27248	.728	.053397
.44	.05968	.473	.087161	.94	.27683	.916	.052866
2.45	1.06402	11.588	0.086294	2.95	1.28117	19.106	0.052340
.46	.06836	.705	.085435	.96	.28551	.298	.051819
.47	.07271	.822	.084585	.97	.28985	.492	.051303
.48	.07705	.941	.083743	.98	.29420	.688	.050793
.49	.08139	12.061	.082910	.99	.29854	.886	.050287
2.50	1.08574	12.182	0.082085	3.00	1.30288	20.086	0.049787

TABLE 18 (*continued*).

EXPONENTIAL FUNCTION.

x	$\log_{10}(e^x)$	e^x	e^{-x}	x	$\log_{10}(e^x)$	e^x	e^{-x}
3.00	1.30288	20.086	0.049787	3.50	1.52003	33.115	0.030197
.01	.30723	.287	.049292	.51	.52437	.448	.029897
.02	.31157	.491	.048801	.52	.52872	.784	.029599
.03	.31591	.697	.048316	.53	.53306	34.124	.029305
.04	.32026	.905	.047835	.54	.53740	.467	.029013
3.05	1.32460	21.115	0.047359	3.55	1.54175	34.813	0.028725
.06	.32894	.328	.046888	.56	.54609	35.163	.028439
.07	.33328	.542	.046421	.57	.55043	.517	.028156
.08	.33763	.758	.045959	.58	.55477	.874	.027876
.09	.34197	.977	.045502	.59	.55912	36.234	.027598
3.10	1.34631	22.198	0.045049	3.60	1.56346	36.598	0.027324
.11	.35066	.421	.044601	.61	.56780	.966	.027052
.12	.35500	.646	.044157	.62	.57215	37.338	.026783
.13	.35934	.874	.043718	.63	.57649	.713	.026516
.14	.36368	23.104	.043283	.64	.58083	38.092	.026252
3.15	1.36803	23.336	0.042852	3.65	1.58517	38.475	0.025991
.16	.37237	.571	.042426	.66	.58952	.861	.025733
.17	.37671	.807	.042004	.67	.59386	39.252	.025476
.18	.38106	24.047	.041586	.68	.59820	.646	.025223
.19	.38540	.288	.041172	.69	.60255	40.045	.024972
3.20	1.38974	24.533	0.040762	3.70	1.60689	40.447	0.024724
.21	.39409	.779	.040357	.71	.61123	.854	.024478
.22	.39843	25.028	.039955	.72	.61558	41.264	.024234
.23	.40277	.280	.039557	.73	.61992	.679	.023993
.24	.40711	.534	.039164	.74	.62426	42.098	.023754
3.25	1.41146	25.790	0.038774	3.75	1.62860	42.521	0.023518
.26	.41580	26.050	.038388	.76	.63295	.948	.023284
.27	.42014	.311	.038006	.77	.63729	43.380	.023052
.28	.42449	.576	.037628	.78	.64163	.816	.022823
.29	.42883	.843	.037254	.79	.64598	44.256	.022596
3.30	1.43317	27.113	0.036883	3.80	1.65032	44.701	0.022371
.31	.43751	.385	.036516	.81	.65466	45.150	.022148
.32	.44186	.660	.036153	.82	.65900	.604	.021928
.33	.44620	.938	.035793	.83	.66335	46.063	.021710
.34	.45054	28.219	.035437	.84	.66769	.525	.021494
3.35	1.45489	28.503	0.035084	3.85	1.67203	46.993	0.021280
.36	.45923	.789	.034735	.86	.67638	47.465	.021068
.37	.46357	29.079	.034390	.87	.68072	.942	.020858
.38	.46792	.371	.034047	.88	.68506	48.424	.020651
.39	.47226	.666	.033709	.89	.68941	.911	.020445
3.40	1.47660	29.964	0.033373	3.90	1.69375	49.402	0.020242
.41	.48094	30.265	.033041	.91	.69809	.899	.020041
.42	.48529	.569	.032712	.92	.70243	50.400	.019841
.43	.48963	.877	.032387	.93	.70678	.907	.019644
.44	.49397	31.187	.032065	.94	.71112	51.419	.019448
3.45	1.49832	31.500	0.031746	3.95	1.71546	51.935	0.019255
.46	.50266	.817	.031430	.96	.71981	52.457	.019063
.47	.50700	32.137	.031117	.97	.72415	.985	.018873
.48	.51134	.460	.030807	.98	.72849	53.517	.018686
.49	.51569	.786	.030501	.99	.73283	54.055	.018500
3.50	1.52003	33.115	0.030197	4.00	1.73718	54.598	0.018316

TABLE 18 *(continued)*.

EXPONENTIAL FUNCTION.

x	$\log_{10}(e^x)$	e^x	e^{-x}	x	$\log_{10}(e^x)$	e^x	e^{-x}
4.00	1.73718	54.598	0.018316	4.50	1.95433	90.017	0.011109
.01	.74152	55.147	.018133	.51	.95867	.922	.010998
.02	.74586	.701	.017953	.52	.96301	91.836	.010889
.03	.75021	56.261	.017774	.53	.96735	92.759	.010781
.04	.75455	.826	.017597	.54	.97170	93.691	.010673
4.05	1.75889	57.397	0.017422	4.55	1.97604	94.632	0.010567
.06	.76324	.974	.017249	.56	.98038	95.583	.010462
.07	.76758	58.557	.017077	.57	.98473	96.544	.010358
.08	.77192	59.145	.016907	.58	.98907	97.514	.010255
.09	.77626	.740	.016739	.59	.99341	98.494	.010153
4.10	1.78061	60.340	0.016573	4.60	1.99775	99.484	0.010052
.11	.78495	.947	.016408	.61	2.00210	100.48	.009952
.12	.78929	61.559	.016245	.62	.00644	101.49	.009853
.13	.79364	62.178	.016083	.63	.01078	102.51	.009755
.14	.79798	.803	.015923	.64	.01513	103.54	.009658
4.15	1.80232	63.434	0.015764	4.65	2.01947	104.58	0.009562
.16	.80667	64.072	.015608	.66	.02381	105.64	.009466
.17	.81101	.715	.015452	.67	.02816	106.70	.009372
.18	.81535	65.366	.015299	.68	.03250	107.77	.009279
.19	.81969	66.023	.015146	.69	.03684	108.85	.009187
4.20	1.82404	66.686	0.014996	4.70	2.04118	109.95	0.009095
.21	.82838	67.357	.014846	.71	.04553	111.05	.009005
.22	.83272	68.033	.014699	.72	.04987	112.17	.008915
.23	.83707	.717	.014552	.73	.05421	113.30	.008826
.24	.84141	69.408	.014408	.74	.05856	114.43	.008739
4.25	1.84575	70.105	0.014264	4.75	2.06290	115.58	0.008652
.26	.85009	.810	.014122	.76	.06724	116.75	.008566
.27	.85444	71.522	.013982	.77	.07158	117.92	.008480
.28	.85878	72.240	.013843	.78	.07593	119.10	.008396
.29	.86312	.966	.013705	.79	.08027	120.30	.008312
4.30	1.86747	73.700	0.013569	4.80	2.08461	121.51	0.008230
.31	.87181	74.440	.013434	.81	.08896	122.73	.008148
.32	.87615	75.189	.013300	.82	.09330	123.97	.008067
.33	.88050	.944	.013168	.83	.09764	125.21	.007987
.34	.88484	76.708	.013037	.84	.10199	126.47	.007907
4.35	1.88918	77.478	0.012907	4.85	2.10633	127.74	0.007828
.36	.89352	78.257	.012778	.86	.11067	129.02	.007750
.37	.89787	79.044	.012651	.87	.11501	130.32	.007673
.38	.90221	79.838	.012525	.88	.11936	131.63	.007597
.39	.90655	80.640	.012401	.89	.12370	132.95	.007521
4.40	1.91090	81.451	0.012277	4.90	2.12804	134.29	0.007447
.41	.91524	82.269	.012155	.91	.13239	135.64	.007372
.42	.91958	83.096	.012034	.92	.13673	137.00	.007299
.43	.92392	.931	.011914	.93	.14107	138.38	.007227
.44	.92827	84.775	.011796	.94	.14541	139.77	.007155
4.45	1.93261	85.627	0.011679	4.95	2.14976	141.17	0.007083
.46	.93695	86.488	.011562	.96	.15410	142.59	.007013
.47	.94130	87.357	.011447	.97	.15844	144.03	.006943
.48	.94564	88.235	.011333	.98	.16279	145.47	.006874
.49	.94998	89.121	.011221	.99	.16713	146.94	.006806
4.50	1.95433	90.017	0.011109	5.00	2.17147	148.41	0.006738

TABLE 18 (*continued*).

EXPONENTIAL FUNCTION.

x	$\log_{10}(e^x)$	e^x	e^{-x}	x	$\log_{10}(e^x)$	e^x	e^{-x}
5.00	2.17147	148.41	0.006738	5.0	2.17147	148.41	0.006738
.01	.17582	149.90	.006671	.1	.21490	164.02	.006097
.02	.18016	151.41	.006605	.2	.25833	181.27	.005517
.03	.18450	152.93	.006539	.3	.30176	200.34	.004992
.04	.18884	154.47	.006474	.4	.34519	221.41	.004517
5.05	2.19319	156.02	0.006409	5.5	2.38862	244.69	0.004087
.06	.19753	157.59	.006346	.6	.43205	270.43	.003698
.07	.20187	159.17	.006282	.7	.47548	298.87	.003346
.08	.20622	160.77	.006220	.8	.51891	330.30	.003028
.09	.21056	162.39	.006158	.9	.56234	365.04	.002739
5.10	2.21490	164.02	0.006097	6.0	2.60577	403.43	0.002479
.11	.21924	165.67	.006036	.1	.64920	445.86	.002243
.12	.22359	167.34	.005976	.2	.69263	492.75	.002029
.13	.22793	169.02	.005917	.3	.73606	544.57	.001836
.14	.23227	170.72	.005858	.4	.77948	601.85	.001662
5.15	2.23662	172.43	0.005799	6.5	2.82291	665.14	0.001503
.16	.24096	174.16	.005742	.6	.86634	735.10	.001360
.17	.24530	175.91	.005685	.7	.90977	812.41	.001231
.18	.24965	177.68	.005628	.8	.95320	897.85	.001114
.19	.25399	179.47	.005572	.9	.99663	992.27	.001008
5.20	2.25833	181.27	0.005517	7.0	3.04006	1096.6	0.000912
.21	.26267	183.09	.005462	.1	.08349	1212.0	.000825
.22	.26702	184.93	.005407	.2	.12692	1339.4	.000747
.23	.27136	186.79	.005354	.3	.17035	1480.3	.000676
.24	.27570	188.67	.005300	.4	.21378	1636.0	.000611
5.25	2.28005	190.57	0.005248	7.5	3.25721	1808.0	0.000553
.26	.28439	192.48	.005195	.6	.30064	1998.2	.000500
.27	.28873	194.42	.005144	.7	.34407	2208.3	.000453
.28	.29307	196.37	.005092	.8	.38750	2440.6	.000410
.29	.29742	198.34	.005042	.9	.43093	2697.3	.000371
5.30	2.30176	200.34	0.004992	8.0	3.47436	2981.0	0.000335
.31	.30610	202.35	.004942	.1	.51779	3294.5	.000304
.32	.31045	204.38	.004893	.2	.56121	3641.0	.000275
.33	.31479	206.44	.004844	.3	.60464	4023.9	.000249
.34	.31913	208.51	.004796	.4	.64807	4447.1	.000225
5.35	2.32348	210.61	0.004748	8.5	3.69150	4914.8	0.000203
.36	.32782	212.72	.004701	.6	.73493	5431.7	.000184
.37	.33216	214.86	.004654	.7	.77836	6002.9	.000167
.38	.33650	217.02	.004608	.8	.82179	6634.2	.000151
.39	.34085	219.20	.004562	.9	.86522	7332.0	.000136
5.40	2.34519	221.41	0.004517	9.0	3.90865	8103.1	0.000123
.41	.34953	223.63	.004472	.1	.95208	8955.3	.000112
.42	.35388	225.88	.004427	.2	.99551	9897.1	.000101
.43	.35822	228.15	.004383	.3	4.03894	10938.	.000091
.44	.36256	230.44	.004339	.4	.08237	12088.	.000083
5.45	2.36690	232.76	0.004296	9.5	4.12580	13360.	0.000075
.46	.37125	235.10	.004254	.6	.16923	14765.	.000068
.47	.37559	237.46	.004211	.7	.21266	16318.	.000061
.48	.37993	239.85	.004169	.8	.25609	18034.	.000055
.49	.38428	242.26	.004128	.9	.29952	19930.	.000050
5.50	2.38862	244.69	0.004087	10.0	4.34294	22026.	0.000045

TABLE 19.

EXPONENTIAL FUNCTIONS.

Value of e^{x^2} and e^{-x^2} and their logarithms.

x	e^{x^2}	$\log e^{x^2}$	e^{-x^2}	$\log e^{-x^2}$
0.1	1.0101	0.00434	0.99005	$\bar{1}.99566$
2	1.0408	01737	96079	98263
3	1.0942	03909	91393	96091
4	1.1735	06949	85214	93051
5	1.2840	10857	77880	89143
0.6	1.4333	0.15635	0.69768	$\bar{1}.84365$
7	1.6323	21280	61263	78720
8	1.8965	27795	52729	72205
9	2.2479	35178	44486	64822
1.0	2.7183	43429	36788	56571
1.1	3.3535	0.52550	0.29820	$\bar{1}.47450$
2	4.2207	62538	23693	37462
3	5.4195	73396	18452	26604
4	7.0993	85122	14086	14878
5	9.4877	97716	10540	02284
1.6	1.2936 × 10	1.11179	0.77305 × 10^{-1}	$\bar{2}.88821$
7	1.7993 “	25511	55576 “	74489
8	2.5534 “	40711	39164 “	59289
9	3.6966 “	56780	27052 “	43220
2.0	5.4598 “	73718	18316 “	26282
2.1	8.2269 “	1.91524	0.12155 “	$\bar{2}.08476$
2	1.2647 × 10^2	2.10199	79071 × 10^{-2}	$\bar{3}.89801$
3	1.9834 “	29742	50418 “	70258
4	3.1735 “	50154	31511 “	49846
5	5.1801 “	71434	19305 “	28566
2.6	8.6264 “	2.93583	0.11592 “	$\bar{3}.06417$
7	1.4656 × 10^3	3.16601	68233 × 10^{-8}	$\bar{4}.83399$
8	2.5402 “	40487	39367 “	59513
9	4.4918 “	65242	22263 “	34758
3.0	8.1031 “	90865	12341 “	09135
3.1	1.4913 × 10^4	4.17357	0.67055 × 10^{-4}	$\bar{5}.82643$
2	2.8001 “	44718	35713 “	55282
3	5.3637 “	72947	18644 “	27053
4	1.0482 × 10^5	5.02044	95402 × 10^{-5}	$\bar{6}.97956$
5	2.0898 “	32011	47851 “	67989
3.6	4.2507 “	5.62846	0.23526 “	$\bar{6}.37154$
7	8.8205 “	94549	11337 “	05451
8	1.8673 × 10^6	6.27121	53553 × 10^{-6}	$\bar{7}.72879$
9	4.0329 “	60562	24796 “	39438
4.0	8.8861 “	94871	11254 “	05129
4.1	1.9975 × 10^7	7.30049	0.50062 × 10^{-7}	$\bar{8}.69951$
2	4.5809 “	66095	21830 “	33905
3	1.0718 × 10^8	8.03010	93303 × 10^{-8}	$\bar{9}.96990$
4	2.5582 “	40794	39089 “	59206
5	6.2296 “	79446	16052 “	20554
4.6	1.5476 × 10^9	9.18967	0.64614 × 10^{-9}	$\overline{10}.81033$
7	3.9225 “	59357	25494 “	40643
8	1.0142 × 10^{10}	10.00614	98595 × 10^{-10}	$\overline{11}.99386$
9	2.6755 “	42741	37376 “	57259
5.0	7.2005 “	85736	13888 “	14264

TABLE 20.

EXPONENTIAL FUNCTIONS.

Values of $e^{\frac{\pi}{4}x}$ and $e^{-\frac{\pi}{4}x}$ and their logarithms.

x	$e^{\frac{\pi}{4}x}$	$\log e^{\frac{\pi}{4}x}$	$e^{-\frac{\pi}{4}x}$	$\log e^{-\frac{\pi}{4}x}$
1	2.1933	0.34109	0.45594	$\bar{1}.65891$
2	4.8105	.68219	.20788	.31781
3	1.0551×10	1.02328	$.94780 \times 10^{-1}$	$\bar{2}.97672$
4	2.3141 "	.36438	.43214 "	.63562
5	5.0754 "	.70547	.19703 "	.29453
6	1.1132×10^{2}	2.04656	0.89833×10^{-2}	$\bar{3}.95344$
7	2.4415 "	.38766	.40958 "	.61234
8	5.3549 "	.72875	.18674 "	.27125
9	1.1745×10^{3}	3.06985	$.85144 \times 10^{-3}$	$\bar{4}.93015$
10	2.5760 "	.41094	.38820 "	.58906
11	5.6498 "	3.75203	0.17700 "	$\bar{4}.24797$
12	1.2392×10^{4}	4.09313	$.80700 \times 10^{-4}$	$\bar{5}.90687$
13	2.7178 "	.43422	.36794 "	.56578
14	5.9610 "	.77532	.16776 "	.22468
15	1.3074×10^{5}	5.11641	$.76487 \times 10^{-5}$	$\bar{6}.88359$
16	2.8675 "	5.45751	0.34873 "	$\bar{6}.54249$
17	6.2893 "	.79860	.15900 "	.20140
18	1.3794×10^{6}	6.13969	$.72495 \times 10^{-6}$	$\bar{7}.86031$
19	3.0254 "	.48079	.33053 "	.51921
20	6.6356 "	.82188	.15070 "	.17812

TABLE 21.

EXPONENTIAL FUNCTIONS.

Values of $e^{\frac{\sqrt{\pi}}{4}x}$ and $e^{-\frac{\sqrt{\pi}}{4}x}$ and their logarithms.

x	$e^{\frac{\sqrt{\pi}}{4}x}$	$\log e^{\frac{\sqrt{\pi}}{4}x}$	$e^{-\frac{\sqrt{\pi}}{4}x}$	$\log e^{-\frac{\sqrt{\pi}}{4}x}$
1	1.5576	0.19244	0.64203	$\bar{1}.80756$
2	2.4260	.38488	.41221	.61512
3	3.7786	.57733	.26465	.42267
4	5.8853	.76977	.16992	.23023
5	9.1666	.96221	.10909	.03779
6	14.277	1.15465	0.070041	$\bar{2}.84535$
7	22.238	.34709	.044968	.65291
8	34.636	.53953	.028871	.46047
9	53.948	.73198	.018536	.26802
10	84.027	.92442	.011901	.07558
11	130.88	2.11686	0.0076408	$\bar{3}.88314$
12	203.85	.30930	.0049057	.69070
13	317.50	.50174	.0031496	.49826
14	494.52	.69418	.0020222	.30582
15	770.24	.88663	.0012983	.11337
16	1199.7	3.07907	0.00083355	$\bar{4}.92093$
17	1868.6	.27151	.00053517	.72849
18	2910.4	.46395	.00034360	.53605
19	4533.1	.65639	.00022060	.34361
20	7060.5	.84883	.00014163	.15117

TABLE 22. — Exponential Functions.

Value of e^x and e^{-x} and their logarithms.

x	e^x	log e^x	e^{-x}	x	e^x	log e^x	e^{-x}
1/64	1.0157	0.00679	0.98450	1/3	1.3956	0.14476	0.71653
1/32	.0317	.01357	.96923	1/2	.6487	.21715	.60653
1/16	.0645	.02714	.93941	3/4	2.1170	.32572	.47237
1/10	.1052	.04343	.90484	1	.7183	.43429	.36788
1/9	.1175	.04825	.89484	5/4	3.4903	.54287	.28650
1/8	1.1331	0.05429	0.88250	3/2	4.4817	0.65144	0.22313
1/7	.1536	.06204	.86688	7/4	5.7546	.76002	.17377
1/6	.1814	.07238	.84648	2	7.3891	.86859	.13534
1/5	.2214	.08686	.81873	9/4	9.4877	.97716	.10540
1/4	.2840	.10857	.77880	5/2	12.1825	1.08574	.08208

TABLE 23. — Least Squares.

$$\text{Values of } P = \frac{2}{\sqrt{\pi}} \int_0^{hx} e^{-(hx)^2}\, d\,(hx).$$

This table gives the value of P, the probability of an observational error having a value positive or negative equal to or less than x when h is the measure of precision, $P = \frac{2}{\sqrt{\pi}} \int_0^{hx} e^{-(hx)^2} d(hx)$. For values of the inverse function see the table on Diffusion.

hx	0	1	2	3	4	5	6	7	8	9
0.0		.01128	.02256	.03384	.04511	.05637	.06762	.07886	.09008	.10128
.1	.11246	.12362	.13476	.14587	.15695	.16800	.17901	.18999	.20094	.21184
.2	.22270	.23352	.24430	.25502	.26570	.27633	.28690	.29742	.30788	.31828
.3	.32863	.33891	.34913	.35928	.36936	.37938	.38933	.39921	.40901	.41874
.4	.42839	.43797	.44747	.45689	.46623	.47548	.48466	.49375	.50275	.51167
0.5	.52050	.52924	.53790	.54646	.55494	.56332	.57162	.57982	.58792	.59594
.6	.60386	.61168	.61941	.62705	.63459	.64203	.64938	.65663	.66378	.67084
.7	.67780	.68467	.69143	.69810	.70468	.71116	.71754	.72382	.73001	.73610
.8	.74210	.74800	.75381	.75952	.76514	.77067	.77610	.78144	.78669	.79184
.9	.79691	.80188	.80677	.81156	.81627	.82089	.82542	.82987	.83423	.83851
1.0	.84270	.84681	.85084	.85478	.85865	.86244	.86614	.86977	.87333	.87680
.1	.88021	.88353	.88679	.88997	.89308	.89612	.89910	.90200	.90484	.90761
.2	.91031	.91296	.91553	.91805	.92051	.92290	.92524	.92751	.92973	.93190
.3	.93401	.93606	.93807	.94002	.94191	.94376	.94556	.94731	.94902	.95067
.4	.95229	.95385	.95538	.95686	.95830	.95970	.96105	.96237	.96365	.96490
1.5	.96611	.96728	.96841	.96952	.97059	.97162	.97263	.97360	.97455	.97546
.6	.97635	.97721	.97804	.97884	.97962	.98038	.98110	.98181	.98249	.98315
.7	.98379	.98441	.98500	.98558	.98613	.98667	.98719	.98769	.98817	.98864
.8	.98909	.98952	.98994	.99035	.99074	.99111	.99147	.99182	.99216	.99248
.9	.99279	.99309	.99338	.99366	.99392	.99418	.99443	.99466	.99489	.99511
2.0	.99532	.99552	.99572	.99591	.99609	.99626	.99642	.99658	.99673	.99688
.1	.99702	.99715	.99728	.99741	.99753	.99764	.99775	.99785	.99795	.99805
.2	.99814	.99822	.99831	.99839	.99846	.99854	.99861	.99867	.99874	.99880
.3	.99886	.99891	.99897	.99902	.99906	.99911	.99915	.99920	.99924	.99928
.4	.99931	.99935	.99938	.99941	.99944	.99947	.99950	.99952	.99955	.99957
2.5	.99959	.99961	.99963	.99965	.99967	.99969	.99971	.99972	.99974	.99975
.6	.99976	.99978	.99979	.99980	.99981	.99982	.99983	.99984	.99985	.99986
.7	.99987	.99987	.99988	.99989	.99989	.99990	.99991	.99991	.99992	.99992
.8	.99992	.99993	.99993	.99994	.99994	.99994	.99995	.99995	.99995	.99996
.9	.99996	.99996	.99996	.99997	.99997	.99997	.99997	.99997	.99997	.99998
3.0	.99998	.99999	.99999	1.00000						

Taken from a paper by Dr. James Burgess 'on the Definite Integral $\frac{2}{\sqrt{\pi}} \int_0^t e^{-t^2}\, dt$, with Extended Tables of Values.' Trans. Roy. Soc. of Edinburgh, vol. xxxix, 1900, p. 257.

TABLE 24.

LEAST SQUARES.

This table gives the values of the probability P, as defined in last table, corresponding to different values of x / r where r is the "probable error." The probable error r is equal to $0.47694 / h$.

$\frac{x}{r}$	0	1	2	3	4	5	6	7	8	9
0.0	.00000	.00538	.01076	.01614	.02152	.02690	.03228	.03766	.04303	.04840
0.1	.05378	.05914	.06451	.06987	.07523	.08059	.08594	.09129	.09663	.10197
0.2	.10731	.11264	.11796	.12328	.12860	13391	.13921	.14451	.14980	.15508
0.3	.16035	.16562	.17088	.17614	.18138	.18662	.19185	.19707	.20229	.20749
0.4	.21268	.21787	.22304	.22821	.23336	.23851	.24364	.24876	.25388	.25898
0.5	.26407	.26915	.27421	.27927	.28431	.28934	.29436	.29936	.30435	.30933
0.6	.31430	.31925	.32419	.32911	.33402	.33892	.34380	.34866	.35352	.35835
0.7	.36317	.36798	.37277	.37755	.38231	.38705	.39178	.39649	.40118	.40586
0.8	.41052	.41517	.41979	.42440	.42899	.43357	.43813	.44267	.44719	.45169
0.9	.45618	.46064	.46509	.46952	.47393	.47832	.48270	.48705	.49139	.49570
1.0	.50000	.50428	.50853	.51277	.51699	.52119	.52537	.52952	.53366	.53778
1.1	.54188	.54595	.55001	.55404	.55806	.56205	.56602	.56998	.57391	.57782
1.2	.58171	.58558	.58942	.59325	.59705	.60083	.60460	.60833	.61205	.61575
1.3	.61942	.62308	.62671	.63032	.63391	.63747	.64102	.64454	.64804	.65152
1.4	.65498	.65841	.66182	.66521	.66858	.67193	.67526	.67856	.68184	.68510
1.5	.68833	.69155	.69474	.69791	.70106	.70419	.70729	.71038	.71344	.71648
1.6	.71949	.72249	.72546	.72841	.73134	.73425	.73714	.74000	.74285	.74567
1.7	.74847	.75124	.75400	.75674	.75945	.76214	.76481	.76746	.77009	.77270
1.8	.77528	.77785	.78039	.78291	.78542	.78790	.79036	.79280	.79522	.79761
1.9	.79999	.80235	.80469	.80700	.80930	.81158	.81383	.81607	.81828	.82048
2.0	.82266	.82481	.82695	.82907	.83117	.83324	.83530	.83734	.83936	.84137
2.1	.84335	.84531	.84726	.84919	.85109	.85298	.85486	.85671	.85854	.86036
2.2	.86216	.86394	.86570	.86745	.86917	.87088	.87258	.87425	.87591	.87755
2.3	.87918	.88078	.88237	.88395	.88550	.88705	.88857	.89008	.89157	.89304
2.4	.89450	.89595	.89738	.89879	.90019	.90157	.90293	.90428	.90562	.90694
2.5	.90825	.90954	.91082	.91208	.91332	.91456	.91578	.91698	.91817	.91935
2.6	.92051	.92166	.92280	.92392	.92503	.92613	.92721	.92828	.92934	.93038
2.7	.93141	.93243	.93344	.93443	.93541	.93638	.93734	.93828	.93922	.94014
2.8	.94105	.94195	.94284	.94371	.94458	.94543	.94627	.94711	.94793	.94874
2.9	.94954	.95033	.95111	.95187	.95263	.95338	.95412	.95484	.95557	.95628
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
3	.95698	.96346	.96910	.97397	.97817	.98176	.98482	.98743	.98962	.99147
4	.99302	.99431	.99539	99627	.99700	.99760	.99808	.99848	.99879	.99905
5	.99926	.99943	.99956	.99966	.99974	.99980	.99985	.99988	.99991	.99993

TABLE 25.

LEAST SQUARES.

Values of the factor $0.6745\sqrt{\frac{1}{n-1}}$.

This factor occurs in the equation $r_s = 0.6745\sqrt{\frac{\Sigma v^2}{n-1}}$ for the probable error of a single observation, and other similar equations.

n	=	1	2	3	4	5	6	7	8	9
00			0.6745	0.4769	0.3894	0.3372	0.3016	0.2754	0.2549	0.2385
10	0.2248	0.2133	.2034	.1947	.1871	.1803	.1742	.1686	.1636	.1590
20	.1547	.1508	.1472	.1438	.1406	.1377	.1349	.1323	.1298	.1275
30	.1252	.1231	.1211	.1192	.1174	.1157	.1140	.1124	.1109	.1094
40	.1080	.1066	.1053	.1041	.1029	.1017	.1005	.0994	.0984	.0974
50	0.0964	0.0954	0.0944	0.0935	0.0926	0.0918	0.0909	0.0901	0.0893	0.0886
60	.0878	.0871	.0864	.0857	.0850	.0843	.0837	.0830	.0824	.0818
70	.0812	.0806	.0800	.0795	.0789	.0784	.0779	.0774	.0769	.0764
80	.0759	.0754	.0749	.0745	.0740	.0736	.0732	.0727	.0723	.0719
90	.0715	.0711	.0707	.0703	.0699	.0696	.0692	.0688	.0685	.0681

TABLE 26.—LEAST SQUARES.

Values of the factor $0.6745\sqrt{\frac{1}{n(n-1)}}$.

This factor occurs in the equation $r_0=0.6745\sqrt{\frac{\Sigma v^2}{n(n-1)}}$ for the probable error of the arithmetic mean.

n =		1	2	3	4	5	6	7	8	9
00			0.4769	0.2754	0.1947	0.1508	0.1231	0.1041	0.0901	0.0795
10	0.0711	0.0643	.0587	.0540	.0500	.0465	.0435	.0409	.0386	.0365
20	.0346	.0329	.0314	.0300	.0287	.0275	.0265	.0255	.0245	.0237
30	.0229	.0221	.0214	.0208	.0201	.0196	.0190	.0185	.0180	.0175
40	.0171	.0167	.0163	.0159	.0155	.0152	.0148	.0145	.0142	.0139
50	0.0136	0.0134	0.0131	0.0128	0.0126	0.0124	0.0122	0.0119	0.0117	0.0115
60	.0113	.0111	.0110	.0108	.0106	.0105	.0103	.0101	.0100	.0098
70	.0097	.0096	.0094	.0093	.0092	.0091	.0089	.0088	.0087	.0086
80	.0085	.0084	.0083	.0082	.0081	.0080	.0079	.0078	.0077	.0076
90	.0075	.0075	.0074	.0073	.0072	.0071	.0071	.0070	.0069	.0068

TABLE 27.—LEAST SQUARES.

Values of the factor $0.8453\sqrt{\frac{1}{n(n-1)}}$.

This factor occurs in the approximate equation $r=0.8453\frac{\Sigma v}{\sqrt{n(n-1)}}$ for the probable error of a single observation.

n =		1	2	3	4	5	6	7	8	9
00			0.5978	0.3451	0.2440	0.1890	0.1543	0.1304	0.1130	0.0996
10	0.0891	0.0806	.0736	.0677	.0627	.0583	.0546	.0513	.0483	.0457
20	.0434	.0412	.0393	.0376	.0360	.0345	.0332	.0319	.0307	.0297
30	.0287	.0277	.0268	.0260	.0252	.0245	.0238	.0232	.0225	.0220
40	.0214	.0209	.0204	.0199	.0194	.0190	.0186	.0182	.0178	.0174
50	0.0171	0.0167	0.0164	0.0161	0.0158	0.0155	0.0152	0.0150	0.0147	0.0145
60	.0142	.0140	.0137	.0135	.0133	.0131	.0129	.0127	.0125	.0123
70	.0122	.0120	.0118	.0117	.0115	.0113	.0112	.0111	.0109	.0108
80	.0106	.0105	.0104	.0102	.0101	.0100	.0099	.0098	.0097	.0096
90	.0094	.0093	.0092	.0091	.0090	.0089	.0089	.0088	.0087	.0086

TABLE 28.—LEAST SQUARES.

Values of $0.8453\frac{1}{n\sqrt{n-1}}$.

This factor occurs in the approximate equation $r_0=0.8453\frac{1}{n\sqrt{n-1}}$ for the probable error of the arithmetical mean.

n =		1	2	3	4	5	6	7	8	9
00			0.4227	0.1993	0.1220	0.0845	0.0630	0.0493	0.0399	0.0332
10	0.0282	0.0243	.0212	.0188	.0167	.0151	.0136	.0124	.0114	.0105
20	.0097	.0090	.0084	.0078	.0073	.0069	.0065	.0061	.0058	.0055
30	.0052	.0050	.0047	.0045	.0043	.0041	.0040	.0038	.0037	.0035
40	.0034	.0033	.0031	.0030	.0029	.0028	.0027	.0027	.0026	.0025
50	0.0024	0.0023	0.0023	0.0022	0.0022	0.0021	0.0020	0.0020	0.0019	0.0019
60	.0018	.0018	.0017	.0017	.0017	.0016	.0016	.0016	.0015	.0015
70	.0015	.0014	.0014	.0014	.0013	.0013	.0013	.0013	.0012	.0012
80	.0012	.0012	.0011	.0011	.0011	.0011	.0011	.0010	.0010	.0010
90	.0010	.0010	.0010	.0009	.0009	.0009	.0009	.0009	.0009	.0009

TABLE 29.

LEAST SQUARES.

Observation equations:

$$\begin{array}{l} a_1z_1 + b_1z_2 + \ldots \; l_1z_q = M_1, \text{ weight } p_1 \\ a_2z_1 + b_2z_2 + \ldots \; l_2z_q = M_2, \text{ weight } p_2 \\ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ a_nz_1 + b_nz_2 + \ldots \; l_nz_q = M_n, \text{ weight } p_n. \end{array}$$

Auxiliary equations:

$$\begin{array}{ll} [paa] & = p_1a_1^2 + p_2a_2^2 + \ldots \; p_na_n^2. \\ [pab] & = p_1a_1b_1 + p_2a_2b_2 + \ldots \; p_na_nb_n. \\ \cdot \quad \cdot & \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ [paM] & = p_1a_1M_1 + p_2a_2M_2 + \ldots \; p_na_nM_n. \end{array}$$

Normal equations:

$$\begin{array}{l} [paa]z_1 + [pab]z_2 + \ldots \; [pal]z_q = [paM] \\ [pab]z_1 + [pbb]z_2 + \ldots \; [pbl]z_q = [pbM] \\ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ [pla]z_1 + [plb]z_2 + \ldots \; [pll]z_q = [plM]. \end{array}$$

Solution of normal equations in the form,

$$\begin{array}{l} z_1 = A_1[paM] + B_1[pbM] + \ldots \; L_1[plM] \\ z_2 = A_2[paM] + B_2[pbM] + \ldots \; L_2[plM] \\ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ z_q = A_n[paM] + B_n[pbM] + \ldots \; L_n[plM], \end{array}$$

gives:

$$\text{weight of } z_1 = p_{z1} = (A_1)^{-1}; \text{ probable error of } z_1 = \frac{r}{\sqrt{p_{z_1}}}$$

$$\text{weight of } z_2 = p_{z2} = (B_2)^{-1}; \text{ probable error of } z_2 = \frac{r}{\sqrt{p_{z_2}}}$$

$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

$$\text{weight of } z_q = p_{z_q} = (L_n)^{-1}; \text{ probable error of } z_q = \frac{r}{\sqrt{p_{z_q}}}$$

wherein

$$r = \text{probable error of observation of weight unity}$$

$$= 0.6745\sqrt{\frac{\Sigma pv^2}{n-q}}. \quad (q \text{ unknowns.})$$

Arithmetical mean, n observations:

$$r = 0.6745\sqrt{\frac{\Sigma v^2}{n-1}} = \frac{0.8453\,\Sigma v}{\sqrt{n(n-1)}}. \quad \text{(approx.)} = \text{probable error of observation of weight unity.}$$

$$r_0 = 0.6745\sqrt{\frac{\Sigma v^2}{n(n-1)}} = \frac{0.8453\,\Sigma v}{n\sqrt{n-1}}. \quad \text{(approx.)} = \text{probable error of mean.}$$

Weighted mean, n observations:

$$r = 0.6745\sqrt{\frac{\Sigma p v^2}{n-1}}; \; r_0 = \frac{r}{\sqrt{\Sigma p}} = 0.6745\sqrt{\frac{\Sigma p v^2}{(n-1)\,\Sigma p}}$$

Probable error (R) of a function (Z) of several observed quantities $z_1, z_2, \ldots$ whose probable errors are respectively, $r_1, r_2, \ldots$

$$Z = f(z_1, z_2, \ldots)$$

$$R^2 = \left(\frac{\partial Z}{\partial z_1}\right)^2 r_1^2 + \left(\frac{\partial Z}{\partial z_2}\right)^2 r_2^2 + \ldots$$

Examples:

$$Z = z_1 \pm z_2 + \ldots \qquad R^2 = r_1^2 + r_2^2 + \ldots$$

$$Z = Az_1 \pm Az_2 \pm \ldots \qquad R^2 = A^2 r_1^2 + B^2 r_2^2 + \ldots$$

$$Z = z_1 z_2. \qquad R^2 = z_1 r_2^2 + z_2 r_1^2.$$

TABLE 30.

DIFFUSION.

Inverse * values of $v/c = 1 - \frac{2}{\sqrt{\pi}} \int_0^q e^{-q^2} dq$.

$\log x = \log (2q) + \log \sqrt{kt}$. t expressed in seconds.
$= \log \delta + \log \sqrt{kt}$. t expressed in days.
$= \log \gamma + \log \sqrt{kt}$. " " years.
k = coefficient of diffusion.†
c = initial concentration.
v = concentration at distance x, time t.

v/c	log $2q$	$2q$	log δ	δ	log γ	γ
0.00	$+\infty$	$+\infty$	$+\infty$	$+\infty$	∞	∞
.01	0.56143	3.6428	3.02970	1070.78	4.31098	20463.
.02	.51719	3.2900	2.98545	967.04	.26674	18481.
.03	.48699	3.0690	.95525	902.90	.23654	17240.
.04	.46306	2.9044	.93132	853.73	.21261	16316.
0.05	0.44276	2.7718	2.91102	814.74	4.19231	15571.
.06	.42486	2.6598	.89311	781.83	.17440	14942.
.07	.40865	2.5624	.87691	753.20	.15820	14395.
.08	.39372	2.4758	.86198	727.75	.14327	13908.
.09	.37979	2.3977	.84804	704.76	.12933	13469.
0.10	0.36664	2.3262	2.83490	683.75	4.11619	13067.
.11	.35414	2.2602	.82240	664.36	.10369	12697.
.12	.34218	2.1988	.81044	646.31	.09173	12352.
.13	.33067	2.1413	.79893	629.40	.08022	12029.
.14	.31954	2.0871	.78780	613.47	.06909	11724.
0.15	0.30874	2.0358	2.77699	598.40	4.05828	11436.
.16	.29821	1.9871	.76647	584.08	.04776	11162.
.17	.28793	1.9406	.75619	570.41	.03748	10901.
.18	.27786	1.8961	.74612	557.34	.02741	10652.
.19	.26798	1.8534	.73624	544.80	.01753	10412.
0.20	0.25825	1.8124	2.72651	532.73	4.00780	10181.
.21	.24866	1.7728	.71692	521.10	3.99821	9958.9
.22	.23919	1.7346	.70745	509.86	.98874	9744.1
.23	.22983	1.6976	.69808	498.98	.97937	9536.2
.24	.22055	1.6617	.68880	488.43	.97010	9334.6
0.25	0.21134	1.6268	2.67960	478.19	3.96089	9138.9
.26	.20220	1.5930	.67046	468.23	.95175	8948.5
.27	.19312	1.5600	.66137	458.53	.94266	8763.2
.28	.18407	1.5278	.65232	449.08	.93361	8582.5
.29	.17505	1.4964	.64331	439.85	.92460	8406.2
0.30	0.16606	1.4657	2.63431	430.84	3.91560	8233.9
.31	.15708	1.4357	.62533	422.02	.90662	8065.4
.32	.14810	1.4064	.61636	413.39	.89765	7900.4
.33	.13912	1.3776	.60738	404.93	.88867	7738.8
.34	.13014	1.3494	.59840	396.64	.87969	7580.3
0.35	0.12114	1.3217	2.58939	388.50	3.87068	7424.8
.36	.11211	1.2945	.58037	380.51	.86166	7272.0
.37	.10305	1.2678	.57131	372.66	.85260	7122.0
.38	.09396	1.2415	.56222	364.93	.84351	6974.4
.39	.08482	1.2157	.55308	357.34	.83437	6829.2
0.40	0.07563	1.1902	2.54389	349.86	3.82518	6686.2
.41	.06639	1.1652	.53464	342.49	.81593	6545.4
.42	.05708	1.1405	.52533	335.22	.80662	6406.6
.43	.04770	1.1161	.51595	328.06	.79724	6269.7
.44	.03824	1.0920	.50650	320.99	.78779	6134.6
0.45	0.02870	1.0683	2.49696	314.02	3.77825	6001.3
.46	.01907	1.0449	.48733	307.13	.76862	5869.7
.47	.00934	1.0217	.47760	300.33	.75889	5739.7
.48	9.99951	0.99886	.46776	293.60	.74905	5611.2
.49	.98956	0.97624	.45782	286.96	.73911	5484.1
0.50	9.97949	0.95387	2.44775	280.38	3.72904	5358.4

---

* Kelvin, Mathematical and Physical Papers, vol. III. p. 428; Becker, Am. Jour. of Sci. vol. III. 1897, p. 280.

† For direct values see table 23.

DIFFUSION.

v/c	log 2*q*	2*q*	log δ	δ	log γ	γ
0.50	9.97949	0.95387	2.44775	280.38	3.72904	5358.4
.51	.96929	.93174	.43755	273.87	.71884	5234.1
.52	.95896	.90983	.42722	267.43	.70851	5111.0
.53	.94848	.88813	.41674	261.06	.69803	4989.1
.54	.93784	.86665	.40610	254.74	.68739	4868.4
0.55	9.92704	0.84536	2.39530	248.48	3.67659	4748.9
.56	.91607	.82426	.38432	242.28	.66561	4630.3
.57	.90490	.80335	.37316	236.13	.65445	4512.8
.58	.89354	.78260	.36180	230.04	.64309	4396.3
.59	.88197	.76203	.35023	223.99	.63152	4280.7
0.60	9.87018	0.74161	2.33843	217.99	3.61973	4166.1
.61	.85815	.72135	.32640	212.03	.60770	4052.2
.62	.84587	.70124	.31412	206.12	.59541	3939.2
.63	.83332	.68126	.30157	200.25	.58286	3827.0
.64	.82048	.66143	.28874	194.42	.57003	3715.6
0.65	9.80734	0.64172	2.27560	188.63	3.55689	3604.9
.66	.79388	.62213	.26214	182.87	.54343	3494.9
.67	.78008	.60266	.24833	177.15	.52962	3385.4
.68	.76590	.58331	.23416	171.46	.51545	3276.8
.69	.75133	.56407	.21959	165.80	.50088	3168.7
0.70	9.73634	0.54493	2.20459	160.17	3.48588	3061.1
.71	.72089	.52588	.18915	154.58	.47044	2954.2
.72	.70495	.50694	.17321	149.01	.45450	2847.7
.73	.68849	.48808	.15675	143.47	.43804	2741.8
.74	.67146	.46931	.13972	137.95	.42101	2636.4
0.75	9.65381	0.45062	2.12207	132.46	3.40336	2531.4
.76	.63550	.43202	.10376	126.99	.38505	2426.9
.77	.61646	.41348	.08471	121.54	.36600	2322.7
.78	.59662	.39502	.06487	116.11	.34616	2219.0
.79	.57590	.37662	.04416	110.70	.32545	2115.7
0.80	9.55423	0.35829	2.02249	105.31	3.30378	2012.7
.81	.53150	.34001	1.99975	99.943	.28104	1910.0
.82	.50758	.32180	.97584	94.589	.25713	1807.7
.83	.48235	.30363	.95061	89.250	.23190	1705.7
.84	.45564	.28552	.92389	83.926	.20518	1603.9
0.85	9.42725	0.26745	1.89551	78.615	3.17680	1502.4
.86	.39695	.24943	.86521	73.317	.14650	1401.2
.87	.36445	.23145	.83271	68.032	.11400	1300.2
.88	.32940	.21350	.79766	62.757	.07895	1199.4
.89	.29135	.19559	.75961	57.492	3.04090	1098.7
0.90	9.24972	0.17771	1.71797	52.236	2.99926	998.31
.91	.20374	.15986	.67200	46.989	.95329	898.03
.92	.15239	.14203	.62065	41.750	.90194	797.89
.93	.09423	.12423	.56249	36.516	.84378	697.88
.94	9.02714	.10645	.49539	31.289	.77668	597.98
0.95	8.94783	0.08868	1.41609	26.067	2.69738	498.17
.96	.85082	.07093	.31907	20.848	.60036	398.44
.97	.72580	.05319	.19406	15.633	.47535	298.78
.98	.54965	.03545	.01791	10.421	.29920	199.16
.99	.24859	.01773	9.71684	5.21007	1.99813	99.571
1.00	−∞	0.00000	−∞	0.00000	−∞	0.000

TABLE 31.

GAMMA FUNCTION.*

$$\text{Value of } \log \int_0^\infty e^{-x} x^{n-1} dx + 10.$$

Values of the logarithms + 10 of the "Second Eulerian Integral" (Gamma function) $\int_0^\infty e^{-x} x^{n-1} dx$ or $\log \Gamma(n) + 10$ for values of n between 1 and 2. When n has values not lying between 1 and 2 the value of the function can be readily calculated from the equation $\Gamma(n+1) = n\Gamma(n) = n(n-1) \ldots (n-r)\Gamma(n-r)$.

n	0	1	2	3	4	5	6	7	8	9
1.00	9.99——	97497	95001	92512	90030	87555	85087	82627	80173	77727
1.01	75287	72855	70430	68011	65600	63196	60798	58408	56025	53648
1.02	51279	48916	46561	44212	41870	39535	37207	34886	32572	30265
1.03	27964	25671	23384	21104	18831	16564	14305	12052	09806	07567
1.04	05334	03108	00889	98677	96471	94273	92080	89895	87716	85544
1.05	9.9883379	81220	79068	76922	74783	72651	70525	68406	66294	64188
1.06	62089	59996	57910	55830	53757	51690	49630	47577	45530	43489
1.07	41455	39428	37407	35392	33384	31382	29387	27398	25415	23439
1.08	21469	19506	17549	15599	13655	11717	09785	07860	05941	04029
1.09	02123	00223	98329	96442	94561	92686	90818	88956	87100	85250
1.10	9.9783407	81570	79738	77914	76095	74283	72476	70676	68882	67095
1.11	65313	63538	61768	60005	58248	56497	54753	53014	51281	49555
1.12	47834	46120	44411	42709	41013	39323	37638	35960	34288	32622
1.13	30962	29308	27659	26017	24381	22751	21126	19508	17896	16289
1.14	14689	13094	11505	09922	08345	06774	05209	03650	02096	00549
1.15	9.9699007	97471	95941	94417	92898	91386	89879	88378	86883	85393
1.16	83910	82432	80960	79493	78033	76578	75129	73686	72248	70816
1.17	69390	67969	66554	65145	63742	62344	60952	59566	58185	56810
1.18	55440	54076	52718	51366	50019	48677	47341	46011	44687	43368
1.19	42054	40746	39444	38147	36856	35570	34290	33016	31747	30483
1.20	9.9629225	27973	26725	25484	24248	23017	21792	20573	19358	18150
1.21	16946	15748	14556	13369	12188	11011	09841	08675	07515	06361
1.22	05212	04068	02930	01796	00669	99546	98430	97318	96212	95111
1.23	594015	92925	91840	90760	89685	88616	87553	86494	85441	84393
1.24	83350	82313	81280	80253	79232	78215	77204	76198	75197	74201
1.25	9.9573211	72226	71246	70271	69301	68337	67377	66423	65474	64530
1.26	63592	62658	61730	60806	59888	58975	58067	57165	56267	55374
1.27	54487	53604	52727	51855	50988	50126	49268	48416	47570	46728
1.28	45891	45059	44232	43410	42593	41782	40975	40173	39376	38585
1.29	37798	37016	36239	35467	34700	33938	33181	32429	31682	30940
1.30	9.9530203	29470	28743	28021	27303	26590	25883	25180	24482	23789
1.31	23100	22417	21739	21065	20396	19732	19073	18419	17770	17125
1.32	16485	15850	15220	14595	13975	13359	12748	12142	11541	10944
1.33	10353	09766	09184	08606	08034	07466	06903	06344	05791	05242
1.34	04698	04158	03624	03094	02568	02048	01532	01021	00514	00012
1.35	9.9499515	99023	98535	98052	97573	97100	96630	96166	95706	95251
1.36	94800	94355	93913	93477	93044	92617	92194	91776	91362	90953
1.37	90549	90149	89754	89363	88977	88595	88218	87846	87478	87115
1.38	86756	86402	86052	85707	85366	85030	84698	84371	84049	83731
1.39	83417	83108	82803	82503	82208	81916	81630	81348	81070	80797
1.40	9.9480528	80263	80003	79748	79497	79250	79008	78770	78537	78308
1.41	78084	77864	77648	77437	77230	77027	76829	76636	76446	76261
1.42	76081	75905	75733	75565	75402	75243	75089	74939	74793	74652
1.43	74515	74382	74254	74130	74010	73894	73783	73676	73574	73476
1.44	73382	73292	73207	73125	73049	72976	72908	72844	72784	72728

---

* Legendre's "Exercises de Calcul Intégral," tome ii.

GAMMA FUNCTION.

n	0	1	2	3	4	5	6	7	8	9
1.45	9.9472677	72630	72587	72549	72514	72484	72459	72437	72419	72406
1.46	72397	72393	72392	72396	72404	72416	72432	72452	72477	72506
1.47	72539	72576	72617	72662	72712	72766	72824	72886	72952	73022
1.48	73097	73175	73258	73345	73436	73531	73630	73734	73841	73953
1.49	74068	74188	74312	74440	74572	74708	74848	74992	75141	75293
1.50	9.9475449	75610	75774	75943	76116	76292	76473	76658	76847	77040
1.51	77237	77437	77642	77851	78064	78281	78502	78727	78956	79189
1.52	79426	79667	79912	80161	80414	80671	80932	81196	81465	81738
1.53	82015	82295	82580	82868	83161	83457	83758	84062	84370	84682
1.54	84998	85318	85642	85970	86302	86638	86977	87321	87668	88019
1.55	9.9488374	88733	89096	89463	89834	90208	90587	90969	91355	91745
1.56	92139	92537	92938	93344	93753	94166	94583	95004	95429	95857
1.57	96289	96725	97165	97609	98056	98508	98963	99422	99885	00351
1.58	500822	01296	01774	02255	02741	03230	03723	04220	04720	05225
1.59	05733	06245	06760	07280	07803	08330	08860	09395	09933	10475
1.60	9.9511020	11569	12122	12679	13240	13804	14372	14943	15519	16098
1.61	16680	17267	17857	18451	19048	19649	20254	20862	21475	22091
1.62	22710	23333	23960	24591	25225	25863	26504	27149	27798	28451
1.63	29107	29766	30430	31097	31767	32442	33120	33801	34486	35175
1.64	35867	36563	37263	37966	38673	39383	40097	40815	41536	42260
1.65	9.9542989	43721	44456	45195	45938	46684	47434	48187	48944	49704
1.66	50468	51236	52007	52782	53560	54342	55127	55916	56708	57504
1.67	58303	59106	59913	60723	61536	62353	63174	63998	64825	65656
1.68	66491	67329	68170	69015	69864	70716	71571	72430	73293	74159
1.69	75028	75901	76777	77657	78540	79427	80317	81211	82108	83008
1.70	9.9583912	84820	85731	86645	87563	88484	89409	90337	91268	92203
1.71	93141	94083	95028	95977	96929	97884	98843	99805	00771	01740
1.72	602712	03688	04667	05650	06636	07625	08618	09614	10613	11616
1.73	12622	13632	14645	15661	16681	17704	18730	19760	20793	21830
1.74	22869	23912	24959	26009	27062	28118	29178	30241	31308	32377
1.75	9.9633451	34527	35607	36690	37776	38866	39959	41055	42155	43258
1.76	44364	45473	46586	47702	48821	49944	51070	52199	53331	54467
1.77	55606	56749	57894	59043	60195	61350	62509	63671	64836	66004
1.78	67176	68351	69529	70710	71895	73082	74274	75468	76665	77866
1.79	79070	80277	81488	82701	83918	85138	86361	87588	88818	90051
1.80	9.9691287	92526	93768	95014	96263	97515	98770	00029	01291	02555
1.81	703823	05095	06369	07646	08927	10211	11498	12788	14082	15378
1.82	16678	17981	19287	20596	21908	23224	24542	25864	27189	28517
1.83	29848	31182	32520	33860	35204	36551	37900	39254	40610	41969
1.84	43331	44697	46065	47437	48812	50190	51571	52955	54342	55733
1.85	9.9757126	58522	59922	61325	62730	64139	65551	66966	68384	69805
1.86	71230	72657	74087	75521	76957	78397	79839	81285	82734	84186
1.87	85640	87098	88559	90023	91490	92960	94433	95909	97389	98871
1.88	800356	01844	03335	04830	06327	07827	09331	10837	12346	13859
1.89	15374	16893	18414	19939	21466	22996	24530	26066	27606	29148
1.90	9.9830693	32242	33793	35348	36905	38465	40028	41595	43164	44736
1.91	46311	47890	49471	51055	52642	54232	55825	57421	59020	60621
1.92	62226	63834	65445	67058	68675	70294	71917	73542	75170	76802
1.93	78436	80073	81713	83356	85002	86651	88302	89957	91614	93275
1.94	94938	96605	98274	99946	01621	03299	04980	06663	08350	10039
1.95	9.9911732	13427	15125	16826	18530	20237	21947	23659	25375	27093
1.96	28815	30539	32266	33995	35728	37464	39202	40943	42688	44435
1.97	46185	47937	49693	51451	53213	54977	56744	58513	60286	62062
1.98	63840	65621	67405	69192	70982	72774	74570	76368	78169	79972
1.99	81779	83588	85401	87216	89034	90854	92678	94504	96333	98165

TABLE 32.

ZONAL SPHERICAL HARMONICS.*

Degrees	P_1	P_2	P_3	P_4	P_5	P_6	P_7
0	+ 1.0000	+ 1.0000	+ 1.0000	+ 1.0000	+ 1.0000	+ 1.0000	+ 1.0000
1	.9998	.9995	.9991	.9985	.9977	.9968	.9957
2	.9994	.9982	.9963	.9939	.9909	.9872	.9830
3	.9986	.9959	.9918	.9863	.9795	.9714	.9620
4	.9976	.9927	.9854	.9758	.9638	.9495	.9329
5	+ 0.9962	+ 0.9886	+ 0.9773	+ 0.9623	+ 0.9437	+ 0.9216	+ 0.8962
6	.9945	.9836	.9674	.9459	.9194	.8881	.8522
7	.9925	.9777	.9557	.9267	.8911	.8492	.8016
8	.9903	.9709	.9423	.9048	.8589	.8054	.7449
9	.9877	.9633	.9273	.8803	.8232	.7570	.6830
10	+ 0.9848	+ 0.9548	+ 0.9106	+ 0.8532	+ 0.7840	+ 0.7045	+ 0.6164
11	.9816	.9454	.8923	.8238	.7417	.6483	.5462
12	.9781	.9352	.8724	.7920	.6966	.5891	.4731
13	.9744	.9241	.8511	.7582	.6489	.5273	.3980
14	.9703	.9122	.8283	.7224	.5990	.4635	.3218
15	+ 0.9659	+ 0.8995	+ 0.8042	+ 0.6847	+ 0.5471	+ 0.3983	+ 0.2455
16	.9613	.8860	.7787	.6454	.4937	.3323	+ .1700
17	.9563	.8718	.7519	.6046	.4391	.2661	+ .0961
18	.9511	.8568	.7240	.5624	.3836	.2002	+ .0248
19	.9455	.8410	.6950	.5192	.3276	.1353	− .0433
20	+ 0.9397	+ 0.8245	+ 0.6649	+ 0.4750	+ 0.2715	+ 0.0719	− 0.1072
21	.9336	.8074	.6338	.4300	.2156	+ .0106	.1664
22	.9272	.7895	.6019	.3845	.1602	− .0481	.2202
23	.9205	.7710	.5692	.3386	.1057	− .1038	.2680
24	.9135	.7518	.5357	.2926	.0525	− .1558	.3094
25	+ 0.9063	+ 0.7321	+ 0.5016	+ 0.2465	+ 0.0009	− 0.2040	− 0.3441
26	.8988	.7117	.4670	.2007	− .0489	.2478	.3717
27	.8910	.6908	.4319	.1553	− .0964	.2869	.3922
28	.8829	.6694	.3964	.1105	− .1415	.3212	.4053
29	.8746	.6474	.3607	.0665	− .1839	.3502	.4113
30	+ 0.8660	+ 0.6250	+ 0.3248	+ 0.0234	− 0.2233	− 0.3740	− 0.4102
31	.8572	.6021	.2887	− .0185	.2595	.3924	.4022
32	.8480	.5788	.2527	− .0591	.2923	.4053	.3877
33	.8387	.5551	.2167	− .0982	.3216	.4127	.3671
34	.8290	.5310	.1809	− .1357	.3473	.4147	.3409
35	+ 0.8192	+ 0.5065	+ 0.1454	− 0.1714	− 0.3691	− 0.4114	− 0.3096
36	.8090	.4818	.1102	.2052	.3871	.4031	.2738
37	.7986	.4567	.0755	.2370	.4011	.3898	.2343
38	.7880	.4314	.0413	.2666	.4112	.3719	.1918
39	.7771	.4059	.0077	.2940	.4174	.3497	.1470
40	+ 0.7660	+ 0.3802	− 0.0252	− 0.3190	− 0.4197	− 0.3236	− 0.1006
41	.7547	.3544	.0574	.3416	.4181	.2939	− .0535
42	.7431	.3284	.0887	.3616	.4128	.2610	− .0064
43	.7314	.3023	.1191	.3791	.4038	.2255	+ .0398
44	.7193	.2762	.1485	.3940	.3914	.1878	+ .0846
45	+ 0.7071	+ 0.2500	− 0.1768	− 0.4063	− 0.3757	− 0.1484	+ 0.1271
46	.6947	.2238	.2040	.4158	.3568	− .1078	.1667
47	.6820	.1977	.2300	.4227	.3350	− .0665	.2028
48	.6691	.1716	.2547	.4270	.3105	− .0251	.2350
49	.6561	.1456	.2781	.4286	.2836	+ .0161	.2626
50	+ 0.6428	+ 0.1198	− 0.3002	− 0.4275	− 0.2545	+ 0.0564	+ 0.2854

---

* Calculated by Mr. C. E. Van Orstrand for this publication.

TABLE 32 (*continued*).

ZONAL SPHERICAL HARMONICS.

Degrees	P_1	P_2	P_3	P_4	P_5	P_6	P_7
50	+ 0.6428	+ 0.1198	— 0.3002	— 0.4275	— 0.2545	+ 0.0564	+ 0.2854
51	.6293	.0941	.3209	.4239	.2235	.0954	.3031
52	.6157	.0686	.3401	.4178	.1910	.1326	.3154
53	.6018	.0433	.3578	.4093	.1571	.1677	.3221
54	.5878	.0182	.3740	.3984	.1223	.2002	.3234
55	+ 0.5736	— 0.0065	— 0.3886	— 0.3852	— 0.0868	+ 0.2297	+ 0.3191
56	.5592	.0310	.4016	.3698	— .0509	.2560	.3095
57	.5446	.0551	.4131	.3524	— .0150	.2787	.2947
58	.5299	.0788	.4229	.3331	+ .0206	.2976	.2752
59	.5150	.1021	.4310	.3119	+ .0557	.3125	.2512
60	+ 0.5000	— 0.1250	— 0.4375	— 0.2891	+ 0.0898	+ 0.3232	+ 0.2231
61	.4848	.1474	.4423	.2647	.1229	.3298	.1916
62	.4695	.1694	.4455	.2390	.1545	.3321	.1572
63	.4540	.1908	.4471	.2121	.1844	.3302	.1203
64	.4384	.2117	.4470	.1841	.2123	.3240	.0818
65	+ 0.4226	— 0.2321	— 0.4452	— 0.1552	+ 0.2381	+ 0.3138	+ 0.0422
66	.4067	.2518	.4419	.1256	.2615	.2997	+ .0022
67	.3907	.2710	.4370	.0955	.2824	.2819	— .0375
68	.3746	.2895	.4305	.0651	.3005	.2606	— .0763
69	.3584	.3074	.4225	.0344	.3158	.2362	— .1135
70	+ 0.3420	— 0.3245	— 0.4130	— 0.0038	+ 0.3281	+ 0.2089	— 0.1485
71	.3256	.3410	.4021	+ .0267	.3373	.1791	.1808
72	.3090	.3568	.3898	.0568	.3434	.1472	.2099
73	.2924	.3718	.3761	.0864	.3463	.1136	.2352
74	.2756	.3860	.3611	.1153	.3461	.0788	.2563
75	+ 0.2588	— 0.3995	— 0.3449	+ 0.1434	+ 0.3427	+ 0.0431	— 0.2730
76	.2419	.4122	.3275	.1705	.3362	+ .0070	.2850
77	.2250	.4241	.3090	.1964	.3267	— .0290	.2921
78	.2079	.4352	.2894	.2211	.3143	— .0644	.2942
79	.1908	.4454	.2688	.2443	.2990	— .0990	.2913
80	+ 0.1736	— 0.4548	— 0.2474	+ 0.2659	+ 0.2810	— 0.1321	— 0.2835
81	.1564	.4633	.2251	.2859	.2606	.1635	.2708
82	.1392	.4709	.2020	.3040	.2378	.1927	.2536
83	.1219	.4777	.1783	.3203	.2129	.2193	.2321
84	.1045	.4836	.1539	.3345	.1861	.2431	.2067
85	+ 0.0872	— 0.4886	— 0.1291	+ 0.3468	+ 0.1577	— 0.2638	— 0.1778
86	.0698	.4927	.1038	.3569	.1278	.2810	.1460
87	.0523	.4959	.0781	.3648	.0969	.2947	.1117
88	.0349	.4982	.0522	.3704	.0651	.3045	.0755
89	.0175	.4995	.0262	.3739	.0327	.3105	.0381
90	+ 0.0000	— 0.5000	— 0.0000	+ 0.3750	+ 0.0000	— 0.3125	— 0.0000

TABLE 33.

ELLIPTIC INTEGRALS.

Values of $\int_0^{\frac{\pi}{2}}(1-\sin^2\theta\sin^2\phi)^{\pm\frac{1}{2}}\,d\phi$.

This table gives the values of the integrals between 0 and $\pi/2$ of the function $(1-\sin^2\theta\sin^2\phi)^{\pm\frac{1}{2}}\,d\phi$ for different values of the modulus corresponding to each degree of θ between 0 and 90.

θ	$\int_0^{\frac{\pi}{2}}\frac{d\phi}{(1-\sin^2\theta\sin^2\phi)^{\frac{1}{2}}}$		$\int_0^{\frac{\pi}{2}}(1-\sin^2\theta\sin^2\phi)^{\frac{1}{2}}d\phi$		θ	$\int_0^{\frac{\pi}{2}}\frac{d\phi}{(1-\sin^2\theta\sin^2\phi)^{\frac{1}{2}}}$		$\int_0^{\frac{\pi}{2}}(1-\sin^2\theta\sin^2\phi)^{\frac{1}{2}}d\phi$	
	Number.	Log.	Number.	Log.		Number.	Log.	Number.	Log.
0°	1.5708	0.196120	1.5708	0.196120	**45°**	1.8541	0.268127	1.3506	0.130541
1	5709	196153	5707	196087	6	8691	271644	3418	127690
2	5713	196252	5703	195988	7	8848	275267	3329	124788
3	5719	196418	5697	195822	8	9011	279001	3238	121836
4	5727	196649	5689	195591	9	9180	282848	3147	118836
5°	1.5738	0.196947	1.5678	0.195293	**50°**	1.9356	0.286811	1.3055	0.115790
6	5751	197312	5665	194930	1	9539	290895	2963	112698
7	5767	197743	5649	194500	2	9729	295101	2870	109563
8	5785	198241	5632	194004	3	9927	299435	2776	106386
9	5805	198806	5611	193442	4	2.0133	303901	2681	103169
10°	1.5828	0.199438	1.5589	0.192815	**55°**	2.0347	0.308504	1.2587	0.099915
1	5854	200137	5564	192121	6	0571	313247	2492	096626
2	5882	200904	5537	191362	7	0804	318138	2397	093303
3	5913	201740	5507	190537	8	1047	323182	2301	089950
4	5946	202643	5476	189646	9	1300	328384	2206	086569
15°	1.5981	0.203615	1.5442	0.188690	**60°**	2.1565	0.333753	1.2111	0.083164
6	6020	204657	5405	187668	1	1842	339295	2015	079738
7	6061	205768	5367	186581	2	2132	345020	1920	076293
8	6105	206948	5326	185428	3	2435	350936	1826	072834
9	6151	208200	5283	184210	4	2754	357053	1732	069364
20°	1.6200	0.209522	1.5238	0.182928	**65°**	2.3088	0.363384	1.1638	0.065889
1	6252	210916	5191	181580	6	3439	369940	1545	062412
2	6307	212382	5141	180168	7	3809	376736	1453	058937
3	6365	213921	5090	178691	8	4198	383787	1362	055472
4	6426	215533	5037	177150	9	4610	391112	1272	052020
25°	1.6490	0.217219	1.4981	0.175545	**70°**	2.5046	0.398730	1.1184	0.048589
6	6557	218981	4924	173876	1	5507	406665	1096	045183
7	6627	220818	4864	172144	2	5998	414943	1011	041812
8	6701	222732	4803	170348	3	6521	423596	0927	038481
9	6777	224723	4740	168489	4	7081	432660	0844	035200
30°	1.6858	0.226793	1.4675	0.166567	**75°**	2.7681	0.442176	1.0764	0.031976
1	6941	228943	4608	164583	6	8327	452196	0686	028819
2	7028	231173	4539	162537	7	9026	462782	0611	025740
3	7119	233485	4469	160429	8	9786	474008	0538	022749
4	7214	235880	4397	158261	9	3.0617	485967	0468	019858
35°	1.7312	0.238359	1.4323	0.156031	**80°**	3.1534	0.498777	1.0401	0.017081
6	7415	240923	4248	153742	1	2553	512591	0338	014432
7	7522	243575	4171	151393	2	3699	527613	0278	011927
8	7633	246315	4092	148985	3	5004	544120	0223	009584
9	7748	249146	4013	146519	4	6519	562514	0172	007422
40°	1.7868	0.252068	1.3931	0.143995	**85°**	3.8317	0.583396	1.0127	0.005465
1	7992	255085	3849	141414	6	4.0528	607751	0086	003740
2	8122	258197	3765	138778	7	3387	637355	0053	002278
3	8256	261406	3680	136086	8	7427	676027	0026	001121
4	8396	264716	3594	133340	9	5.4349	735192	0008	000326
45°	1.8541	0.268127	1.3506	0.130541	**90°**	∞	∞	1.0000	———

TABLE 34.

MOMENTS OF INERTIA, RADII OF GYRATION, AND WEIGHTS.

In each case the axis is supposed to traverse the centre of gravity of the body. The axis is one of symmetry. The mass of a unit of volume is w.

Body.	Axis.	Weight.	Moment of Inertia I_0.	Square of Radius of Gyration ρ_0^2.
Sphere of radius r	Diameter	$\frac{4\pi w r^3}{3}$	$\frac{8\pi w r^5}{15}$	$\frac{2r^2}{5}$
Spheroid of revolution, polar axis $2a$, equatorial diameter $2r$	Polar axis	$\frac{4\pi w a r^2}{3}$	$\frac{8\pi w a r^4}{15}$	$\frac{2r^2}{5}$
Ellipsoid, axes $2a$, $2b$, $2c$	Axis $2a$	$\frac{4\pi w abc}{3}$	$\frac{4\pi w abc(b^2+c^2)}{15}$	$\frac{b^2+c^2}{5}$
Spherical shell, external radius r, internal r'	Diameter	$\frac{4\pi w(r^3-r'^3)}{3}$	$\frac{8\pi w(r^5-r'^5)}{15}$	$\frac{2(r^5-r'^5)}{5(r^3-r'^3)}$
Ditto, insensibly thin, radius r, thickness dr	Diameter	$4\pi w r^2 dr$	$\frac{8\pi w r^4 dr}{3}$	$\frac{2r^2}{3}$
Circular cylinder, length $2a$, radius r	Longitudinal axis $2a$	$2\pi w a r^2$	$\pi w a r^4$	$\frac{r^2}{2}$
Elliptic cylinder, length $2a$, transverse axes $2b$, $2c$	Longitudinal axis $2a$	$2\pi w abc$	$\frac{\pi w abc(b^2+c^2)}{2}$	$\frac{b^2+c^2}{4}$
Hollow circular cylinder, length $2a$, external radius r, internal r'	Longitudinal axis $2a$	$2\pi w a(r^2-r'^2)$	$\pi w a(r^4-r'^4)$	$\frac{r^2+r'^2}{2}$
Ditto, insensibly thin, thickness dr	Longitudinal axis $2a$	$4\pi w a r dr$	$4\pi w a r^3 dr$	r^2
Circular cylinder, length $2a$, radius r	Transverse diameter	$2\pi w a r^2$	$\frac{\pi w a r^2(3r^2+4a^2)}{6}$	$\frac{r^2}{4}+\frac{a^2}{3}$
Elliptic cylinder, length $2a$, transverse axes $2a$, $2b$	Transverse axis $2b$	$2\pi w abc$	$\frac{\pi w abc(3c^2+4a^2)}{6}$	$\frac{c^2}{4}+\frac{a^2}{3}$
Hollow circular cylinder, length $2a$, external radius r, internal r'	Transverse diameter	$2\pi w a(r^2-r'^2)$	$\frac{\pi w a}{6}\left\{\begin{matrix}3(r^4-r'^4)\\+4a^2(r^2-r'^2)\end{matrix}\right\}$	$\frac{r^2+r'^2}{4}+\frac{a^2}{3}$
Ditto, insensibly thin, thickness dr	Transverse diameter	$4\pi w a r dr$	$\pi w a(2r^3+\frac{4}{3}a^2 r)dr$	$\frac{r^2}{2}+\frac{a^2}{3}$
Rectangular prism, dimensions $2a$, $2b$, $2c$	Axis $2a$	$8wabc$	$\frac{8wabc(b^2+c^2)}{3}$	$\frac{b^2+c^2}{3}$
Rhombic prism, length $2a$, diagonals $2b$, $2c$	Axis $2a$	$4wabc$	$\frac{2wabc(b^2+c^2)}{3}$	$\frac{b^2+c^2}{6}$
Ditto	Diagonal $2b$	$4wabc$	$\frac{2wabc(c^2+2a^2)}{3}$	$\frac{c^2}{6}+\frac{a^2}{3}$

(Taken from Rankine.)

TABLE 35.

STRENGTH OF MATERIALS.

The strength of most materials varies so that the following figures serve only as a rough indication of the strength of a particular sample.

TABLE 35 (a). — Metals.

Name of Metal.	Tensile strength in pounds per sq. in.
Aluminum wire	30000–40000
Brass wire	50000–150000
Bronze wire, phosphor, hard-drawn	110000–140000
Bronze wire, silicon, hard-drawn	95000–115000
Bronze: Cu, 58.54 parts; Zn, 38.70; Al, 0.21; with 2.55 parts of the alloy, Sn, 29.03, wrought iron, 58.06, ferro-manganese, 12.91	60000–75000
Copper wire, hard-drawn	60000–70000
Gold wire	20000
Iron, cast	13000–33000
" wire, hard-drawn	80000–120000
" " annealed	50000–60000
Lead, cast or drawn	2600–3300
Palladium *	39000
Platinum * wire	50000
Silver * wire	42000
Steel	80000–330000
" wire, maximum	460000
" Specially treated nickel-steel, approx. comp. 0.40 C; 3.25 Ni; treatment secret	250000
" piano wire, 0.033 in. diam.	357000–390000
" piano wire, 0.051 in. diam.	325000–337000
Tin, cast or drawn	4000–5000
Zinc, cast	7000–13000
" drawn	22000–30000

According to Boys, quartz fibres have a tensile strength of between 116000 and 167000 pounds per square inch.

* Authority of Wertheim.

TABLE 35 (b). — Stones.*

Material.	Size of test piece.	Resistance to crushing in pds. per sq. in.
Marble	4 in. cubes	7600–20700
Tufa	2 " "	7700–11600
Brownstone	– – –	7300–23600
Sandstone	4 in. cubes	2400–29300
Granite	4 " "	9700–34000
Limestone	4 " "	6000–25000

* Data furnished by the U. S. Geological Survey.

TABLE 35 (c). — Brick.*

Kind of Brick.	Resistance to crushing in pds. per sq. in.	
	Tested flatwise.	Tested on edge.
Soft burned	1800–4000	1600–3000
Medium burned	4000–6000	3000–4500
Hard burned	6000–8500	4500–6500
Vitrified	8500–25000	6500–20000
Sand-lime	1800–4000	

Brick piers laid up in 1 part Portland cement, 3 of sand, have from 20 to 40 per cent the crushing strength of the brick.

* Data furnished by the U. S. Geological Survey.

TABLE 35 (d). — Concretes.*

Coarse Aggregate.	Proportions by volume. Cement : sand : aggregate.	Size of test piece.	Resistance to crushing in pds. per sq. in.
Sandstone	1 : 5 : 14 to 1 : 1 : 5	12 in. cube	1550–3860
Cinders	1 : 3 : 6 " 1 : 1 : 3	12 " "	790–2050
Limestone	1 : 4 : 8 " 1 : 2 : 4	12 " "	1200–2840
Conglomerate	1 : 6 : 12 " 1 : 2 : 4	12 " "	1080–3830
Trap	1 : 2 : 9 " 1 : 2 : 4	12 " "	820–2960

* Data furnished by the U. S. Geological Survey.

TABLE 36.

STRENGTH OF MATERIALS.

Average Results of Timber Tests.

The test pieces were SMALL and SELECTED. Endwise compression tests of some of the first lot, made when green and containing over 40 per cent moisture, showed a diminishing in strength of 50 to 75 per cent.

See also Table 37. A particular sample may vary greatly from these data, which can indicate only in a general way the relative values of a kind of timber. Note that the data below are from selected samples and therefore probably high.

The upper lot are from the U. S. Forestry circular No. 15; the lower from the tests made for the 10th U. S. Census.

NAME OF SPECIES.	TRANSVERSE TESTS.		COMPRESSION.		SHEARING.
	Modulus of rupture. lb./sq. in.	Modulus of elasticity. lbs./sq. in.	‖ to grain. lbs./sq. in.	⊥ to grain. lbs./sq. in.	Along the grain. lbs./sq. in.
Long-leaf pine	12,600	2,070,000	8,000	1260	835
Cuban pine	13,600	2,370,000	8,700	1200	770
Short-leaf pine	10,100	1,680,000	6,500	1050	770
Loblolly pine	11,300	2,050,000	7,400	1150	800
White pine	7,900	1,390,000	5,400	700	400
Red pine	9,100	1,620,000	6,700	1000	500
Spruce pine	10,000	1,640,000	7,300	1200	800
Bald cypress	7,900	1,290,000	6,000	800	500
White cedar	6,300	910,000	5,200	700	400
Douglass spruce	7,900	1,680,000	5,700	800	500
White oak	13,100	2,090,000	8,500	2200	1000
Overcup oak	11,300	1,620,000	7,300	1900	1000
Post oak	12,300	2,030,000	7,100	3000	1100
Cow oak	11,500	1,610,000	7,400	1900	900
Red oak	11,400	1,970,000	7,200	2300	1100
Texan oak	13,100	1,860,000	8,100	2000	900
Yellow oak	10,800	1,740,000	7,300	1800	1100
Water oak	12,400	2,000,000	7,800	2000	1100
Willow oak	10,400	1,750,000	7,200	1600	900
Spanish oak	12,000	1,930,000	7,700	1800	900
Shagbark hickory	16,000	2,390,000	9,500	2700	1100
Mockernut hickory	15,200	2,320,000	10,100	3100	1100
Water hickory	12,500	2,080,000	8,400	2400	1000
Bitternut hickory	15,000	2,280,000	9,600	2200	1000
Nutmeg hickory	12,500	1,940,000	8,800	2700	1100
Pecan hickory	15,300	2,530,000	9,100	2800	1200
Pignut hickory	18,700	2,730,000	10,900	3200	1200
White elm	10,300	1,540,000	6,500	1200	800
Cedar elm	13,500	1,700,000	8,000	2100	1300
White ash	10,800	1,640,000	7,200	1900	1100
Green ash	11,600	2,050,000	8,000	1700	1000
Sweet gum	9,500	1,700,000	7,100	1400	800
Poplar	9,400	1,330,000	5,000	1120	
Basswood	8,340	1,172,000	5,190	880	
Ironwood	7,540	1,158,000	5,275	2000	
Sugar maple	16,500	2,250,000	8,800	3600	
White maple	14,640	1,800,000	6,850	2580	
Box elder	7,580	873,000	4,580	1580	
Black walnut	11,900	1,560,000	8,000	2680	
Sycamore	7,000	790,000	6,400	2700	
Hemlock	9,480	1,138,000	5,400	1100	
Red fir	13,270	1,870,000	7,780	1750	
Tamarack	13,150	1,917,000	7,400	1480	
Red cedar	11,800	938,000	6,300	2000	
Cottonwood	10,440	1,450,000	5,000	1100	
Beech	16,200	1,730,000	6,770	2840	

TABLE 37.

UNIT STRESSES FOR STRUCTURAL TIMBER EXPRESSED IN POUNDS PER SQUARE INCH.

Recommended by the Committee on Wooden Bridges and Trestles, American Railway Engineering Association, 1909.

KIND OF TIMBER.	BENDING.			SHEARING.			
	Extreme fibre stress.		Modulus of elasticity.	Parallel to grain.		Longitudinal shear in beams.	
	Average ultimate.	Safe stress.	Average.	Average ultimate	Safe stress.	Average ultimate.	Safe stress.
Douglass fir	6100	1200	1,510,000	690	170	270	110
Long-leaf pine	6500	1300	1,610,000	720	180	300	120
Short-leaf pine	5600	1100	1,480,000	710	170	330	130
White pine	4400	900	1,130,000	400	100	180	70
Spruce	4800	1000	1,310,000	600	150	170	70
Norway pine	4200	800	1,190,000	590	130	250	100
Tamarack	4600	900	1,220,000	670	170	260	100
Western hemlock	5800	1100	1,480,000	630	160	270*	100
Redwood	5000	900	800,000	300	80	–	–
Bald cypress	4800	900	1,150,000	500	120	–	–
Red cedar	4200	800	860,000	–	–	–	–
White oak	5700	1100	1,150,000	840	210	270	110

KIND OF TIMBER.	COMPRESSION						Ratio of length of stringer to depth.
	Perpendicular to grain.		Parallel to grain.		For columns under 15 diams. Safe stress.	Formulas for safe stress in long columns over 15 diameters.†	
	Elastic limit.	Safe stress.	Average ultimate.	Safe stress.			
Douglass fir	630	310	3600	1200	900	$1200(1-L/60 . D)$	10
Long-leaf pine	520	260	3800	1300	980	$1300(1-L/60 . D)$	10
Short-leaf pine	340	170	3400	1100	830	$1100(1-L/60 . D)$	10
White pine	290	150	3000	1000	750	$1000(1-L/60 . D)$	10
Spruce	370	180	3200	1100	830	$1100(1-L/60 . D)$	–
Norway pine	–	150	2600*	800	600	$800(1-L/60 . D)$	–
Tamarack	–	220	3200*	1000	750	$1000(1-L/60 . D)$	–
Western hemlock	440	220	3500	1200	900	$1200(1-L/60 . D)$	–
Redwood	400	150	3300	900	680	$900(1-L/60 . D)$	–
Bald cypress	340	170	3900	1100	830	$1100(1-L/60 . D)$	–
Red cedar	470	230	2800	900	680	$900(1-L/60 . D)$	–
White oak	920	450	3500	1300	980	$1300(1-L/60 . D)$	12

These unit stresses are for a green condition of the timber and are to be used without increasing the live-load stresses for impact.

* Partially air-dry.

† L = length in inches. D = least side in inches.

ELASTIC MODULI.

TABLE 38. — Rigidity Modulus.

If to the four consecutive faces of a cube a tangential stress is applied, opposite in direction on adjacent sides, the modulus of rigidity is obtained by dividing the numerical value of the tangential stress per unit area (kg. per sq. mm.) by the number representing the change of angles on the non-stressed faces, measured in radians.

Substance.	Rigidity Modulus.	Reference.	Substance.	Rigidity Modulus.	Reference.
Aluminum	3350	14	Quartz fibre	2888	20
" cast	2580	5	" "	2380	21
Brass	3550	10	Silver	2960	5
"	3715	11	"	2650	10
" cast, 60 Cu + 12 Sn	3700	5	"	2566	16
Bismuth, slowly cooled	1240	5	" hard-drawn	2816	11
Bronze, cast, 88 Cu + 12 Sn	4060	5	Steel	8290	16
Cadmium, cast	2450	5	" cast	7458	15
Copper, cast	4780	5	" cast, coarse gr.	8070	5
"	4213	18	" silver-	7872	11
"	4450	10	Tin, cast	1730	5
"	4664	19	"	1543	19
Gold	2850	5	Zinc	3880	5
"	3950	14	"	3820	19
Iron, cast	5210	5	Platinum	6630	16
"	6706	15	"	6220	22
"	7975	10	Glass	2350	–
"	6940	7	"	2730	–
"	8108	16	Clay rock	1770	23
"	7505	14	Granite	1280	23
Magnesium, cast	1710	5	Marble	1190	23
Nickel	7820	5	Slate	2290	23
Phosphor bronze	4359	11			

References 1–16, see Table 48.
17 Grätz, Wied. Ann. 28, 1886.
18 Savart, Pogg. Ann. 16, 1829.
19 Kiewiet, Diss. Göttingen, 1886.
20 Threlfall, Philos. Mag. (5) 30, 1890.
21 Boys, Philos. Mag. (5) 30, 1890.
22 Thomson, Lord Kelvin.
23 Gray and Milne.
24 Adams-Coker, Carnegie Publ. No. 46, 1906.

TABLE 39. — Variation of the Rigidity Modulus with the Temperature.

$n_t = n_o (1 - at - \beta t^2 - \gamma t^3)$, where t = temperature Centigrade.

Substance.	n_o	$a 10^6$	$\beta 10^8$	$\gamma 10^{10}$	Authority.
Brass	2652	2158	48	32	Pisati, Nuovo Cimento, 5, 34, 1879.
"	3200	455	36	–	Kohlrausch-Loomis, Pogg. Ann. 141.
Copper	3972	2716	—23	47	Pisati, loc. cit.
"	3900	572	28	–	K and L. loc. cit.
Iron	8108	206	19	—11	Pisati, loc. cit.
"	6940	483	12	–	K and L. loc. cit.
Platinum	6632	111	50	—8	Pisati, loc. cit.
Silver	2566	387	38	11	" " "
Steel	8290	187	59	—9	" " "

$n_t^* = n_{15} [1 - \alpha (t - 15)]$; Horton, Philos. Trans. 204 A, 1905.

Copper	4.37*	α =.00039	Platinum	6.46*	α = .00012	Tin	1.50*	α = .00416
Copper (commercial)	3.80	.00038	Gold	2.45	.00031	Lead	0.80	.00164
Iron	8.26	.00029	Silver	2.67	.00048	Cadmium	2.31	.0058
Steel	8.45	.00026	Aluminum	2.55	.00148	Quartz	3.00	.00012

* Modulus of rigidity in 10^{11} dynes per sq. cm.

TABLE 40.

ELASTIC MODULI.

Young's Modulus.

$$\text{Young's Modulus} = \frac{\text{Intensity of longitudinal stress (kg. per sq. mm.)}}{\text{Elongation per unit length}}.$$

Substance.	Temp. °C	Young's Modulus.	Reference.	Substance.	Temp. °C.	Young's Modulus.	Reference.
Aluminum	20	7200	1	Nickel-steel, 5½% ni.	–	19900	13
“	12.3	7462	2	“ “ 25% “	–	18600	13
Lead, drawn	15	1803	3	Palladium, annealed	15	9709	3
“ annealed	15	1727	3	Phosphor-bronze	–	12010	11
Bronze	–	9194	4	Platinum, drawn	15	17044	3
Cadmium	–	7070	5	“ annealed	15	15518	3
Delta metal	–	11697	6	“	13.2	16020	2
Iron, drawn	15	20869	3	“ drawn	10	15989	1
“ annealed	15	20794	3	Silver, drawn	15	7357	3
“	0	20310	7	“ annealed	15	7140	3
“	–	21740	8	Steel wire, drawn	15	18810	3
“ cast	–	11713	4	“ “ annealed	15	17280	3
“ soft	15.6	15750	9	Steel, cast, drawn	15	19550	3
“ drawn	20	19385	1	“ “ annealed	15	19560	3
“ drawn	–	20500	10	“ Bessemer	-	21136	4
Gold, drawn	15	8131	3	“ puddle	–	21112	4
“ annealed	15	5585	3	“ mild	15.5	21700	9
“ drawn	12.9	8630	2	“ very soft	–	20705	13
Copper, drawn	15	12450	3	“ half soft	–	20910	13
“ annealed	15	10520	3	“ hard	–	20600	13
“ drawn	0	12140	7	Bismuth	–	3190	5
“ drawn	20	12550	1	Zinc, drawn	15	8734	3
“ electr. h'd d'n	19.5	13220	9	Tin, drawn	15	4148	3
Brass, drawn	15	8543	3	“ cast	–	1700	13
“	0	9810	7	Glass	–	6000 to 8000	-
“ drawn	–	10220	11				
“	–	9930	10				
“	–	10450	9	Carbon	–	1500 to 2500	-
German silver	–	12094	4				
“ “ h'd d'n	–	11550	11				
“ “	20	13300	9	Marbles	–	6316	24
Nickel	–	20300	5	Granites	–	5159	24
“	–	22790	12	Basic intrusives	–	8985	24
“ hard drawn	–	23950	11	Rocks: See Nagaoka, Philos. Mag. 1900.			
“	11.5	21680	2				

1 Slotte, Acta Soc. Fenn. 26, 1899; 29, 1900.
2 Meyer, Wied. Ann. 59, 1896.
3 Wertheim, Ann. chim. phys. (3) 12, 1844.
4 Pscheidl, Wien. Ber. II, 79, 1879.
5 Voigt, Wied. Ann. 48, 1893.
6 Amagat, C. R. 108, 1889.
7 Kohlrausch, Loomis, Pogg. Ann. 141, 1871.
8 Thomas, Drude Ann. 1, 1900.
9 Gray, etc., Proc. Roy. Soc. 67, 1900.
10 Baumeister, Wied. Ann. 18, 1883.
11 Searle, Philos. Mag. (5) 49, 1900.
12 Cantone, Wied. Beibl. 14, 1890.
13 Mercadier, C. R. 113, 1891.
14 Katzenelsohn, Diss. Berlin, 1887.
15 Wertheim, Pogg. Ann. 78, 1849.
16 Pisati, Nuovo Cimento, 5, 34, 1879.
References 17–19, see Table 47.

Compiled partly from Landolt-Börnstein's Physikalisch-Chemische Tabellen.

TABLES 41-44.

COMPRESSIBILITY, HARDNESS, CONTRACTION OF ELEMENTS.

TABLE 41. — Compressibility of the More Important Solid Elements.

Arranged in order of the increasing atomic weights. The numbers give the mean elastic change of volume for one megabar (0.987 atm.) between 100 and 500 megabars, multiplied by 10^5.

Lithium	8.8	Potassium	31.5	Selenium	11.8	Iodine	13.
Carbon	0.5	Calcium	5.5	Bromine	51.8	Cæsium	61.
Sodium	15.4	Chromium	0.7	Rubidium	40.	Platinum	0.21
Magnesium	2.7	Manganese	0.7	Molybdium	0.26	Gold	0.47
Aluminum	1.3	Iron	0.40	Palladium	0.38	Mercury	3.71
Silicon	0.16	Nickel	0.27	Silver	0.84	Thallium	2.6
Red phosphorus	9.0	Copper	0.54	Cadmium	1.9	Lead	2.2
Sulphur	12.5	Zinc	1.5	Tin	1.6	Bismuth	2.8
Chlorine	95.	Arsenic	4.3	Antimony	2.2		

Stull, Zeitschr. Phys Chem 61, 1907.

TABLE 42. — Hardness.

Agate	7.	Brass	3-4.	Iridosmium	7.	Sulphur	1.5-2.5
Alabaster	1.7	Calimine	5.	Iron	4-5.	Stibnite	2
Alum	2-2.5	Calcite	3.	Kaolin	1.	Serpentine	3-4.
Aluminum	2.	Copper	2.5-3.	Loess (0°)	0.3	Silver	2.5-3.
Amber	2-2.5	Corundum	9.	Magnetite	6.	Steel	5-8.5
Andalusite	7.5	Diamond	10.	Marble	3-4.	Talc	1.
Anthracite	2.2	Dolomite	3.5-4.	Meerschaum	2-3.	Tin	1.5
Antimony	3.3	Feldspar	6.	Mica	2.8	Topaz	8.
Apatite	5.	Flint	7.	Opal	4-6.	Tourmaline	7.3
Aragonite	3.5	Fluorite	4.	Orthoclase	6.	Wax (0°)	0.2
Arsenic	3.5	Galena	2.5	Palladium	4.8	Wood's metal	3.
Asbestos	5.	Garnet	7.	Phosphorbronze	4.		
Asphalt	1-2.	Glass	4.5-6.5	Platinum	4.3		
Augite	6.	Gold	2.5-3.	Plat-iridium	6.5		
Barite	3.3	Graphite	0.5-1.	Pyrite	6.3		
Beryl	7.8	Gypsum	1.6-2.	Quartz	7.		
Bell-metal	4.	Hematite	6.	Rock-salt	2.		
Bismuth	2.5	Hornblende	5.5	Ross' metal	2.5-3.0		
Boric acid	3.	Iridium	6.	Silver chloride	1.3		

From Landolt-Bornstein-Meyerhoffer Tables: Auerbachs, Winklemann, Handb. der Phys. 1891.

TABLE 43. — Relative Hardness of the Elements.

C	10.0	Ru	6.5	Cu	3.0	Au	2.5	Sn	1.8	Li	0.6
B	9.5	Mn	5.0	Sb	3.0	Te	2.3	Sr	1.8	P	0.5
Cr	9.0	Pd	4.8	Al	2.9	Cd	2.0	Ca	1.5	K	0.5
Os	7.0	Fe	4.5	Ag	2.7	S	2.0	Ga	1.5	Na	0.4
Si	7.0	Pt	4.3	Bi	2.5	Se	2.0	Pb	1.5	Rb	0.3
Ir	6.5	As	3.5	Zn	2.5	Mg	2.0	In	1.2	Cs	0.2

Rydberg, Zeitschr. Phys Chem 33, 1900

TABLE 44. — Ratio, ρ, of Transverse Contraction to Longitudinal Extension under Tensile Stress.

(Poisson's Ratio.)

Metal	Pb	Au	Pd	Pt	Ag	Cu	Al	Bi	Sn	Ni	Cd	Fe
ρ	0.45	0.42	0.39	0.39	0.38	0.35	0.34	0.33	0.33	0.31	0.30	0.28

From data from Physikalisch-Technischen Reichsanstalt, 1907.

ρ for: marbles, 0.27; granites, 0.24; basic-intrusives, 0.26; glass, 0.23. Adams-Coker, 1906.

TABLE 45.

ELASTICITY OF CRYSTALS.*

The formulæ were deduced from experiments made on rectangular prismatic bars cut from the crystal. These bars were subjected to cross bending and twisting and the corresponding Elastic Moduli deduced. The symbols $\alpha\ \beta\ \gamma$, $\alpha_1\ \beta_1\ \gamma_1$ and $\alpha_2\ \beta_2\ \gamma_2$ represent the direction cosines of the length, the greater and the less transverse dimensions of the prism with reference to the principal axis of the crystal. E is the modulus for extension or compression, and T is the modulus for torsional rigidity. The moduli are in grams per square centimeter.

Barite.

$$\frac{10^{10}}{E} = 16.13\alpha^4 + 18.51\beta^4 + 10.42\gamma^4 + 2(38.79\beta^2\gamma^2 + 15.21\gamma^2\alpha^2 + 8.88\alpha^2\beta^2)$$

$$\frac{10^{10}}{T} = 69.52\alpha^4 + 117.66\beta^4 + 116.46\gamma^4 + 2(20.16\beta^2\gamma^2 + 85.29\gamma^2\alpha^2 + 127.35\alpha^2\beta^2)$$

Beryl (Emerald).

$$\frac{10^{10}}{E} = 4.325\sin^4\phi + 4.619\cos^4\phi + 13.328\sin^2\phi\cos^2\phi$$

$$\frac{10^{10}}{T} = 15.00 - 3.675\cos^4\phi_2 - 17.536\cos^2\phi\cos^2\phi_1$$

where $\phi\ \phi_1\ \phi_2$ are the angles which the length, breadth, and thickness of the specimen make with the principal axis of the crystal.

Fluorspar.

$$\frac{10^{10}}{E} = 13.05 - 6.26(\alpha^4 + \beta^4 + \gamma^4)$$

$$\frac{10^{10}}{T} = 58.04 - 50.08(\beta^2\gamma^2 + \gamma^2\alpha^2 + \alpha^2\beta^2)$$

Pyrite.

$$\frac{10^{10}}{E} = 5.08 - 2.24(\alpha^4 + \beta^4 + \gamma^4)$$

$$\frac{10^{10}}{T} = 18.60 - 17.95(\beta^2\gamma^2 + \gamma^2\alpha^2 + \alpha^2\beta^2)$$

Rock salt.

$$\frac{10^{10}}{E} = 33.48 - 9.66(\alpha^4 + \beta^4 + \gamma^4)$$

$$\frac{10^{10}}{T} = 154.58 - 77.28(\beta^2\gamma^2 + \gamma^2\alpha^2 + \alpha^2\beta^2)$$

Sylvine.

$$\frac{10^{10}}{E} = 75.1 - 48.2(\alpha^4 + \beta^4 + \gamma^4)$$

$$\frac{10^{10}}{T} = 306.0 - 192.8(\beta^2\gamma^2 + \gamma^2\alpha^2 + \alpha^2\beta^2)$$

Topaz.

$$\frac{10^{10}}{E} = 4.341\alpha^4 + 3.460\beta^4 + 3.771\gamma^4 + 2(3.879\beta^2\gamma^2 + 2.856\gamma^2\alpha^2 + 2.39\alpha^2\beta^2)$$

$$\frac{10^{10}}{T} = 14.88\alpha^4 + 16.54\beta^4 + 16.45\gamma^4 + 30.89\beta^2\gamma^2 + 40.89\gamma^2\alpha^2 + 43.51\alpha^2\beta^2$$

Quartz.

$$\frac{10^{10}}{E} = 12.734(1 - \gamma^2)^2 + 16.693(1 - \gamma^2)\gamma^2 + 9.705\gamma^4 - 8.460\beta\gamma(3\alpha^2 - \beta^2)$$

$$\frac{10^{10}}{T} = 19.665 + 9.060\gamma_2^2 + 22.984\gamma^2\gamma_1^2 - 16.920[(\gamma\beta_1 + \beta\gamma_1)(3\alpha\alpha_1 - \beta\beta_1) - \beta_2\gamma_2)]$$

---

* These formulæ are taken from Voigt's papers (Wied. Ann. vols. 31, 34, and 35).

TABLE 46.

ELASTICITY OF CRYSTALS.

Some particular values of the Elastic Moduli are here given. Under E are given moduli for extension or compression in the directions indicated by the subscripts and explained in the notes, and under T the moduli for torsional rigidities round the axes similarly indicated. Moduli in grams per sq. cm.

(a) ISOMETRIC SYSTEM.*

Substance.	E_a	E_b	E_c	T_a	Authority.
Fluorspar	1473×10^6	1008×10^6	910×10^6	345×10^6	Voigt.†
Pyrite	3530×10^6	2530×10^6	2310×10^6	1075×10^6	"
Rock salt	419×10^6	349×10^6	303×10^6	129×10^6	"
"	403×10^6	339×10^6	—	—	Koch.‡
Sylvine	401×10^6	209×10^6	—	—	"
"	372×10^6	196×10^6	—	655×10^6	Voigt.
Sodium chlorate	405×10^6	319×10^6	—	—	Koch.
Potassium alum	181×10^6	199×10^6	—	—	Beckenkamp.§
Chromium alum	161×10^6	177×10^6	—	—	"
Iron alum	186×10^6	—	—	—	"

(b) ORTHORHOMBIC SYSTEM.‖

Substance.	E_1	E_2	E_3	E_4	E_5	E_6	Authority.
Barite	620×10^6	540×10^6	959×10^6	376×10^6	702×10^6	740×10^6	Voigt.
Topaz	2304×10^6	2890×10^6	2652×10^6	2670×10^6	2893×10^6	3180×10^6	"

Substance.	$T_{12} = T_{21}$	$T_{13} = T_{31}$	$T_{23} = T_{32}$	Authority.
Barite	283×10^6	293×10^6	121×10^6	Voigt.
Topaz	1336×10^6	1353×10^6	1104×10^6	"

In the MONOCLINIC SYSTEM, Coromilas (Zeit. für Kryst. vol. 1) gives

Gypsum $\begin{cases} E_{max} = 887 \times 10^6 \text{ at } 21.9^\circ \text{ to the principal axis.} \\ E_{min} = 313 \times 10^6 \text{ at } 75.4^\circ \quad \text{" " "} \end{cases}$

Mica $\begin{cases} E_{max} = 2213 \times 10^6 \text{ in the principal axis.} \\ E_{min} = 1554 \times 10^6 \text{ at } 45^\circ \text{ to the principal axis.} \end{cases}$

In the HEXAGONAL SYSTEM, Voigt gives measurements on a beryl crystal (emerald). The subscripts indicate inclination in degrees of the axis of stress to the principal axis of the crystal.

$E_0 = 2165 \times 10^6$, $E_{45} = 1796 \times 10^6$, $E_{90} = 2312 \times 10^6$,

$T_0 = 667 \times 10^6$, $T_{90} = 883 \times 10^6$. The smallest cross dimension of the prism experimented on (see Table 82), was in the principal axis for this last case.

In the RHOMBOHEDRAL SYSTEM, Voigt has measured quartz. The subscripts have the same meaning as in the hexagonal system.

$E_0 = 1030 \times 10^6$, $E_{-45} = 1305 \times 10^6$, $E_{+45} = 850 \times 10^6$, $E_{90} = 785 \times 10^6$,

$T_0 = 508 \times 10^6$, $T_{90} = 348 \times 10^6$.

Baumgarten ¶ gives for calcite

$E_0 = 501 \times 10^6$, $E_{-45} = 441 \times 10^6$, $E_{+45} = 772 \times 10^6$, $E_{90} = 790 \times 10^6$.

---

* In this system the subscript *a* indicates that compression or extension takes place along the crystalline axis, and distortion round the axis. The subscripts *b* and *c* correspond to directions equally inclined to two and normal to the third and equally inclined to all three axes respectively.

† Voigt, "Wied. Ann." 31, p. 474, p. 701, 1887; 34, p. 981, 1888; 36, p. 642, 1888.

‡ Koch, "Wied. Ann." 18, p. 325, 1882.

§ Beckenkamp, "Zeit. für Kryst." vol. 10.

‖ The subscripts 1, 2, 3 indicate that the three principal axes are the axes of stress; 4, 5, 6 that the axes of stress are in the three principal planes at angles of 45° to the corresponding axes.

¶ Baumgarten, "Pogg. Ann." 152, p. 369, 1879.

COMPRESSIBILITY OF GASES.

TABLE 47.—Relative Volumes at Various Pressures and Temperatures, the volume at 0° C and at 1 atmosphere being taken as 1 000 000.

Atm.	Oxygen.			Air.			Nitrogen.			Hydrogen.		
	0°	99°.5	199°.5	0°	99°.4	200°.4	0°	99°.5	199°.6	0°	99°.3	200°.5
100	9265	–	–	9730	–	–	9910	–	–	–	–	–
200	4570	7000	9095	5050	7360	9430	5195	7445	9532	5690	7567	9420
300	3208	4843	6283	3658	5170	6622	3786	5301	6715	4030	5286	6520
400	2629	3830	4900	3036	4170	5240	3142	4265	5331	3207	4147	5075
500	2312	3244	4100	2680	3565	4422	2780	3655	4515	2713	3462	4210
600	2115	2867	3570	2450	3180	3883	2543	3258	3973	2387	3006	3627
700	1979	2610	3202	2288	2904	3502	2374	2980	3589	2149	2680	3212
800	1879	2417	2929	2168	2699	3219	2240	2775	3300	1972	2444	2900
900	1800	2268	2718	2070	2544	3000	2149	2616	3085	1832	2244	2657
1000	1735	2151	–	1992	2415	2828	2068	–	–	1720	2093	–

Amagat: C. R. 111, p. 871, 1890; Ann. chim. phys. (6) 29, pp. 68 and 505, 1893.

TABLE 48.—Ethylene.

pv at 0° C and 1 atm. = 1.

Atm.	0°	10°	20°	30°	40°	60°	80°	100°	137°.5	198°.5
46	–	0.562	0.684	–	–	–	–	–	–	–
48	–	0.508	–	–	–	–	–	–	–	–
50	0.176	0.420	0.629	0.731	0.814	0.954	1.077	1.192	1.374	1.652
52	–	0.240	0.598	–	–	–	–	–	–	–
54	–	0.229	0.561	–	–	–	–	–	–	–
56	–	0.227	0.524	–	–	–	–	–	–	–
100	0.310	0.331	0.360	0.403	0.471	0.668	0.847	1.005	1.247	1.580
150	0.441	0.459	0.485	0.515	0.551	0.649	0.776	0.924	1.178	1.540
200	0.565	0.585	0.610	0.638	0.669	0.744	0.838	0.946	1.174	1.537
300	0.806	0.827	0.852	0.878	0.908	0.972	1.048	1.133	1.310	1.628
500	1.256	1.280	1.308	1.337	1.367	1.431	1.500	1.578	1.721	1.985
1000	2.289	2.321	2.354	2.387	2.422	2.493	2.566	2.643	2.798	–

Amagat, C. R. 111, p. 871, 1890; 116, p. 946, 1893.

TABLE 49.—Ethylene.

Pressure in meters of mercury.	Relative values of pv at —									
	16°.3	20°.3	30°.1	40°.0	50°.0	60°.0	70°.0	79°.9	89°.9	100°.0
30	1950	2055	2220	2410	2580	2715	2865	2970	3090	3225
60	810	900	1190	1535	1875	2100	2310	2500	2680	2860
90	1065	1115	1195	1325	1510	1710	1930	2160	2375	2565
120	1325	1370	1440	1540	1660	1780	1950	2115	2305	2470
150	1590	1625	1690	1785	1880	1990	2125	2250	2390	2540
180	1855	1890	1945	2035	2130	2225	2340	2450	2565	2700
210	2110	2145	2200	2285	2375	2470	2565	2680	2790	2910
240	2360	2395	2450	2540	2625	2720	2810	2910	3015	3125
270	2610	2640	2710	2790	2875	2965	3060	3150	3240	3345
300	2860	2890	2960	3040	3125	3215	3300	3380	3470	3560
320	3035	3065	3125	3200	3285	3375	3470	3545	3625	3710

Amagat, Ann. chim. phys. (5) 22, p. 353, 1881.

COMPRESSIBILITY OF GASES.

TABLE 50. — Carbon Dioxide.

Pressure in metres of mercury.	Relative values of pv at —								
	18°.2	35°.1	40°.2	50°.0	60°.0	70°.0	80°.0	90°.0	100°.0
30	liquid	2360	2460	2590	2730	2870	2995	3120	3225
50	–	1725	1900	2145	2330	2525	2685	2845	2980
80	625	750	825	1200	1650	1975	2225	2440	2635
110	825	930	980	1090	1275	1550	1845	2105	2325
140	1020	1120	1175	1250	1360	1525	1715	1950	2160
170	1210	1310	1360	1430	1520	1645	1780	1975	2135
200	1405	1500	1550	1615	1705	1810	1930	2075	2215
230	1590	1690	1730	1800	1890	1990	2090	2210	2340
260	1770	1870	1920	1985	2070	2166	2265	2375	2490
290	1950	2060	2100	2170	2260	2340	2440	2550	2655
320	2135	2240	2280	2360	2440	2525	2620	2725	2830

Atm	Relative values of pv ; pv at 0° C. and 1 atm. = 1.										
	0°	10°	20°	30°	40°	60°	80°	100°	137°	198°	258°
50	0.105	0.114	0.680	0.775	0.750	0.984	1.096	1.206	1.380	–	–
100	0.202	0.213	0.229	0.255	0.309	0.661	0.873	1.030	1.259	1.582	1.847
150	0.295	0.309	0.326	0.346	0.377	0.485	0.681	0.878	1.159	1.530	1.818
300	0.559	0.578	0.599	0.623	0.649	0.710	0.790	0.890	1.108	1.493	1.820
500	0.891	0.913	0.938	0.963	0.990	1.054	1.124	1.201	1.362	1.678	–
1000	1.656	1.685	1.716	1.748	1.780	1.848	1.921	1.999	–	–	–

Amagat, C. R. 111, p. 871, 1890; Ann. chim. phys. (5) 22, p. 353, 1881; (6) 29, pp. 68 and 405, 1893.

TABLE 51. — Compressibility of Gases.

Gas.	$\frac{p.v.\ (\frac{1}{2}\text{ atm.})}{p_0v_0\ (1\text{ atm.})}$	$\frac{1}{p.v.}\frac{d(p.v.)}{dp} = a.$	t	a $t = 0$	Density. O = 32, 0°C P = 76cm	Density. Very small pressure.
O_2	1.00038	— .00076	11.2°	— .00094	32.	32.
H_2	0.99974	+ .00052	10.7	+ .00053	2.015 (16°)	2.0173
N_2	1.00015	— .00030	14.9	— .00056	28.005	28.016
CO	1.00026	— .00052	13.8	— .00081	28.000	28.003
CO_2	1.00279	— .00558	15.0	— .00668	44.268	44.014
N_2O	1.00327	— .00654	11.0	— .00747	44.285	43.996
Air	1.00026	— .00046	11.4	–	–	–
NH_3	1.00632	–	–	–	–	–

Rayleigh, Zeitschr. Phys. Chem. 52, p. 705, 1905.

TABLE 52. — Compressibility of Air and Oxygen between 18° and 22° C.

Pressures in metres of mercury, pv, relative.

Air	p	24.07	34.90	45.24	55.30	64.00	72.16	84.22	101.47	214.54	304.04
	pv	26968	26908	26791	26789	26778	26792	26840	27041	29585	32488
O_2	p	24.07	34.89	–	55.50	64.07	72.15	84.19	101.06	214.52	303.03
	pv	26843	26614	–	26185	26050	25858	25745	25639	26536	28756

Amagat, C. R. 1879.

RELATION BETWEEN PRESSURE, TEMPERATURE AND VOLUME OF SULPHUR DIOXIDE AND AMMONIA.*

TABLE 53.—Sulphur Dioxide.

Original volume 100000 under one atmosphere of pressure and the temperature of the experiments as indicated at the top of the different columns.

Pressure in Atmos.	Corresponding Volume for Experiments at Temperature —			Volume.	Pressure in Atmospheres for Experiments at Temperature —		
	58°.0	99°.6	183°.2		58°.0	99°.6	183°.2
10	8560	9440	-	10000	-	9.60	-
12	6360	7800	-	9000	9.60	10.35	-
14	4040	6420	-	8000	10.40	11.85	-
16	-	5310	-	7000	11.55	13.05	-
18	-	4405	-	6000	12.30	14.70	-
20	-	4030	-	5000	13.15	16.70	-
24	-	3345	-	4000	14.00	20.15	-
28	-	2780	3180	3500	14.40	23.00	-
32	-	2305	2640	3000	-	26.40	29.10
36	-	1935	2260	2500	-	30.15	33.25
40	-	1450	2040	2000	-	35.20	40.95
50	-	-	1640	1500	-	39.60	55.20
60	-	-	1375	1000	-	-	76.00
70	-	-	1130	500	-	-	117.20
80	-	-	930				
90	-	-	790				
100	-	-	680				
120	-	-	545				
140	-	-	430				
160	-	-	325				

TABLE 54.—Ammonia.

Original volume 100000 under one atmosphere of pressure and the temperature of the experiments as indicated at the top of the different columns.

Pressure in Atmos.	Corresponding Volume for Experiments at Temperature —			Volume.	Pressure in Atmospheres for Experiments at Temperature —			
	46°.6	99°.6	183°.6		30°.2	46°.6	99°.6	183°.0
10	9500	-	-	10000	8.85	9.50		-
12.5	7245	7635	-	9000	9.60	10.45		-
15	5880	6305	-	8000	10.40	11.50	12.00	-
20	-	4645	4875	7000	11.05	13.00	13.60	-
25	-	3560	3835	6000	11.80	14.75	15.55	-
30	-	2875	3185	5000	12.00	16.60	18.60	19.50
35	-	2440	2680	4000	-	18.35	22.70	24.00
40	-	2080	2345	3500	-	18.30	25.40	27.20
45	-	1795	2035	3000	-	-	29.20	31.50
50	-	1490	1775	2500	-	-	34.25	37.35
55	-	1250	1590	2000	-	-	41.45	45.50
60	-	975	1450	1500	-	-	49.70	58.00
70	-	-	1245	1000	-	-	59.65	93.60
80	-	-	1125					
90	-	-	1035					
100	-	-	950					

---

* From the experiments of Roth, "Wied. Ann." vol. 11, 1880.

TABLE 55.

COMPRESSIBILITY OF LIQUIDS.

If V_1 is the volume under pressure p_1 atmospheres at $t°C$, and V_2 is volume at pressure p_2 and the same temperature, then the compressibility coefficient may be defined at that temperature as:

$$\beta_t = \frac{1}{V_1} \cdot \frac{V_1 - V_2}{p_2 - p_1}.$$

In absolute units (referred to megadynes) the coefficient is $\frac{1}{1.0137}\beta_t$.

Substance.	t.	Pressures.	$\beta \cdot 10^6$	Reference.	Substance.	t.	Pressures.	$\beta \cdot 10^6$	Reference.
	°					°			
Acetone	0.00	1–500	82	1	Methyl alcohol	100.	8.68–37.3	221	3
"	0.00	500–1000	59	"	" "	18.10	8	120	2
"	0.00	1000–1500	47	"	Nitric acid	20.3	1–32	338	11
"	99.5	8.94–36.5	276	3	Oils: Almond	17.	–	55	8
Benzole	5.95	8	83	2	Olive	20.5	–	63	"
"	17.9	8	92	"	Paraffin	14.8	–	63	6
"	15.4	1–4	87	4	Petroleum	16.5	–	70	12
"	78.8	1–4	126	"	Rock	19.4	–	75	8
Carbon bisulphide	0.00	1–500	66	1	Rape-seed	20.3	–	60	"
" "	0.00	500–1000	53	"	Turpentin	19.7	–	79	"
" "	0.00	1000–1500	43	"	Toluene	10.	–	79	13
" "	49.2	1000–1500	51	"	"	100.	–	150	"
Chloroform	0.	–	101	5	Xylene	10.	–	74	15
"	20.	–	128	"	"	100.	–	132	"
"	40.	–	162	"	Paraffins: C_6H_{14}	23.	0–1	159	14
"	60.	–	204	"	C_7H_{16}	"	"	134	"
"	100.	8–9	211	3	C_8H_{18}	"	"	121	"
"	100.	19–34	206	"	C_9H_{20}	"	"	113	"
Collodium	14.8		97	6	$C_{10}H_{22}$	"	"	105	"
Ethyl alcohol	28.	150–200	86	7	$C_{12}H_{26}$	"	"	92	"
" "	28.	150–400	81	"	$C_{14}H_{30}$	"	"	83	"
" "	65.	150–200	110	"	$C_{16}H_{34}$	"	"	75	"
" "	65.	150–400	100	"	Water	0.	1–25	52.5	1
" "	100.	150–200	168	"	"	10.	"	50.0	"
" "	100.	150–400	132	"	"	20.	"	49.1	"
" "	185.	150–200	320	"	"	0.	25–50	51.6	"
" "	185.	150–400	245	"	"	10.	"	49.2	"
" "	310.	150–200	4200	"	"	20.	"	47.6	"
" "	310.	150–400	1530	"	"	0.	1–100	51.1	"
" "	0.	1–50	96	1	"	10.	"	48.3	"
" "	20.	1–50	112	"	"	20.	"	46.8	"
" "	40.	1–50	125	"	"	50.	"	44.9	"
" "	0.	100–200	85	"	"	100.	"	47.8	"
" "	0.	300–400	73	"	"	0.	100–200	49.2	"
" "	20.	300–400	78	"	"	10.	"	46.1	"
" "	40.	300–400	87	"	"	20.	"	44.2	"
" "	0.	500–600	64	"	"	50.	"	42.5	"
" "	0.	700–800	56	"	"	100.	"	46.8	"
" "	20.	700–800	62	"	"	0.	1–500	47.5	"
" "	40.	700–800	65	"	"	20.4	"	43.4	"
" "	0.	900–1000	52	"	"	48.85	"	41.6	"
Ethyl chloride	11.	8.5–34.2	138	3	"	0.	500–1000	41.6	"
" "	15.2	8.7–37.2	153	"	"	0.	1000–1500	35.8	"
" "	61.5	12.6–34.4	256	"	"	20.4	"	33.8	"
" "	99.0	12.8–34.5	495	"	"	48.85	"	32.5	"
Glycerine	20.5	–	25	8	"	0.	1500–2000	32.4	"
"	14.8	–	22	6	"	0.	2000–2500	29.2	"
Mercury	0.	–	3.92	9	"	0.	2500–3000	26.1	"
"	0.	–	3.90	10	"	48.85	"	25.4	"
Methyl alcohol	14.7	8.50–37.1	104	3					

For references see page 80.

TABLE 56.

COMPRESSIBILITY AND BULK MODULI OF SOLIDS.

Solid.		Compression per unit volume per atmo. × 10^6.	Authority.	Calculated values of bulk modulus in —	
				Grams per sq. cm.	Pounds per sq. in.
Crystals:	Barite	1.93	Voigt	535 × 10^6	7.61 × 10^6
	Beryl	0.747	“	1384 “	19.68 “
	Fluorspar	1.20	“	860 “	12.24 “
	Pyrites	1.14	“	906 “	12.89 “
	Quartz	2.67	“	387 “	5.50 “
	Rock salt	4.20*	“	246 “	3.50 “
	Sylvine	7.45*	“	138 “	1.97 “
	Topaz	0.61	“	1694 “	24.11 “
	Tourmaline	0.113	“	9140 “	130.10 “
Brass		0.95	Amagat	1090 “	15.48 “
Copper		0.86	Buchanan	1202 “	17.10 “
Delta metal		1.02	Amagat	1012 “	14.41 “
Lead		2.76	“	374 “	5.32 “
Steel		0.68	“	1518 “	21.61 “
Glass		2.2–2.9	“	405 “	5.76 “

NOTE: Winklemann, Schott, and Straulel (Wied Ann. 61, 63, 1897; 68, 1899) give the following coefficients (among others) for various Jena glasses in terms of the volume decrease divided by the increase of pressure expressed in kilograms per square millimeter:

The following values in cm^2 / Kg of 10^6 × Compressibility are given for the corresponding temperatures by Grüneisen Ann. der Phys. 33, p. 65, 1910.

Al. — 191°, 1.32; 17°, 1.46; 125°, 1.70. Fe. — 190°, 0.61; 18°, 0.63; 165°, 0.67.
Cu. — 191°, 0.72; 17°, 0.77; 165°, 0.83. Ag. — 191°, 0.71; 16°, 0.76; 166°, 0.86.
Pt. — 189°, 0.37; 17°, 0.39; 164°, 0.40. Pb. — 191°, (2.5); 14°, (3.2)

No.	Glass.	Compressibility.	No.	Glass.	Compressibility
665		7520	2154	Kalibleisilicat	3660
1299	Barytborosilicat	5800	S 208	Heaviest Bleisilicat	3550
16	Natronkalkzinksilicat	4530	500	Very Heavy “	3510
278		3790	S 196	Tonerdborat with sodium, baryte	3470

* Röntgen and Schneider by piezometric experiments obtained 5.0 × 10^{-6} for rock salt, and 5.6 × 10^{-6} for sylvine (Wied. Ann., vol. 31).

References to Tables 55 and 56.

Liquids (Table 55):
1 Amagat, Ann. chim. phys. (6) 29, 1893.
2 Röntgen, Wied. Ann. 44, p. 1, 1891.
3 Amagat, C. R. 68, p. 1170, 1869; Ann. chim. phys. (5) 28, 1883.
4 Pagliani-Palazzo, Mem. Acad. Lin. (3) 19, 1883.
5 Grimaldi, Zeitschr. Phys. Chem. 1, 1887.
6 de Metz, Wied. Ann. 41, p. 663, 1890; 47, p. 706, 1892.
7 Barus, Sill. Journ. 39, p. 478, 1890; 41, 1891; Bull. U.S. Geol. Surv. 1892.
8 Quincke, Wied. Ann. 19, p. 401, 1883.
9 Amagat, Ann. chim. phys. (6) 22, p. 95, 1891.
10 Aimé, Ann. chim. phys. (3) 8, p. 268, 1843.
11 Colladon-Sturm, Pogg. Ann. 12, p. 39, 1828.
12 Martini.
13 de Heen, Bull. Acad. Roy. Belg. (3) 9, 1885.
14 Bartoli, Rend Lomb. (2) 28, 29, 1896.
15 Protz, Ann. der Phys. (4) 31, p. 127, 1910.
See also Bridgman, Proc. Ann. Acad. 48, p. 309, 1912 (H_2O) 49, p. 3, 1913 (alcohols, etc.); 49, p. 627, 1914 (high pressure technique).

Solids (Table 56):
Amagat, C. R. 108, p. 228, 1889; J. de Phys. (2) 8, p. 197, 1889.
Buchanan, Proc. Roy. Soc. Edinb. 10, 1880.
Voigt, Wied. Ann. 31, 1887; 34, 1888, 36, 1888.

TABLE 57.

SPECIFIC GRAVITIES CORRESPONDING TO THE BAUMÉ SCALE.

The specific gravities are for 15.56°C (60°F) referred to water at the same temperature as unity. For specific gravities less than unity the values are calculated from the formula:

$$\text{Degrees Baumé} = \frac{140}{\text{Specific Gravity}} - 130.$$

For specific gravities greater than unity from:

$$\text{Degrees Baumé} = 145 - \frac{145}{\text{Specific Gravity}}.$$

Specific Gravities less than 1.

Specific Gravity.	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
	Degrees Baumé.									
0.60	103.33	99.51	95.81	92.22	88.75	85.38	82.12	78.95	75.88	72.90
.70	70.00	67.18	64.44	61.78	59.19	56.67	54.21	51.82	49.49	47.22
.80	45.00	42.84	40.73	38.68	36.67	34.71	32.79	30.92	29.09	27.30
.90	25.56	23.85	22.17	20.54	18.94	17.37	15.83	14.33	12.86	11.41
1.00	10.00									

Specific Gravities greater than 1.

Specific Gravity.	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
	Degrees Baumé.									
1.00	0.00	1.44	2.84	4.22	5.58	6.91	8.21	9.49	10.74	11.97
1.10	13.18	14.37	15.54	16.68	17.81	18.91	20.00	21.07	22.12	23.15
1.20	24.17	25.16	26.15	27.11	28.06	29.00	29.92	30.83	31.72	32.60
1.30	33.46	34.31	35.15	35.98	36.79	37.59	38.38	39.16	39.93	40.68
1.40	41.43	42.16	42.89	43.60	44.31	45.00	45.68	46.36	47.03	47.68
1.50	48.33	48.97	49.60	50.23	50.84	51.45	52.05	52.64	53.23	53.80
1.60	54.38	54.94	55.49	56.04	56.58	57.12	57.65	58.17	58.69	59.20
1.70	59.71	60.20	60.70	61.18	61.67	62.14	62.61	63.08	63.54	63.99
1.80	64.44	64.89	65.33	65.76	66.20	66.62				

REDUCTIONS OF WEIGHINGS IN AIR TO VACUO.

TABLE 58.

When the weight M in grams of a body is determined in air, a correction is necessary for the buoyancy of the air equal to $M\delta(1/d - 1/d_1)$ where δ = the density (wt. of 1 ccm in grams = 0.0012) of the air during the weighing, d the density of the body, d_1 that of the weights. δ for various barometric values and humidities may be determined from Tables 153 to 155. The following table is computed for $\delta = 0.0012$. The corrected weight $= M + kM/1000$.

Density of body weighed d.	Correction factor, k.			Density of body weighed d.	Correction factor, k.		
	Pt. Ir. weights $d_1 = 21.5$.	Brass weights 8.4.	Quartz or Al. weights 2.65.		Pt. Ir. weights $d_1 = 21.5$.	Brass weights 8.4.	Quartz or Al. weights 2.65.
.5	+ 2.34	+ 2.26	+ 1.95	1.6	+ 0.69	+ 0.61	+ 0.30
.6	+ 1.91	+ 1.86	+ 1.55	1.7	+ .65	+ .56	+ .25
.7	+ 1.66	+ 1.57	+ 1.26	1.8	+ .62	+ .52	+ .21
.75	+ 1.55	+ 1.46	+ 1.15	1.9	+ .58	+ .49	+ .18
.80	+ 1.44	+ 1.36	+ 1.05	2.0	+ .54	+ .46	+ .15
.85	+ 1.36	+ 1.27	+ 0.96	2.5	+ .43	+ .34	+ .03
.90	+ 1.28	+ 1.19	+ .88	3.0	+ .34	+ .26	— .05
.95	+ 1.21	+ 1.12	+ .81	4.0	+ .24	+ .16	— .15
1.00	+ 1.14	+ 1.06	+ .75	6.0	+ .14	+ .06	— .25
1.1	+ 1.04	+ 0.95	+ .64	8.0	+ .09	+ .01	— .30
1.2	+ 0.94	+ .86	+ .55	10.0	+ .06	— .02	— .33
1.3	+ .87	+ .78	+ .47	15.0	+ .03	— .06	— .37
1.4	+ .80	+ .71	+ .40	20.0	+ .004	— .08	— .39
1.5	+ .75	+ .66	+ .35	22.0	— .001	— .09	— .40

TABLE 59. — Reductions of Densities in Air to Vacuo.

(This correction may be accomplished through the use of the above table for each separate weighing.)

If s is the density of the substance as calculated from the uncorrected weights, S its true density, and L the true density of the liquid used, then the vacuum correction to be applied to the uncorrected density, s, is $0.0012(1 - s/L)$.

Let W_s = uncorrected weight of substance, W_l = uncorrected weight of the liquid displaced by the substance, then by definition, $s = LW_s/W_l$. Assuming D to be the density of the balance of weights, $W_s\{1 + 0.0012(1/S - 1/D)\}$ and $W_l\{1 + 0.0012(1/L - 1/D)\}$ are the true weights of the substance and liquid respectively (assuming that the weighings are made under normal atmospheric corrections, so that the weight of 1 cc. of air is 0.0012 gram).

$$\text{Then the true density } S = \frac{W_s\{1 + 0.0012(1/S - 1/D)\}}{W_l\{1 + 0.0012(1/L - 1/D)\}} L.$$

But from above $W_s/W_l = s/L$, and since L is always large compared with 0.0012,

$$S - s = 0.0012(1 - s/L).$$

The values of $0.0012(1 - s/L)$ for densities up to 20 and for liquids of density 1 (water), 0.852 (xylene) and 13.55 (mercury) follow:

(See reference below for discussion of density determinations).

Density of substance s.	Corrections.			Density of substance s	Corrections.	
	L = 1 Water.	L = 0.852 Xylene.	L = 13.55 Mercury.		L = 1 Water.	L = 13.55 Mercury.
0.8	+ 0.00024	-	-	11.	— 0.0120	+ 0.0002
0.9	+ .00012	-	-	12.	— .0132	+ .0001
1.	0.0000	— 0.0002	+ 0.0011	13.	— .0144	0.0000
2.	— .0012	— .0016	+ .0010	14.	— .0156	0.0000
3.	— .0024	— .0030	+ .0009	15.	— .0168	— .0001
4.	— .0036	— .0044	+ .0008	16.	— .0180	— .0002
5.	— .0048	— .0058	+ .0008	17.	— .0192	— .0003
6.	— .0060	— .0073	+ .0007	18.	— .0204	— .0004
7.	— .0072	— .0087	+ .0006	19.	— .0216	— .0005
8.	— .0084	— .0101	+ .0005	20.	— .0228	— .0006
9.	— .0096	— .0115	+ .0004			
10.	— .0108	— .0129	+ .0003			

Johnston and Adams, J. Am. Chem. Soc. 34, p. 563, 1912.

TABLE 60.

DENSITY OR MASS IN GRAMS PER CUBIC CENTIMETER OF THE ELEMENTS, LIQUID OR SOLID.

N. B. The density of a specimen may depend considerably on its state and previous treatment.

Element.	Physical State.	Grams per cu. cm.*	Temperature.†	Authority.
Aluminum	cast	2.56–2.58		
“	wrought	2.65–2.80		
“	pure	2.58	4	Mallet, 1882.
Antimony	vacuo-distilled	6.618	20	Kahlbaum, 1902.
“	ditto-compressed	6.691	20	“
“	amorphous	6.22		Hérard.
Argon	liquid	1.3845	— 183	Baly-Donnan.
“	“	1.4233	— 189	“ “
Arsenic	crystallized	5.73	14	
“	amorph. br.-black	3.70		Geuther.
“	yellow	3.88		Linck.
Barium		3.78		Guntz.
Bismuth	solid	9.70–9.90		
“	electrolytic	9.747		Classen, 1890.
“	vacuo-distilled	9.781	20	Kahlbaum, 1902.
“	liquid	10.00	271	Vincentini-Omodei.
“	solid	9.67	271	“ “
Boron	crystal	2.535		Wigand.
“	amorph. pure	2.45		Moissan.
Bromine	liquid	3.12		Richards-Stull.
Cadmium	cast	8.54–8.57		
“	wrought	8.67		
“	vacuo-distilled	8.648	20	Kahlbaum, 1902.
“	solid	8.37	318	Vincentini-Omodei.
“	liquid	7.99	318	“ “
Cæsium		1.873	20	Richards-Brink.
Calcium		1.54		Brink.
Carbon	diamond	3.52		Wigand.
“	graphite	2.25		“
Cerium	electrolytic	6.79		Muthmann-Weiss.
“	pure	7.02		“ “
Chlorine	liquid	1.507	— 33.6	Drugman-Ramsay.
Chromium		6.52–6.73		
“	pure	6.92	20	Moissan.
Cobalt		8.71	21	Tilden, Ch. C. 1898.
Columbium		8.4	15	Muthmann-Weiss.
Copper	cast	8.30–8.95		
“	drawn	8.93–8.95		
“	wrought	8.85–8.95		
“	electrolytic	8.88–8.95		
“	vacuo-distilled	8.9326	20	Kahlbaum, 1902.
“	ditto-compressed	8.9376	20	“ “
“	liquid	8.217		Roberts-Wrightson.
Erbium		4.77		St. Meyer, Z. Ph. Ch. 37.
Fluorine	liquid	1.14	— 200	Moissan-Dewar.
Gallium		5.93	23	de Boisbaudran.
Germanium		5.46	20	Winkler.
Glucinum		1.85		Humpidge.
Gold	cast	19.3		
“	wrought	19.33		
“	vacuo-distilled	18.88	20	Kahlbaum, 1902.
“	ditto-compressed	19.27	20	“
Helium	liquid	0.15	— 269	Onnes, 1908.
Hydrogen	liquid	0.070	— 252	Dewar, Ch. News, 1904.
Indium		7.28		Richards.

* To reduce to pounds per cu. ft. multiply by 62.4.

† Where the temperature is not given, ordinary atmospheric temperature is understood.

Compiled from Clarke's Constants of Nature, Landolt-Börnstein-Meyerhoffer's Tables, and other sources. Where no authority is stated, the values are mostly means from various sources.

TABLE 60 (*continued*).

DENSITY OR MASS IN GRAMS PER CUBIC CENTIMETER OF THE ELEMENTS, LIQUID OR SOLID.

Element.	Physical State	Grams per cu. cm.*	Temperature.†	Authority.
Iridium		22.42	17	Deville-Debray
Iodine		4.940	20	Richards-Stull
Iron	pure	7.85–7.88		
"	gray cast	7.03–7.13		
"	white cast	7.58–7.73		
"	wrought	7.80–7.90		
"	liquid	6.88		Roberts-Austen
"	steel	7.60–7.80		
Krypton	liquid	2.16	—146	Ramsay-Travers
Lanthanum		6.15		Muthmann-Weiss
Lead	cast	11.37	24	Reich
"	wrought	11.36	24	"
"	solid	11.005	325	Vincentini-Omodei
"	liquid	10.645	325	" "
"	vacuo-distilled	11.342	20	Kahlbaum, 1902
"	ditto-compressed	11.347	20	" "
Lithium		0.534	20	Richards-Brink, '07
Magnesium		1.741		Voigt
Manganese		7.42		Prelinger
Mercury	liquid	13.596	0	Regnault, Volkmann
"	"	13.546	20	
"	"	13.690	—38.8	Vincentini-Omodei
"	solid	14.193	—38.8	Mallet
"	"	14.383	—188	Dewar, 1902
Molybdenum		9.01		Moissan
Neodymium		6.96		Muthmann-Weiss
Nickel		8.60–8.90		
Nitrogen	liquid	0.810	—195	Baly-Donnan, 1902
"	"	0.854	—205	" " "
Osmium		22.5		Deville-Debray
Oxygen	liquid	1.14	—184	
Palladium		12.16		Richards-Stull
Phosphorus	white	1.83		
"	red	2.20		
"	metallic	2.34	15	Hittorf
Platinum		21.37	20	Richards-Stull
Potassium		0.870	20	Richards-Brink, '07
"	solid	0.851	62.1	Vincentini-Omodei
"	liquid	0.830	62.1	" "
Præsodymium		6.475		Muthmann-Weiss
Rhodium		12.44		Holborn Henning
Rubidium		1.532	20	Richards-Brink, '07
Ruthenium		12.06	0	Toby
Samarium		7.7–7.8		Muthmann-Weiss
Selenium		4.3–4.8		
Silicon	cryst.	2.42	20	Richards-Stull-Brink
"	amorph.	2.35	15	Vigoroux
Silver	cast	10.42–10.53		
"	wrought	10.6		
"	vacuo-distilled	10.492	20	Kahlbaum, 1902
"	ditto-compressed	10.503	20	" "
"	liquid	9.51		Wrightson
Sodium		0.9712	20	Richards-Brink, '07
"	solid	0.9519	97.6	Vincentini-Omodei
"	liquid	0.9287	97.6	" "
"		1.0066	—188	Dewar
Strontium		2.50–2.58		Matthiessen
Sulphur		2.0–2.1		
"	liquid	1.811	113	Vincentini-Omodei

---

* To reduce to pounds per cubic ft. multiply by 62.4.

† Where the temperature is not given, ordinary atmosphere temperature is understood.

TABLE 60 (*continued*). — **Density or Mass in grams per cubic centimeter and pounds per cubic foot of the elements, liquid or solid.**

Element.	Physical State.	Grams per cu. cm.	Tempera-ture.	Authority.
Tantalum		16.6		
Tellurium	crystallized	6.25		
“	amorphous	6.02	20	Beljankin.
Thallium		11.86		Richards-Stull.
Thorium		12.16	17	Bolton.
Tin	white, cast	7.29		Matthiessen.
“	“ wrought	7.30		
“	“ crystallized	6.97–7.18		
“	“ solid	7.184	226	Vincentini-Omodei
“	“ liquid	6.99	226	Vincentini-Omodei
“	gray	5.8		
Titanium		4.5	18	Mixter.
Tungsten		18.6–19.1		
Uranium		18.7	13	Zimmermann.
Vanadium		5.69		Ruff-Martin.
Xenon	liquid	3.52	109	Ramsay-Travers.
Yttrium		3.80		St. Meyer.
Zinc	cast	7.04–7.16		
“	wrought	7.19		
“	vacuo-distilled	6.92	20	Kahlbaum, 1902.
“	ditto-compressed	7.13	20	“ “
“	liquid	6.48		Roberts-Wrightson.
Zirconium		6.44		

TABLE 61. — **Mass in grams per cubic centimeter and in pounds per cubic foot of different kinds of wood.**

The wood is supposed to be seasoned and of average dryness.

Wood.	Grams per cubic centimeter.	Pounds per cubic foot.	Wood.	Grams per cubic centimeter.	Pounds per cubic foot.
Alder	0.42–0.68	26–42	Hazel	0.60–0.80	37–49
Apple	0.66–0.84	41–52	Hickory	0.60–0.93	37–58
Ash	0.65–0.85	40–53	Holly	0.76	47
Bamboo	0.31–0.40	19–25	Iron-bark	1.03	64
Basswood. See Linden.			Juniper	0.56	35
Beech	0.70–0.90	43–56	Laburnum	0.92	57
Blue gum	1.00	62	Lancewood	0.68–1.00	42–62
Birch	0.51–0.77	32–48	Lignum vitæ	1.17–1.33	73–83
Box	0.95–1.16	59–72	Linden or Lime-tree	0.32–0.59	20–37
Bullet-tree	1.05	65	Locust	0.67–0.71	42–44
Butternut	0.38	24	Logwood	.91	57
Cedar	0.49–0.57	30–35	Mahogany, Honduras	0.66	41
Cherry	0.70–0.90	43–56	“ Spanish	0.85	53
Cork	0.22–0.26	14–16	Maple	0.62–0.75	39–47
Dogwood	0.76	47	Oak	0.60–0.90	37–56
Ebony	1.11–1.33	69–83	Pear-tree	0.61–0.73	38–45
Elm	0.54–0.60	34–37	Plum-tree	0.66–0.78	41–49
Fir or Pine, American			Poplar	0.35–0.5	22–31
White	0.35–0.50	22–31	Satinwood	0.95	59
“ Larch	0.50–0.56	31–35	Sycamore	0.40–0.60	24–37
“ Pitch	0.83–0.85	52–53	Teak, Indian	0.66–0.88	41–55
“ Red	0.48–0.70	30–44	“ African	0.98	61
“ Scotch	0.43–0.53	27–33	Walnut	0.64–0.70	40–43
“ Spruce	0.48–0.70	30–44	Water gum	1.00	62
“ Yellow	0.37–0.60	23–37	Willow	0.40–0.60	24–37
Greenheart	0.93–1.04	58–65			

---

* Where the temperature is not given, ordinary atmospheric temperature is understood.

TABLE 62.

DENSITY OR MASS IN GRAMS PER CUBIC CENTIMETER AND POUNDS PER CUBIC FOOT OF VARIOUS SOLIDS.

N. B. The density of a specimen depends considerably on its state and previous treatment; especially is this the case with porous materials.

Material.	Grams per cu. cm.	Pounds per cu. foot.
Agate	2.5–2.7	156–168
Alabaster:		
Carbonate	2.69–2.78	168–173
Sulphate	2.26–2.32	141–145
Albite	2.62–2.65	163–165
Amber	1.06–1.11	66– 69
Amphiboles	2.9–3.2	180–200
Anorthite	2.74–2.76	171–172
Anthracite	1.4–1.8	87–112
Asbestos	2.0–2.8	125–175
Asphalt	1.1–1.5	69– 94
Basalt	2.4–3.1	150–190
Beeswax	0.96–0.97	60– 61
Beryl	2.69–2.7	168–168
Biotite	2.7–3.1	170–190
Bone	1.7–2.0	106–125
Brick	1.4–2.2	87–137
Butter	0.86–0.87	53– 54
Calamine	4.1–4.5	255–280
Caoutchouc	0.92–0.99	57– 62
Celluloid	1.4	87
Cement, set	2.7–3.0	170–190
Chalk	1.9–2.8	118–175
Charcoal: oak	0.57	35
pine	0.28–0.44	18– 28
Chrome yellow	6.00	374
Chromite	4.32–4.57	270–285
Cinnabar	8.12	507
Clay	1.8–2.6	122–162
Coal, soft	1.2–1.5	75– 94
Cocoa butter	0.89–0.91	56– 57
Coke	1.0–1.7	62–105
Copal	1.04–1.14	65– 71
Corundum	3.9–4.0	245–250
Diamond:		
Anthracitic	1.66	104
Carbonado	3.01–3.25	188–203
Diorite	2.52	157
Dolomite	2.84	177
Ebonite	1.15	72
Emery	4.0	250
Epidote	3.25–3.5	203–218·
Feldspar	2.55–2.75	159–172
Flint	2.63	164
Fluorite	3.18	198
Gamboge	1.2	75
Garnet	3.15–4.3	197–268
Gas carbon	1.88	117
Gelatine	1.27	180
Glass: common	2.4–2.8	150–175
flint	2.9–5.9	180–370
Glue	1.27	80
Granite	2.64–2.76	165–172
Graphite	2.30–2.72	144–170
Gum arabic	1.3–1.4	80– 85
Gypsum	2.31–2.33	144–145
Hematite	4.9–5.3	306–330
Hornblende	3.0	187
Ice	0.917	57.2
Ilmenite	4.5–5.	280–310
Ivory	1.83–1.92	114–120
Labradorite	2.7–2.72	168–170
Lava: basaltic	2.8–3.0	175–185
trachytic	2.0–2.7	125–168
Leather: dry	0.86	54
greased	1.02	64
Lime: mortar	1.65–1.78	103–111
slaked	1.3–1.4	81– 87
Limestone	2.68–2.76	167–171
Litharge:		
Artificial	9.3–9.4	580–585
Natural	7.8–8.0	490–500
Magnetite	4.9–5.2	306–324
Malachite	3.7–4.1	231–256
Marble	2.6–2.84	160–177
Meerschaum	0.99–1.28	62– 80
Mica	2.6–3.2	165–200
Muscovite	2.76–3.00	172–225
Ochre	3.5	218
Oligoclase	2.65–2.67	165–167
Olivine	3.27–3.37	204–210
Opal	2.2	137
Orthoclase	2.58–2.61	161–163
Paper	0.7–1.15	44– 72
Paraffin	0.87–0.91	54– 57
Peat	0.84	52
Pitch	1.07	67
Porcelain	2.3–2.5	143–156
Porphyry	2.6–2.9	162–181
Pyrite	4.95–5.1	309–318
Quartz	2.65	165
Quartzite	2.73	170
Resin	1.07	67
Rock salt	2.18	136
Rutile	6.00–6.5	374–406
Sandstone	2.14–2.36	134–147
Serpentine	2.50–2.65	156–165
Slag, furnace	2.0–3.9	125–240
Slate	2.6–3.3	162–205
Soapstone	2.6–2.8	162–175
Starch	1.53	95
Sugar	1.61	100
Talc	2.7–2.8	168–174
Tallow	0.91–0.97	57– 60
Topaz	3.5–3.6	219–223
Tourmaline	3.0–3.2	190–200
Zircon	4.68–4.70	292–293

TABLE 63.

DENSITY OR MASS IN GRAMS PER CUBIC CENTIMETER AND POUNDS PER CUBIC FOOT OF VARIOUS ALLOYS (BRASSES AND BRONZES).

Alloy.	Grams per cubic centimeter.	Pounds per cubic foot.
Brasses: Yellow, 70Cu + 30Zn, cast	8.44	527
“ “ “ rolled	8.56	534
“ “ “ drawn	8.70	542
“ Red, 90Cu + 10Zn	8.60	536
“ White, 50Cu + 50Zn	8.20	511
Bronzes: 90Cu + 10Sn	8.78	548
“ 85Cu + 15Sn	8.89	555
“ 80Cu + 20Sn	8.74	545
“ 75Cu + 25Sn	8.83	551
German Silver: Chinese, 26.3Cu + 36.6Zn + 36.8Ni	8.30	518
“ “ Berlin (1) 52Cu + 26Zn + 22Ni	8.45	527
“ “ “ (2) 59Cu + 30Zn + 11Ni	8.34	520
“ “ “ (3) 63Cu + 30Zn + 6Ni	8.30	518
“ “ Nickelin	8.77	547
Lead and Tin: 87.5Pb + 12.5Sn	10.60	661
“ “ “ 84Pb + 16Sn	10.33	644
“ “ “ 77.8Pb + 22.2Sn	10.05	627
“ “ “ 63.7Pb + 36.3Sn	9.43	588
“ “ “ 46.7Pb + 53.3Sn	8.73	545
“ “ “ 30.5Pb + 69.5Sn	8.24	514
Bismuth, Lead, and Tin: 53Bi + 40Pb + 7Cd	10.56	659
Wood's Metal: 50Bi + 25Pb + 12.5Cd + 12.5Sn	9.70	605
Cadmium and Tin: 32Cd + 68Sn	7.70	480
Gold and Copper: 98Au + 2Cu	18.84	1176
“ “ “ 96Au + 4Cu	18.36	1145
“ “ “ 94Au + 6Cu	17.95	1120
“ “ “ 92Au + 8Cu	17.52	1093
“ “ “ 90Au + 10Cu	17.16	1071
“ “ “ 88Au + 12Cu	16.81	1049
“ “ “ 86Au + 14Cu	16.47	1027
Aluminum and Copper: 10Al + 90Cu	7.69	480
“ “ “ 5Al + 95Cu	8.37	522
“ “ “ 3Al + 97Cu	8.69	542
Aluminum and Zinc: 91Al + 9Zn	2.80	175
Platinum and Iridium: 90Pt + 10Ir	21.62	1348
“ “ “ 85Pt + 15Ir	21.62	1348
“ “ “ 66.67Pt + 33.33Ir	21.87	1364
“ “ “ 5Pt + 95Ir	22.38	1396
Constantin: 60Cu + 40Ni	8.88	554
Magnalium: 70Al + 30Mg	2.0	125
Manganin: 84Cu + 12Mn + 4Ni	8.5	530
Platinoid: German silver + little Tungsten	9.0	560

TABLE 64.—DENSITIES OF VARIOUS NATURAL AND ARTIFICIAL MINERALS.

(See also Table 62.)

Name and Formula.	Density grams per cc.	Sp. Vol. cc. per gram.	Reference.
Pure compounds, all at 25°C			
Magnesia, MgO	3.603	.2775	1
Lime, CaO	3.306	.3025	2
Forms of SiO_2:			
Quartz, natural	2.646	.3779	"
" artificial	2.642	.3785	"
Cristobalite, artificial	2.319	.4312	"
Silica glass	2.206	.4533	"
Forms of Al_2SiO_5:			
Sillimanite glass	2.53	.395	3
Sillimanite cryst.	3.022	.3309	"
Forms of $MgSiO_3$:			
β Monoclinic pyroxene	3.183	.3142	5
α' Orthorhombic pyroxene	3.166	.3159	"
β' Monoclinic amphibole			"
γ' Orthorhombic amphibole	2.849	.3510	"
Glass	2.735	.3656	"
Forms of $CaSiO_3$:			
α (Pseudo-wollastonite)	2.904	.3444	2
β (Wollastonite)	2.906	.3441	"
Glass	2.895	.3454	"
Forms of Ca_2SiO_4:			
α — calcium-orthosilicate	3.26	.307	"
β — " "	3.27	.306	"
γ — " "	2.965	.337	"
β' — " "			
Lime-alumina compounds:			
$3CaO \cdot Al_2O_3$	3.029	.3301	3
$5CaO \cdot 3Al_2O_3$	2.820	.3546	"
$CaO \cdot Al_2O_3$	2.972	.3365	"
$3CaO \cdot 5Al_2O_3$			
$3CaO \cdot 5Al_2O_3$, unstable form	3.04	.329	"
Forms of $MgSiO_3 \cdot CaSiO_3$:			
Diopside, natural, cryst.	3.258	.3069	4
" artificial, "	3.265	.3063	"
" glass	2.846	.3514	1

Name and Formula.	Density grams per cc.	Sp. Vol. cc. per gram.	Reference.
Feldspars:			
Albite glass, $NaAlSi_3O_8$, art.	2.375	.4210	6
Albite cryst., $NaAlSi_3O_8$, art.	2.597	.3851	"
Anorthite glass, $CaAl_2Si_2O_8$, art.	2.692	.3715	"
Anorthite cryst., $CaAl_2Si_2O_8$, art.	2.757	.3627	"
Soda anorthite, $NaAlSiO_4$, art.	2.563	.3902	7
Borax, glass, $Na_2B_4O_7$	2.36	.423	6
" cryst. "	2.27	.440	"
Fluorite, natural, CaF_2 (20°)	3.180	.3145	8
$(NH_4)_2SO_4$ (30°)	1.765	.5666	9
K_2SO_4 (30°)	2.657	.3764	"
KCl, fine powder (30°)	1.984	.5040	"
Forms of ZnS:			
Sphalerite, natural*	4.090	.2444	10
Wurtzite, artificial†	4.087	.2447	"
Greenockite, artificial	4.820	.2075	"
Forms of HgS:			
Cinnabar, artificial	8.176	.1223	"
Metacinnabar, artificial	7.58	.132	"
Minerals:			
Gehlenite, from Velardena	3.03	.330	11
Spurrite, from Velardena, $2Ca_2SiO_4 \cdot CaCO_3$	3.005	.3328	"
Hillebrandite, from Velardena, $CaSiO_3 \cdot Ca(OH)_2$	2.684	.3726	"
Pyrite, natural, FeS_2	5.012	.1995	10
Marcasite, natural, FeS_2	4.873	.2052	"

* Only 0.15% Fe total impurity.
† Same composition as Sphalerite.

References: 1, Larsen 1909; 2, Day and Shepherd; 3, Shepherd and Rankin, 1909; 4, Allen and White, 1909; 5, Allen, Wright and Clement, 1906; 6, Day and Allen, 1905; 7, Washington and Wright, 1910; 8, Merwin, 1911; 9, Johnston and Adams, 1911; 10, Allen and Crenshaw, 1912; 11, Wright, 1908.

All the data of this table are from the Geophysical Laboratory, Washington.

TABLE 65.—DENSITIES OF MOLTEN TIN AND TIN-LEAD EUTECTIC.

Temperature	250°C.	300°	400°	500°	600°	900°	1200°	1400°	1600°
Molten tin	6.982	6.943	6.875	6.814	6.755	6.578	6.399	6.280	6.162
37 pts. Pb, 63, Sn.*	8.011	7.965	7.879	7.800	7.731	–	–	–	–

* Melts at 181. Day and Sosman, Geophysical Laboratory, unpublished.

For further densities inorganic substances see table 238.
" " " organic " " " 244.

WEIGHT OF SHEET METAL.

TABLE 66. — Weight of Sheet Metal. (Metric Measure.)

This table gives the weight in grams of a plate one meter square and of the thickness stated in the first column.

Thickness in thousandths of a cm.	Iron.	Copper.	Brass.	Aluminum.	Platinum.	Gold.	Silver.
1	78.0	89.0	85.6	26.7	215.0	193.0	105.0
2	156.0	178.0	171.2	53.4	430.0	386.0	210.0
3	234.0	267.0	256.8	80.1	645.0	579.0	315.0
4	312.0	356.0	342.4	106.8	860.0	772.0	420.0
5	390.0	445.0	428.0	133.5	1075.0	965.0	525.0
6	468.0	534.0	513.6	160.2	1290.0	1158.0	630.0
7	546.0	623.0	599.2	186.9	1505.0	1351.0	735.0
8	624.0	712.0	684.8	213.6	1720.0	1544.0	840.0
9	702.0	801.0	770.4	240.3	1935.0	1737.0	945.0
10	780.0	890.0	856.0	267.0	2150.0	1930.0	1050.0

TABLE 67. — Weight of Sheet Metal. (British Measure.)

Thickness in Mils.	Iron.	Copper.	Brass.	Aluminum.		Platinum.	
	Pounds per Sq. Foot.	Pounds per Sq. Foot.	Pounds per Sq. Foot.	Pounds per Sq. Foot.	Ounces per Sq. Foot.	Pounds per Sq. Foot.	Ounces per Sq. Foot.
1	.04058	.04630	.04454	.01389	.2222	.1119	1.790
2	.08116	.09260	.08908	.02778	.4445	.2237	3.579
3	.12173	.13890	.13363	.04167	.6667	.3356	5.369
4	.16231	.18520	.17817	.05556	.8890	.4474	7.158
5	.20289	.23150	.22271	.06945	1.1112	.5593	8.948
6	.24347	.27780	.26725	.08334	1.3335	.6711	10.738
7	.28405	.32411	.31179	.09723	1.5557	.7830	12.527
8	.32463	.37041	.35634	.11112	1.7780	.8948	14.317
9	.36520	.41671	.40088	.12501	2.0002	1.0067	16.106
10	.40578	.46301	.44542	.13890	2.2224	1.1185	17.896

Thickness in Mils.	Gold.		Silver.	
	Troy Ounces per Sq. Foot.	Grains per Sq. Foot.	Troy Ounces per Sq. Foot.	Grains per Sq. Foot.
1	1.4642	702.8	0.7967	382.4
2	2.9285	1405.7	1.5933	764.8
3	4.3927	2108.5	2.3900	1147.2
4	5.8570	2811.3	3.1867	1529.6
5	7.3212	3514.2	3.9833	1912.0
6	8.7854	4217.0	4.7800	2294.4
7	10.2497	4919.8	5.5767	2676.8
8	11.7139	5622.7	6.3734	3059.2
9	13.1782	6325.5	7.1700	3441.6
10	14.6424	7028.3	7.9667	3824.0

TABLE 68.

DENSITY OF LIQUIDS.

Density or mass in grams per cubic centimeter and in pounds per cubic foot of various liquids.

Liquid.	Grams per cubic centimeter.	Pounds per cubic foot.	Temp. C.
Acetone	0.792	49.4	20°
Alcohol, ethyl	0.807	50.4	0
“ methyl	0.810	50.5	0
Anilin	1.035	64.5	0
Benzol	0.899	56.1	0
Bromine	3.187	199.0	0
Carbolic acid (crude)	0.950–0.965	59.2–60.2	15
Carbon disulphide	1.293	80.6	0
Chloroform	1.480	92.3	18
Ether	0.736	45.9	0
Gasoline	0.66–0.69	41.0–43.0	–
Glycerine	1.260	78.6	0
Milk	1.028–1.035	64.2–64.6	–
Naphtha (wood)	0.848–0.810	52.9–50.5	0
Naphtha (petroleum ether)	0.665	41.5	15
Oils: Amber	0.800	49.9	15
Anise-seed	0.996	62.1	16
Camphor	0.910	56.8	–
Castor	0.969	60.5	15
Cocoanut	0.925	57.7	15
Cotton Seed	0.926	57.8	16
Creosote	1.040–1.100	64.9–68.6	15
Lard	0.920	57.4	15
Lavender	0.877	54.7	16
Lemon	0.844	52.7	16
Linseed (boiled)	0.942	58.8	15
Olive	0.918	57.3	15
Palm	0.905	56.5	15
Pine	0.850–0.860	53.0–54.0	15
Poppy	0.924	57.7	–
Rapeseed (crude)	0.915	57.1	15
“ (refined)	0.913	57.0	15
Resin	0.955	59.6	15
Train *or* Whale	0.918–0.925	57.3–57.7	15
Turpentine	0.873	54.2	16
Valerian	0.965	60.2	16
Petroleum	0.878	54.8	0
“ (light)	0.795–0.805	49.6–50.2	15
Pyroligneous acid	0.800	49.9	0
Water	1.000	62.4	4

TABLE 69.

DENSITY OF GASES.

The following table gives the density of the gases at 0° C, 76 cm. pressure, at sea-level and latitude 45° relative to air as unity and under the same conditions; also the weight of one liter in grams and one cubic foot in pounds.

Gas.	Specific Gravity.	Grams per liter.	Pounds per cubic foot.	Reference.
Air	1.000	1.2928	.08071	Rayleigh; Leduc.
Acetylene	0.92	1.1620	.07254	Berthelot, 1860.
Ammonia	0.597	0.7706	.04811	Leduc, C. R. 125, 1897.
Argon	1.379	1.782	.1112	Ramsey-Travers, Proc. R. Soc. 67, 1900.
Bromine	5.524	7.1388	.4457	Jahn, 1882.
Butane	2.01	2.594	.16194	Frankland, Ann. Ch. Pharm. 71.
Carbon dioxide	1.5291	1.9768	.12341	Guye, Pintza, 1908.
" monoxide	0.9672	1.2506	.07807	Rayleigh, Proc. R. Soc. 62, 1897.
Chlorine	2.491	3.1674	.19774	Leduc, C. R. 125, 1897.
Coal gas from	0.320	0.414	.02583	
to	0.740	0.957	.05973	
Cyanogen	1.806	2.3229	.14522	Gay-Lussac.
Ethane	1.0494	1.3567	.08470	Baume, Perot, J. Ch. et Phys. 1908.
Fluorine	1.26	1.697	.1059	Moissan, C. R. 109.
Helium	1.368	0.1787	.01116	Ramsay-Travers, Proc. R. Soc. 67, 1900.
Hydrofluoric acid	0.7126	0.894	.05581	Thorpe-Hambley, J. Chem. Soc. 53.
Hydrobromic acid	2.71	3.6163	.2258	Löwig, Gmelin-Kraut, Org. Chem.
Hydrochloric acid	1.2684	1.6398	.10237	Guye-Gazarian, 1908.
Hydrogen	0.0696	0.09004	.005621	Rayleigh, Proc. R. Soc. 53, 1893.
Hydrogen sulphide	1.1895	1.5230	.09508	Leduc, C. R. 125, 1897.
Krypton	2.868	3.708	.2315	Watson, J. Ch. Soc. 1910.
Methane	0.5576	0.7160	.04470	Thomson.
Neon	0.6963	0.9002	.0558	Watson, J. Ch. Soc. 1910.
Nitrogen	0.9673	1.2514	.07812	Rayleigh, Proc. R. Soc. 62, 1897.
Nitric oxide, NO	1.0367	1.3402	.08367	Guye, Davila, 1908.
Nitrous oxide, N_2O	1.5298	1.9777	.12347	Guye, Pintza, 1908.
Oxygen	1.053	1.4292	.08922	Rayleigh, Proc. R. Soc. 62, 1897.
Sulphur dioxide	2.2639	2.9266	.18271	Jaquerod, Pintza, 1908.
Steam at 100°	0.469	0.581	.0363	
Xenon	4.526	5.851	.3653	Watson, J. Ch. Soc. 1910.

Compiled partly from Landolt-Börnstein-Meyerhoffer's Physikalisch-Chemische Tabellen.

TABLE 70.

DENSITY OF AQUEOUS SOLUTIONS.*

The following table gives the density of solutions of various salts in water. The numbers give the weight in grams per cubic centimeter. For brevity the substance is indicated by formula only.

Substance.	Weight of the dissolved substance in 100 parts by weight of the solution.									Temp. C.	Authority.
	5	10	15	20	25	30	40	50	60		
K_2O	1.047	1.098	1.153	1.214	1.284	1.354	1.503	1.659	1.809	15.	Schiff.
KOH	1.040	1.082	1.027	1.076	1.229	1.286	1.410	1.538	1.666	15.	"
Na_2O	1.073	1.144	1.218	1.284	1.354	1.421	1.557	1.689	1.829	15.	"
$NaOH$	1.058	1.114	1.169	1.224	1.279	1.331	1.436	1.539	1.642	15.	"
NH_3	0.978	0.959	0.940	0.924	0.909	0.896	–	–	–	16.	Carius.
NH_4Cl	1.015	1.030	1.044	1.058	1.072	–	–	–	–	15.	Gerlach.
KCl	1.031	1.065	1.099	1.135	–	–	–	–	–	15.	"
$NaCl$	1.035	1.072	1.110	1.150	1.191	–	–	–	–	15.	"
$LiCl$	1.029	1.057	1.085	1.116	1.147	1.181	1.255	–	–	15.	"
$CaCl_2$	1.041	1.086	1.132	1.181	1.232	1.286	1.402	–	–	15.	"
$CaCl_2 + 6H_2O$	1.019	1.040	1.061	1.083	1.105	1.128	1.176	1.225	1.276	18.	Schiff.
$AlCl_3$	1.030	1.072	1.111	1.153	1.196	1.241	1.340	–	–	15.	Gerlach.
$MgCl_2$	1.041	1.085	1.130	1.177	1.226	1.278	–	–	–	15.	"
$MgCl_2+6H_2O$	1.014	1.032	1.049	1.067	1.085	1.103	1.141	1.183	1.222	24.	Schiff.
$ZnCl_2$	1.043	1.089	1.135	1.184	1.236	1.289	1.417	1.563	1.737	19.5	Kremers.
$CdCl_2$	1.043	1.087	1.138	1.193	1.254	1.319	1.469	1.653	1.887	19.5	"
$SrCl_2$	1.044	1.092	1.143	1.198	1.257	1.321	–	–	–	15.	Gerlach.
$SrCl_2 + 6H_2O$	1.027	1.053	1.082	1.111	1.042	1.174	1.242	1.317	–	15.	"
$BaCl_2$	1.045	1.094	1.147	1.205	1.269	–	–	–	–	15.	"
$BaCl_2 + 2H_2O$	1.035	1.075	1.119	1.166	1.217	1.273	–	–	–	21.	Schiff.
$CuCl_2$	1.044	1.091	1.155	1.221	1.291	1.360	1.527	–	–	17.5	Franz.
$NiCl_2$	1.048	1.098	1.157	1.223	1.299	–	–	–	–	17.5	"
$HgCl_2$	1.041	1.092	–	–	–	–	–	–	–	20.	Mendelejeff.
Fe_2Cl_6	1.041	1.086	1.130	1.179	1.232	1.290	1.413	1.545	1.668	17.5	Hager.
$PtCl_4$	1.046	1.097	1.153	1.214	1.285	1.362	1.546	1.785	–	–	Precht.
$SnCl_2 + 2H_2O$	1.032	1.067	1.104	1.143	1.185	1.229	1.329	1.444	1.580	15.	Gerlach.
$SnCl_4 + 5H_2O$	1.029	1.058	1.089	1.122	1.157	1.193	1.274	1.365	1.467	15.	"
$LiBr$	1.033	1.070	1.111	1.154	1.202	1.252	1.366	1.498	–	19.5	Kremers.
KBr	1.035	1.073	1.114	1.157	1.205	1.254	1.364	–	–	19.5	"
$NaBr$	1.038	1.078	1.123	1.172	1.224	1.279	1.408	1.563	–	19.5	"
$MgBr_2$	1.041	1.085	1.135	1.189	1.245	1.308	1.449	1.623	–	19.5	"
$ZnBr_2$	1.043	1.091	1.144	1.202	1.263	1.328	1.473	1.648	1.873	19.5	"
$CdBr_2$	1.041	1.088	1.139	1.197	1.258	1.324	1.479	1.678	–	19.5	"
$CaBr_2$	1.042	1.087	1.137	1.192	2.250	1.313	1.459	1.639	–	19.5	"
$BaBr_2$	1.043	1.090	1.142	1.199	1.260	1.327	1.483	1.683	–	19.5	"
$SrBr_2$	1.043	1.089	1.140	1.198	1.260	1.328	1.489	1.693	1.953	19.5	"
KI	1.036	1.076	1.118	1.164	1.216	1.269	1.394	1.544	1.732	19.5	"
LiI	1.036	1.077	1.122	1.170	1.222	1.278	1.412	1.573	1.775	19.5	"
NaI	1.038	1.080	1.126	1.177	1.232	1.292	1.430	1.598	1.808	19.5	"
ZnI_2	1.043	1.089	1.138	1.194	1.253	1.316	1.467	1.648	1.873	19.5	"
CdI_2	1.042	1.086	1.136	1.192	1.251	1.317	1.474	1.678	–	19.5	"
MgI_2	1.041	1.086	1.137	1.192	1.252	1.318	1.472	1.666	1.913	19.5	"
CaI_2	1.042	1.088	1.138	1.196	1.258	1.319	1.475	1.663	1.908	19.5	"
SrI_2	1.043	1.089	1.140	1.198	1.260	1.328	1.489	1.693	1.953	19.5	"
BaI_2	1.043	1.089	1.141	1.199	1.263	1.331	1.493	1.702	1.968	19.5	"
$NaClO_3$	1.035	1.068	1.106	1.145	1.188	1.233	1.329	–	–	19.5	"
$NaBrO_3$	1.039	1.081	1.127	1.176	1.229	1.287	–	–	–	19.5	"
KNO_3	1.031	1.064	1.099	1.135	–	–	–	–	–	15.	Gerlach.
$NaNO_3$	1.031	1.065	1.101	1.140	1.180	1.222	1.313	1.416	–	20.2	Schiff.
$AgNO_3$	1.044	1.090	1.140	1.195	1.255	1.322	1.479	1.675	1.918	15.	Kohlrausch.

---

* Compiled from two papers on the subject by Gerlach in the "Zeit. für Anal. Chim.," vols. 8 and 27.

TABLE 70 (*continued*).

DENSITY OF AQUEOUS SOLUTIONS.

Substance.	Weight of the dissolved substance in 100 parts by weight of the solution.									Temp. C.	Authority.
	5	10	15	20	25	30	40	50	60		
NH_4NO_3 . . .	1.020	1.041	1.063	1.085	1.107	1.131	1.178	1.229	1.282	17.5	Gerlach.
$Zn(NO_3)_2$ . . .	1.048	1.095	1.146	1.201	1.263	1.325	1.456	1.597	–	17.5	Franz.
$Zn(NO_3)_2+6H_2O$	–	1.054	–	1.113	–	1.178	1.250	1.329	–	14.	Oudemans.
$Ca(NO_3)_2$ . . .	1.037	1.075	1.118	1.162	1.211	1.260	1.367	1.482	1.604	17.5	Gerlach.
$Cu(NO_3)_2$ . . .	1.044	1.093	1.143	1.203	1.263	1.328	1.471	–	–	17.5	Franz.
$Sr(NO_3)_2$ . . .	1.039	1.083	1.129	1.179	–	–	–	–	–	19.5	Kremers.
$Pb(NO_3)_2$ . . .	1.043	1.091	1.143	1.199	1.262	1.332	–	–	–	17.5	Gerlach.
$Cd(NO_3)_2$ . . .	1.052	1.097	1.150	1.212	1.283	1.355	1.536	1.759	–	17.5	Franz.
$Co(NO_3)_2$ . . .	1.045	1.090	1.137	1.192	1.252	1.318	1.465	–	–	17.5	“
$Ni(NO_3)_2$ . . .	1.045	1.090	1.137	1.192	1.252	1.318	1.465	–	–	17.5	“
$Fe_2(NO_3)_6$ . . .	1.039	1.076	1.117	1.160	1.210	1.261	1.373	1.496	1.657	17.5	“
$Mg(NO_3)_2+6H_2O$	1.018	1.038	1.060	1.082	1.105	1.129	1.179	1.232	–	21	Schiff.
$Mn(NO_3)_2+6H_2O$	1.025	1.052	1.079	1.108	1.138	1.169	1.235	1.307	1.386	8	Oudemans.
K_2CO_3	1.044	1.092	1.141	1.192	1.245	1.300	1.417	1.543	–	15	Gerlach.
$K_2CO_3 + 2H_2O$.	1.037	1.072	1.110	1.150	1.191	1.233	1.320	1.415	1.511	15.	“
$Na_2CO_310H_2O$.	1.019	1.038	1.057	1.077	1.098	1.118	–	–	–	15.	“
$(NH_4)_2SO_4$ . .	1.027	1.055	1.084	1.113	1.142	1.170	1.226	1.287	–	19.	Schiff.
$Fe_2(SO_4)_3$ . . .	1.045	1.096	1.150	1.207	1.270	1.336	1.489	–	–	18.	Hager.
$FeSO_4 + 7H_2O$.	1.025	1.053	1.081	1.111	1.141	1.173	1.238	–	–	17.2	Schiff.
$MgSO_4$	1.051	1.104	1.161	1.221	1.284	–	–	–	–	15	Gerlach.
$MgSO + 7H_2O$.	1.025	1.050	1.075	1.101	1.129	1.155	1.215	1.278	–	15.	“
$Na_2So_4 + 10H_2O$	1.019	1.039	1.059	1.081	1.102	1.124	–	–	–	15.	“
$CuSO_4 + 5H_2O$.	1.031	1.064	1.098	1.134	1.173	1.213	–	–	–	18.	Schiff.
$MnSO_4 + 4H_2O$.	1.031	1.064	1.099	1.135	1.174	1.214	1.303	1.398	–	15.	Gerlach.
$ZnSO_4 + 7H_2O$.	1.027	1.057	1.089	1.122	1.156	1.191	1.269	1.351	1.443	20.5	Schiff.
$Fe_2(SO)_3+K_2SO_4$ $+24H_2O$ . . .	1.026	1.045	1.066	1.088	1.112	1.141	–	–	–	17.5	Franz.
$Cr_2(SO)_3+K_2SO_4$ $+ 24H_2O$ . .	1.016	1.033	1.051	1.073	1.099	1.126	1.188	1.287	1.454	17.5	“
$MgSO_4 + K_2SO_4$ $+ 6H_2O$ . . .	1.032	1.066	1.101	1.138	–	–	–	–	–	15.	Schiff.
$(NH_4)_2SO_4 +$ $FeSO_4 + 6H_2O$	1.028	1.058	1.090	1.122	1.154	1.191	–	–	–	19.	“
K_2CrO_4	1.039	1.082	1.127	1.174	1.225	1.279	1.397	–	–	19.5	“
$K_2Cr_2O_7$ . . .	1.035	1.071	1.108	–	–	–	–	–	–	19.5	Kremers.
$Fe(Cy)_6K_4$ . . .	1.028	1.059	1.092	1.126	–	–	–	–	–	15.	Schiff.
$Fe(Cy)_6K_3$ . . .	1.025	1.053	1.070	1.113	–	–	–	–	–	13	“
$Pb(C_2H_3O_2)_2 +$ $3H_2O$	1.031	1.064	1.100	1.137	1.177	1.220	1.315	1.426	–	15.	Gerlach.
$2NaOH + As_2O_5$ $+ 24H_2O$ . .	1.020	1.042	1.066	1.089	1.114	1.140	1.194	–	–	14.	Schiff.
	5	10	15	20	30	40	60	80	100		
SO_3	1.040	1.084	1.132	1.179	1.277	1.389	1.564	1.840	–	15.	Brineau.
SO_2	1.013	1.028	1.045	1.063	–	–	–	–	–	4.	Schiff.
N_2O_5	1.033	1.069	1.104	1.141	1.217	1.294	1.422	1.506	–	15.	Kolb.
$C_4H_6O_6$	1.021	1.047	1.070	1.096	1.150	1.207	–	–	–	15.	Gerlach.
$C_6H_8O_7$	1.018	1.038	1.058	1.079	1.123	1.170	1.273	–	–	15.	“
Cane sugar . . .	1.019	1.039	1.060	1.082	1.129	1.178	1.289	–	–	17.5	“
HCl	1.025	1.050	1.075	1.101	1.151	1.200	–	–	–	15.	Kolb.
HBr	1.035	1.073	1.114	1.158	1.257	1.376	–	–	–	14.	Topsöe.
HI	1.037	1.077	1.118	1.165	1.271	1.400	–	–	–	13.	“
H_2SO_4	1.032	1.069	1.106	1.145	1.223	1.307	1.501	1.732	1.838	15.	Kolb.
H_2SiFl_6	1.040	1.082	1.127	1.174	1.273	–	–	–	–	17.5	Stolba.
P_2O_5	1.035	1.077	1.119	1.167	1.271	1.385	1.676	–	–	17.5	Hager.
$P_2O_5 + 3H_2O$ . .	1.027	1.057	1.086	1.119	1.188	1.264	1.438	–	–	15.	Schiff.
HNO	1.028	1.056	1.088	1.119	1.184	1.250	1.373	1.459	1.528	15.	Kolb.
$C_2H_4O_2$	1.007	1.014	1.021	1.028	1.041	1.052	1.068	1.075	1.055	15.	Oudemans.

TABLE 71.

DENSITY OF PURE WATER FREE FROM AIR.

[Under standard pressure (76 cm), at every tenth part of a degree of the international hydrogen scale from 0° to 41° C, in grams per milliliter [1]]

Degrees Centigrade.	Tenths of Degrees.										Mean Differences.
	0	1	2	3	4	5	6	7	8	9	
0	0.999 8681	8747	8812	8875	8936	8996	9053	9109	9163	9216	+ 59
1	9267	9315	9363	9408	9452	9494	9534	9573	9610	9645	+ 41
2	9679	9711	9741	9769	9796	9821	9844	9866	9887	9905	+ 24
3	9922	9937	9951	9962	9973	9981	9988	9994	9998	*0000	+ 8
4	1.000 0000	*9999	*9996	*9992	*9986	*9979	*9970	*9960	*9947	*9934	— 8
5	0.999 9919	9902	9884	9864	9842	9819	9795	9769	9742	9713	— 24
6	9682	9650	9617	9582	9545	9507	9468	9427	9385	9341	— 39
7	9296	9249	9201	9151	9100	9048	8994	8938	8881	8823	— 53
8	8764	8703	8641	8577	8512	8445	8377	8308	8237	8165	— 67
9	8091	8017	7940	7863	7784	7704	7622	7539	7455	7369	— 81
10	7282	7194	7105	7014	6921	6826	6729	6632	6533	6432	— 95
11	6331	6228	6124	6020	5913	5805	5696	5586	5474	5362	—108
12	5248	5132	5016	4898	4780	4660	4538	4415	4291	4166	—121
13	4040	3912	3784	3654	3523	3391	3257	3122	2986	2850	—133
14	2712	2572	2431	2289	2147	2003	1858	1711	1564	1416	—145
15	1266	1114	0962	0809	0655	0499	0343	0185	0026	*9865	—156
16	0.998 9705	9542	9378	9214	9048	8881	8713	8544	8373	8202	—168
17	8029	7856	7681	7505	7328	7150	6971	6791	6610	6427	—178
18	6244	6058	5873	5686	5498	5309	5119	4927	4735	4541	—190
19	4347	4152	3955	3757	3558	3358	3158	2955	2752	2549	—200
20	2343	2137	1930	1722	1511	1301	1090	0878	0663	0449	—211
21	0233	0016	*9799	*9580	*9359	*9139	*8917	*8694	*8470	*8245	—221
22	0.997 8019	7792	7564	7335	7104	6873	6641	6408	6173	5938	—232
23	5702	5466	5227	4988	4747	4506	4264	4021	3777	3531	—242
24	3286	3039	2790	2541	2291	2040	1788	1535	1280	1026	—252
25	0770	0513	0255	*9997	*9736	*9476	*9214	*8951	*8688	*8423	—261
26	0.996 8158	7892	7624	7356	7087	6817	6545	6273	6000	5726	—271
27	5451	5176	4898	4620	4342	4062	3782	3500	3218	2935	—280
28	2652	2366	2080	1793	1505	1217	0928	0637	0346	0053	—289
29	0.995 9761	9466	9171	8876	8579	8282	7983	7684	7383	7083	—298
30	6780	6478	6174	5869	5564	5258	4950	4642	4334	4024	—307
31	3714	3401	3089	2776	2462	2147	1832	1515	1198	0880	—315
32	0561	0241	*9920	*9599	*9276	*8954	*8630	*8304	*7979	*7653	—324
33	0.994 7325	6997	6668	6338	6007	5676	5345	5011	4678	4343	—332
34	4007	3671	3335	2997	2659	2318	1978	1638	1296	0953	—340
35	0610	0267	*9922	*9576	*9230	*8883	*8534	*8186	*7837	*7486	—347
36	0.993 7136	6784	6432	6078	5725	5369	5014	4658	4301	3943	—355
37	3585	3226	2866	2505	2144	1782	1419	1055	0691	0326	—362
38	0.992 9960	9593	9227	8859	8490	8120	7751	7380	7008	6636	—370
39	6263	5890	5516	5140	4765	4389	4011	3634	3255	2876	—377
40	2497	2116	1734	1352	0971	0587	0203	*9818	*9433	*9047	—384
41	0.991 8661										

---

[1] According to P. Chappuis, Bureau international des Poids et Mesures, Travaux et Mémoires, 13; 1907.

Table 72.

VOLUME IN CUBIC CENTIMETERS AT VARIOUS TEMPERATURES OF A CUBIC CENTIMETER OF WATER FREE FROM AIR AT THE TEMPERATURE OF MAXIMUM DENSITY.

Hydrogen Thermometer Scale.

Temp. C.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	1.000132	125	118	112	106	100	095	089	084	079
1	073	069	064	059	055	051	047	043	039	035
2	032	029	026	023	020	018	016	013	011	009
3	008	006	005	004	003	002	001	001	000	000
4	000	000	000	001	001	002	003	004	005	007
5	008	010	012	014	016	018	021	023	026	029
6	032	035	039	042	046	050	054	058	062	066
7	070	075	080	085	090	095	101	106	112	118
8	124	130	137	142	149	156	162	169	176	184
9	191	198	206	214	222	230	238	246	254	263
10	272	281	290	299	308	317	327	337	347	357
11	367	377	388	398	409	420	430	441	453	464
12	476	487	499	511	522	534	547	559	571	584
13	596	609	623	636	649	661	675	688	702	715
14	729	743	757	772	786	800	815	830	844	859
15	873	890	905	920	935	951	967	983	998	015*
16	1.001031	047	063	080	097	113	130	147	164	182
17	198	216	233	252	269	287	305	323	341	358
18	378	396	415	433	452	471	490	510	529	548
19	568	588	606	626	646	667	687	707	728	748
20	769	790	811	832	853	874	895	916	938	960
21	981	002*	024*	046*	068*	091*	113*	135*	158*	181*
22	1.002203	226	249	271	295	319	342	364	389	412
23	436	459	483	507	532	556	581	605	629	654
24	679	704	729	754	779	804	829	854	879	905
25	932	958	983	010*	036*	061*	088*	115*	141*	168*
26	1.003195	221	248	275	302	330	357	384	412	439
27	467	495	523	550	579	607	635	663	692	720
28	749	776	806	836	865	893	922	951	981	011*
29	1.004041	069	100	129	160	189	220	250	280	310
30	341	371	403	432	464	494	526	557	588	619
31	651	682	713	744	777	808	840	872	904	936
32	968	001*	033*	066*	098*	132*	163*	197*	229*	263*
33	1.005296	328	361	395	427	461	496	530	562	597
34	631	665	698	732	768	802	836	871	904	940
35	975	009*	044*	078*	115*	150*	185*	219*	255*	290*

Reciprocals of the preceding table.

TABLE 73.

DENSITY AND VOLUME OF WATER.

The mass of one cubic centimeter at 4° C. is taken as unity.

Temp. C.	Density.	Volume.	Temp. C.	Density.	Volume.
−10°	0.99815	1.00186	**+35°**	0.99406	1.00598
−9	843	157	36	371	633
−8	869	131	37	336	669
−7	892	108	38	300	706
−6	912	088	39	263	743
−5	0.99930	1.00070	**40**	0.99225	1.00782
−4	945	055	41	187	821
−3	958	042	42	147	861
−2	970	031	43	107	901
−1	979	021	44	066	943
+0	0.99987	1.00013	**45**	0.99025	1.00985
1	993	007	46	0.98982	1.01028
2	997	003	47	940	072
3	999	001	48	896	116
4	1.00000	1.00000	49	852	162
5	0.99999	1.00001	**50**	0.98807	1.01207
6	997	003	51	762	254
7	993	007	52	715	301
8	988	012	53	669	349
9	981	019	54	621	398
10	0.99973	1.00027	**55**	0.98573	1.01448
11	963	037	60	324	705
12	952	048	65	059	979
13	940	060	70	0.97781	1.02270
14	927	073	75	489	576
15	0.99913	1.00087	**80**	0.97183	1.02899
16	897	103	85	0.96865	1.03237
17	880	120	90	534	590
18	862	138	95	192	959
19	843	157	100	0.95838	1.04343
20	0.99823	1.00177	**110**	0.9510	1.0515
21	802	198	120	.9434	1.0601
22	780	220	130	.9352	1.0693
23	757	244	140	.9264	1.0794
24	733	268	150	.9173	1.0902
25	0.99708	1.00293	**160**	0.9075	1.1019
26	682	320	170	.8973	1.1145
27	655	347	180	.8866	1.1279
28	627	375	190	.8750	1.1429
29	598	404	200	.8628	1.1590
30	0.99568	1.00434	**210**	0.850	1.177
31	537	465	220	.837	1.195
32	506	497	230	.823	1.215
33	473	530	240	.809	1.236
34	440	563	250	.794	1.259

---

* From — 10° to 0° the values are due to means from Pierre, Weidner, and Rosetti; from 0° to 41°, to Chappuis, 42° to 100°, to Thiesen; 110° to 250°, to means from the works of Ramsey, Young, Waterston, and Hirn.

Table 74.

DENSITY OF MERCURY.

Density or mass in grams per cubic centimeter, and the volume in cubic centimeters of one gram of mercury.

Temp. C.	Mass in grams per cu. cm.	Volume of 1 gram in cu. cms.	Temp. C.	Mass in grams per cu. cm.	Volume of 1 gram in cu. cms.
—10°	13.6202	0.0734205	**30°**	13.5217	0.0739552
—9	6177	4338	31	5193	9685
—8	6152	4472	32	5168	9819
—7	6128	4606	33	5144	9953
—6	6103	4739	34	5119	40087
—5	13.6078	0.0734873	**35**	13.5095	0.0740221
—4	6053	5006	36	5070	0354
—3	6029	5140	37	5046	0488
—2	6004	5273	38	5021	0622
—1	5979	5407	39	4997	0756
0	13.5955	0.0735540	**40**	13.4973	0.0740890
1	5930	5674	50	4729	2230
2	5905	5808	60	4486	3572
3	5880	5941	70	4243	4916
4	5856	6075	80	4001	6262
5	13.5831	0.0736208	**90**	13.3776	0.0747611
6	5807	6342	100	3518	8961
7	5782	6476	110	3283	50285
8	5757	6609	120	3044	1633
9	5733	6743	130	2805	2982
10	13.5708	0.0736877	**140**	13.2567	0.0754334
11	5683	7010	150	2330	5688
12	5659	7144	160	2093	7044
13	5634	7278	170	1856	8402
14	5610	7411	180	1620	9764
15	13.5585	0.0737545	**190**	13.1384	0.0761128
16	5560	7679	200	1148	2495
17	5536	7812	210	0913	3865
18	5511	7946	220	0678	5239
19	5487	8080	230	0443	6616
20	13.5462	0.0738213	**240**	13.0209	0.0767996
21	5438	8347	250	12.9975	9381
22	5413	8481	260	9741	70769
23	5389	8615	270	9507	2161
24	5364	8748	280	9273	3558
25	13.5340	0.0738882	**290**	12.9039	0.0774958
26	5315	9016	300	8806	6364
27	5291	9150	310	8572	7774
28	5266	9284	320	8339	9189
29	5242	9417	330	8105	80609
30	13.5217	0.0739551	**340**	12.7872	0.0782033
			350	7638	3464
			360	7405	4900

Thiesen und Scheel, Tätigkeitber. Phys.-Techn. Reichsanstalt, 1897–1898; Chappuis, Trav. Bur. Int. 13, 1903.
Thiesen, Scheel, Sell; Wiss. Abh. Phys.-Techn. Reichsanstalt 2, p. 184, 1895.

TABLE 75.

DENSITIES OF MIXTURES OF ETHYL ALCOHOL AND WATER IN GRAMS PER MILLILITER.

The densities in this table are numerically the same as specific gravities at the various temperatures in terms of water at 4° C. as unity. Based upon work done at U. S. Bureau of Standards. See Bulletin Bur. Stds. vol. 9, no. 3; contains extensive bibliography; also Circular 19, 1913.

Per cent C_2H_5OH by weight	Temperatures.						
	10° C.	15° C.	20° C.	25° C.	30° C.	35° C.	40° C.
0	0.99973	0.99913	0.99823	0.99708	0.99568	0.99406	0.99225
1	785	725	636	520	379	217	034
2	602	542	453	336	194	031	.98846
3	426	365	275	157	014	.98849	663
4	258	195	103	.98984	.98839	672	485
5	098	032	.98938	817	670	501	311
6	.98946	.98877	780	656	507	335	142
7	801	729	627	500	347	172	.97975
8	660	584	478	346	189	009	808
9	524	442	331	193	031	.97846	641
10	393	304	187	043	.97875	685	475
11	267	171	047	.97897	723	527	312
12	145	041	.97910	753	573	371	150
13	026	.97914	775	611	424	216	.96989
14	.97911	790	643	472	278	063	829
15	800	669	514	334	133	.96911	670
16	692	552	387	199	.96990	760	512
17	583	433	259	062	844	607	352
18	473	313	129	.96923	697	452	189
19	363	191	.96997	782	547	294	023
20	252	068	864	639	395	134	.95856
21	139	.96944	729	495	242	.95973	687
22	024	818	592	348	087	809	516
23	.96907	689	453	199	.95929	643	343
24	787	558	312	048	769	476	168
25	665	424	168	.95895	607	306	.94991
26	539	287	020	738	442	133	810
27	406	144	.95867	576	272	.94955	625
28	268	.95996	710	410	098	774	438
29	125	844	548	241	.94922	590	248
30	.95977	686	382	067	741	403	055
31	823	524	212	.94890	557	214	.93860
32	665	357	038	709	370	021	662
33	502	186	.94860	525	180	.93825	461
34	334	011	679	337	.93986	626	257
35	162	.94832	494	146	790	425	051
36	.94986	650	306	.93952	591	221	.92843
37	805	464	114	756	390	016	634
38	620	273	.93919	556	186	.92808	422
39	431	079	720	353	.92979	597	208
40	238	.93882	518	148	770	385	.91992
41	042	682	314	.92940	558	170	774
42	.93842	478	107	729	344	.91952	554
43	639	271	.92897	516	128	733	332
44	433	062	685	301	.91910	513	108
45	226	.92852	472	085	692	291	.90884
46	017	640	257	.91868	472	069	660
47	.92806	426	041	649	250	.90845	434
48	593	211	.91823	429	028	621	207
49	379	.91995	604	208	.90805	396	.89979
50	162	776	384	.90985	580	168	750

DENSITY OF MIXTURES OF ETHYL ALCOHOL AND WATER IN GRAMS PER MILLILITER.

Per cent C_2H_5OH by weight	Temperature.						
	10° C.	15° C.	20° C.	25° C.	30° C.	35° C.	40° C.
50	0.92162	0.91776	0.91384	0.90985	0.90580	0.90168	0.89750
51	.91943	555	160	760	353	.89940	519
52	723	333	.90936	534	125	710	288
53	502	110	711	307	.89896	479	056
54	279	.90885	485	079	667	248	.88823
55	055	659	258	.89850	437	016	589
56	.90831	433	031	621	206	.88784	356
57	607	207	.89803	392	.88975	552	122
58	381	.89980	574	162	744	319	.87888
59	154	752	344	.88931	512	085	653
60	.89927	523	113	699	278	.87851	417
61	698	293	.88882	466	044	615	180
62	468	062	650	233	.87809	379	.86943
63	237	.88830	417	.87998	574	142	705
64	006	597	183	763	337	.86905	466
65	.88774	364	.87948	527	100	667	227
66	541	130	713	291	.86863	429	.85987
67	308	.87895	477	054	625	190	747
68	074	660	241	.86817	387	.85950	507
69	.87839	424	004	579	148	710	266
70	602	187	.86766	340	.85908	470	025
71	365	.86949	527	100	667	228	.84783
72	127	710	287	.85859	426	.84986	540
73	.86888	470	047	618	184	743	297
74	648	229	.85806	376	.84941	500	053
75	408	.85988	564	134	698	257	.83809
76	168	747	322	.84891	455	013	564
77	.85927	505	079	647	211	.83768	319
78	685	262	.84835	403	.83966	523	074
79	442	018	590	158	720	277	.82827
80	197	.84772	344	.83911	473	029	578
81	.84950	525	096	664	224	.82780	329
82	702	277	.83848	415	.82974	530	079
83	453	028	599	164	724	279	.81828
84	203	.83777	348	.82913	473	027	576
85	.83951	525	095	660	220	.81774	322
86	697	271	.82840	405	.81965	519	067
87	441	014	583	148	708	262	.80811
88	181	.82754	323	.81888	448	003	552
89	.82919	492	062	626	186	.80742	291
90	654	227	.81797	362	.80922	478	028
91	386	.81959	529	094	655	211	.79761
92	114	.688	257	.80823	384	.79941	491
93	.81839	413	.80983	549	111	669	220
94	561	134	705	272	.79835	393	.78947
95	278	.80852	424	.79991	555	114	670
96	.80991	566	138	706	271	.78831	388
97	698	274	.79846	415	.78981	542	100
98	399	.79975	547	117	684	247	.77806
99	094	670	243	.78814	382	.77946	507
100	.79784	360	.78934	506	075	641	203

TABLE 76.

DENSITIES OF AQUEOUS MIXTURES OF METHYL ALCOHOL, CANE SUGAR, OR SULPHURIC ACID.

Per cent by weight of substance.	Methyl Alcohol. $D\frac{15^\circ}{4^\circ}$ C.	Cane Sugar. 20°	Sulphuric Acid. $D\frac{20^\circ}{4^\circ}$ C.	Per cent by weight of substance.	Methyl Alcohol. $D\frac{15^\circ}{4^\circ}$ C.	Cane Sugar. 20°	Sulphuric Acid. $D\frac{20^\circ}{4^\circ}$ C.
0	0.99913	0.998234	0.99823	50	0.91852	1.229567	1.39505
1	.99727	1.002120	1.00506	51	.91653	1.235085	1.40487
2	.99543	1.006015	1.01178	52	.91451	1.240641	1.41481
3	.99370	1.009934	1.01839	53	.91248	1.246234	1.42487
4	.99198	1.013881	1.02500	54	.91044	1.251866	1.43503
5	.99029	1.017854	1.03168	55	.90839	1.257535	1.44530
6	.98864	1.021855	1.03843	56	.90631	1.263243	1.45568
7	.98701	1.025885	1.04527	57	.90421	1.268989	1.46615
8	.98547	1.029942	1.05216	58	.90210	1.274774	1.47673
9	.98394	1.034029	1.05909	59	.89996	1.280595	1.48740
10	.98241	1.038143	1.06609	60	.89781	1.286456	1.49818
11	.98093	1.042288	1.07314	61	.89563	1.292354	1.50904
12	.97945	1.046462	1.08026	62	.89341	1.298291	1.51999
13	.97802	1.050665	1.08744	63	.89117	1.304267	1.53102
14	.97660	1.054900	1.09468	64	.88890	1.310282	1.54213
15	.97518	1.059165	1.10199	65	.88662	1.316334	1.55333
16	.97377	1.063460	1.10936	66	.88433	1.322425	1.56460
17	.97237	1.067789	1.11679	67	.88203	1.328554	1.57595
18	.97096	1.072147	1.12428	68	.87971	1.334722	1.58739
19	.96955	1.076537	1.13183	69	.87739	1.340928	1.59890
20	.96814	1.080959	1.13943	70	.87507	1.347174	1.61048
21	.96673	1.085414	1.14709	71	.87271	1.353456	1.62213
22	.96533	1.089900	1.15480	72	.87033	1.359778	1.63384
23	.96392	1.094420	1.16258	73	.86792	1.366139	1.64560
24	.96251	1.098971	1.17041	74	.86546	1.372536	1.65738
25	.96108	1.103557	1.17830	75	.86300	1.378971	1.66917
26	.95963	1.108175	1.18624	76	.86051	1.385446	1.68095
27	.95817	1.112828	1.19423	77	.85801	1.391956	1.69268
28	.95668	1.117512	1.20227	78	.85551	1.398505	1.70433
29	.95518	1.122231	1.21036	79	.85300	1.405091	1.71585
30	.95366	1.126984	1.21850	80	.85048	1.411715	1.72717
31	.95213	1.131773	1.22669	81	.84794	1.418374	1.73827
32	.95056	1.136596	1.23492	82	.84536	1.425072	1.74904
33	.94896	1.141453	1.24320	83	.84274	1.431807	1.75943
34	.94734	1.146345	1.25154	84	.84009	1.438579	1.76932
35	.94570	1.151275	1.25992	85	.83742	1.445388	1.77860
36	.94404	1.156238	1.26836	86	.83475	1.452232	1.78721
37	.94237	1.161236	1.27685	87	.83207	1.459114	1.79509
38	.94067	1.166269	1.28543	88	.82937	1.466032	1.80223
39	.93894	1.171340	1.29407	89	.82667	1.472986	1.80864
40	.93720	1.176447	1.30278	90	.82396	1.479976	1.81438
41	.93543	1.181592	1.31157	91	.82124	1.487002	1.81950
42	.93365	1.186773	1.32043	92	.81849	1.494063	1.82401
43	.93185	1.191993	1.32938	93	.81568	1.501158	1.82790
44	.93001	1.197247	1.33843	94	.81285	1.508289	1.83115
45	.92815	1.202540	1.34759	95	.80999	1.515455	1.83368
46	.92627	1.207870	1.35686	96	.80713	1.522656	1.83548
47	.92436	1.213238	1.36625	97	.80428	1.529891	1.83637
48	.92242	1.218643	1.37574	98	.80143	1.537161	1.83605
49	.92048	1.224086	1.38533	99	.79859	1.544462	
50	.91852	1.229567	1.39505	100	.79577	1.551800	

(1) Calculated from the specific gravity determinations of Doroschevski and Rozhdestvenski at 15°/15° C.; J. Russ., Phys. Chem. Soc., 41, p. 977, 1909.

(2) According to Dr. F. Plato; Wiss. Abh. der K. Normal-Eichungs-Kommission, 2, p. 153, 1900.

(3) Calculated from Dr. Domke's table; Wiss. Abh. der K. Normal-Eichungs-Kommission, 5, p. 131, 1900.

All reprinted from Circular 19, U.S. Bureau of Standards, 1913.

TABLE 77.

VELOCITY OF SOUND IN SOLIDS.

The numbers given in this table refer to the velocity of sound along a bar of the substance, and hence depend on the Young's Modulus of elasticity of the material. The elastic constants of most of the materials given in this table vary through a somewhat wide range, and hence the numbers can only be taken as rough approximations to the velocity which may be obtained in any particular case. When temperatures are not marked, between 10° and 20° is to be understood.

Substance.		Temp. C.	Velocity in meters per second.	Velocity in feet per second.	Authority.
Metals:	Aluminum	° –	5104	16740	Masson.
	Brass	–	3500	11480	Various.
	Cadmium	–	2307	7570	Masson.
	Cobalt	–	4724	15500	“
	Copper	20	3560	11670	Wertheim.
	“	100	3290	10800	“
	“	200	2950	9690	“
	Gold (soft)	20	1743	5717	“
	“ (hard)	–	2100	6890	Various.
	Iron and soft steel	–	5000	16410	“
	Iron	20	5130	16820	Wertheim.
	“	100	5300	17390	“
	“	200	4720	15480	“
	“ cast steel	20	4990	16360	“
	“ “ “	200	4790	15710	“
	Lead	20	1227	4026	“
	Magnesium	–	4602	15100	Melde.
	Nickel	–	4973	16320	Masson.
	Palladium	–	3150	10340	Various.
	Platinum	20	2690	8815	Wertheim.
	“	100	2570	8437	“
	“	200	2460	8079	“
	Silver	20	2610	8553	“
	“	100	2640	8658	“
	Tin	–	2500	8200	Various.
	Zinc	–	3700	12140	“
Various:	Brick	–	3652	11980	Chladni.
	Clay rock	–	3480	11420	Gray & Milne.
	Cork	–	500	1640	Stefan.
	Granite	–	3950	12960	Gray & Milne.
	Marble	–	3810	12500	“
	Paraffin	15	1304	4280	Warburg.
	Slate	–	4510	14800	Gray & Milne.
	Tallow	16	390	1280	Warburg.
	Tuff	–	2850	9350	Gray & Milne.
	Glass { from	–	5000	16410	Various.
	Glass { to	–	6000	19690	“
	Ivory	–	3013	9886	Ciccone & Campanile.
	Vulcanized rubber (black)	0	54	177	Exner.
	Vulcanized rubber (black)	50	31	102	“
	“ “ (red)	0	69	226	“
	“ “ “	70	34	111	“
	Wax	17	880	2890	Stefan.
	“	28	441	1450	“
Woods:	Ash, along the fibre	–	4670	15310	Wertheim.
	“ across the rings	–	1390	4570	“
	“ along the rings	–	1260	4140	“
	Beech, along the fibre	–	3340	10960	“
	“ across the rings	–	1840	6030	“
	“ along the rings	–	1415	4640	“
	Elm, along the fibre	–	4120	13516	“
	“ across the rings	–	1420	4665	“
	“ along the rings	–	1013	3324	“
	Fir, along the fibre	–	4640	15220	“
	Maple “	–	4110	13470	“
	Oak “	–	3850	12620	“
	Pine “	–	3320	10900	“
	Poplar “	–	4280	14050	“
	Sycamore “	–	4460	14640	“

TABLE 78.

VELOCITY OF SOUND IN LIQUIDS AND GASES.

For gases, the velocity of sound = $\sqrt{\gamma P/\rho}$, where P is the pressure, ρ the density, and γ the ratio of specific heat at constant pressure to that at constant volume (see Table 265).

Substance.	Temp. C.	Velocity in meters per second.	Velocity in feet per second.	Authority.
Liquids: Alcohol, 95%	12.5°	1241.	4072.	Dorsing, 1908.
"	20.5	1213.	3980.	"
Ammonia, conc.	16.	1663.	5456.	"
Benzol	17.	1166.	3826.	"
Carbon bisulphide	15.	1161.	3809.	"
Chloroform	15.	983.	3225.	"
Ether	15.	1032.	3386.	"
NaCl, 10% sol.	15.	1470.	4823.	"
" 15% "	15.	1530.	5020.	"
" 20% "	15.	1650.	5414.	"
Turpentine oil	15.	1326.	4351.	"
Water, air-free	13.	1441.	4728.	"
" " "	19.	1461.	4794.	"
" " "	31.	1505.	4938.	"
" Lake Geneva	9.	1435.	4708.	Colladon-Sturm.
" Seine river	15.	1437.	4714.	Wertheim.
" " "	30.	1528.	5013.	"
" " "	60.	1724.	5657.	"
Gases: Air, dry, CO_2-free	0.	331.78	1088.5	Rowland.
" "	0.	331.36	1087.1	Violle, 1900.
" " CO_2-free	0.	331.92	1089.0	Thiesen, 1908.
" 1 atmosphere	0.	331.7	1088.	Mean.
" 25 "	0.	332.0	1089.	" (Witkowski).
" 50 "	0.	334.7	1098.	" "
" 100 "	0.	350.6	1150.	" "
"	20.	344.	1129.	
"	100.	386.	1266.	Stevens.
"	500.	553.	1814.	"
"	1000.	700.	2297.	"
Ammonia	0.	415.	1361.	Masson.
Carbon monoxide	0.	337.1	1106.	Wullner.
" "	0.	337.4	1107.	Dulong.
" dioxide	0.	258.0	846.	Brockendahl, 1906.
" disulphide	0.	189.	620.	Masson.
Chlorine	0.	206.4	677.	Martini.
"	0.	205.3	674.	Strecker.
Ethylene	0.	314.	1030.	Dulong.
Hydrogen	0.	1269.5	4165.	"
"	0.	1286.4	4221.	Zoch.
Illuminating gas	0.	490.4	1609.	"
Methane	0.	432.	1417.	Masson.
Nitric oxide	0.	325.	1066.	"
Nitrous oxide	0.	261.8	859.	Dulong.
Oxygen	0.	317.2	1041.	"
Vapors: Alcohol	0.	230.6	756.	Masson.
Ether	0.	179.2	588.	"
Water	0.	401.	1315.	"
"	100.	404.8	1328.	Treitz, 1903.
"	130.	424.4	1392.	"

NOTE: The values from Ammonia to Methane inclusive are for closed tubes.

MUSICAL SCALES.

The pitch relations between two notes may be expressed precisely (1) by the ratio of their vibration frequencies; (2) by the number of equally-tempered semitones between them (E. S.); also, less conveniently, (3) by the common logarithm of the ratio in (1); (4) by the lengths of the two portions of the tense string which will furnish the notes; and (5) in terms of the octave as unity. The ratio in (4) is the reciprocal of that in (1); the number for (5) is 1/12 of that for (2); the number for (2) is nearly 40 times that for (3).

Table 79 gives data for the middle octave, including vibration frequencies for three standards of pitch; $a = 435$ double vibrations per second, is the international standard and was adopted by the American Piano Manufacturers' Association. The "just-diatonic scale" of C-major is usually deduced, following Chladni, from the ratios of the three perfect major triads reduced to one octave, thus:

4 : 5 : 6
4 : 5 : 6 4 : 5 : 6
F A C E G B D
16 20 24 30 36 45 54
24 27 30 32 36 40 45 48

Other equivalent ratios and their values in E. S. are given in Table 80. By transferring D to the left and using the ratio 10 : 12 : 15 the scale of A-minor is obtained, which agrees with that of C-major except that D = 26 2/3. Nearly the same ratios are obtained from a series of harmonics beginning with the eighth; also by taking 12 successive perfect or Pythagorean fifths or fourths and reducing to one octave. Such calculations are most easily made by adding and subtracting intervals expressed in E. S. The notes needed to furnish a just major scale in other keys may be found by successive transpositions by fifths or fourths as shown in Table 80. Disregarding the usually negligible difference of 0.02 E. S., the table gives the 24 notes to the octave required in the simplest enharmonic organ; the notes fall into pairs that differ by a comma, 0.22 E. S. The line "mean tone" is based on Dom Bedos' rule for tuning the organ (1746). The tables have been checked by the data in Ellis' Helmholtz's "Sensations of Tone."

TABLE 79.

Note.	Interval.		Ratios.		Logarithms.		Number of Vibrations per second.				Beats for 0.1 E. S.
	Tempered.	Just.	Just.	Tempered.	Just.	Tempered.	Just.	Just.	Just.	Tempered.	
	E. S.	E. S.									
c′	0	0.	1.00	1.00000	0.0000	0.00000	*256*	*264*	258.7	258.7	1.50
	1			1.05926		.02509				274.0	
d′	2	2.04	1.125	1.12246	.05115	.05017	288	297	291.0	290.3	1.68
	3			1.18921		.07526				307.6	
e′	4	3.86	1.25	1.25992	.09691	.10034	320	330	323.4	325.9	1.89
f′	5	4.98	1.33	1.33484	.12494	.12543	341.3	352	344.9	345.3	2.00
	6			1.41421		.15051				365.8	
g′	7	7.02	1.50	1.49831	.17609	.17560	384	396	388	387.5	2.25
	8			1.58740		.20069				410.6	
a′	9	8.84	1.67	1.68179	.22185	.22577	426.7	*440*	431.1	*435.0*	2.52
	10			1.78180		.25086				460.9	
b′	11	10.88	1.875	1.88775	.27300	.27594	480	495	485.0	488.3	2.83
c″	12	12.00	2.00	2.00000	.30103	.30103	512	528	517.3	517.3	3.00

TABLE 80.

Key of		C		D		E	F		G		A		B	C
7 ♯s	C♯		1.14 0.92		3.18 2.96		5.00 4.78	6.12 5.90		8.16 7.94		9.98 9.76		12.02 11.80
6 "	F♯		1.14 0.92		2.96 2.74		5.00 4.78	6.12 5.90		8.16 7.94		9.98 9.76	11.10 10.88	
5 "	B		1.14 0.92		2.96 2.74	4.08 3.86		6.12 5.90		7.94 7.72		9.98 9.76	11.10 10.88	
4 "	E		0.92 0.70		2.96 2.74	4.08 3.86		6.12 5.90		7.94 7.72	9.06 8.84		11.10 10.88	
3 "	A		0.92 0.70	2.04 1.82		4.08 3.86		5.90 5.68		7.94 7.72	9.06 8.84		11.10 10.88	
2 "	D		0.92	2.04		4.08		5.90	7.02		9.06		10.88	
1 ♯	G	0.00		2.04		3.86		5.90	7.02		9.06		10.88	12.00
	C	0.00		2.04		3.86	4.98		7.02		8.84		10.88	12.00
1 ♭	F	0.00		1.82		3.86	4.98		7.02		8.84	9.96		12.00
2 ♭s	B♭	0.00		1.82	2.94		4.98		6.80		8.84	9.96		12.00
3 "	E♭	−.22		1.82	2.94		4.98		6.80	7.92		9.96		11.78
4 "	A♭	−.22	0.90		2.94		4.76		6.80	7.92		9.96		11.78
5 "	D♭	−.22	0.90		2.94		4.76	5.88		7.92		9.74		11.78
6 "	G♭		0.90		2.72		4.76	5.88		7.92		9.74	10.86	
7 "	C♭		0.90		2.72	3.84		5.88		7.70		9.74	10.86	
Harmonic Series		8 0.0	$\binom{1.71}{1.05}$	9 2.04	$\binom{19}{2.98}$	10 3.86	$\binom{21}{4.70}$	11 5.51	12 7.02	$\binom{25}{7.73}$	13 8.41	14 9.69	15 10.88	16 12.00
Cycle of fifths		0.0	1.14	2.04	3.18	4.08	5.22	6.12	7.02	8.16	9.06	10.20	11.10	12.24
Cycle of fourths		0.0	0.90	1.80	2.94	3.84	4.98	5.88	6.78	7.92	8.82	9.96	10.86	11.76
Mean tone		0.0	0.76	1.93	3.11	3.86	5.03	5.79	6.97	7.72	8.90	10.07	10.83	12.00
Equal 7 step		0.0		1.71	3 43		5.14		6.86		8.57	10.29		12.00

TABLE 81.

ACCELERATION OF GRAVITY.

For Sea Level and Different Latitudes.

Calculated from Helmert's formula:

$$g = 9^{\mathrm{m}}.78030\ (1 + 0.005302\ \sin.^2\ \Phi - 0.000007\ \sin.^2 2\Phi)$$

Latitude Φ	g cm. per sec. per sec.	Log. g	g feet per sec. per sec.	Latitude Φ	g cm. per sec. per sec.	Log. g	g feet per sec. per sec.
0°	978.030	2.9903522	32.0875	50°	981.066	2.9916982	32.1871
5	.069	.9903695	.0888	51	.155	.9917376	.1901
10	.186	.9904214	.0927	52	.244	.9917770	.1930
12	.253	.9904512	.0949	53	.331	.9918156	.1959
14	.332	.9904863	.0974	54	.418	.9918540	.1987
15	978.376	2.9905058	32.0989	55	981.503	2.9918916	32.2015
16	.422	.9905262	.1004	56	.588	.9919292	.2043
17	.471	.9905480	.1020	57	.672	.9919664	.2070
18	.523	.9905710	.1037	58	.754	.9920027	.2097
19	.577	.9905950	.1055	59	.835	.9920385	.2124
20	978.634	2.9906203	32.1074	60	981.914	2.9920735	32.2150
21	.693	.9906465	.1093	61	.992	.9921080	.2175
22	.754	.9906736	.1113	62	982.068	.9921415	.2200
23	.818	.9907019	.1134	63	.142	.9921743	.2224
24	.884	.9907313	.1156	64	.215	.9922066	.2248
25	978.952	2.9907614	32.1178	65	982.285	2.9922375	32.2271
26	979.022	.9907925	.1201	66	.354	.9922680	.2294
27	.094	.9908244	.1224	67	.420	.9922972	.2316
28	.168	.9908572	.1249	68	.485	.9923259	.2337
29	.244	.9908909	.1274	69	.546	.9923529	.2357
30	979.321	2.9909250	32.1299	70	982.606	2.9923794	32.2377
31	.400	.9909601	.1325	71	.663	.9924046	.2395
32	.481	.9909960	.1351	72	.718	.9924289	.2413
33	.562	.9910319	.1378	73	.770	.9924519	.2430
34	.646	.9910691	.1406	74	.820	.9924740	.2447
35	979.730	2.9911064	32.1433	75	982.866	2.9924943	32.2462
36	.815	.9911441	.1461	76	.911	.9925142	.2477
37	.902	.9911827	.1490	77	.952	.9925323	.2490
38	.989	.9912212	.1518	78	.990	.9925491	.2503
39	980 077	.9912602	.1547	79	983.026	.9925650	.2514
40	980.166	2.9912996	32.1576	80	983.058	2.9925791	32.2525
41	.255	.9913391	.1605	81	.088	.9925924	.2535
42	.345	.9913789	.1635	82	.115	.9926043	.2544
43	.435	.9914188	.1664	83	.138	.9926145	.2551
44	.525	.9914587	.1694	84	.159	.9926238	.2558
45	980.616	2.9914989	32.1724	85	983.176	2.9926312	32.2564
46	.706	.9915388	.1753	86	.190	.9926375	.2568
47	.797	.9915791	.1783	87	.201	.9926423	.2572
48	.887	.9916190	.1813	88	.209	.9926459	.2574
49	.977	.9916588	.1842	90	.216	.9926489	.2577

To reduce log. g (cm. per sec. per sec.) to log. g (ft. per sec. per sec.) add log. $0.03280833 = 8.5159842 - 10$.

CORRECTION FOR ALTITUDE.

— 0.0003086 cm. per meter when altitude is in meters.
— 0.0000003086 ft. per foot when altitude is in feet.

Altitude.	Correction.	Altitude.	Correction.
200 m.	0.0617 cm./sec.^{2}	200 ft.	0.000617 ft./sec.^{2}
300	.0926	300	.000926
400	.1234	400	.001234
500	.1543	500	.001543
600	.1852	600	.001852
700	.2160	700	.002160
800	.2469	800	.002469
900	.2777	900	.002777

Table 82.
GRAVITY.

In this table the results of a number of the more recent gravity determinations are brought together. They serve to show the degree of accuracy which may be assumed for the numbers in Table 81. In general, gravity is a little lower than the calculated value for stations far inland and slightly higher on the coast line.

Place.	Latitude. N. +, S. —.	Elevation in meters.	Gravity, $\frac{\text{cm.}}{\text{sec}^2}$		Reference.
			Observed.	Reduced to sea level.	
Singapore	1° 17′	14	978.08	978.08	1
Georgetown, Ascension	—7 56	5	978.25	978.25	2
Green Mountain, Ascension	—7 57	686	978.10	978.23	2
Loanda, Angola	—8 49	46	978.15	978.16	2
Caroline Islands	—10 00	2	978.37	978.37	3
Bridgetown, Barbadoes	13 04	18	978.18	978.18	2
Jamestown, St. Helena	—15 55	10	978.67	978.67	2
Longwood, "	—15 57	533	978.53	978.59	2
Pakaoao, Sandwich Islands	20 43	3001	978.28	978.85	3
Lahaina, " "	20 52	3	978.86	978.86	3
Haiki, " "	20 56	117	978.91	978.93	3
Honolulu, " "	21 18	3	978.97	978.97	3
St. Georges, Bermuda	32 23	2	979.77	979.77	2
Sidney, Australia	—33 52	43	979.68	979.69	1
Cape Town	—33 56	11	979.62	979.62	2
Tokio, Japan	35 41	6	979.95	979.95	1
Auckland, New Zealand	—36 52	43	979.68	979.69	1
Mount Hamilton, Cal. (Lick Obs.)	37 20	1282	979.66	979.91	4
" " " "	37 20	1282	979.68	979.92	5
San Francisco, Cal.	37 47	114	979.96	979.98	4
" " "	37 47	114	980.02	980.04	5
Washington, D. C.*	38 53	10	980.11	980.11	4
Denver, Colo.	39 54	1645	979.68	979.98	5
York, Pa.	39 58	122	980.12	980.14	6
Ebensburgh, Pa.	40 27	651	980.08	980.20	6
Allegheny, Pa.	40 28	348	980.09	980.15	6
Hoboken, N. J.	40 44	11	980.27	980.27	4
Salt Lake City, Utah	40 46	1288	979.82	980.05	5
Chicago, Ill.	41 49	165	980.34	980.37	5
Pampaluna, Spain	42 49	450	980.34	980.42	7
Montreal, Canada	45 31	100	980.73	980.75	5
Geneva, Switzerland	46 12	405	980.58	980.64	8
" "	46 12	405	980.60	980.66	9
Berne, "	46 57	572	980.61	980.69	9
Zurich, "	47 23	466	980.67	980.74	9
Paris, France	48 50	67	980.96	980.97	8
Kew, England	51 28	7	981.20	981.20	8
Berlin, Germany	52 30	49	981.26	981.27	8
Port Simpson, B. C.	54 34	6	981.46	981.46	4
Burroughs Bay, Alaska	55 59	0	981.51	981.51	4
Wrangell, "	56 28	7	981.60	981.60	4
Sitka, "	57 03	8	981.69	981.69	4
St. Paul's Island, "	57 07	12	981.67	981.67	4
Juneau, "	58 18	5	981.74	981.74	4
Pyramid Harbor, "	59 10	5	981.82	981.82	4
Yakutat Bay, "	59 32	4	981.83	981.83	4

1 Smith: "United States Coast and Geodetic Survey Report for 1884," App. 14.
2 Preston: "United States Coast and Geodetic Survey Report for 1890," App. 12.
3 Preston: Ibid. 1888, App. 14.
4 Mendenhall: Ibid. 1891, App. 15.
5 Defforges: "Comptes Rendus," vol. 118, p. 231.
6 Pierce: "U. S. C. and G. S. Rep. 1883," App. 19.
7 Cebrian and Los Arcos: "Comptes Rendus des Séances de la Commission Permanente de l'Association Géodesique International," 1893.
8 Pierce: "U. S. C. and G. S. Report 1876, App. 15, and 1881, App. 17."
9 Messerschmidt: Same reference as 7.

---

* For references 1-4, values are derived by comparative experiments with invariable pendulums, the value for Washington taken as 980.111. For the latter see Appendix 5 of the Coast and Geodetic Survey Report for 1901.

TABLE 83.

SUMMARY OF RESULTS OF THE VALUE OF GRAVITY (g) AT STATIONS IN THE UNITED STATES AND ALASKA.*

Station.	Latitude.	Longitude.	Elevation.	g observed.
	° ′ ″	° ′ ″	Meters.	cm./sec.^{2}
Calais, Me.	45 11 11	67 16 54	38	980.630
Boston, Mass.	42 21 33	71 03 50	22	980.395
Cambridge, Mass.	42 22 48	71 07 45	14	980.397
Worcester, Mass.	42 16 29	71 48 28	170	980.323
New York, N. Y.	40 48 27	73 57 43	38	980.266
Princeton, N. J.	40 20 57	74 39 28	64	980.177
Philadelphia, Pa.	39 57 06	75 11 40	16	980.195
Ithaca, N. Y.	42 27 04	76 29 00	247	980.299
Baltimore, Md.	39 17 50	76 37 30	30	980.096
Washington, C. & G. S.	38 53 13	77 00 32	14	980.111
Washington, Smithsonian	38 53 20	77 01 32	10	980.113
Charlottesville, Va.	38 02 01	78 30 16	166	979.937
Deer Park, Md.	39 25 02	79 19 50	770	979.934
Charleston, S. C.	32 47 14	79 56 03	6	979.545
Cleveland, Ohio	41 30 22	81 36 38	210	980.240
Key West, Fla.	24 33 33	81 48 25	1	978.969
Atlanta, Ga.	33 44 58	84 23 18	324	979.523
Cincinnati, Ohio	39 08 20	84 25 20	245	980.003
Terre Haute, Ind.	39 28 42	87 23 49	151	980.071
Chicago, Ill.	41 47 25	87 36 03	182	980.277
Madison, Wis. (Univ. of Wis.)	43 04 35	89 24 00	270	980.364
New Orleans, La.	29 56 58	90 04 14	2	979.323
St. Louis, Mo.	38 38 03	90 12 13	154	980.000
Little Rock, Ark.	34 44 57	92 16 24	89	979.720
Kansas City, Mo.	39 05 50	94 35 21	278	979.989
Galveston, Tex.	29 18 12	94 47 29	3	979.271
Austin, Texas (University)	30 17 11	97 44 14	189	979.282
Austin, Texas (Capitol)	30 16 30	97 44 16	170	979.287
Ellsworth, Kan.	38 43 43	98 13 32	469	979.925
Laredo, Tex.	27 30 29	99 31 12	129	979.081
Wallace, Kan.	38 54 44	101 35 26	1005	979.754
Colorado Springs, Col.	38 50 44	104 49 02	1841	979.489
Denver, Col.	39 40 36	104 56 55	1638	979.608
Pike's Peak, Col.	38 50 20	105 02 02	4293	978.953
Gunnison, Col.	38 32 33	106 56 02	2340	979.341
Grand Junction, Col.	39 04 09	108 33 56	1398	979.632
Green River, Utah	38 59 23	110 09 56	1243	979.635
Grand Canyon, Wyo.	44 43 16	110 29 44	2386	979.898
Norris Geyser Basin, Wyo.	44 44 09	110 42 02	2276	979.949
Lower Geyser Basin, Wyo.	44 33 21	110 48 08	2200	979.931
Pleasant Valley Jct., Utah	39 50 47	111 00 46	2191	979.511
Salt Lake City, Utah	40 46 04	111 53 46	1322	979.802
Ft. Egbert, Eagle, Alaska	64 47 22	141 12 24	174	982.182

---

* All the values in this table depend on relative determination of gravity and an adopted value for gravity at Washington (Coast and Geodetic Survey Office) of 980.111. This adopted value was the result of the determination in 1900 of the relative value of gravity at Potsdam and at Washington. See footuote on previous page.

LENGTH OF THE SECONDS PENDULUM.

TABLE 84. — Length of Seconds Pendulum at Sea Level for Different Latitudes.*

Latitude.	Length in centimeters.	Log.	Length in inches.	Log.	Latitude.	Length in centimeters.	Log.	Length in inches.	Log.
0	99.0950	1.996052	39.0131	1.591218	**50**	99.4027	1.997398	39.1348	1.592563
5	.0989	6069	.0152	1234	55	.4471	7592	.1524	2758
10	.1108	6121	.0200	1287	60	.4888	7774	.1687	2939
15	.1302	6206	.0274	1372	65	.5263	7938	.1835	3103
20	.1562	6320	.0378	1485	70	.5587	8079	.1962	3244
25	99.1884	1.996461	39.0506	1.591627	**75**	99.5850	1.998194	39.2067	1.593360
30	.2259	6625	.0652	1790	80	.6045	8279	.2143	3444
35	.2672	6806	.0816	1972	85	.6165	8331	.2190	3496
40	.3116	7000	.0990	2166	90	.6206	8349	.2206	3514
45	.3571	7199	.1169	2364					

* Calculated from force of gravity table by the formula $l = g/\pi^2$. For each 100 feet of elevation subtract 0.000596 centimeters, or 0.000235 inches, or .0000196 feet.

TABLE 85. — Length of the Seconds Pendulum.*

Date of determination.	Number of observation stations.	Range of latitude included by the stations.	Length of pendulum in meters. for latitude ϕ.	Corresponding length of pendulum for lat. 45°	Reference.
1799	15	From $+67^\circ 05'$ to $-33^\circ 56'$	$0.990631 + .005637 \sin^2\phi$	0.993450	1
1816	31	“ $+74^\circ 53'$ “ $-51^\circ 21'$	$0.990743 + .005466 \sin^2\phi$	0.993976	2
1821	8	“ $+38^\circ 40'$ “ $-60^\circ 45'$	$0.990880 + .005340 \sin^2\phi$	0.993550	3
1825	25	“ $+79^\circ 50'$ “ $-12^\circ 59'$	$0.990977 + .005142 \sin^2\phi$	0.993548	4
1827	41	“ $+79^\circ 50'$ “ $-51^\circ 35'$	$0.991026 + .005072 \sin^2\phi$	0.993562	5
1829	5	“ $0^\circ 0'$ “ $+67^\circ 04'$	$0.990555 + .005679 \sin^2\phi$	0.993395	6
1830	49	“ $+79^\circ 51'$ “ $-51^\circ 35'$	$0.991017 + .005087 \sin^2\phi$	0.993560	7
1833	—	“ — “ —	$0.990941 + .005142 \sin^2\phi$	0.993512	8
1869	51	“ $+79^\circ 50'$ “ $-51^\circ 35'$	$0.990970 + .005185 \sin^2\phi$	0.993554†	9
1876	73	“ $+79^\circ 50'$ “ $-62^\circ 56'$	$0.991011 + .005105 \sin^2\phi$	0.993563	10
1884	123	“ $+79^\circ 50'$ “ $-62^\circ 56'$	$0.990918 + .005262 \sin^2\phi$	0.993549	11
Combining the above results			$0.990910 + .005290 \sin^2\phi$	0.993555	12

1 Laplace: "Traité de Mécanique Céleste," T. 2, livre 3, chap. 5, sect. 42.
2 Mathieu: "Sur les expériences du pendule;" in "Connaissance des Temps 1816." Additions, pp. 314–341, p. 332.
3 Biot et Arago: "Recueil d'Observations géodésiques, etc." Paris, 1821, p. 575.
4 Sabine: "An Account of Experiments to determine the Figure of the Earth, etc., by Sir Edward Sabine." London, 1825, p. 352.
5 Saigey: "Comparaison des Observations du pendule à diverses latitudes; faites par MM. Biot, Kater, Sabine, de Freycinet, et Duperry;" in "Bulletin des Sciences Mathématiques, etc.," T. 1, pp. 31–43, and 171–184. Paris, 1827.
6 Pontécoulant: "Théorie analytique du Système du monde," Paris, 1829, T. 2, p. 466.
7 Airy: "Figure of the Earth;" in "Encyc. Met." 2d Div. vol. 3, p. 230.
8 Poisson: "Traité de Mécanique," T. 1, p. 377; "Connaissance des Temps," 1834, pp. 32–33; and Puissant: "Traité de géodésie," T. 2, p. 464.
9 Unferdinger: "Das Pendel als geodätisches Instrument;" in Grunert's "Archiv," 1869, p. 316.
10 Fischer: "Die Gestalt der Erde und die Pendelmessungen;" in "Ast. Nach." 1876, col. 87.
11 Helmert: "Die mathematischen und physikalischen Theorieen der höheren Geodäsie, von Dr. F. R. Helmert," II. Theil. Leipzig, 1884, p. 241.
12 Harkness.

---

* The data here given with regard to the different determinations which have been made of the length of the seconds pendulum are quoted from Harkness (Solar Parallax and its Related Constants, Washington, 1891).

† Calculated from a logarithmic expression given by Unferdinger.

TABLES 86-87.

MISCELLANEOUS GEODETIC DATA.*

TABLE 86.

Length of the seconds pendulum at sea level $= l = 39.012540 + 0.208268 \sin^2 \phi$ inches.
$= 3.251045 + 0.017356 \sin^2 \phi$ feet.
$= 0.9909910 + 0.005290 \sin^2 \phi$ meters.

Acceleration produced by gravity per second per second mean solar time . . . $= g = 32.086528 + 0.171293 \sin^2 \phi$ feet.
$= 977.9886 + 5.2210 \sin^2 \phi$ centimeters.

	Clarke Spheroid.	U. S. C. & G. Survey.
Equatorial radius	$= a = 6378206$ meters; 3963.225 miles.	6378388 ± 18 meters; 3963.339 miles.
Polar semi-diameter	$= b = 6356584$ meters; 3949.790 miles.	6356909 meters; 3949.992 miles.
Reciprocal of flattening	$= \frac{a}{a-b} = 295.0$	297.0 ± 0.5
Square of eccentricity	$= e^2 = \frac{a^2-b^2}{a^2} = 0.006768658$	0.0067237 ± 0.0000120.

Difference between geographical and geocentric latitude $= \phi - \phi' =$
$688.2242'' \sin 2\phi - 1.1482'' \sin 4\phi + 0.0026'' \sin 6\phi$.

Mean density of the Earth $= 5.5247 \pm 0.0013$ (Burgess Phys. Rev. 1902).

Continental surface density of the Earth $= 2.67$ } Harkness.
Mean density outer ten miles of earth's crust $= 2.40$ }

Moments of inertia of the Earth; the principal moments being taken as A, B, and C, and C the greater:

$$\frac{C-A}{C} = 0.00326521 = \frac{1}{306.259};$$
$$C - A = 0.001064767\, Ea^2;$$
$$A = B = 0.325029\, Ea^2;$$
$$C = 0.326094\, Ea^2;$$

where E is the mass of the Earth and a its equatorial semidiameter.

TABLE 87. — Length of Degrees on the Earth's Surface.

At Lat.	Miles per degree		Km. per degree		At Lat.	Miles per degree		Km. per degree	
	of Long.	of Lat.	of Long.	of Lat.		of Long.	of Lat.	of Long.	of Lat.
0°	69.17	68.70	111.32	110.57	55°	39.77	69.17	64.00	111.33
10	68.13	68.72	109.64	110.60	60	34.67	69.23	55.80	111.42
20	65.03	68.79	104.65	110.70	65	29.32	69.28	47.18	111.50
30	59.96	68.88	96.49	110.85	70	23.73	69.32	38.19	111.57
40	53.06	68.99	85.40	111.03	75	17.96	69.36	28.90	111.62
45	49.00	69.05	78.85	111.13	80	12.05	69.39	19.39	111.67
50	44.55	69.11	71.70	111.23	90	0.00	69.41	0.00	111.70

For more complete table see "Smithsonian Geographical Tables."

TABLE 88.

MISCELLANEOUS ASTRONOMICAL DATA.

Length of sidereal year $= 365.2563578$ mean solar days;
$= 365$ days 6 hours 9 minutes 9.314 seconds.

Length of tropical year $= 365.242199870 - 0.0000062124 \frac{t-1850}{100}$ mean solar days;
$= 365$ days 5 hours 48 minutes $\left(46.069 - 0.53675 \frac{t-1850}{100}\right)$ seconds.

Length of sidereal month
$= 27.321661162 - 0.00000026240 \frac{t-1800}{100}$ days;
$= 27$ days 7 hours 43 minutes $\left(11.524 - 0.022671 \frac{t-1800}{100}\right)$ seconds.

Length of synodical month
$= 29.530588435 - 0.00000030696 \frac{t-1800}{100}$ days;
$= 29$ days 12 hours 44 minutes $\left(2.841 - 0.026522 \frac{t-1800}{100}\right)$ seconds.

Length of sidereal day $= 86164.09965$ mean solar seconds.

N. B. — The factor containing t in the above equations (the year at which the values of the quantities are required) may in all ordinary cases be neglected.

Mean distance from earth to sun $= 92900000$ miles $= 149500000$ kilometers.
Eccentricity of the earth's orbit $= e =$

$$0.01675104 - 0.0000004180\,(t - 1900) - 0.000000126 \left(\frac{t-1900}{100}\right)^2.$$

Solar parallax $= 8.7997'' \pm 0.003$ (Weinberg, A. N. 165, 1904);
8.807 ± 0.0027 (Hinks, Eros, 7);
8.799 (Samson, Jupiter satellites; Harvard observations).
Lunar parallax $= 3422.68''$.
Mean distance from earth to moon $= 60.2669$ terrestrial radii;
$= 238854$ miles;
$= 384393$ kilometers.
Lunar inequality of the earth $= L = 6.454''$.
Parallactic inequality of the moon $= Q = 124.80''$.
Mean motion of moon's node in 365.25 days $= \mu = -19^\circ\, 21'\, 19.6191'' + 0.14136'' \left(\frac{t-1800}{100}\right)$
Eccentricity and inclination of the moon's orbit $= e_2 = 0.05490807$.
Delaunay's $\gamma = \sin \frac{1}{2} I = 0.044886793$.
$I = 5^\circ\, 08'\, 43.3546''$.
Constant of nutation $= 9.2'$.
Constant of aberration $= 20.4962 \pm 0.006$ (Weinberg, l. c.).*
Time taken by light to traverse the mean radius of the earth's orbit
$= 498.82 \pm 0.1$ seconds (Weinberg);
$= 498.64$ (Samson).
Velocity of light $= 186330$ miles per second (Weinberg);
$= 299870 \pm 0.03$ kilometers per second.
General precession $= 50.2564'' + 0.000222\,(t - 1900)$.
Obliquity of the ecliptic $= 23^\circ\, 27'\, 8.26'' - 0.4684\,(t - 1900)$.
Gravitation constant $= 666.07 \times 10^{-10}\ \mathrm{cm}^3/\mathrm{gr.\ sec}^2 \pm 0.16 \times 10^{-10}$.

---

* Recent work of Doolittle's and others indicates a value not less than 20.51.

Table 89.—Planetary Data.

Body.	Reciprocals of masses.	Mean distance from the sun. Km.	Sidereal period. Mean days	Equatorial diameter. Km.	Inclination of orbit.	Mean density. $H_2O=1$	Gravity at surface.
Sun	1.	—	—	1391067	—	1.39	27.6
Mercury	6000000.	58 x 10^6	87.97	4842	7°.003	4.86	.3
Venus	408000.	108 "	224.70	12394	3.393	5.2	7.9
Earth*	329390.	149 "	365.26	12756	—	5.52	1.00
Mars	3093500.	228 "	686.98	7320	1.850	3.90	.4
Jupiter	1047.35	778 "	4332.59	145250	1.308	1.36	2.6
Saturn	3501.6	1426 "	10759.20	123040	2.492	.63	1.01
Uranus	22869.	2869 "	30586.29	48590	0.773	1.34	.95
Neptune	19700.	4495 "	60188.71	56040	1.778	1.28	.97
Moon	† 81.45	38 x 10^4	27.32	3473	5.147	3.37	.17

* Earth and moon. † Relative to earth. Inclination of axes: Sun 7°.25; Earth 23°.45; Mars 24°.6; Jupiter 3°.1; Saturn 26°.8; Neptune 27°.2. Others doubtful.

Table 90.—Equation of Time.

The equation of time when + is to be added to the apparent solar time to give mean time. When the place is not on a standard meridian (75'th, etc.) its difference in longitude in time from that meridian must be subtracted when east, added when west to get standard time (75'th meridian time, etc.). The equation varies from year to year cyclically, and the figure following the ± sign gives a rough idea of this variation.

	M.	S.		M.	S.		M.	S.		M.	S.
Jan. 1	+ 3	26±14	Apr. 1	+4	2± 7	July 1	+3	31±5	Oct. 1	—10	12± 8
15	+ 9	25± 9	15	+0	8± 5	15	+5	42±3	15	—14	5± 6
Feb. 1	+13	42± 4	May 1	—2	54±10	Aug. 1	+6	9±3	Nov. 1	—16	19± 2
15	+14	20± 2	15	—3	49± 1	15	+4	24±5	15	—15	22± 4
Mar. 1	+12	34± 4	June 1	—2	28± 3	Sept. 1	+0	2±7	Dec. 1	—10	58± 8
15	+ 9	9± 6	15	+0	8± 4	15	—4	41±9	15	— 4	53±10

Table 91.—Miscellaneous Astronomical Data.

Apex of Solar Motion:

From proper motions, R. $A._{1810} = 17\ 51^m$, $Dec._{1810} = + 31.4$ (Weersma, Gron. Publ. 21.)
From radial velocities, R. $A._{1900} = 17^h 54^m$, $Dec._{1900} = + 25.1$ (Campbell, Lick. Bull. 196.)
Velocity = 19.5 Km. per sec. (Campbell.)

Nearest star so far as known: α Centauri, parallax = 0.759″ (Gron. Publ. 24) distance = 4.3 light years.

Stars of both greatest proper motion and greatest radial velocity so far as known:* Cordova, V243; proper motion = 8.70″ in position angle 130° radial velocity + 242 Km. per sec. (Campbell, Stellar Motions, 1913). Parallax = 0.319″ (Gron. Publ. 24, also proper motion). Distance = 10.2 light years.

Average velocities with regard to center of gravity of the stellar system, according to Campbell (Stellar Motion, 1913):

Type B Stars:	6.6 Km. per sec.	Type G Stars:	15.0 Km. per sec.
" A "	10.9 " " "	" K "	16.8 " " "
" F "	14.4 " " "	" M "	17.1 " " "

Sun's magnitude = — 26.5, sending the earth 90,000,000,000 times as much light as the star Aldebaran.

Ratio of total radiation of sun to that of moon about	100,000 to 1	Langley.
" " " light " " " " " " "	400,000 to 1	

---

* Lalande, 1966, $R.A._{1910}$ $1^h 3^m.9$, $Dec._{1910}$ 61°.4′ in 1913 was found to have a radial velocity (of approach) of 326 Km. per sec. (Mount Wilson Solar Observatory.)

TERRESTRIAL MAGNETISM.

Secular Change of Declination.

Changes in the magnetic declination between 1810, the date of the earliest available observations, and 1910, for one or more places in each state and territory.

State.	Station.	1810	1820	1830	1840	1850	1860	1870	1880	1890	1900	1910
		°	°	°	°	°	°	°	°	°	°	°
Ala.	Montgomery	5.6E	5.8E	5.8E	5.6E	5.4E	5.0E	4.5E	3.9E	3.2E	2.8E	2.9E
Alas.	Sitka	–	–	–	–	–	28.7E	29.0E	29.3E	29.5E	29.7E	30.2E
	Kodiak	–	–	–	–	–	26.1E	25.6E	25.1E	24.7E	24.4E	24.1E
	Unalaska	–	–	–	–	–	20.4E	20.1E	19.6E	19.0E	18.3E	17.5E
	St. Michael	–	–	–	–	–	–	–	24.7E	23.1E	22.1E	21.4E
Ariz.	Holbrook	–	–	–	–	13.6E	13.7E	13.8E	13.7E	13.4E	13.5E	13.9E
	Prescott	–	–	–	–	13.3E	13.5E	13.7E	13.6E	13.5E	13.7E	14.3E
Ark.	Little Rock	8.6E	8.8E	9.0E	9.0E	8.8E	8.6E	8.2E	7.6E	7.0E	6.6E.	6.9E
Cal.	Los Angeles	12.1E	12.6E	13.2E	13.6E	14.0E	14.2E	14.4E	14.6E	14.6E	14.9E	15.5E
	San José	15.0E	15.5E	16.0E	16.4E	16.8E	17.1E	17.3E	17.5E	17.5E	17.8E	18.5E
Cal.	Redding	15.6E	16.1E	16.6E	17.0E	17.4E	17.8E	18.1E	18.2E	18.3E	18.6E	19.3E
Colo.	Pueblo	–	–	–	–	13.8E	13.8E	13.8E	13.5E	13.0E	12.9E	13.3E
	Glenwood Sp.	–	–	–	–	16.1E	16.2E	16.3E	16.1E	15.7E	15.6E	16.1E
Conn.	Hartford	5.1W	5.6W	6.1W	6.8W	7.5W	8.2W	8.7W	9.4W	9.8W	10.4W	11.0W
Del.	Dover	1.6W	1.9W	2.3W	2.8W	3.4W	4.0W	4.7W	5.3W	5.9W	6.4W	7.0W
D. C.	Washington	0.5E	0.3E	0.0	0.5W	1.0W	1.7W	2.4W	3.0W	3.6W	4.2W	4.7W
Fla.	Jacksonville	5.1E	5.1E	4.9E	4.6E	4.2E	3.7E	3.1E	2.4E	1.8E	1.3E	1.2E
	Pensacola	7.7E	7.8E	7.7E	7.5E	7.2E	6.8E	6.2E	5.6E	5.0E	4.5E	4.4E
	Tampa	6.4E	6.2E	5.9E	5.5E	5.0E	4.5E	3.9E	3.3E	2.8E	2.3E	2.0E
Ga.	Macon	5.9E	5.9E	5.7E	5.4E	5.0E	4.5E	3.9E	3.2E	2.6E	2.1E	2.0E
Haw.	Honolulu	–	–	–	–	9.4E	9.4E	9.5E	9.8E	10.1E	10.4E	10.6E
Idaho	Pocatello	–	–	–	–	17.4E	17.7E	17.8E	17.9E	17.7E	17.8E	18.4E
	Boise	–	–	–	–	18.0E	18.4E	18.6E	18.7E	18.6E	18.8E	19.4E
Ill.	Bloomington	6.3E	6.5E	6.6E	6.5E	6.3E	5.9E	5.4E	4.7E	4.1E	3.6E	3.4E
Ind.	Indianapolis	5.0E	5.1E	5.0E	4.7E	4.4E	3.8E	3.2E	2.6E	2.0E	1.4E	1.1E
Ia.	Des Moines	–	10.2E	10.4E	10.5E	10.4E	10.2E	9.7E	9.1E	8.4E	7.9E	8.1E
Kans.	Emporia	–	–	–	–	11.6E	11.5E	11.2E	10.7E	10.1E	9.8E	10.1E
	Ness City	–	–	–	–	12.4E	12.4E	12.2E	11.9E	11.4E	11.1E	11.4E
Ky.	Lexington	4.5E	4.5E	4.4E	4.1E	3.6E	3.1E	2.5E	1.9E	1.2E	0.7E	0.5E
	Princeton	6.8E	7.0E	7.0E	6.8E	6.5E	6.1E	5.6E	5.0E	4.3E	3.8E	3.7E
La.	Alexandria	8.4E	8.7E	8.8E	8.8E	8.7E	8.4E	8.0E	7.4E	6.9E	6.6E	6.8E
Me.	Eastport	13.6W	14.4W	15.2W	16.0W	17.0W	17.7W	18.2W	18.6W	18.7W	19.0W	19.4W
	Portland	9.0W	9.6W	10.3W	11.0W	11.6W	12.3W	12.8W	13.4W	13.9W	14.4W	14.8W
Md.	Baltimore	0.9W	1.1W	1.4W	1.9W	2.4W	3.1W	3.8W	4.4W	5.0W	5.6W	6.1W
Mass.	Boston	7.3W	7.8W	8.4W	9.1W	9.8W	10.5W	11.0W	11.5W	12.0W	12.6W	13.1W
Mass.	Pittsfield	5.7W	6.1W	6.7W	7.4W	8.1W	8.7W	9.3W	10.0W	10.4W	11.0W	11.5W
Mich.	Marquette	–	6.7E	6.7E	6.5E	6.0E	5.4E	4.6E	3.8E	3.0E	2.3E	2.0E
	Lansing	–	4.2E	4.1E	3.8E	3.3E	2.8E	2.1E	1.3E	0.5E	0.0E	0.4E
Minn.	Northome	–	10.4E	10.7E	10.8E	10.7E	10.4E	10.0E	9.3E	8.6E	8.0E	8.1E
	Mankato	–	11.3E	11.6E	11.7E	11.6E	11.3E	10.9E	10.4E	9.5E	9.0E	9.1E

---

* Tables have been compiled from United States Magnetic Tables and Magnetic Charts for 1905, published by the Coast and Geodetic Survey in 1908.

TABLE 92 (*continued*).

TERRESTRIAL MAGNETISM (*continued*).

Secular Change of Declination (*continued*).

State.	Station.	1810	1820	1830	1840	1850	1860	1870	1880	1890	1900	1910
		°	°	°	°	°	°	°	°	°	°	°
Miss.	Jackson	8.2E	8.4E	8.5E	8.4E	8.2E	7.9E	7.5E	6.9E	6.4E	6.0E	6.2E
Mo.	Sedalia	–	10.0E	10.2E	10.2E	10.1E	9.8E	9.4E	8.7E	8.0E	7.6E	7.9E
Mont.	Forsyth	–	–	–	18.2E	18.5E	18.6E	18.6E	18.4E	17.9E	17.8E	18.3E
	Helena	–	–	–	18.9E	19.3E	19.6E	19.8E	19.6E	19.4E	19.5E	20.0E
Nebr.	Hastings	–	11.6E	12.0E	12.1E	12.1E	12.0E	11.7E	11.2E	10.5E	10.2E	10.5E
Nebr.	Alliance	–	–	–	–	15.4E	15.4E	15.3E	14.8E	14.3E	14.2E	14.5E
Nev.	Elko	–	–	–	–	17.3E	17.6E	17.7E	17.7E	17.6E	17.8E	18.3E
	Hawthorne	–	–	–	–	16.3E	16.6E	16.9E	17.0E	17.0E	17.3E	17.8E
N. H.	Hanover	7.1W	7.5W	8.2W	8.9W	9.8W	10.5W	11.1W	11.6W	12.0W	12.5W	13.0W
N. J.	Trenton	2.8W	3.1W	3.5W	4.1W	4.7W	5.4W	6.0W	6.7W	7.2W	7.8W	8.4W
N. M.	Santa Rosa	–	–	–	–	12.7E	12.8E	12.7E	12.5E	12.1E	12.0E	12.4E
	Laguna	–	–	–	–	13.4E	13.6E	13.6E	13.4E	13.0E	13.0E	13.5E
N. Y.	Albany	5.6W	5.8W	6.3W	6.9W	7.6W	8.4W	9.1W	9.8W	10.2W	10.8W	11.4W
	Elmira	2.2W	2.4W	2.8W	3.3W	4.0W	4.8W	5.4W	6.3W	7.0W	7.6W	8.1W
N. C.	Newbern	1.7E	1.6E	1.3E	0.8E	0.3E	0.3W	1.0W	1.6W	2.2W	2.8W	3.3W
N. C.	Salisbury	3.9E	3.8E	3.6E	3.2E	2.7E	2.1E	1.5E	0.8E	0.2E	0.4W	0.7W
N. Dak.	Jamestown	–	–	–	–	14.5E	14.3E	14.0E	13.5E	12.7E	12.4E	12.8E
	Dickinson	–	–	–	–	17.6E	17.6E	17.4E	17.0E	16.4E	16.2E	16.6E
Ohio	Columbus	3.4E	3.4E	3.2E	2.9E	2.4E	1.8E	1.2E	0.6E	0.0	0.7W	1.1W
Okla.	Okmulgee	–	–	–	–	10.2E	10.1E	9.8E	9.4E	8.8E	8.5E	8.9E
Okla.	Enid	–	–	–	–	11.2E	11.1E	10.9E	10.5E	9.9E	9.7E	10.1E
Oreg.	Sumpter	–	–	–	–	19.3E	19.7E	20.0E	20.2E	20.2E	20.4E	21.0E
	Detroit	16.7E	17.4E	18.0E	18.6E	19.2E	19.7E	20.1E	20.4E	20.5E	20.8E	21.5E
Pa.	Philadelphia	2.2W	2.4W	2.8W	3.4W	4.1W	4.8W	5.5W	6.3W	6.8W	7.4W	8.0W
	Altoona	0.5W	0.6W	0.9W	1.3W	1.8W	2.4W	3.1W	3.8W	4.5W	5.1W	5.6W
P. R.	San Juan	–	–	–	–	–	–	–	–	–	1.0W	2.0W
R. I.	Newport	6.6W	7.1W	7.7W	8.4W	9.1W	9.8W	10.3W	10.8W	11.3W	11.9W	12.4W
S. C.	Columbia	4.4E	4.3E	4.1E	3.7E	3.2E	2.7E	2.1E	1.4E	0.8E	0.2E	0.1W
S. D.	Huron	–	–	–	13.1E	13.1E	12.9E	12.6E	12.1E	11.4E	11.1E	11.4E
	Rapid City	–	–	–	–	16.4E	16.4E	16.3E	15.8E	15.3E	15.1E	15.4E
Tenn.	Chattanooga	5.3E	5.3E	5.1E	4.8E	4.4E	3.9E	3.3E	2.6E	2.0E	1.5E	1.3E
	Huntington	–	7.4E	7.4E	7.3E	7.0E	6.6E	6.1E	5.5E	4.9E	4.4E	4.3E
Tex.	Houston	–	8.9E	9.2E	9.3E	9.3E	9.2E	8.9E	8.5E	7.9E	7.7E	8.1E
	San Antonio	–	–	9.6E	9.8E	9.9E	9.8E	9.6E	9.3E	8.9E	8.7E	9.1E
	Pecos	–	–	10.8E	11.0E	11.1E	11.1E	11.0E	10.8E	10.4E	10.3E	10.7E
Tex.	Floydada	–	–	–	–	11.3E	11.3E	11.2E	10.9E	10.4E	10.3E	10.7E
Utah	Salt Lake	–	–	–	–	16.4E	16.6E	16.7E	16.5E	16.3E	16.5E	17.0E
Vt.	Rutland	6.8W	7.2W	7.8W	8.5W	9.2W	10.0W	10.6W	11.2W	11.6W	12.1W	12.7W
Va.	Richmond	0.8E	0.6E	0.3W	0.1W	0.6W	1.2W	1.8W	2.5W	3.1W	3.7W	4.2W
	Lynchburg	1.9E	1.8E	1.6E	1.2E	0.8E	0.2E	0.5W	1.2W	1.8W	2.4W	2.8W
Wash.	Wilson Creek					21.3E	21.6E	21.9E	21.9E	22.1E	22.4E	22.9E
	Seattle	19.1E	19.7E	20.3E	20.8E	21.3E	21.8E	22.1E	22.3E	22.6E	23.0E	23.5E
W. Va.	Charleston	2.3E	2.2E	2.0E	1.6E	1.1E	0.5E	0.2W	0.9W	1.5W	2.1W	2.6W
Wis.	Madison	–	8.6E	8.7E	8.6E	8.3E	7.8E	7.2E	6.4E	5.6E	5.0E	4.9E
Wyo.	Douglas	–	–	–	–	15.8E	16.0E	16.0E	15.8E	15.4E	15.3E	15.7E
	Green River	–	–	–	–	16.8E	17.0E	17.0E	16.9E	16.6E	16.6E	17.0E

TERRESTRIAL MAGNETISM (*continued*).

TABLE 93. — Dip or Inclination.

This table gives for the epoch January 1, 1905, the values of the magnetic dip, I, corresponding to the longitudes west of Greenwich in the heading and the north latitudes in the first column.

	65°	70°	75°	80°	85°	90°	95°	100°	105°	110°	115°	120°	125°
°	°	°	°	°	°	°	°	°	°	°	°	°	°
19	-	-	48.8	49.1	47.5	46.3	44.8	44.2	43.9	-	-	-	-
21	-	-	51.0	51.1	50.0	49.3	48.2	47.0	46.5	-	-	-	-
23	-	-	53.7	53.0	52.4	51.8	50.7	49.6	48.8	48.2	-	-	-
25	-	-	56.3	56.0	55.0	54.5	53.2	52.4	51.5	50.6	49.8	48.3	-
27	-	-	58.9	58.1	57.6	56.8	55.6	54.7	53.9	53.1	52.6	51.0	-
29	-	60.7	61.0	60.2	59.8	58.9	58.2	57.2	56.2	55.5	54.8	53.7	-
31	-	63.0	63.1	62.6	62.0	61.3	60.6	59.6	58.7	57.7	56.7	56.0	-
33	-	65.0	65.0	64.6	64.0	63.5	62.7	62.0	61.0	59.8	58.9	58.1	-
35	-	67.0	66.9	66.5	66.0	65.6	64.9	63.7	62.7	62.3	61.0	60.2	-
37	-	68.6	68.9	68.6	68.2	67.7	66.9	66.2	65.1	64.6	62.9	62.2	-
39	-	70.3	70.6	70.4	70.2	69.7	68.8	68.1	67.2	66.1	65.0	64.0	62.8
41	-	71.8	72.2	72.2	71.9	71.4	70.8	69.8	68.9	67.8	66.8	65.6	64.7
43	-	73.5	73.9	74.1	73.8	73.3	72.6	71.6	70.7	69.6	68.6	67.5	66.3
45	74.4	74.8	75.6	75.5	75.4	75.0	74.3	73.6	72.4	71.5	70.3	69.2	68.1
47	75.7	76.2	76.9	76.8	76.9	76.8	76.0	75.2	74.2	73.0	71.8	70.8	69.9
49	76.8	78.1	78.2	78.3	78.7	78.1	77.5	76.8	75.8	74.5	73.5	72.3	71.4

TABLE 94. — Secular Change of Dip.

Values of magnetic dip for places designated by the north latitudes and longitudes west of Greenwich in the first two columns for January 1st of the years in the heading. The degrees are given in the third column and minutes in the succeeding columns.

Latitude.	Longitude.		1855	1860	1865	1870	1875	1880	1885	1890	1895	1900	1905	1910
°	°	°	′	′	′	′	′	′	′	′	′	′	′	′
25	80	55+	49	49	48	46	43	40	35	35	39	48	60	77
25	110	49+	08	20	30	39	46	55	61	68	76	86	96	106
30	83	60+	66	70	73	74	73	67	57	51	53	63	78	96
30	100	57+	44	49	58	67	70	65	60	61	68	77	90	105
30	115	54+	53	62	69	71	70	72	75	79	85	91	96	101
35	80	66+	57	58	57	54	45	35	26	21	20	22	30	38
35	90	65+	65	59	51	44	37	32	26	25	25	27	36	48
35	105	62+	-	-	-	32	30	24	24	24	28	34	42	50
35	120	60+	03	06	08	08	07	06	08	11	13	14	12	08
40	75	71+	82	82	78	73	65	55	43	33	27	24	24	24
40	90	70+	30	31	34	37	36	32	29	26	25	26	30	36
40	105	67+	-	-	-	56	53	51	51	51	52	56	60	65
40	120	64+	-	48	46	44	44	44	44	44	45	45	48	48
45	65	74+	116	110	101	92	80	68	57	46	35	28	24	20
45	75	75+	103	99	95	90	85	73	62	53	43	38	36	34
45	90	74+	81	81	81	79	77	75	68	63	61	59	60	60
45	105	72+	-	-	-	-	-	22	20	20	21	22	24	27
45	122.5	68+	35	34	37	40	40	39	37	34	30	26	24	20
49	92	78+	26	25	24	22	20	20	15	12	11	09	06	04
49	120	72+	-	26	24	22	22	19	20	19	19	19	18	16

TERRESTRIAL MAGNETISM (*continued*).

TABLE 95.—Horizontal Intensity.

This table gives for the epoch January 1, 1905, the horizontal intensity, H, expressed in C. G. S. units, corresponding to the longitudes in the heading and the latitudes in the first column.

	65°	70°	75°	80°	85°	90°	95°	100°	105°	110°	115°	120°	125°
°													
19	-	-	.307	.314	.319	.322	.328	.332	.331				
21	-	-	.301	.309	.314	.316	.320	.324	.324				
23	-	-	.293	.303	.305	.309	.312	.315	.317	.320			
25	-	-	.284	.292	.295	.299	.304	.307	.308	.309	.312	.304	
27	-	-	.274	.280	.286	.289	.296	.298	.300	.303	.306	.298	
29	-	.257	.262	.269	.276	.281	.286	.289	.292	.294	.297	.291	
31	-	.246	.251	.256	.263	.269	.274	.277	.282	.284	.285	.282	
33	-	.233	.239	.245	.251	.257	.262	.266	.270	.273	.274	.274	
35	-	.220	.225	.232	.240	.242	.248	.253	.256	.259	.262	.265	
37	-	.208	.209	.218	.222	.226	.232	.238	.245	.246	.252	.251	
39	-	.197	.198	.203	.206	.212	.217	.224	.229	.237	.240	.242	.245
41	-	.184	.185	.186	.192	.196	.202	.207	.216	.223	.228	.240	.236
43	-	.170	.170	.169	.175	.178	.187	.194	.201	.210	.215	.222	.226
45	.161	.157	.155	.156	.157	.162	.169	.177	.190	.192	.199	.208	.215
47	.145	.144	.140	.142	.142	.150	.152	.161	.170	.180	.188	.196	.201
49	.131	.129	.125	.126	.124	.129	.138	.146	.153	.165	.175	.182	.187

TABLE 96. —Secular Change of Horizontal Intensity.

Values of horizontal intensity in C. G. S. units for places designated by the latitude and longitude in the first two columns for January 1 of the years in the heading.

Latitude.	Longitude.	1855	1860	1865	1870	1875	1880	1885	1890	1895	1900	1905	1910
°	°												
25	80	.3099	.3086	.3073	.3057	.3042	.3025	.3008	.2990	.2970	.2949	.2920	.2890
25	110	.3229	.3218	.3204	.3189	.3170	.3155	.3143	.3130	.3117	.3104	.3090	.3075
30	83	.2803	.2795	.2788	.2780	.2772	.2763	.2752	.2740	.2725	.2706	.2680	.2644
30	100	–	–	.2961	.2942	.2924	.2907	.2891	.2877	.2865	.2850	.2830	.2804
30	115	.3040	.3026	.3011	.2996	.2979	.2964	.2952	.2940	.2929	.2920	.2910	.2898
35	80	.2384	.2379	.2374	.2369	.2367	.2363	.2359	.2352	.2347	.2337	.2320	.2296
35	90	-	–	–	.2462	.2462	.2461	.2458	.2455	.2447	.2437	.2430	.2399
35	105	–	–	–	–	.2620	.2608	.2599	.2590	.2583	.2573	.2560	.2544
35	120	–	–	–	.2720	.2707	.2695	.2683	.2672	.2663	.2656	.2650	.2644
40	75	.1880	.1883	.1891	.1902	.1911	.1919	.1925	.1930	.1931	.1928	.1920	.1909
40	90	–	.2086	.2082	.2079	.2076	.2075	.2074	.2072	.2068	.2060	.2050	.2036
40	105	–	–	–	.2272	.2266	.2261	.2257	.2253	.2248	.2240	.2230	.2217
40	120	–	–	–	.2429	.2420	.2412	.2406	.2399	.2392	.2386	.2380	.2379
45	65	.1504	.1514	.1525	.1537	.1553	.1567	.1578	.1589	.1600	.1608	.1610	.1610
45	75	.1483	.1485	.1488	.1495	.1506	.1516	.1527	.1538	.1546	.1550	.1550	.1554
45	90	–	.1635	.1633	.1631	.1628	.1626	.1624	.1623	.1624	.1623	.1620	.1616
45	105	–	–	–	.1920	.1919	.1918	.1916	.1913	.1910	.1906	.1900	.1892
45	122.5	.2175	.2170	.2162	.2153	.2145	.2135	2127	.2121	.2117	.2115	.2115	.2115
49	92	.1332	.1330	.1328	.1324	.1321	.1319	.1318	.1318	.1321	.1324	.1330	.1335
49	120	.1841	.1841	.1840	.1839	.1836	.1831	.1826	.1821	.1819	.1820	.1820	.1824

TERRESTRIAL MAGNETISM *(continued)*.

TABLE 97. — Total Intensity.

This table gives for the epoch January 1, 1905, the values of total intensity, F, expressed in C. G. S. units corresponding to the longitudes in the heading and the latitudes in the first column.

	65°	70°	75°	80°	85°	90°	95°	100°	105°	110°	115°	120°	125°
°													
19	–	–	.466	.480	.472	.466	.462	.463	.459	–	–	–	–
21	–	–	.478	.492	.489	.485	.480	.475	.471	–	–	–	–
23	–	–	.495	.504	.500	.500	.493	.486	.481	.480	–	–	–
25	–	–	.512	.522	.514	.515	.507	.503	.495	.487	.483	.457	–
27	–	–	.530	.530	.534	.528	.524	.516	.509	.505	.504	.474	–
29	–	.525	.540	.541	.549	.544	.543	.534	.525	.519	.515	.492	–
31	–	.542	.555	.556	.560	.560	.558	.547	.543	.531	.519	.504	–
33	–	.551	.566	.571	.572	.576	.571	.567	.557	.543	.530	.518	–
35	–	.563	.574	.582	.590	.586	.584	.571	.558	.557	.540	.533	–
37	–	.570	.581	.598	.598	.596	.591	.590	.582	.573	.553	.538	–
39	–	.584	.596	.605	.608	.611	.600	.600	.591	.585	.568	.552	.536
41	–	.589	.605	.608	.618	.614	.614	.600	.600	.590	.579	.581	.552
43	–	.599	.613	.617	.627	.619	.625	.614	.608	.602	.589	.580	.562
45	.599	.599	.623	.623	.623	.626	.624	.627	.628	.605	.590	.586	.576
47	.587	.604	.618	.622	.626	.657	.628	.630	.624	.616	.602	.596	.585
49	.574	.626	.611	.621	.633	.626	.638	.639	.624	.617	.616	.599	.588

TABLE 98. — Secular Change of Total Intensity.

Values of total intensity in C. G. S. units for places designated by the latitudes and longitudes in the first two columns for January 1 of the years in the heading. (Computed from Tables 92 and 94.)

Latitude	Longitude.	1855	1860	1865	1870	1875	1880	1885	1890	1895	1900	1905	1910
°	°												
25	80	.5516	.5493	.5467	.5434	.5400	.5364	.5322	.5290	.5264	.5247	.5222	.5206
25	110	.4935	.4938	.4933	.4925	.4908	.4902	.4891	.4883	.4876	.4873	.4868	.4860
30	83	.5800	.5796	.5790	.5777	.5757	.5720	.5668	.5625	.5600	.5590	.5581	.5559
30	100	–	–	.5583	.5570	.5544	.5499	.5456	.5432	.5427	.5421	.5416	.5405
30	115	.5285	.5280	.5269	.5247	.5215	.5194	.5179	.5167	.5160	.5158	.5151	.5140
35	80	.6089	.6080	.6063	.6038	.5996	.5946	.5900	.5863	.5874	.5830	.5818	.5789
35	90	–	–	–	.5991	.5964	.5942	.5912	.5901	.5882	.5865	.5858	.5852
35	105	–	–	–	–	.5674	.5629	.5610	.5590	.5588	.5585	.5582	.5572
35	120	–	–	–	.5462	.5433	.5406	.5388	.5374	.5361	.5350	.5332	.5309
40	75	.6206	.6216	6220	.6227	.6212	.6182	.6136	.6098	.6070	.6045	.6019	.5985
40	90	–	.6254	.6258	.6264	.6250	.6226	.6208	.6187	.6170	.6151	.6141	.6135
40	105	–	–	–	.6048	.6019	.5997	5986	.5976	.5967	.5963	.5953	.5940
40	120	–	–	–	.5691	.5670	.5651	.5637	.5620	.5608	.5593	.5590	.5591
45	65	.6188	.6186	.6167	.6152	.6134	.6107	.6077	.6048	.6019	.6005	.5987	.5962
45	75	.6454	.6431	.6413	.6404	.6412	.6363	.6327	.6306	.6266	.6247	.6233	.6235
45	90	–	.6465	.6457	.6434	.6408	.6386	.6330	.6291	.6382	.6264	.6259	.6244
45	105	–	–	–	–	–	.6332	.6314	.6303	.6299	.6392	.6284	.6275
45	122.5	.5956	.5938	.5930	.5918	.5896	.5864	.5834	.5804	.5776	.5754	.5745	.5728
49	92	.6643	.6624	.6604	.6566	.6533	.6523	.6472	.6445	.6451	.6447	.6450	.6456
49	120	–	.6100	.6085	.6071	.6061	.6028	.6017	.5995	.5988	.5992	.5986	.5988

TABLE 99.

AGONIC LINE.

The line of no declination appears to be still moving westward in the United States, but the line of no annual change is only a short distance to the west of it, so that it is probable that the extreme westerly position will soon be reached.

Lat. N.	Longitudes of the agonic line for the years—				
	1800	1850	1875	1890	1905
°	°	°	°	°	°
25	-	-	-	75.5	76.1
30	-	-	-	78.6	79.7
35	-	76.7	79.0	79.9	81.7
6	75.2	77.3	79.7	80.5	82.8
7	76.3	77.7	80.6	82.2	83.5
8	76.7	78.3	81.3	82.6	83.6
9	76.9	78.7	81.6	82.2	83.6
40	77.0	79.3	81.6	82.7	84.0
1	77.9	80.4	81.8	82.8	84.6
2	79.1	81.0	82.6	83.7	84.8
3	79.4	81.2	83.1	84.3	85.0
4	79.8	-	83.3	84.9	85.5
45	-	-	83.6	85.2	86.0
6	-	-	84.2	84.8	86.4
7	-	-	85.1	85.4	86.4
8	-	-	86.0	85.9	86.5
9	-	-	86.5	86.3	87.2

TABLE 100.

RECENT VALUES OF THE MAGNETIC ELEMENTS AT MAGNETIC OBSERVATORIES.

(Compiled by the Department of Terrestrial Magnetism, Carnegie Institution of Washington.)

Place.	Latitude.	Longitude.	Middle of year.	Magnetic Elements.				
				Declination.	Inclination.	Intensity (C.G.S. units).		
						Hor'l.	Ver'l.	Total.
	° ′	° ′		° ′	° ′			
Pawlowsk	59 41N	30 29E	1907	1 09.9E	70 37.7N	.1650	.4694	.4975
Sitka	57 03N	135 20W	1910	30 16.4E	74 32.2N	.1559	.5637	.5849
Katharinenburg	57 03N	60 38E	1907	10 35.5E	70 52.2N	.1762	.5081	.5378
Rude Skov	55 51N	12 27E	1910	9 28.7W	68 45.0N	.1738	.4468	.4794
Eskdalemuir	55 19N	3 12W	1911	18 12.4W	69 37.1N	.1685	.4534	.4837
Stonyhurst	53 51N	2 28W	1912	17 03.6W	68 41.4N	.1740	.4460	.4787
Wilhelmshaven	53 32N	8 09E	1910	11 37.0W	67 30.5N	.1812	.4377	.4737
Potsdam	52 23N	13 04E	1912	8 45.9W	66 20.4N	.1880	.4291	.4685
Seddin	52 17N	13 01E	1912	8 47.2W	66 17.4N	.1884	.4290	.4685
Irkutsk	52 16N	104 16E	1905	1 58.1E	70 25.0N	.2001	.5625	.5970
De Bilt	52 06N	5 11E	1910	12 58.2W	66 46.5N	.1854	.4321	.4702
Valencia	51 56N	10 15W	1911	20 38.1W	68 12.1N	.1789	.4473	.4817
Clausthal	51 48N	10 20E	1905	10 40.3W	....	...	...	...
Bochum	51 29N	7 14E	1911	11 48.3W	....	...	...	...
Kew	51 28N	0 19W	1911	15 55.3W	66 57.2N	.1850	.4349	.4726
Greenwich	51 28N	0 00	1911	15 33.0W	66 52.1N	.1852	.4337	.4716
Uccle	50 48N	4 21E	1911	13 13.9W	66 00.1N	.1902	.4273	.4677
Hermsdorf	50 46N	16 14E	1912	7 06.9W	....	...	...	...
Beuthen	50 21N	18 55E	1908	6 12.3W	...	...	...	...
Falmouth	50 09N	5 05W	1912	17 24.2W	66 26.6N	.1880	.4312	.4704
Prague	50 05N	14 25E	1910	8 09.6W	....	...	...	...
Cracow	50 04N	19 58E	1911	5 18.1W	64 15.5N	...	...	...
St. Helier (Jersey)	49 12N	2 05W	1907	16 27.4W	65 34.5N	...	...	...
Val Joyeux	48 49N	2 01E	1911	14 17.6W	64 41.6N	.1974	.4176	.4619
Munich	48 09N	11 37E	1910	9 31.5W	63 08.4N	.2064	.4075	.4568
Kremsmünster	48 03N	14 08E	1904	9 02.4W	....	...	...	...
O'Gyalla (Pesth)	47 53N	18 12E	1911	6 25.6W	....	.2107	...	...
Odessa	46 26N	30 46E	1910	3 35.9W	62 26.9N	.2171	.4161	.4693
Pola	44 52N	13 51E	1911	8 17.5W	60 03.6N	.2219	.3853	.4446
Agincourt (Toronto)	43 47N	79 16W	1910	6 03.9W	74 38.5N	.1627	.5923	.6142
Perpignan	42 42N	2 53E	1910	12 44.8W	....	...	...	...
Tiflis	41 43N	44 48E	1905	2 41.6E	56 02.8N	.2545	.3780	.4557
Capodimonte	40 52N	14 15E	1911	....	56 11.7N	...	...	...
Ebro (Tortosa)	40 49N	0 31E	1911	13 18.6W	57 54.8N	.2326	.3709	.4378
Coimbra	40 12N	8 25W	1911	16 27.4W	58 46.4N	.2301	.3795	.4438
Mount Weather	39 04N	77 53W	1908	3 39.2W	....	...	...	...
Baldwin	38 47N	95 10W	1908	8 33.0E	68 47.8N	.2171	.5597	.6003
Cheltenham	38 44N	76 50W	1910	5 41.4W	70 35.4N	.1983	.5626	.5966
Athens	37 59N	23 42E	1908	4 53.0W	52 11.7N	.2620	.3361	.4262
San Fernando	36 28N	6 12W	1911	15 05.2W	54 31.5N	.2489	...	...
Tokio	35 41N	139 45E	1910	4 58.2W	49 07.3N	.3001	.3467	.4585
Tucson	32 15N	110 50W	1910	13 25.8E	59 19.6N	.2741	.4621	.5372
Zi-ka-wei	31 12N	121 26E	1907	2 33.6W	45 36.6N	.3306	.3377	.4726
Dehra Dun	30 19N	78 03E	1910	2 31.9E	43 54.8N	.3326	.3202	.4617
Helwan	29 52N	31 20E	1912	2 25.4W	40 43.7N	.3006	.2588	.3967
Barrackpore	22 46N	88 22E	1910	0 55.5E	30 42.2N	.3733	.2217	.4341
Hongkong	22 18N	114 10E	1910	0 00.4E	30 58.8N	.3711	.2228	.4328
Honolulu	21 19N	158 04W	1910	9 29.7E	39 47.2N	.2916	.2428	.3795
Toungoo	18 56N	96 27E	1910	0 24.9E	23 02.1N	.3880	.1650	.4216
Alibág	18 38N	72 52E	1912	0 51.2E	23 56.1N	.3687	.1637	.4034
Vieques	18 09N	65 26W	1910	2 20.6W	49 52.0N	.2886	.3424	.4478
Antipolo	14 36N	121 10E	1911	0 40.9E	16 18.2N	.3820	.1117	.3981
Kodaikanal	10 14N	77 28E	1910	0 55.0W	3 45.2N	.3748	.0246	.3757
Batavia-Butenzorg	6 11S	106 49E	1909	0 49.5E	31 09.2S	.3668	.2218	.4286
St. Paul de Loanda	8 48S	13 13E	1910	16 12.3W	35 32.2S	.2012	.1437	.2473
Samoa (Apia)	13 48S	171 46W	1908	9 41.9E	29 21.7S	.3561	.2004	.4086
Tananarive	18 55S	47 32E	1907	9 29.7W	54 05.7S	.2533	.3499	.4319
Mauritius	20 06S	57 33E	1911	9 18.5W	53 30.6S	.2331	.3151	.3920
Rio de Janeiro	22 55S	43 11W	1906	8 55.3W	13 57.2S	.2477	.0617	.2553
			1910	9 40.0W	....	...	...	...

PRESSURE OF COLUMNS OF MERCURY AND WATER.

British and metric measures. Correct at 0° C. for mercury and at 4° C. for water.

Metric Measure.			British Measure.		
Cms. of Hg.	Pressure in grams per sq. cm.	Pressure in pounds per sq. inch.	Inches of Hg.	Pressure in grams per sq. cm.	Pressure in pounds per sq. inch.
1	13.5956	0.193376	**1**	34.533	0.491174
2	27.1912	0.386752	2	69.066	0.982348
3	40.7868	0.580128	3	103.598	1.473522
4	54.3824	0.773504	4	138.131	1.964696
5	67.9780	0.966880	5	172.664	2.455870
6	81.5736	1.160256	**6**	207.197	2.947044
7	95.1692	1.353632	7	241.730	3.438218
8	108.7648	1.547008	8	276.262	3.929392
9	122.3604	1.740384	9	310.795	4.420566
10	135.9560	1.933760	10	345.328	4.911740
Cms. of H_2O.	Pressure in grams per sq. cm.	Pressure in pounds per sq. inch.	Inches of H_2O.	Pressure in grams per sq. cm.	Pressure in pounds per sq. inch.
1	1	0.0142234	**1**	2.54	0.036127
2	2	0.0284468	2	5.08	0.072255
3	3	0.0426702	3	7.62	0.108382
4	4	0.0568936	4	10.16	0.144510
5	5	0.0711170	5	12.70	0.180637
6	6	0.0853404	**6**	15.24	0.216764
7	7	0.0995638	7	17.78	0.252892
8	8	0.1137872	8	20.32	0.289019
9	9	0.1280106	9	22.86	0.325147
10	10	0.1422340	10	25.40	0.361274

REDUCTION OF BAROMETRIC HEIGHT TO STANDARD TEMPERATURE.[*]

Corrections for brass scale and English measure.		Corrections for brass scale and metric measure.		Corrections for glass scale and metric measure.	
Height of barometer in inches.	α in inches for temp. F.	Height of barometer in mm.	α in mm. for temp. C.	Height of barometer in mm.	α in mm. for temp. C.
15.0	0.00135	**400**	0.0651	**50**	0.0086
16.0	.00145	410	.0668	100	.0172
17.0	.00154	420	.0684	150	.0258
17.5	.00158	430	.0700	200	.0345
18.0	.00163	440	.0716	250	.0431
18.5	.00167	450	.0732	300	.0517
19.0	.00172	460	.0749	350	.0603
19.5	.00176	470	.0765		
		480	.0781	**400**	0.0689
20.0	0.00181	490	.0797	450	.0775
20.5	.00185			500	.0861
21.0	.00190	**500**	0.0813	520	.0895
21.5	.00194	510	.0830	540	.0930
22.0	.00199	520	.0846	560	.0965
22.5	.00203	530	.0862	580	.0999
23.0	.00208	540	.0878		
23.5	.00212	550	.0894	**600**	0.1034
		560	.0911	610	.1051
24.0	0.00217	570	.0927	620	.1068
24.5	.00221	580	.0943	630	.1085
25.0	.00226	590	.0959	640	.1103
25.5	.00231			650	.1120
26.0	.00236	**600**	0.0975	660	.1137
26.5	.00240	610	.0992		
27.0	.00245	620	.1008	**670**	0.1154
27.5	.00249	630	.1024	680	.1172
		640	.1040	690	.1189
28.0	0.00254	650	.1056	700	.1206
28.5	.00258	660	.1073	710	.1223
29.0	.00263	670	.1089	720	.1240
29.2	.00265	680	.1105	730	.1258
29.4	.00267	690	.1121		
29.6	.00268			**740**	0.1275
29.8	.00270	**700**	0.1137	750	.1292
30.0	.00272	710	.1154	760	.1309
		720	.1170	770	.1327
30.2	0.00274	730	.1186	780	.1344
30.4	.00276	740	.1202	790	.1361
30.6	.00277	750	.1218	800	.1378
30.8	.00279	760	.1235		
31.0	.00281	770	.1251	**850**	0.1464
31.2	.00283	780	.1267	900	.1551
31.4	.00285	790	.1283	950	.1639
31.6	.00287	**800**	.1299	1000	.1723

[*] The height of the barometer is affected by the relative thermal expansion of the mercury and the glass, in the case of instruments graduated on the glass tube, and by the relative expansion of the mercury and the metallic inclosing case, usually of brass, in the case of instruments graduated on the brass case. This relative expansion is practically proportional to the first power of the temperature. The above tables of values of the coefficient of relative expansion will be found to give corrections almost identical with those given in the International Meteorological Tables. The numbers tabulated under α are the values of α in the equation $H_t = H_t' - \alpha(t' - t)$ where H_t is the height at the standard temperature, H_t' the observed height at the temperature t', and $\alpha(t' - t)$ the correction for temperature. The standard temperature is 0° C. for the metric system and 28°.5 F. for the English system. The English barometer is correct for the temperature of melting ice at a temperature of approximately 28°.5 F., because of the fact that the brass scale is graduated so as to be standard at 62° F., while mercury has the standard density at 32° F.

EXAMPLE.—A barometer having a brass scale gave $H = 765$ mm. at 25° C.; required, the corresponding reading at 0° C. Here the value of α is the mean of .1235 and .1251, or .1243; ∴ $\alpha(t' - t) = .1243 \times 25 = 3.11$. Hence $H_0 = 765 - 3.11 = 761.89$

N. B.—Although α is here given to three and sometimes to four significant figures, it is seldom worth while to use more than the nearest two-figure number. In fact, all barometers have not the same values for α, and when great accuracy is wanted the proper coefficients have to be determined by experiment.

CORRECTION OF BAROMETER TO STANDARD GRAVITY.

Altitude term. Correction is to be subtracted.

Correction in millimeters for elevation above sea level in first column and height of barometer in top line.

Corrections in hundredths of an inch for elevation above sea level in last column and height of barometer in bottom line.

Height above sea level in meters.	Observed height of barometer in millimeters.									
	400	450	500	550	600	650	700	750	800	
100							.014	.015	.016	
200							.028	.030	.032	
300							.041	.044	.047	
400							.055	.059	.063	
500						.064	.068	.073	.078	
600						.077	.082	.088		
700						.090	.096	.102		
800						.103	.109	.117		
900						.115	.123	.131		
1000				.108	.118	.128	.137	.146		
1100				.118	.130	.141	.150			
1200				.129	.142	.154	.164			
1300				.140	.153	.166	.178			
1400				.151	.165	.179	.191			
1500			.147	.162	.176	.191	.205			
1600			.157	.172	.188	.204				
1700			.167	.183	.200	.217				
1800			.177	.194	.212	.230			1.255	15000
1900			.187	.204	.224	.242			1.213	14500
2000		.176	.196	.215	.235	.255		1.340	1.172	14000
2100		.185	.206	.226	.247			1.292	1.130	13500
2200		.194	.216	.237	.259			1.244	1.088	13000
2300		.203	.226	.248	.271		1.345	1.196	1.046	12500
2400		.212	.236	.259	.283		1.291	1.149	1.004	12000
2500	.195	.220	.245	.270	.295		1.237	1.101	.962	11500
2600	.203	.229	.255			1.315	1.184	1.053	.920	11000
2700	.211	.238	.265			1.255	1.130	1.005	.879	10500
2800	.219	.247	.275			1.196	1.076	.957	.837	10000
2900	.227	.256	.285		1.050	1.136	1.022	.909	.795	9500
3000	.235	.265	.294		.984	1.076	.969	.861	.753	9000
3100	.243	.274			.918	1.016	.915	.813		8500
3200	.251	.283			.853	.957	.861	.765		8000
3300	.259	.292		1.077	.787	.897	.807			7500
3400	.267	.201		1.005	.721	.837	.753			7000
3500	.275	.309		.934	.655	.777	.700			6500
3600	.283			.862	.789	.718				6000
3700	.291			.790	.724	.658				5500
3800	.299		.779	.718	.658	.598				5000
3900	.307		.701	.646	.592					4500
4000	.314		.623	.574	.526					4000
			.545	.503	.461					3500
		.503	.467	.431	.395					3000
		.419	.389	.359						2500
	.359	.335	.311	.287						2000
	.269	.251	.233	.215						1500
.192	.179	.167	.155							1000
.096	.090	.084	.078							500
32	30	28	26	24	22	20	18	16	14	Height above sea level in feet.
Observed height of barometer in inches.										

TABLE 104.

REDUCTION OF BAROMETER TO STANDARD GRAVITY.*

Reduction to Latitude 45°. — English Scale.

N. B. From latitude 0° to 44° the correction is to be subtracted.
From latitude 90° to 46° the correction is to be added.

Latitude.		Height of the barometer in inches.											
		19	20	21	22	23	24	25	26	27	28	29	30
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
0°	**90°**	0.051	0.053	0.056	0.059	0.061	0.064	0.067	0.069	0.072	0.074	0.077	0.080
5	**85**	0.050	0.052	0.055	0.058	0.060	0.063	0.066	0.068	0.071	0.073	0.076	0.079
6	84	.049	.052	.055	.057	.060	.062	.065	.068	.070	.073	.076	.078
7	83	.049	.052	.054	.057	.059	.062	.065	.067	.070	.072	.075	.077
8	82	.049	.051	.054	.056	.059	.061	.064	.067	.069	.072	.074	.077
9	81	.048	.051	.053	.056	.058	.061	.063	.066	.068	.071	.073	.076
10	**80**	0.048	0.050	0.053	0.055	0.058	0.060	0.063	0.065	0.068	0.070	0.073	0.075
11	79	.047	.049	.052	.054	.057	.059	.062	.064	.067	.069	.072	.074
12	78	.046	.049	.051	.054	.056	.058	.061	.063	.066	.068	.071	.073
13	77	.045	.048	.050	.053	.055	.057	.060	.062	.065	.067	.069	.072
14	76	.045	.047	.049	.052	.054	.056	.059	.061	.063	.066	.068	.071
15	**75**	0.044	0.046	0.048	0.051	0.053	0.055	0.058	0.060	0.062	0.065	0.067	0.069
16	74	.043	.045	.047	.050	.052	.054	.056	.059	.061	.063	.065	.068
17	73	.042	.044	.046	.049	.051	.053	.055	.057	.060	.062	.064	.066
18	72	.041	.043	.045	.047	.050	.052	.054	.056	.058	.060	.062	.065
19	71	.040	.042	.044	.046	.048	.050	.052	.055	.057	.059	.061	.063
20	**70**	0.039	0.041	0.043	0.045	0.047	0.049	0.051	0.053	0.055	0.057	0.059	0.061
21	69	.038	.040	.042	.044	.045	.047	.049	.051	.053	.055	.057	.059
22	68	.036	.038	.040	.042	.044	.046	.048	.050	.052	.054	.056	.057
23	67	.035	.037	.039	.041	.043	.044	.046	.048	.050	.052	.054	.055
24	66	.034	.036	.037	.039	.041	.043	.045	.046	.048	.050	.052	.053
25	**65**	0.033	0.034	0.036	0.038	0.039	0.041	0.043	0.044	0.046	0.048	0.050	0.051
26	64	.031	.033	.034	.036	.038	.039	.041	.043	.044	.046	.048	.049
27	63	.030	.031	.033	.034	.036	.038	.039	.041	.042	.044	.045	.047
28	62	.028	.030	.031	.033	.034	.036	.037	.039	.040	.042	.043	.045
29	61	.027	.028	.030	.031	.032	.034	.035	.037	.038	.039	.041	.042
30	**60**	0.025	0.027	0.028	0.029	0.031	0.032	0.033	0.035	0.036	0.037	0.039	0.040
31	59	.024	.025	.026	.027	.029	.030	.031	.032	.034	.035	.036	.037
32	58	.022	.023	.025	.026	.027	.028	.029	.030	.032	.033	.034	.035
33	57	.021	.022	.023	.024	.025	.026	.027	.028	.029	.030	.031	.032
34	56	.019	.020	.021	.022	.023	.024	.025	.026	.027	.028	.029	.030
35	**55**	0.017	0.018	0.019	0.020	0.021	0.022	0.023	0.024	0.025	0.025	0.026	0.027
36	54	.016	.016	.017	.018	.019	.020	.021	.021	.022	.023	.024	.025
37	53	.014	.015	.015	.016	.017	.018	.018	.019	.020	.021	.021	.022
38	52	.012	.013	.014	.014	.015	.015	.016	.017	.017	.018	.019	.019
39	51	.011	.011	.012	.012	.013	.013	.014	.014	.015	.015	.016	.017
40	**50**	0.009	0.009	0.010	0.010	0.011	0.011	0.012	0.012	0.012	0.013	0.013	0.014
41	49	.007	.007	.008	.008	.009	.009	.009	.010	.010	.010	.011	.011
42	48	.005	.006	.006	.006	.006	.007	.007	.007	.008	.008	.008	.008
43	47	.004	.004	.004	.004	.004	.004	.005	.005	.005	.005	.005	.006
44	46	.002	.002	.002	.002	.002	.002	.002	.002	.003	.003	.003	.003

---

* "Smithsonian Meteorological Tables," p. 58.

TABLE 105.

REDUCTION OF BAROMETER TO STANDARD GRAVITY.*

Reduction to Latitude 45°. — Metric Scale.

N. B. — From latitude 0° to 44° the correction is to be subtracted.
From latitude 90° to 46° the correction is to be added.

Latitude.		Height of the barometer in millimeters.											
		520	560	600	620	640	660	680	700	720	740	760	780
		mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
0°	**90°**	1.38	1.49	1.60	1.65	1.70	1.76	1.81	1.86	1.92	1.97	2.02	2.08
5	**85**	1.36	1.47	1.57	1.63	1.68	1.73	1.78	1.84	1.89	1.94	1.99	2.04
6	84	1.35	1.46	1.56	1.61	1.67	1.72	1.77	1.82	1.87	1.93	1.98	2.03
7	83	1.34	1.45	1.55	1.60	1.65	1.70	1.76	1.81	1.86	1.91	1.96	2.01
8	82	1.33	1.43	1.54	1.59	1.64	1.69	1.74	1.79	1.84	1.89	1.94	2.00
9	81	1.32	1.42	1.52	1.57	1.62	1.67	1.72	1.77	1.82	1.87	1.92	1.97
10	**80**	1.30	1.40	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95
11	79	1.28	1.38	1.48	1.53	1.58	1.63	1.68	1.73	1.78	1.83	1.88	1.93
12	78	1.26	1.36	1.46	1.51	1.56	1.60	1.65	1.70	1.75	1.80	1.85	1.90
13	77	1.24	1.34	1.44	1.48	1.53	1.58	1.63	1.67	1.72	1.77	1.82	1.87
14	76	1.22	1.32	1.41	1.46	1.50	1.55	1.60	1.65	1.69	1.74	1.79	1.83
15	**75**	1.20	1.29	1.38	1.43	1.48	1.52	1.57	1.61	1.66	1.71	1.75	1.80
16	74	1.17	1.26	1.35	1.40	1.44	1.49	1.54	1.58	1.63	1.67	1.72	1.76
17	73	1.15	1.24	1.32	1.37	1.41	1.45	1.50	1.54	1.59	1.63	1.68	1.72
18	72	1.12	1.21	1.29	1.34	1.38	1.42	1.46	1.51	1.55	1.59	1.64	1.68
19	71	1.09	1.17	1.26	1.30	1.34	1.38	1.43	1.47	1.51	1.55	1.59	1.64
20	**70**	1.06	1.14	1.22	1.26	1.31	1.35	1.39	1.43	1.47	1.51	1.55	1.59
21	69	1.03	1.11	1.19	1.23	1.27	1.31	1.35	1.38	1.42	1.46	1.50	1.54
22	68	1.00	1.07	1.15	1.19	1.23	1.26	1.30	1.34	1.38	1.42	1.46	1.49
23	67	0.96	1.04	1.11	1.15	1.18	1.22	1.26	1.29	1.33	1.37	1.41	1.44
24	66	.93	1.00	1.07	1.10	1.14	1.18	1.21	1.25	1.28	1.32	1.35	1.39
25	**65**	0.89	0.96	1.03	1.06	1.10	1.13	1.16	1.20	1.23	1.27	1.30	1.33
26	64	.85	.92	0.98	1.02	1.05	1.08	1.11	1.15	1.18	1.21	1.25	1.28
27	63	.81	.88	.94	0.97	1.00	1.03	1.06	1.10	1.13	1.16	1.19	1.22
28	62	.77	.83	.89	.92	0.95	0.98	1.01	1.04	1.07	1.10	1.13	1.16
29	61	.73	.79	.85	.87	.90	.93	0.96	0.99	1.02	1.04	1.07	1.10
30	**60**	0.69	0.75	0.80	0.83	0.85	0.88	0.91	0.94	0.96	0.98	1.01	1.04
31	59	.65	.70	.75	.77	.80	.82	.85	.87	.90	.92	0.95	0.97
32	58	.61	.65	.70	.72	.75	.77	.79	.82	.84	.86	.89	.91
33	57	.56	.61	.65	.67	.69	.71	.74	.76	.78	.80	.82	.84
34	56	.52	.56	.60	.62	.64	.66	.68	.70	.72	.74	.76	.78
35	**55**	0.47	0.51	0.55	0.56	0.58	0.60	0.62	0.64	0.66	0.67	0.69	0.71
36	54	.43	.46	.49	.51	.53	.54	.56	.58	.59	.61	.63	.64
37	53	.38	.41	.44	.45	.47	.48	.50	.51	.53	.54	.56	.57
38	52	.33	.36	.39	.40	.41	.43	.44	.45	.46	.48	.49	.50
39	51	.29	.31	.33	.34	.35	.37	.38	.39	.40	.41	.42	.43
40	**50**	0.24	0.26	0.28	0.29	0.30	0.31	0.31	0.32	0.33	0.34	0.35	0.36
41	49	.19	.21	.22	.23	.24	.24	.25	.26	.27	.27	.28	.29
42	48	.14	.16	.17	.17	.18	.18	.19	.19	.20	.21	.21	.22
43	47	.10	.10	.11	.12	.12	.12	.13	.13	.13	.14	.14	.14
44	46	.05	.05	.06	.06	.06	.06	.06	.07	.07	.07	.07	.07

---

* "Smithsonian Meteorological Tables," p. 59.

TABLE 106. — Correction of the Barometer for Capillarity.*

1. METRIC MEASURE.

Diameter of tube in mm.	Height of Meniscus in Millimeters.							
	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8
	Correction to be added in millimeters.							
4	0.83	1.22	1.54	1.98	2.37	–	–	–
5	.47	0.65	0.86	1.19	1.45	1.80	–	–
6	.27	.41	.56	0.78	0.98	1.21	1.43	–
7	.18	.28	.40	.53	.67	0.82	0.97	1.13
8	–	.20	.29	.38	.46	.56	.65	0.77
9	–	.15	.21	.28	.33	.40	.46	.52
10	–	–	.15	.20	.25	.29	.33	.37
11	–	–	.10	.14	.18	.21	.24	.27
12	–	–	.07	.10	.13	.15	.18	.19
13	–	–	.04	.07	.10	.12	.13	.14

2. BRITISH MEASURE.

Diameter of tube in inches.	Height of Meniscus in Inches.							
	.01	.02	.03	.04	.05	.06	.07	.08
	Correction to be added in hundredths of an inch.							
.15	2.36	4.70	6.86	9.23	11.56	–	–	–
.20	1.10	2.20	3.28	4.54	5.94	7.85	–	–
.25	0.55	1.20	1.92	2.76	3.68	4.72	5.88	–
.30	.36	0.79	1.26	1.77	2.30	2.88	3.48	4.20
.35	–	.51	0.82	1.15	1.49	1.85	2.24	2.65
.40	–	.40	.61	0.81	1.02	1.22	1.42	1.62
.45	–	–	.32	.51	0.68	0.83	0.96	1.15
.50	–	–	.20	.35	.47	.56	.64	0.71
.55	–	–	.08	.20	.31	.40	.47	.52

* The first table is from Kohlrausch (Experimental Physics), and is based on the experiments of Mendelejeff and Gutkowski (Jour. de Phys. Chem. Geo. Petersburg, 1877, or Wied. Beib. 1877). The second table has been calculated from the same data by conversion into inches and graphic interpolation.

TABLE 107. — Volume of Mercury Meniscus in Cu. Mm.

Height of meniscus.	Diameter of tube in mm.										
	14	15	16	17	18	19	20	21	22	23	24
mm.											
1.6	157	185	214	245	280	318	356	398	444	492	541
1.8	181	211	244	281	320	362	407	455	507	560	616
2.0	206	240	278	319	362	409	460	513	571	631	694
2.2	233	271	313	358	406	459	515	574	637	704	776
2.4	262	303	350	400	454	511	573	639	708	781	859
2.6	291	338	388	444	503	565	633	706	782	862	948

Scheel und Heuse, Annalen der Physik, 33, p. 291, 1910.

AERODYNAMICS.

The pressure on a plane surface normal to the wind is for ordinary wind velocities expressed by

$$P = kwav^2$$

where k is a constant depending on the units employed, w the mass of unit volume of the air, a the area of the surface and v the velocity of the wind.* Engineers generally use the table of values of P given by Smeaton in 1759. This table was calculated from the formula

$$P = .00492\, v^2$$

and gives the pressure in pounds per square foot when v is expressed in miles per hour. The corresponding formula when v is expressed in feet per second is

$$P = .00228\, v^2.$$

Later determinations do not agree well together, but give on the average somewhat lower values for the coefficient. The value of w depends, of course, on the temperature and the barometric pressure. Langley's experiments give $kw = .00166$ at ordinary barometric pressure and 10° C. temperature.

For planes inclined at an angle α less than 90° to the direction of the wind the pressure may be expressed as

$$P_\alpha = F_\alpha P_{90}.$$

Table 108, founded on the experiments of Langley, gives the value of F_α for different values of α. The word *aspect*, in the headings, is used by him to define the position of the plane relative to the direction of motion. The numerical value of the aspect is the ratio of the linear dimension transverse to the direction of motion to the linear dimension, a vertical plane through which is parallel to the direction of motion.

TABLE 108. — Values of F_α in Equation $P_\alpha = F_\alpha P_{90}$.

Plane 30 in. × 4.8 in. Aspect 6 (nearly).		Plane 12 in. × 12 in. Aspect 1.		Plane 6 in. × 24 in. Aspect ¼.	
α	F_α	α	F_α	α	F_α
0°	0.00	0°	0.00	0°	0.00
5	0.28	5	0.15	5	0.07
10	0.44	10	0.30	10	0.17
15	0.55	15	0.44	15	0.29
20	0.62	20	0.57	20	0.43
25	0.66	25	0.69	25	0.58
30	0.69	30	0.78	30	0.71
35	0.72	35	0.84	–	–
40	0.74	40	0.88	–	–
45	0.76	45	0.91	–	–
50	0.78	50	–	–	–

* The following pressures in pounds per square inch show roughly the influence of the shape and size of the resisting surface (Dines' results). The wind velocity was 20.9 miles per hour. The flat plates were ⅜ in. thick.

Square, sides 4 in.	1.51	Plate, 6 in. diam. 90° cone at back	1.49
Circle, same area	1.51	Same, cone in front	0.98
Rectangle, 16 in. by 1	1 70	" sharp 30° cone at back	1.54
Square, 12 in. sides	1.57	" cone in front	0.60
Circle, same area	1 55	5 in. Robinson cup on 8½ in. of ½ in. rod	1.68
Rectangle, 24 in. by 6	1.59	Same, with back to wind	0.73
Square, sides 16 in.	1.52	9 in. cup on 6½ in. of ⅝ in. rod	1.75
Plate, 6 in. diam. 4¾ thick	1.45	Same, with back to wind	0.60
Ditto, curved side to wind	0.92	2½ in. cup on 9¾ in. of ¼ in. rod	2.60
Sphere, 6 in. diam.	0.67	Same, with back to wind	1.04

AERODYNAMICS.

On the basis of the results given in Table 108 Langley states the following condition for the soaring of an aeroplane 76.2 centimeters long and 12.2 centimeters broad, weighing 500 grams, — that is, a plane one square foot in area, weighing 1.1 pounds. It is supposed to soar in a horizontal direction, with aspect 6.

TABLE 109. — Data for the Soaring of Planes 76.2 × 12.2 cms. weighing 500 Grams, Aspect 6.

Inclination to the horizontal α.	Soaring speed v.		Work expended per minute (activity).		Weight of planes of like form, capable of soaring at speed v with the expenditure of one horse power.	
	Meters per sec.	Feet per sec.	Kilogram meters.	Foot pounds.	Kilograms.	Pounds.
2°	20.0	66	24	174	95.0	209
5	15.2	50	41	297	55.5	122
10	12.4	41	65	474	34.8	77
15	11.2	37	86	623	26.5	58
30	10.6	35	175	1268	13.0	29
45	11.2	37	336	2434	6.8	15

In general, if $\rho = \frac{\text{weight}}{\text{area}}$

Soaring speed $v = \sqrt{\frac{\rho}{k} \cdot \frac{1}{F_\alpha \cos \alpha}}$

Activity per unit of weight $= v \tan \alpha$

The following data for curved surfaces are due to Wellner (Zeits. für Luftschifffahrt, x., Oct. 1893).

Let the surface be so curved that its intersection with a vertical plane parallel to the line of motion is a parabola whose height is about $\frac{1}{12}$ the subtending chord, and let the surface be bounded by an elliptic outline symmetrical with the line of motion. Also, let the angle of inclination of the chord of the surface be α, and the angle between the direction of resultant air pressure and the normal to the direction of motion be β. Then $\beta < \alpha$, and the soaring speed is $v = \sqrt{\frac{\rho}{k} \cdot \frac{1}{F_\alpha \cos \beta}}$, while the activity per unit of weight $= v \tan \beta$.

The following series of values were obtained from experiments on moving trains and in the wind.

Angle of inclination $\alpha =$	$-3°$	$0°$	$+3°$	$6°$	$9°$	$12°$
Inclination factor $F_\alpha =$	0.20	0.50	0.75	0.90	1.00	1.05
$\tan \beta =$	0.01	0.02	0.03	0.04	0.10	0.17

Thus a curved surface shows finite soaring speeds when the angle of inclination α is zero or even slightly negative. Above $\alpha = 12°$ curved surfaces rapidly lose any advantage they may have for small inclinations.

TABLE 110. — Friction.

The following table of coefficients of friction f and its reciprocal $1/f$, together with the angle of friction or angle of repose ϕ, is quoted from Rankine's "Applied Mechanics." It was compiled by Rankine from the results of General Morin and other authorities, and is sufficient for all ordinary purposes.

Material.	f	$1/f$	ϕ
Wood on wood, dry	.25–.50	4.00–2.00	14.0–26.5
" " " soapy	.20	5.00	11.5
Metals on oak, dry	.50–.60	2.00–1.67	26.5–31.0
" " " wet	.24–.26	4.17–3.85	13.5–14.5
" " " soapy	.20	5.00	11.5
" " elm, dry	.20–.25	5.00–4.00	11.5–14.0
Hemp on oak, dry	.53	1.89	28.0
" " " wet	.33	3.00	18.5
Leather on oak	.27–.38	3.70–2.86	15.0–19.5
" " metals, dry	.56	1.79	29.5
" " " wet	.36	2.78	20.0
" " " greasy	.23	4.35	13.0
" " " oily	.15	6.67	8.5
Metals on metals, dry	.15–.20	6.67–5.00	8.5–11.5
" " " wet	.3	3.33	16.5
Smooth surfaces, occasionally greased	.07–.08	14.3–12.50	4.0–4.5
" " continually greased	.05	20.00	3.0
" " best results	.03–.036	33.3–27.6	1.75–2.0
Steel on agate, dry *	.20	5.00	11.5
" " " oiled *	.107	9.35	6.1
Iron on stone	.30–.70	3.33–1.43	16.7–35.0
Wood on stone	About .40	2.50	22.0
Masonry and brick work, dry	.60–.70	1.67–1.43	33.0–35.0
" " " " damp mortar	.74	1.35	36.5
" on dry clay	.51	1.96	27.0
" " moist clay	.33	3.00	18.25
Earth on earth	.25–1.00	4.00–1.00	14.0–45.0
" " " dry sand, clay, and mixed earth	.38–.75	2.63–1.33	21.0–37.0
" " " damp clay	1.00	1.00	45.0
" " " wet clay	.31	3.23	17.0
" " " shingle and gravel	.81–1.11	1.23–0.9	39.0–48.0

* Quoted from a paper by Jenkin and Ewing, "Phil. Trans. R. S." vol. 167. In this paper it is shown that in cases where "static friction" exceeds "kinetic friction" there is a gradual increase of the coefficient of friction as the speed is reduced towards zero.

TABLE 111. — Lubricants.

The best lubricants are in general the following: Low temperatures, light mineral lubricating oils. Very great pressures, slow speeds, graphite, soapstone and other solid lubricants. Heavy pressures, slow speeds, ditto and lard, tallow and other greases. Heavy pressures and high speeds, sperm oil, castor oil, heavy mineral oils. Light pressures, high speeds, sperm, refined petroleum olive, rape, cottonseed. Ordinary machinery, lard oil, tallow oil, heavy mineral oils and the heavier vegetable oils. Steam cylinders, heavy mineral oils, lard, tallow. Watches and delicate mechanisms, clarified sperm, neat's-foot, porpoise, olive and light mineral lubricating oils.

TABLE 112. — Lubricants For Cutting Tools.

Material.	Turning.	Chucking.	Drilling.	Tapping Milling.	Reaming.
Tool Steel,	dry or oil	oil or s. w.	oil	oil	lard oil
Soft Steel,	dry or soda water	soda water	oil or s. w.	oil	lard oil
Wrought iron	dry or soda water	soda water	oil or s. w.	oil	lard oil
Cast iron, brass	dry	dry	dry	dry	dry
Copper	dry	dry	dry	dry	mixture
Glass	turpentine or kerosene				

Mixture = $\frac{1}{3}$ crude petroleum, $\frac{2}{3}$ lard oil. Oil = sperm or lard.

Tables 111 and 112 quoted from "Friction and Lost Work in Machinery and Mill Work," Thurston, Wiley and Sons.

TABLE 113.

VISCOSITY.

The coefficient of viscosity is the tangential force per unit area of one face of a plate of the fluid which is required to keep up unit distortion between the faces. Viscosity is thus measured in terms of the temporary rigidity which it gives to the fluid. Solids may be included in this definition when only that part of the rigidity which is due to varying distortion is considered. One of the most satisfactory methods of measuring the viscosity of fluids is by the observation of the rate of flow of the fluid through a capillary tube, the length of which is great in comparison with its diameter. Poiseuille * gave the following formula for calculating the viscosity coefficient in this case: $\mu = \frac{\pi h r^4 s}{8vl}$, where h is the pressure height, r the radius of the tube, s the density of the fluid, v the quantity flowing per unit time, and l the length of the capillary part of the tube. The liquid is supposed to flow from an upper to a lower reservoir joined by the tube, hence h and l are different. The product hs is the pressure under which the flow takes place. Hagenbach † pointed out that this formula is in error if the velocity of flow is sensible, and suggested a correction which was used in the calculation of his results. The amount to be subtracted from h, according to Hagenbach, is $\frac{v^2}{\sqrt{2 \cdot g}}$, where g is the acceleration due to gravity. Gartenmeister ‡ points out an error in this to which his attention had been called by Finkener, and states that the quantity to be subtracted from h should be simply $\frac{v^2}{g}$; and this formula is used in the reduction of his observations. Gartenmeister's formula is the most accurate, but all of them nearly agree if the tube be long enough to make the rate of flow very small. None of the formulæ take into account irregularities in the distortion of the fluid near the ends of the tube, but this is probably negligible in all cases here quoted from, although it probably renders the results obtained by the "viscosimeter" commonly used for testing oils useless for our purpose.

The term "specific viscosity" is sometimes used in the headings of the tables; it means the ratio of the viscosity of the fluid under consideration to the viscosity of water at a specified temperature.

The friction of a fluid is proportional to the size of the rubbing surface, to $\frac{dv}{dx}$, where v is the velocity of motion in a direction perpendicular to the rubbing surface, and to a constant known as the viscosity.

(a) Variation of Viscosity of Water, with Temperature. Dynes per sq. cm.

Temp. C.	Poiseville. 1846.	Sprung. 1876.	Slotte. 1883.	Thorpe-Rogers. 1894.§	Hosking. 1909.‖	Temp. C.	Slotte. 1883.	Thorpe-Rogers 1894.	Hosking. 1909.‖
0°	0.01716	0.01778	0.01808	0.01778	0.01793	55°	0.00510	0.00506	.00508
5	.01515	.01510	.01524	.01510	.01522	60	.00472	.00468	.00469
10	.01309	.01301	.01314	.01303	.01310	65	.00438	.00436	.00436
15	.01146	.01135	.01144	.01134	.01142	70	.00408	.00406	.00406
20	.01008	.01003	.01008	.01002	.01006	75	.00382	.00380	.00380
25	.00897	.00896	.00896	.00891	.00893	80	.00358	.00356	.00356
30	.00803	.00802	.00803	.00798	.00800	85	.00337	.00335	.00335
35	.00721	.00723	.00724	.00720	.00724	90	.00318	.00316	.00316
40	.00653	.00657	.00657	.00654	.00657	95	.00301	.00299	.00300
45	.00595	.00602	.00602	.00597	.00600	100	.00285	.00283	.00284¶
50	–	.00553	.00553	.00548	.00550	153	–	–	.00181¶

(b) Variation of Specific Viscosity of Water with Temperature.‖

0°	1.000	25°	0.498	50°	0.307	75°	0.212	100°	0.158
5°	.849	30	.446	55	.283	80	.199	124°	.124¶
10°	.730	35	.404	60	.262	85	.187	153°	.101¶
15°	.637	40	.367	65	.243	90	.176	–	–
20°	.561	45	.335	70	.226	95	.167	–	–

---

* "Comptes rendus," vol. 15, 1842; "Mém. Serv. Étr." 1846.
† "Pogg. Ann." vol. 109, 1860.
‡ "Zeitschr. Phys. Chem." vol. 6, 1890.
§ Thorpe and Rogers, "Philos. Trans." 185A, p. 397, 1894; "Proc. Roy. Soc." 55, p. 148, 1894.
‖ Hosking, Phil. Mag. 17, p. 502, 1909; 18, p. 260, 1909.
¶ de Haas, Diss. Leiden, 1894.

VISCOSITY.

TABLE 114. — Solution of Alcohol in Water.*

Coefficients of viscosity, in C. G. S. units, for solution of alcohol in water.

Temp. C.	Percentage by weight of alcohol in the mixture.								
	0	8.21	16.60	34.58	43.99	53.36	75.75	87.45	99.72
0°	0.0181	0.0287	0.0453	0.0732	0.0707	0.0632	0.0407	0.0294	0.0180
5	.0152	.0234	.0351	.0558	.0552	.0502	.0344	.0256	.0163
10	.0131	.0195	.0281	.0435	.0438	.0405	.0292	.0223	.0148
15	.0114	.0165	.0230	.0347	.0353	.0332	.0250	.0195	.0134
20	.0101	.0142	.0193	.0283	.0286	.0276	.0215	.0172	.0122
25	0.0090	0.0123	0.0163	0.0234	0.0241	0.0232	0.0187	0.0152	0.0110
30	.0081	.0108	.0141	.0196	.0204	.0198	.0163	.0135	.0100
35	.0073	.0096	.0122	.0167	.0174	.0171	.0144	.0120	.0092
40	.0067	.0086	.0108	.0143	.0150	.0149	.0127	.0107	.0084
45	.0061	.0077	.0095	.0125	.0131	.0130	.0113	.0097	.0077
50	0.0056	0.0070	0.0085	0.0109	0.0115	0.0115	0.0102	0.0088	0.0070
55	.0052	.0063	.0076	.0096	.0102	.0102	.0091	.0086	.0065
60	.0048	.0058	.0069	.0086	.0091	.0092	.0083	.0073	.0060

The following tables (115-116) contain the results of a number of experiments in the viscosity of mineral oils derived from petroleum residues and used for lubricating purposes.†

TABLE 115. — Mineral Oils.‡

Density.	Flashing point. ° C.	Burning point. ° C.	Sp. viscosity. Water at 20° C. = 1.		
			20° C.	50° C.	100° C.
.931	243	274	–	11.30	2.9
.921	216	246	–	7.31	2.5
.906	189	208	–	3.45	1.5
.921	163	190	–	27.80	2.8
.917	132	168	–	–	2.6
.904	170	207	8.65	2.65	1.7
.891	151	182	4.77	1.86	1.3
.878	108	148	2.94	1.48	–
.855	42	45	1.65	–	–
.905	165	202	–	3.10	1.5
.894	139	270	7.60	3.60	1.3
.866	90	224	2.50	1.50	–

TABLE 116. — Oils.

Oil.	Density.	Flashing point. ° C.	Burning point. ° C.	Viscosity at 19° C., water at 19° C. = 1.
Cylinder oil . .	.917	227	274	191
Machine oil . .	.914	213	260	102
Wagon oil . .	.914	148	182	80
" " . .	.911	157	187	70
Naphtha residue	.910	134	162	55
Oleo-naphtha .	.910	219	257	121
" " .	.904	201	242	66
" " .	.894	184	222	26
Oleonid . . .	.884	185	217	28
" best quality	.881	188	224	20
Olive oil . . .	.916	–	–	22
Whale oil . .	.879	–	–	9
" " . .	.875	–	–	8

---

* This table was calculated from the table of fluidities given by Noack (Wied. Ann. vol. 27, p. 217), and shows a maximum for a solution containing about 40 per cent of alcohol. A similar result was obtained for solutions of acetic acid.

† Table 115 is from a paper by Engler in Dingler's "Poly. Jour." vol. 268, p. 76, and Table 116 is from a paper by Lamansky in the same journal, vol. 248, p. 29. The very mixed composition of these oils renders the viscosity a very uncertain quantity, neither the density nor the flashing point being a good guide to viscosity.

‡ The different groups in this table are from different residues.

Table 117.

VISCOSITY.

This table gives some miscellaneous data as to the viscosity of liquids, mostly referring to oils and paraffins. The viscosities are in C. G. S. units.

Liquid.	G. %	Coefficient of viscosity.	Temp. Cent.°	Authority.
Ammonia		0.0160	11.9	Poiseuille.
"		0.0149	14.5	"
Anisol		0.0111	20.0	Gartenmeister.
Colophonium		3×10^{16}	15.	Reiger.
Di-ethyl ether		0.00276	6.7	Thorpe, Roger.
Glycerine		42.20	2.8	Schottner.
"		25.18	8.1	"
"		13.87	14.3	"
"		8.30	20.3	"
"		4.94	26.5	"
Glycerine and water	94.46	7.437	8.5	"
" "	80.31	1.021	8.5	"
" "	64.05	0.222	8.5	"
" "	49.79	0.092	8.5	"
Glycol		0.0219	0.0	Arrhenius.
Menthol, solid		209×10^{10}	14.9	Heydweiller.
" liquid		0.069	34.9	"
Mercury*		0.0184	−20	Koch.
"		0.0170	0.0	"
"		0.0157	20.0	"
"		0.0122	100.0	"
"		0.0102	200.0	"
"		0.0093	300.0	"
Meta-cresol		0.1878	20.0	Gartenmeister.
Olive oil		0.9890	15.0	Brodmann.
Paraffins: Decane		0.0077	22.3	Bartolli & Stracciati.
Dodecane		0.0126	23.3	" "
Heptane		0.0045	24.0	" "
Hexadecane		0.0359	22.2	" "
Hexane		0.0033	23.7	" "
Nonane		0.0062	22.3	" "
Octane		0.0053	22.2	" "
Pentane		0.0026	21.0	" "
Pentadecane		0.0281	22.0	" "
Tetradecane		0.0213	21.9	" "
Tridecane		0.0155	23.3	" "
Undecane		0.0095	22.7	" "
Petroleum (Caucasian)		0.0190	17.5	Petroff.
Phenol		0.127	18.3	Scarpa.
Rape oil		25.3	0.0	O. E. Meyer.
" "		3.85	10.0	"
" "		1.63	20.0	"
" "		0.96	30.0	"

---

*Calculated from the formula $\mu = .017 - .000066t + .00000021t^2 - .00000000025t^3$ (vide Koch, Wied. Ann. vol. 14, p. 1881).

TABLE 118.

VISCOSITY.

This table gives the viscosity of a number of liquids together with their temperature variation. The headings are temperatures in Centigrade degrees, and the numbers under them the coefficients of viscosity in C. G. S. units.*

Liquid.	Temperature Centigrade.								Reference.
	0°	10°	20°	30°	40°	50°	70°	90°	
Acetates: Methyl	–	.0046	.0041	.0036	.0032	.0030	–	–	1
Ethyl	–	.0051	.0044	.0040	.0035	.0032	–	–	1
Propyl	–	.0066	.0059	.0052	.0044	.0039	–	–	1
Allyl	–	.0068	.0061	.0054	.0049	.0044	–	–	1
Amyl	–	.0106	.0089	.0077	.0065	.0058	–	–	1
Acids: Formic	–	.02262	.01804	.01465	.01224	.01025	–	–	2
Acetic	–	.0150	.0126	.0109	.0094	.0082	–	–	1
Propionic	–	.0125	.0107	.0092	.0081	.0073	–	–	3
"	–	.0139	.0118	.0101	.0091	.0080	–	–	1
Butyric	–	.0196	.0163	.0136	.0118	.0102	–	–	2
Valeric	–	.0271	.0220	.0183	.0155	.0127	–	–	3
Salicylic	–	.0320	.0271	.0222	.0181	.0150	–	–	3
Alcohol: Methyl	.00813	.00686	.00591	.00515	.00450	.00396	–	–	4
Ethyl	.01770	.01449	.01192	.00990	.00828	.00698	.00504	–	4
Propyl	.03882	.02917	.02255	.01778	.01403	.01128	.00757	.00526	4
Butyric	.05185	.03872	.02947	.02266	.01780	.01409	.00926	.00633	4
Allyl	.02144	.01703	.01361	.01165	.00911	.00760	.00548	.00407	4
Isopropyl	.04564	.03245	.02369	.01755	.01329	.01026	.00642	–	4
Isobutyl	.08038	.05547	.03906	.02863	.02121	.01609	.00973	.00633	4
Amyl (op.-inac.)	.08532	.06000	.04341	.03206	.02414	.01849	.01147	.00758	4
Aldehyde	.00267	.00244	.00222	–	–	–	–	–	3
Aniline	–	–	.0440	.0319	.0241	.0189	–	–	5
Benzole	.00902	.00759	.00649	.00562	.00492	.00437	.00351	–	4
Bromides: Ethyl	.00478	.00432	.00392	.00357	–	–	–	–	4
Propyl	.00645	.00575	.00517	.00467	.00425	.00388	.00328	–	4
Allyl	.00619	.00552	.00496	.00449	.00410	.00374	.00316	–	4
Ethylene	.02435	.02035	.01716	.01470	.01280	.01124	.00895	.00733	4
Carbon bisulphide	.00429	.00396	.00367	.00342	.00319	–	–	–	4
Carbon dioxide (liq.)	.00099	.00085	.00071	–	–	–	–	–	6
Chlorides: Propyl	.00436	.00390	.00352	.00319	.00291	–	–	–	4
Allyl	.00402	.00358	.00322	.00292	–	–	–	–	4
Ethylene	.01128	.00961	.00833	.00730	.00646	.00576	.00470	–	4
Chloroform	.00700	.00626	.00564	.00511	.00466	.00390	–	–	4
Ether	–	.0026	.0023	.0021	–	–	–	–	1
Ethylbenzole	.00874	.00758	.00666	.00592	.00529	.00477	.00394	.00330	4
Ethylsulphide	.00559	.00496	.00444	.00401	.00363	.00331	.00279	.00237	4
Iodides: Methyl	.00594	.00536	.00487	.00446	.00409	–	–	–[1]	
Ethyl	.00719	.00645	.00583	.00530	.00484	.00444	.00378	–	
Propyl	.00938	.00827	.00737	.00662	.00598	.00544	.00456	.00387	4
Allyl	.00930	.00819	.00726	.00652	.00588	.00534	.00448	.00381	4
Metaxylol	.00802	.00698	.00615	.00547	.00491	.00444	.00369	.00313	4
Nitrobenzene	–	–	.0203	.0170	.0144	.0124	–	–	1
Paraffines: Pentane	.00283	.00256	.00232	.00212	–	–	–	–	4
Hexane	.00396	.00355	.00320	.00290	.00264	.00241	.00221	–	4
Heptane	.00519	.00460	.00410	.00369	.00334	.00303	.00253	.00214	4
Octane	.00703	.00612	.00538	.00478	.00428	.00386	.00318	.00266	4
Isopentane	.00273	.00246	.00223	.00204	–	–	–	–	4
Isohexane	.00371	.00332	.00300	.00272	.00247	.00226	–	–	4
Isoheptane	.00477	.00423	.00379	.00342	.00309	.00282	.00235	.00200	4
Propyl aldehyde	–	.0047	.0041	.0036	.0033	–	–	–	1
Toluene	.00768	.00668	.00586	.00520	.00466	.00420	.00348	.00292	4

1 Pribram-Handl, Wien. Ber. 78, 1878, 80, 1879, 84, 1881.
2 Gartenmeister, Zeitschr. Phys. Chem. 6, 1890.
3 Rellstab, Diss. Bonn, 1868.
4 Thorpe-Roger, Philos. Trans. 185 A, 1894, 189 A, 1897; Proc. Roy. Soc. 55, 1894, 60, 1896; Jour. Chem. Soc. 71, 1897; Chem. News, 75, 1897.
5 Wijkander, Wied. Beibl. 3, 1879.
6 Warburg-Babo, Wied. Ann. 17, 1882.

---

* Calculated from the specific viscosities given in Landolt & Börnstein's Phys. Chem. Tab.

For inorganic acids, see Solutions.

VISCOSITY OF SOLUTIONS.

This table is intended to show the effect of change of concentration and change of temperature on the viscosity of solutions of salts in water. The specific viscosity × 100 is given for two or more densities and for several temperatures in the case of each solution. μ stands for specific viscosity, and *t* for temperature Centigrade.

Salt.	Percentage by weight of salt in solution.	Density.	μ	*t*	μ	*t*	μ	*t*	μ	*t*	Authority.
$BaCl_2$	7.60	–	77.9	10	44.0	30	35.2	50	–	–	Sprung.
“	15.40	–	86.4	“	56.0	“	39.6	“	–	–	“
“	24.34	–	100.7	“	66.2	“	47.7	“	–	–	“
$Ba(NO_3)_2$	2.98	1.027	62.0	15	51.1	25	42.4	35	34.8	45	Wagner.
“	5.24	1.051	68.1	“	54.2	“	44.1	“	36.9	“	“
$CaCl_2$	15.17	–	110.9	10	71.3	30	50.3	50	–	–	Sprung.
“	31.60	–	272.5	“	177.0	“	124.0	“	–	–	“
“	39.75	–	670.0	“	379.0	“	245.5	“	–	–	“
“	44.09	–	–	–	593.1	“	363.2	“	–	–	“
$Ca(NO_3)_2$	17.55	1.171	93.8	15	74.6	25	60.0	35	49.9	45	Wagner.
“	30.10	1.274	144.1	“	112.7	“	90.7	“	75.1	“	“
“	40.13	1.386	242.6	“	217.1	“	156.5	“	128.1	“	“
$CdCl_2$	11.09	1.109	77.5	15	60.5	25	49.1	35	40.7	45	“
“	16.30	1.181	88.9	“	70.5	“	57.5	“	47.2	“	“
“	24.79	1.320	104.0	“	80.4	“	64.6	“	53.6	“	“
$Cd(NO_3)_2$	7.81	1.074	61.9	15	50.1	25	41.1	35	34.0	45	“
“	15.71	1.159	71.8	“	58.7	“	48.8	“	41.3	“	“
“	22.36	1.241	85.1	“	69.0	“	57.3	“	47.5	“	“
$CdSO_4$	7.14	1.068	78.9	15	61.8	25	49.9	35	41.3	45	“
“	14.66	1.159	96.2	“	72.4	“	58.1	“	48.8	“	“
“	22.01	1.268	120.8	“	91.8	“	73.5	“	60.1	“	“
$CoCl_2$	7.97	1.081	83.0	15	65.1	25	53.6	35	44.9	45	“
“	14.86	1.161	111.6	“	85.1	“	73.7	“	58.8	“	“
“	22.27	1.264	161.6	“	126.6	“	101.6	“	85.6	“	“
$Co(NO_3)_2$	8.28	1.073	74.7	15	57.9	25	48.7	35	39.8	45	“
“	15.96	1.144	87.0	“	69.2	“	55.4	“	44.9	“	“
“	24.53	1.229	110.4	“	88.0	“	71.5	“	59.1	“	“
$CoSO_4$	7.24	1.086	86.7	15	68.7	25	55.0	35	45.1	45	“
“	14.16	1.159	117.8	“	95.5	“	76.0	“	61.7	“	“
“	21.17	1.240	193.6	“	146.2	“	113.0	“	89.9	“	“
$CuCl_2$	12.01	1.104	87.2	15	67.8	25	55.1	35	45.6	45	“
“	21.35	1.215	121.5	“	95.8	“	77.0	“	63.2	“	“
“	33.03	1.331	178.4	“	137.2	“	107.6	“	87.1	“	“
$Cu(NO_3)_2$	18.99	1.177	97.3	15	76.0	25	61.5	35	51.3	45	“
“	26.68	1.264	126.2	“	98.8	“	80.9	“	68.6	“	“
“	46.71	1.536	382.9	“	283.8	“	215.3	“	172.2	“	“
$CuSO_4$	6.79	1.055	79.6	15	61.8	25	49.8	35	41.4	45	“
“	12.57	1.115	98.2	“	74.0	“	59.7	“	52.0	“	“
“	17.49	1.163	124.5	“	96.8	“	75.9	“	61.8	“	“
HCl	8.14	1.037	71.0	15	57.9	25	48.3	35	40.1	45	“
“	16.12	1.084	80.0	“	66.5	“	56.4	“	48.1	“	“
“	23.04	1.114	91.8	“	79.9	“	65.9	“	56.4	“	“
$HgCl_2$	0.23	1.002	–	–	58.5	20	46.8	30	38.3	40	“
”	3.55	1.033	76.75	10	59.2	“	46.6	“	38.3	“	“

VISCOSITY OF SOLUTIONS.

Salt.	Percentage by weight of salt in solution.	Density.	μ	t	μ	t	μ	t	μ	t	Authority.
HNO_3	8.37	1.067	66.4	15	54.8	25	45.4	35	37.6	45	Wagner.
"	12.20	1.116	69.5	"	57.3	"	47.9	"	40.7	"	"
"	28.31	1.178	80.3	"	65.5	"	54.9	"	46.2	"	"
H_2SO_4	7.87	1.065	77.8	15	61.0	25	50.0	35	41.7	45	"
"	15.50	1.130	95.1	"	75.0	"	60.5	"	49.8	"	"
"	23.43	1.200	122.7	"	95.5	"	77.5	"	64.3	"	"
KCl	10.23	–	70.0	10	46.1	30	33.1	50	–	–	Sprung.
"	22.21	–	70.0	"	48.6	"	36.4	"	–	–	"
KBr	14.02	–	67.6	10	44.8	30	32.1	50	–	–	"
"	23.16	–	66.2	"	44.7	"	33.2	"	–	–	"
"	34.64	–	66.6	"	47.0	"	35.7	"	–	–	"
KI	8.42	–	69.5	10	44.0	30	31.3	50	–	–	"
"	17.01	–	65.3	"	42.9	"	31.4	"	–	–	"
"	33.03	–	61.8	"	42.9	"	32.4	"	–	–	"
"	45.98	–	63.0	"	45.2	"	35.3	"	–	–	"
"	54.00	–	68.8	"	48.5	"	37.6	"	–	–	"
$KClO_3$	3.51	–	71.7	10	44.7	30	31.5	50	–	–	"
"	5.69	–	–	"	45.0	"	31.4	"	–	–	"
KNO_3	6.32	–	70.8	10	44.6	30	31.8	50	–	–	"
"	12.19	–	68.7	"	44.8	"	32.3	"	–	–	"
"	17.60	–	68.8	"	46.0	"	33.4	"	–	–	"
K_2SO_4	5.17	–	77.4	10	48.6	30	34.3	50	–	–	"
"	9.77	–	81.0	"	52.0	"	36.9	"	–	–	"
K_2CrO_4	11.93	–	75.8	10	62.5	30	41.0	40	–	–	"
"	19.61	–	85.3	"	68.7	"	47.9	"	–	–	"
"	24.26	1.233	97.8	"	74.5	"	54.5	"	–	–	Slotte.
"	32.78	–	109.5	"	88.9	"	62.6	"	–	–	Sprung.
$K_2Cr_2O_7$	4.71	1.032	72.6	10	55.9	20	45.3	30	37.5	40	Slotte.
"	6.97	1.049	73.1	"	56.4	"	45.5	"	37.7	"	"
$LiCl$	7.76	–	96.1	10	59.7	30	41.2	50	–	–	Sprung.
"	13.91	–	121.3	"	75.9	"	52.6	"	–	–	"
"	26.93	–	229.4	"	142.1	"	98.0	"	–	–	"
$Mg(NO_3)_2$	18.62	1.102	99.8	15	81.3	25	66.5	35	56.2	45	Wagner.
"	34.19	1.200	213.3	"	164.4	"	132.4	"	109.9	"	"
"	39.77	1.430	317.0	"	250.0	"	191.4	"	158.1	"	"
$MgSO_4$	4.98	–	96.2	10	59.0	30	40.9	50	–	–	Sprung.
"	9.50	–	130.9	"	77.7	"	53.0	"	–	–	"
"	19.32	–	302.2	"	166.4	"	106.0	"	–	–	"
$MgCrO_4$	12.31	1.089	111.3	10	84.8	20	67.4	30	55.0	40	Slotte.
"	21.86	1.164	167.1	"	125.3	"	99.0	"	79.4	"	"
"	27.71	1.217	232.2	"	172.6	"	133.9	"	106.6	"	"
$MnCl_2$	8.01	1.096	92.8	15	71.1	25	57.5	35	48.1	45	Wagner.
"	15.65	1.196	130.9	"	104.2	"	84.0	"	68.7	"	"
"	30.33	1.337	256.3	"	193.2	"	155.0	"	123.7	"	"
"	40.13	1.453	537.3	"	393.4	"	300.4	"	246.5	"	"

VISCOSITY OF SOLUTIONS.

Salt.	Percentage by weight of salt in solution.	Density.	μ	t	μ	t	μ	t	μ	t	Authority.
$Mn(NO_3)_2$	18.31	1.148	96.0	15	76.4	25	64.5	35	55.6	45	Wagner.
“	29.60	1.323	167.5	“	126.0	“	104.6	“	88.6	“	“
“	49.31	1.506	396.8	“	301.1	“	221.0	“	188.8	“	“
$MnSO_4$	11.45	1.147	129.4	15	98.6	25	78.3	35	63.4	45	“
“	18.80	1.251	228.6	“	172.2	“	137.1	“	107.4	“	“
“	22.08	1.306	661.8	“	474.3	“	347.9	“	266.8	“	“
NaCl	7.95	–	82.4	10	52.0	30	31.8	50	–	–	Sprung.
“	14.31	–	94.8	“	60.1	“	36.9	“	–	–	“
“	23.22	–	128.3	“	79.4	“	47.4	“	–	–	“
NaBr	9.77	–	75.6	10	48.7	30	34.4	50	–	–	“
“	18.58	–	82.6	“	53.5	“	38.2	“	–	–	“
“	27.27	–	95.9	“	61.7	“	43.8	“	–	–	“
NaI	8.83	–	73.1	10	46.0	30	32.4	50	–	–	“
“	17.15	–	73.8	“	47.4	“	33.7	“	–	–	“
“	35.69	–	86.0	“	55.7	“	40.6	“	–	–	“
“	55.47	–	157.2	“	96.4	“	66.9	“	–	–	“
$NaClO_3$	11.50	–	78.7	10	50.0	30	35.3	50	–	–	“
“	20.59	–	88.9	“	56.8	“	40.4	“	–	–	“
“	33.54	–	121.0	“	75.7	“	53.0	“	–	–	“
$NaNO_3$	7.25	–	75.6	10	47.9	30	33.8	50	–	–	“
“	12.35	–	81.2	“	51.0	“	36.1	“	–	–	“
“	18.20	–	87.0	“	55.9	“	39.3	“	–	–	“
“	31.55	–	121.2	“	76.2	“	53.4	“	–	–	“
Na_2SO_4	4.98	–	96.2	10	59.0	30	40.9	50	–	–	“
“	9.50	–	130.9	“	77.7	“	53.0	“	–	–	“
“	14.03	–	187.9	“	107.4	“	71.1	“	–	–	“
“	19.32	–	302.2	“	166.4	“	106.0	“	–	–	“
Na_2CrO_4	5.76	1.058	85.8	10	66.6	20	53.4	30	43.8	40	Slotte.
“	10.62	1.112	103.3	“	79.3	“	63.5	“	52.3	“	“
“	14.81	1.164	127.5	“	97.1	“	77.3	“	63.0	“	“
NH_4Cl	3.67	–	71.5	10	45.0	30	31.9	50	–	–	Sprung.
“	8.67	–	69.1	“	45.3	“	32.6	“	–	–	“
“	15.68	–	67.3	“	46.2	“	34.0	“	–	–	“
“	23.37	–	67.4	“	47.7	“	36.1	“	–	–	“
NH_4Br	15.97	–	65.2	10	43.2	30	31.5	50	–	–	“
“	25.33	–	62.6	“	43.3	“	32.2	“	–	–	“
“	36.88	–	62.4	“	44.6	“	34.3	“	–	–	“
NH_4NO_3	5.97	–	69.6	10	44.3	30	31.6	50	–	–	“
“	12.19	–	66.8	“	44.3	“	31.9	“	–	–	“
“	27.08	–	67.0	“	47.7	“	34.9	“	–	–	“
“	37.22	–	71.7	“	51.2	“	38.8	“	–	–	“
“	49.83	–	81.1	“	63.3	“	48.9	“	–	–	“
$(NH_4)_2SO_4$	8.10	–	107.9	10	52.3	30	37.0	50	–	–	“
“	15.94	–	120.2	“	60.4	“	43.2	“	–	–	“
“	25.51	–	148.4	“	74.8	“	54.1	“	–	–	“

VISCOSITY OF SOLUTIONS.

Salt.	Percentage by weight of salt in solution.	Density.	μ	t	μ	t	μ	t	μ	t	Authority.
$(NH_4)_2CrO_4$	10.52	1.063	79.3	10	62.4	20	–	–	42.4	40	Slotte.
"	19.75	1.120	88.2	"	70.0	"	57.8	30	48.4	–	"
"	28.04	1.173	101.1	"	80.7	"	60.8	"	56.4	–	"
$(NH_4)_2Cr_2O_7$	6.85	1.039	72.5	10	56.3	20	45.8	30	38.0	40	"
"	13.00	1.078	72.6	"	57.2	"	46.8	"	39.1	"	"
"	19.93	1.126	77.6	"	58.8	"	48.7	"	40.9	"	"
$NiCl_2$	11.45	1.109	90.4	15	70.0	25	57.5	35	48.2	45	Wagner.
"	22.69	1.226	140.2	"	109.7	"	87.8	"	72.7	"	"
"	30.40	1.337	229.5	"	171.8	"	139.2	"	111.9	"	"
$Ni(NO_3)_2$	16.49	1.136	90.7	15	70.1	25	57.4	35	48.9	45	"
"	30.01	1.278	135.6	"	105.9	"	85.5	"	70.7	"	"
"	40.95	1.388	222.6	"	169.7	"	128.2	"	152.4	"	"
$NiSO_4$	10.62	1.092	94.6	15	73.5	25	60.1	35	49.8	45	"
"	18.19	1.198	154.9	"	119.9	"	99.5	"	75.7	"	"
"	25.35	1.314	298.5	"	224.9	"	173.0	"	152.4	"	"
$Pb(NO_3)_2$	17.93	1.179	74.0	15	59.1	25	48.5	35	40.3	45	"
"	32.22	1.362	91.8	"	72.5	"	59.6	"	50.6	"	"
$Sr(NO_3)_2$	10.29	1.088	69.3	15	56.0	25	45.9	35	39.1	45	"
"	21.19	1.124	87.3	"	69.2	"	57.8	"	48.1	"	"
"	32.61	1.307	116.9	"	93.3	"	76.7	"	62.3	"	"
$ZnCl_2$	15.33	1.146	93.6	15	72.7	25	57.8	35	48.2	45	"
"	23.49	1.229	111.5	"	86.6	"	69.8	"	57.5	"	"
"	33.78	1.343	151.7	"	117.9	"	90.0	"	72.6	"	"
$Zn(NO_3)_2$	15.95	1.115	80.7	15	64.3	25	52.6	35	43.8	45	"
"	30.23	1.229	104.7	"	85.7	"	69.5	"	57.7	"	"
"	44.50	1.437	167.9	"	130.6	"	105.4	"	87.9	"	"
$ZnSO_4$	7.12	1.106	97.1	15	79.3	25	62.7	35	51.5	45	"
"	16.64	1.195	156.0	"	118.6	"	94.2	"	73.5	"	"
"	23.09	1.281	232.8	"	177.4	"	135.2	"	108.1	"	"

Table 120.

SPECIFIC VISCOSITY.*

Dissolved salt.	Normal solution.		½ normal.		¼ normal.		⅛ normal.		Authority.
	Density.	Specific viscosity.	Density.	Specific viscosity.	Density.	Specific viscosity.	Density.	Specific viscosity.	
Acids : Cl_2O_3	1.0562	1.012	1.0283	1.003	1.0143	1.000	1.0074	0.999	Reyher.
HCl	1.0177	1.067	1.0092	1.034	1.0045	1.017	1.0025	1.009	“
$HClO_3$	1.0485	1.052	1.0244	1.025	1.0126	1.014	1.0064	1.006	“
HNO_3	1.0332	1.027	1.0168	1.011	1.0086	1.005	1.0044	1.003	“
H_2SO_4	1.0303	1.090	1.0154	1.043	1.0074	1.022	1.0035	1.008	Wagner.
Aluminium sulphate	1.0550	1.406	1.0278	1.178	1.0138	1.082	1.0068	1.038	“
Barium chloride	1.0884	1.123	1.0441	1.057	1.0226	1.026	1.0114	1.013	“
“ nitrate	–	–	1.0518	1.044	1.0259	1.021	1.0130	1.008	“
Calcium chloride	1.0446	1.156	1.0218	1.076	1.0105	1.036	1.0050	1.017	“
“ nitrate	1.0596	1.117	1.0300	1.053	1.0151	1.022	1.0076	1.008	“
Cadmium chloride	1.0779	1.134	1.0394	1.063	1.0197	1.031	1.0098	1.020	“
“ nitrate	1.0954	1.165	1.0479	1.074	1.0249	1.038	1.0119	1.018	“
“ sulphate	1.0973	1.348	1.0487	1.157	1.0244	1.078	1.0120	1.033	“
Cobalt chloride	1.0571	1.204	1.0286	1.097	1.0144	1.048	1.0058	1.023	“
“ nitrate	1.0728	1.166	1.0369	1.075	1.0184	1.032	1.0094	1.018	“
“ sulphate	1.0750	1.354	1.0383	1.160	1.0193	1.077	1.0110	1.040	“
Copper chloride	1.0624	1.205	1.0313	1.098	1.0158	1.047	1.0077	1.027	“
“ nitrate	1.0755	1.179	1.0372	1.080	1.0185	1.040	1.0092	1.018	“
“ sulphate	1.0790	1.358	1.0402	1.160	1.0205	1.080	1.0103	1.038	“
Lead nitrate	1.1380	1.101	0.0699	1.042	1.0351	1.017	1.0175	1.007	“
Lithium chloride	1.0243	1.142	1.0129	1.066	1.0062	1.031	1.0030	1.012	“
“ sulphate	1.0453	1.290	1.0234	1.137	1.0115	1.065	1.0057	1.032	“
Magnesium chloride	1.1375	1.201	1.0188	1.094	1.0091	1.044	1.0043	1.021	“
“ nitrate	1.0512	1.171	1.0259	1.082	1.0130	1.040	1.0066	1.020	“
“ sulphate	1.0584	1.367	1.0297	1.164	1.0152	1.078	1.0076	1.032	“
Manganese chloride	1.0513	1.209	1.0259	1.098	1.0125	1.048	1.0063	1.023	“
“ nitrate	1.0690	1.183	1.0349	1.087	1.0174	1.043	1.0093	1.023	“
“ sulphate	1.0728	1.364	1.0365	1.169	1.0179	1.076	1.0087	1.037	“
Nickel chloride	1.0591	1.205	1.0308	1.097	1.0144	1.044	1.0067	1.021	“
“ nitrate	1.0755	1.180	1.0381	1.084	1.0192	1.042	1.0096	1.019	“
“ sulphate	1.0773	1.361	1.0391	1.161	1.0198	1.075	1.0017	1.032	“
Potassium chloride	1.0466	0.987	1.0235	0.987	1.0117	0.990	1.0059	0.993	“
“ chromate	1.0935	1.113	1.0475	1.053	1.0241	1.022	1.0121	1.012	“
“ nitrate	1.0605	0.975	1.0305	0.982	1.0161	0.987	1.0075	0.992	“
“ sulphate	1.0664	1.105	1.0338	1.049	1.0170	1.021	1.0084	1.008	“
Sodium chloride	1.0401	1.097	1.0208	1.047	1.0107	1.024	1.0056	1.013	Reyher.
“ bromide	1.0786	1.064	1.0396	1.030	1.0190	1.015	1.0100	1.008	“
“ chlorate	1.0710	1.090	1.0359	1.042	1.0180	1.022	1.0092	1.012	“
“ nitrate	1.0554	1.065	1.0281	1.026	1.0141	1.012	1.0071	1.007	“
Silver nitrate	1.1386	1.058	1.0692	1.020	1.0348	1.006	1.0173	1.000	Wagner.
Strontium chloride	1.0676	1.141	1.0336	1.067	1.0171	1.034	1.0084	1.014	“
“ nitrate	1.0822	1.115	1.0419	1.049	1.0208	1.024	1.0104	1.011	“
Zinc chloride	1.0590	1.189	1.0302	1.096	1.0152	1.053	1.0077	1.024	“
“ nitrate	1.0758	1.164	1.0404	1.086	1.0191	1.039	1.0096	1.019	“
“ sulphate	1.0792	1.367	1.0402	1.173	1.0198	1.082	1.0094	1.036	“

---

* In the case of solutions of salts it has been found (*vide* Arrhennius, Zeits. für Phys. Chem. vol. 1, p. 285) that the specific viscosity can, in many cases, be nearly expressed by the equation $\mu = \mu_1{}^n$, where μ_1 is the specific viscosity for a normal solution referred to the solvent at the same temperature, and n the number of gramme molecules in the solution under consideration. The same rule may of course be applied to solutions stated in percentages instead of gramme molecules. The table here given has been compiled from the results of Reyher (Zeits. für Phys. Chem. vol. 2, p. 749) and of Wagner (Zeits. für Phys. Chem. vol. 5, p. 31) and illustrates this rule. The numbers are all for 25° C.

TABLE 121.—VISCOSITY OF GASES AND VAPORS.

The values of μ given in the table are 10^6 times the coefficients of viscosity in C. G. S. units.

Substance.	Temp. ° C.	μ.	Reference.	Substance.	Temp. ° C.	μ.	Reference.
Acetone	18.0	78.	1	Chloroform	0.0	95.9	1
Air	-21.4	163.9	2	"	17.4	102.9	"
"	0.0	173.3	"	"	61.2	189.0	3
"	15.0	180.7	"	Ether	0.0	68.9	1
"	99.1	220.3	"	"	16.1	73.2	"
"	182.4	255.9	"	"	36.5	79.3	"
"	302.0	299.3	"	Ethyl iodide	72.3	216.0	3
Alcohol: Methyl	66.8	135.	3	Helium	0.0	189.1	5
" Ethyl	78.4	142.	"	"	15.3	196.9	"
" Propyl, norm.	97.4	142.	"	"	66.6	234.8	"
" Isopropyl	82.8	162.	"	"	184.6	269.9	"
" Butyl, norm.	116.9	143.	"	Hydrogen	-20.6	81.9	2
" Isobutyl	108.4	144.	"	"	15.0	88.9	"
" Tert. butyl	82.9	160.	"	"	99.2	105.9	"
Ammonia	0.0	96.	4	"	182.4	121.5	"
"	20.0	108.	"	"	302.0	139.2	"
Argon	0.0	210.4	5	Mercury	270.0	489.*	8
"	14.7	220.8	"	"	300.0	532.*	"
"	17.9	224.1	"	"	330.0	582.*	"
"	99.7	273.3	"	"	360.0	627.*	"
"	183.7	322.1	"	"	390.0	671.*	"
Benzole	19.0	79.	6	Methane	20.0	120.1	4
"	100.0	118.	"	Methyl iodide	44.0	232.	3
Carbon bisulphide	16.9	92.4	1	" chloride	15.0	105.2	2
" dioxide	-20.7	129.4	2	" "	302.0	213.9	"
" "	15.0	145.7	"	Nitrogen	-21.5	156.3	7
" "	99.1	186.1	"	"	10.9	170.7	"
" "	182.4	222.1	"	"	53.5	189.4	"
" "	302.0	268.2	"	Oxygen	15.4	195.7	"
" monoxide	0.0	163.0	4	"	53.5	215.9	"
" "	20.0	184.0	"	Water vapor	0.0	90.4	1
Chlorine	0.0	128.7	"	" "	16.7	96.7	"
"	20.0	147.0	"	" "	100.0	132.0	9

1 Puluj, Wien. Ber. 69, (2), 1874.
2 Breitenbach, Ann. Phys. 5, 1901.
3 Steudel, Wied. Ann. 16, 1882.
4 Graham, Philos. Trans. Lond. 1846, III.
5 Schultze, Ann. Phys. (4), 5, 6, 1901.
6 Schumann, Wied. Ann. 23, 1884.
7 Obermayer, Wien. Ber. 71, (2a), 1875.
8 Koch, Wied. Ann. 14, 1881, 19, 1883.
9 Meyer-Schumann, Wied. Ann. 13, 1881.

* The values here given were calculated from Koch's table (Wied. Ann. vol. 19, p. 869) by the formula $\mu = 489 [1 + 746 (t-270)]$.

TABLE 122.—VISCOSITY OF AIR. 20.2°C.

Holman, Phil. Mag. 1886	1.810×10^{-4}	Markowski, ditto. 1904	1.835×10^{-4}
Fischer, Phys. Rev. 1909	1.807	Tanzler, Ver. D. Phys. G. 1906	1.836
Grindlay, Gibson, Pr. Roy. Soc. 1908	1.809	Tomlinson, Phil. Trans. 1886	1.811 1.812
Rankine, ditto. 1910	1.814		1.812
Rapp, unpublished	1.810	Hogg, Am. Acad. Proc. 1905	1.808
Breitenbach, Wied. Ann. 1899	1.833	Gilchrist	1.812
Schultze, Ann. der Phys. 1901	1.837		

The viscosity of air at 20.2° may be taken as 1.812×10^{-4} within a probable error of less than 0.2 per cent. Its variation with the temperature may be obtained from Holman's formula $= 1715.50 \times 10^{-7} (1 + 0.00275t - 0.00000034t^2)$. See Phys. Rev. 1913, p. 124, where full references may be obtained.

TABLE 123.

COEFFICIENT OF VISCOSITY OF GASES.

Temperature Coefficients.

If μ_t = the viscosity at $t°$ C., μ_0 = the vicosity at 0°, α = the coefficient of expansion, β, γ, and n = coefficients independent of t, then

(I) $\mu_t = \mu_0(1+\alpha t)^n$. (Meyer, Obermayer, Puluj, Breitenbach.)

(II) $= \mu_0(1+\beta t)$. (Meyer, Obermayer.)

(III) $= \mu_0(1+\alpha t)^{\frac{1}{2}}(1+\gamma t)^2$. (Schumann.)

(IV) $$= \mu_0 \frac{1+\frac{C}{273}}{1+\frac{C}{T}} \sqrt{1+\frac{t}{273}}.$$ (Sutherland.)

Gas.	$\mu_0 10^7$.	a.	Constants.	Range ° C.	Reference.
Air*	–	0.003665	$n=0.77$	0–100	1
"	1733.1	.003665	$C=119.4$	–	2
"	1811.	–	$n=0.7675$	15.0–99.7	3
"	2208.	–	$n=0.7544$	99.7–182.9	"
"	–	–	$n=0.754$; $C=111.3$	–	4
Argon	–	–	$n=0.815$; $C=150.2$	15–100	4
"	2208.	–	$n=0.8227$, $C=169.9$	14.7–99.7	3
"	2733.	–	$n=0.8119$	99.7–183.7	3
Benzole	698.4	.004	$\gamma=0.00185$	18.7–100	5
Carbon dioxide	1387.9	–	$C=239.7$	–	6
" "	1497.2	.003701	$\gamma=0.000889$	12.8–100	5
" "	1382.1	.003701	$\beta=0.00348$; $n=0.941$	−21.5–53.5	7
" monoxide	1625.2	.003665	$\beta=0.00269$; $n=0.738$	17.5–53.5	"
Ether	689.	.004158	$n=0.94$	0–36.5	8
Ethylene	961.3	–	$C=225.9$	–	6
"	922.2	.003665	$\beta=0.00350$; $n=0.958$	−21.5–53.5	7
" chloride	889.03	.003900	$\beta=0.00381$; $n=0.9772$	15.6–157.3	"
Helium	–	–	$n=0.681$; $C=72.2$	0–15.0	4
"	1969.	–	$n=0.6852$; $C=80.3$	15.3–99.6	3
"	2348.	–	$n=0.6771$	99.6–184.6	3
Hydrogen	857.4	.00366	$C=71.7$	–	2
"	–	–	$n=0.681$; $C=72.2$	–	4
Mercury	1620.	.003665	$n=1.6$	273–380	10
Nitrogen	1658.6	.003665	$\beta=0.00269$; $n=0.738$	−21.5–53.5	7
Nitrous oxide	1353.3	.003719	$\beta=0.00345$; $n=0.929$	−21.5–100.3	"
Oxygen	–	–	$n=0.782$; $C=128.2$	–	4

1 Holman, Proc. Amer. Acad. 12, 1876; 21, 1885; Philos. Mag. (5) 3, 1877; 21, 1886.
2 Breitenbach, Wied. Ann. 5, 1901.
3 Schultze, Ann. Phys. (4) 5, 1901.
4 Rayleigh, Proc. Roy. Soc. 62, 1897; 66, 1900; 67, 1900.
5 Schumann, Wied. Ann. 23, 1884.
6 Breitenbach, Ann. Phys. 5, 1901.
7 Obermayer, Wien. Ber. 73 (2A), 1876.
8 Puluj, Wien. Ber. 78 (2), 1878.
9 Schultze, Ann Phys. (4) 6, 1901.
10 Koch, Wied. Ann. 19, 1883.

* See Table 122 for viscosity of air.

Compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.

TABLE 124.

DIFFUSION OF AN AQUEOUS SOLUTION INTO PURE WATER.

If k is the coefficient of diffusion, dS the amount of the substance which passes in the time dt, at the place x, through q sq. cm. of a diffusion cylinder under the influence of a drop of concentration dc/dx, then

$$dS = -kq \frac{dc}{dx} dt.$$

k depends on the temperature and the concentration. c gives the gram-molecules per liter. The unit of time is a day.

Substance.	c	$t°$	k	Reference	Substance.	c	$t°$	k	Reference.
Bromine	0.1	12.	0.8	1	Calcium chloride	0.864	8.5	0.70	4
Chlorine	“	12.	1.22	“	“ “	1.22	9.	0.72	“
Copper sulphate	“	17.	0.39	2	“ “	0.060	9.	0.64	“
Glycerine	“	10.14	0.357	3	“ “	0.047	9.	0.68	“
Hydrochloric acid	“	19.2	2.21	2	Copper sulphate	1.95	17.	0.23	2
Iodine	“	12.	(0.5)	1	“ “	0.95	17.	0.26	“
Nitric acid	“	19.5	2.07	2	“ “	0.30	17.	0.33	“
Potassium chloride	“	17.5	1.38	2	“ “	0.005	17.	0.47	“
“ hydrate	“	13.5	1.72	2	Glycerine	2/8	10.14	0.354	3
Silver nitrate	“	12.	0.985	2	“	6/8	10.14	0.345	“
Sodium chloride	“	15.0	0.94	2	“	10/8	10.14	0.329	“
Urea	“	14.8	0.97	3	“	14/8	10.14	0.300	“
Acetic acid	0.2	13.5	0.77	4	Hydrochloric acid	4.52	11.5	2.93	4
Barium chloride	“	8.	0.66	4	“ “	3.16	11.	2.67	“
Glycerine	“	10.1	3.55	3	“ “	0.945	11.	2.12	“
Sodium actetate	“	12.	0.67	5	“ “	0.387	11.	2.02	“
“ chloride	“	15.0	0.94	2	“ “	0.250	11.	1.84	“
Urea	“	14.8	0.969	3	Magnesium sulphate	2.18	5.5	0.28	4
Acetic acid	1.0	12.	0.74	6	“ “	0.541	5.5	0.32	“
Ammonia	“	15.23	1.54	7	“ “	3.23	10.	0.27	“
Formic acid	“	12.	0.97	7	“ “	0.402	10.	0.34	“
Glycerine	“	10.14	0.339	3	Potassium hydrate	0.75	12.	1.72	6
Hydrochloric acid	“	12.	2.09	6	“ “	0.49	12.	1.70	“
Magnesium sulphate	“	7.	0.30	4	“ “	0.375	12.	1.70	“
Potassium bromide	“	10.	1.13	8	“ nitrate	3.9	17.6	0.89	2
“ hydrate	“	12.	1.72	6	“ “	1.4	17.6	1.10	“
Sodium chloride	“	15 0	0.94	2	“ “	0.3	17.6	1.26	“
“ “	“	14.3	0.964	3	“ “	0.02	17.6	1.28	“
“ hydrate	“	12.	1.11	2	“ sulphate	0.95	19.6	0.79	“
“ iodide	“	10.	0.80	8	“ “	0.28	19.6	0.86	“
Sugar	“	12.	0.254	6	“ “	0.05	19.6	0.97	“
Sulphuric acid	“	12.	1.12	6	“ “	0.02	19.6	1.01	“
Zinc sulphate	“	14.8	0.236	9	Silver nitrate	3.9	12.	0.535	“
Acetic acid	2.0	12.	0.69	6	“ “	0.9	12.	0.88	“
Calcium chloride	“	10.	0.68	8	“ “	0.02	12.	1.035	“
Cadmium sulphate	“	19.04	0.246	9	Sodium chloride	2/8	14.33	1.013	3
Hydrochloric acid	“	12.	2.21	6	“ “	4/8	14.33	0.996	“
Sodium iodide	“	10.	0.90	8	“ “	6/8	14.33	0.980	2
Sulphuric acid	“	12.	1.16	6	“ “	10/8	14.33	0.948	“
Zinc acetate	“	18.05	0.210	9	“ “	14/8	14.33	0.917	“
“ “	“	0.04	0.120	9	Sulphuric acid	9.85	18.	2.36	2
Acetic acid	3.0	12.	0.68	–	“ “	4.85	18.	1.90	“
Potassium carbonate	“	10.	0.60	8	“ “	2.85	18.	1.60	“
“ hydrate	“	12.	1.89	6	“ “	0.85	18.	1.34	“
Acetic acid	4.0	12.	0.66	6	“ “	0.35	18.	1.32	“
Potassium chloride	“	10.	1.27	8	“ “	0.005	18.	1.30	“

1 Euler, Wied. Ann. 63, 1897.
2 Thovert, C. R. 133, 1901; 134, 1902.
3 Heimbrodt, Diss. Leipzig, 1903.
4 Scheffer, Chem. Ber. 15, 1882; 16, 1883; Zeitschr. Phys Chem. 2, 1888.
5 Kawalki, Wied. Ann. 52, 1894; 59, 1896.
6 Arrhenius, Zeitschr. Phys. Chem. 10, 1892.
7 Abegg, Zeitschr. Phys. Chem. 11, 1893.
8 Schuhmeister, Wien. Ber. 79 (2), 1879.
9 Seitz, Wied. Ann. 64, 1898.

Compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.

TABLE 125.

DIFFUSION OF VAPORS.

Coefficients of diffusion of vapors in C. G. S. units. The coefficients are for the temperatures given in the table and a pressure of 76 centimeters of mercury.*

Vapor.	Temp. C. °	k_T for vapor diffusing into hydrogen.	k_T for vapor diffusing into air.	k_T for vapor diffusing into carbon dioxide.
Acids: Formic	0.0	0.5131	0.1315	0.0879
“	65.4	0.7873	0.2035	0.1343
“	84.9	0.8830	0.2244	0.1519
Acetic	0.0	0.4040	0.1061	0.0713
“	65.5	0.6211	0.1578	0.1048
“	98.5	0.7481	0.1965	0.1321
Isovaleric	0.0	0.2118	0.0555	0.0375
“	98.0	0.3934	0.1031	0.0696
Alcohols: Methyl	0.0	0.5001	0.1325	0.0880
“	25.6	0.6015	0.1620	0.1046
“	49.6	0.6738	0.1809	0.1234
Ethyl	0.0	0.3806	0.0994	0.0693
“	40.4	0.5030	0.1372	0.0898
“	66.9	0.5430	0.1475	0.1026
Propyl	0.0	0.3153	0.0803	0.0577
“	66.9	0.4832	0.1237	0.0901
“	83.5	0.5434	0.1379	0.0976
Butyl	0.0	0.2716	0.0681	0.0476
“	99.0	0.5045	0.1265	0.0884
Amyl	0.0	0.2351	0.0589	0.0422
“	99.1	0.4362	0.1094	0.0784
Hexyl	0.0	0.1998	0.0499	0.0351
“	99.0	0.3712	0.0927	0.0651
Benzene	0.0	0.2940	0.0751	0.0527
“	19.9	0.3409	0.0877	0.0609
“	45.0	0.3993	0.1011	0.0715
Carbon disulphide	0.0	0.3690	0.0883	0.0629
“ “	19.9	0.4255	0.1015	0.0726
“ “	32.8	0.4626	0.1120	0.0789
Esters: Methyl acetate	0.0	0.3277	0.0840	0.0557
“ “	20.3	0.3928	0.1013	0.0679
Ethyl “	0.0	0.2373	0.0630	0.0450
“ “	46.1	0.3729	0.0970	0.0666
Methyl butyrate	0.0	0.2422	0.0640	0.0438
“ “	92.1	0.4308	0.1139	0.0809
Ethyl “	0.0	0.2238	0.0573	0.0406
“ “	96.5	0.4112	0.1064	0.0756
“ valerate	0.0	0.2050	0.0505	0.0366
“ “	97.6	0.3784	0.0932	0.0676
Ether	0.0	0.2960	0.0775	0.0552
“	19.9	0.3410	0.0893	0.0636
Water	0.0	0.6870	0.1980	0.1310
“	49.5	1.0000	0.2827	0.1811
“	92.4	1.1794	0.3451	0.2384

---

* Taken from Winkelmann's papers (Wied. Ann. vols. 22, 23, and 26). The coefficients for 0° were calculated by Winkelmann on the assumption that the rate of diffusion is proportional to the absolute temperature. According to the investigations of Loschmidt and of Obermeyer the coefficient of diffusion of a gas, or vapor, at 0° C. and a pressure of 76 centimetres of mercury may be calculated from the observed coefficient at another temperature and pressure by the formula $k_0 = k_T \left(\frac{T_0}{T}\right)^n \frac{76}{p}$, where T is temperature absolute and p the pressure of the gas. The exponent n is found to be about 1.75 for the permanent gases and about 2 for condensible gases. The following are examples: Air — CO_2, $n = 1.968$; CO_2 — N_2O, $n = 2.05$; CO_2 — H, $n = 1.742$; CO — O, $n = 1.785$; H — O, $n = 1.755$; O — N, $n = 1.792$. Winkelmann's results, as given in the above table, seem to give about 2 for vapors diffusing into air, hydrogen or carbon dioxide.

DIFFUSION OF GASES, VAPORS, AND METALS.

TABLE 126. — Coefficients of Diffusion for Various Gases and Vapors.*

Gas or Vapor diffusing.	Gas or Vapor diffused into.	Temp. ° C.	Coefficient of Diffusion.	Authority.
Air	Hydrogen	0	0.661	Schulze.
"	Oxygen	0	0.1775	Obermayer.
Carbon dioxide	Air	0	0.1423	Loschmidt.
" "	"	0	0.1360	Waitz.
" "	Carbon monoxide	0	0.1405	Loschmidt.
" "	" "	0	0.1314	Obermayer.
" "	Hydrogen	0	0.5437	"
" "	Methane	0	0.1465	"
" "	Nitrous oxide	0	0.0983	Loschmidt.
" "	Oxygen	0	0.1802	"
Carbon disulphide	Air	0	0.0995	Stefan.
Carbon monoxide	Carbon dioxide	0	0.1314	Obermayer.
" "	Ethylene	0	0.101	"
" "	Hydrogen	0	0.6422	Loschmidt.
" "	Oxygen	0	0.1802	"
" "	"	0	0.1872	Obermayer.
Ether	Air	0	0.0827	Stefan.
"	Hydrogen	0	0.3054	"
Hydrogen	Air	0	0.6340	Obermayer.
"	Carbon dioxide	0	0.5384	"
"	" monoxide	0	0.6488	"
"	Ethane	0	0.4593	"
"	Ethylene	0	0.4863	"
"	Methane	0	0.6254	"
"	Nitrous oxide	0	0.5347	"
"	Oxygen	0	0.6788	"
Nitrogen	"	0	0.1787	"
Oxygen	Carbon dioxide	0	0.1357	"
"	Hydrogen	0	0.7217	Loschmidt.
"	Nitrogen	0	0.1710	Obermayer.
Sulphur dioxide	Hydrogen	0	0.4828	Loschmidt.
Water	Air	8	0.2390	Guglilemo.
"	"	18	0.2475	"
"	Hydrogen	18	0.8710	"

* Compiled for the most part from a similar table in Landolt & Börnstein's Phys. Chem. Tab.

TABLE 127. — Diffusion of Metals into Metals.

$\frac{dv}{dt} = k\frac{d^2v}{dx^2}$; where x is the distance in direction of diffusion; v, the degree of concentration of the diffusing metal; t, the time; k, the diffusion constant = the quantity of metal in grams diffusing through a sq. cm. in a day when unit difference of concentration (gr. per cu. cm.) is maintained between two sides of a layer one cm. thick.

Diffusing Metal.	Dissolving Metal.	Temperature ° C.	*k*.	Diffusing Metal.	Dissolving Metal.	Temperature ° C.	*k*.
Gold	Lead	555	3.19	Platinum	Lead	492	1.69
"	"	492	3.00	Lead	Tin	555	3.18
"	"	251	0.03	Rhodium	Lead	550	3.04
"	"	200	0.008	Tin	Mercury	15	1.22*
"	"	165	0.004	Lead	"	15	1.0*
"	"	100	0.00002	Zinc	"	15	1.0*
"	Bismuth	555	4.52	Sodium	"	15	0.45*
"	Tin	555	4.65	Potassium	"	15	0.40*
Silver	"	555	4.14	Gold	"	15	0.72*

From Roberts-Austen, Philosophical Transactions, 187A, p. 383, 1896.

* These values are from Guthrie.

TABLE 128.

SOLUBILITY OF INORGANIC SALTS IN WATER; VARIATION WITH THE TEMPERATURE.

The numbers give the number of grams of the *anhydrous* salt soluble in 1000 grams of water at the given temperatures.

Salt.	Temperature Centigrade.										
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
$AgNO_3$	1150	1600	2150	2700	3350	4000	4700	5500	6500	7600	9100
$Al_2(SO_4)_3$	313	335	362	404	457	521	591	662	731	808	891
$Al_2K_2(SO_4)_4$	30	–	–	84	–	–	248	–	–	–	1540
$Al_2(NH_4)_2(SO_4)_4$	26	45	66	91	124	159	211	270	352	–	–
B_2O_3	11	15	22	–	40	–	62	–	95	–	157
$BaCl_2$	316	333	357	382	408	436	464	494	524	556	588
$Ba(NO_3)_2$	50	70	92	116	142	171	203	236	270	306	342
$CaCl_2$	595	650	745	1010	1153	–	1368	1417	1470	1527	1590
$CoCl_2$	405	450	500	565	650	935	940	950	960	–	1030
$CsCl$	1614	1747	1865	1973	2080	2185	2290	2395	2500	2601	2705
$CsNO_3$	93	149	230	339	472	644	838	1070	1340	1630	1970
Cs_2SO_4	1671	1731	1787	1841	1899	1949	1999	2050	2103	2149	2203
$Cu(NO_3)_2$	818	–	1250	–	1598	–	1791	–	2078	–	–
$CuSO_4$	149	–	–	255	295	336	390	457	535	627	735
$FeCl_2$	–	–	685	–	–	820	–	–	1040	1050	1060
Fe_2Cl_6	744	819	918	–	–	3151	–	–	5258	–	5357
$FeSO_4$	156	208	264	330	402	486	550	560	506	430	–
$HgCl_2$	43	66	74	84	96	113	139	173	243	371	540
KBr	540	–	650	–	760	–	860	–	955	–	1050
K_2CO_3	1050	–	–	1140	1170	1210	1270	1330	1400	1470	1560
KCl	285	312	343	373	401	429	455	483	510	538	566
$KClO_3$	33	50	71	101	145	197	260	325	396	475	560
K_2CrO_4	589	609	629	650	670	690	710	730	751	771	791
$K_2Cr_2O_7$	50	85	131	–	292	–	505	–	730	–	1020
$KHCO_3$	225	277	332	390	453	522	600	–	–	–	–
KI	1279	1361	1442	1523	1600	1680	1760	1840	1920	2010	2090
KNO_3	133	209	316	458	639	855	1099	1380	1690	2040	2460
KOH	970	1030	1120	1260	1360	1400	1460	1510	1590	1680	1780
K_2PtCl_6	7	9	11	14	18	22	26	32	38	45	52
K_2SO_4	74	92	111	130	148	165	182	198	214	228	241
$LiOH$	127	127	128	129	130	133	138	144	153	–	175
$MgCl_2$	528	535	545	–	575	–	610	–	660	–	730
$MgSO_4$ . . (7aq)	260	309	356	409	456	–	–	–	–	–	–
“ . . (6aq)	408	422	439	453	–	504	550	596	642	689	738
NH_4Cl	297	333	372	414	458	504	552	602	656	713	773
NH_4HCO_3	119	159	210	270	–	–	–	–	–	–	–
NH_4NO_3	1183	–	–	2418	2970	3540?	4300?	5130?	5800	7400	8710
$(NH_4)_2SO_4$	706	730	754	780	810	844	880	916	953	992	1033
$NaBr$	795	845	903	–	1058	1160	1170	–	1185	–	1205
$Na_2B_4O_7$	–	16	–	39	–	105	200	244	314	408	523
Na_2CO_3 . . (10aq)	71	126	214	409	–	–	–	–	–	–	–
“ . . (7aq)	204	263	335	435	(1aq)	475	464	458	452	452	452
$NaCl$	356	357	358	360	363	367	371	375	380	385	391
$NaClO_3$	820	890	990	–	1235	–	1470	–	1750	–	2040
Na_2CrO_4	317	502	900	–	960	1050	1150	–	1240	–	1260
$Na_2Cr_2O_7$	1630	1700	1800	1970	2200	2480	2830	3230	3860	–	4330
$NaHCO_3$	69	82	96	111	127	145	164	–	–	–	–
Na_2HPO_4	25	39	93	241	639	–	–	949	–	–	988
NaI	1590	1690	1790	1900	2050	2280	2570	–	2950	–	3020
$NaNO_3$	730	805	880	962	1049	1140	1246	1360	1480	1610	1755

Compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.

SOLUBILITY OF SALTS AND GASES IN WATER.

TABLE 128 *(concluded)* — Solubility of Inorganic Salts in Water; Variation with the Temperature.

The numbers give the number of grams of the *anhydrous* salt soluble in 1000 grams of water at the given temperatures.

Salt.	Temperature Centigrade.										
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
$NaOH$	420	515	1090	1190	1290	1450	1740	-	3130	-	-
$Na_4P_2O_7$	32	39	62	99	135	174	220	255	300	-	-
Na_2SO_3	141	-	287	-	495	-	-	-	-	-	330
Na_2SO_4 (10aq)	50	90	194	400	482	468	455	445	437	429	427
" (7aq)	196	305	447	-							
$Na_2S_2O_3$	525	610	700	847	1026	1697	2067	-	2488	2542	2660
$NiCl_2$	-	600	640	680	720	760	810	-	-	-	-
$NiSO_4$	272	-	-	425	-	502	548	594	632	688	776
$PbBr_2$	5	6	8	12	15	20	24	28	33	-	48
$Pb(NO_3)_2$	365	444	523	607	694	787	880	977	1076	1174	1270
$RbCl$	770	844	911	976	1035	1093	1155	1214	1272	1331	1389
$RbNO_3$	195	330	533	813	1167	1556	2000	2510	3090	3750	4520
Rb_2SO_4	364	426	482	535	585	631	674	714	750	787	818
$SrCl_2$	442	483	539	600	667	744	831	896	924	962	1019
SnI_2	-	-	10	12	14	17	21	25	30	34	40
$Sr(NO_3)_2$	395	549	708	876	913	926	940	956	972	990	1011
$Th(SO_4)_2$ (9aq)	7	10	14	20	30	51	-	-	-	-	-
" (4aq)	-	-	-	-	40	25	16	11	-	-	-
$TlCl$	2	2	3	5	6	8	10	13	16	20	-
$TlNO_3$	39	62	96	143	209	304	462	695	1110	2000	4140
Tl_2SO_4	27	37	49	62	76	92	109	127	146	165	-
$Yb_2(SO_4)_3$	442	-	-	-	-	-	104	72	69	58	47
$Zn(NO_3)_2$	948	-	-	-	2069	-	-	-	-	-	-
$ZnSO_4$	-	-	-	-	700	768	-	890	860	920	785

TABLE 129. — Solubility of a Few Organic Salts in Water; Variation with the Temperature.

Salt.	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
$H_2(CO_2)_2$	36	53	102	159	228	321	445	635	978	1200	-
$H_2(CH_2.CO_2)_2$	28	45	69	106	162	244	358	511	708	-	1209
Tartaric acid	1150	1260	1390	1560	1760	1950	2180	2440	2730	3070	3430
Racemic "	92	140	206	291	433	595	783	999	1250	1530	1850
$K(HCO_2)$	2900	-	3350	-	3810	-	4550	-	5750	-	7900
$KH(C_4H_4O_4)$	3	4	6	9	13	18	24	32	45	57	69

TABLE 130. — Solubility of Gases in Water; Variation with the Temperature.

The table gives the weight in grams of the gas which will be absorbed in 1000 grams of water when the partial pressure of the gas plus the vapor pressure of the liquid at the given temperature equals 760 mm.

Gas.	0°	10°	20°	30°	40°	50°	60°	70°	80°
O_2	.0705	.0551	.0443	.0368	.0311	.0263	.0221	.0181	.0135
H_2	.00192	.00174	.00160	.00147	.00138	.00129	.00118	.00102	.00079
N_2	.0293	.0230	.0189	.0161	.0139	.0121	.0105	.0089	.0069
Br_2	431.	248.	148.	94.	62.	40.	28.	18.	11.
Cl_2	-	9·97	7·29	5·72	4·59	3·93	3·30	2.79	2.23
CO_2	3·35	2.32	1.69	1.26	0.97	0.76	0.58	-	-
H_2S	7.10	5·30	3·98	-	-	-	-	-	-
NH_3	987.	689.	535.	422.	-	-	-	-	-
SO_2	228.	162.	113.	78.	54.	-	-	-	-

Compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.

TABLE 131.

CHANGE OF SOLUBILITY PRODUCED BY UNIFORM PRESSURE.*

Pressure in atmospheres.	$CdSO_4 8/3H_2O$ at 25°		$ZnSO_4 \cdot 7H_2O$ at 25°		Mannite at 24.05°		NaCl at 24.05°	
	Conc. of satd. soln. gs. $CdSO_4$ per 100 gs. H_2O	Percentage change.	Conc. of satd. soln. gs. $ZnSO_4$ per 100 gs. H_2O.	Percentage change.	Conc. of satd. soln. gs. mannite per 100 gs. H_2O.	Percentage change.	Conc. of satd. soln. gs. NaCl. per 100 gs. H_2O.	Percentage change.
1	76.80	—	57.95	—	20.66	—	35.90	—
500	78.01	+ 1.57	57.87	— 0.14	21.14	+ 2.32	36.55	+ 1.81
1000	78.84	+ 2.68	57.65	— 0.52	21.40	+ 3.57	37.02	+ 3.12
1500	—	—	—	—	21.64	+ 4.72	37.36	+ 4.07

---

* E. Cohen and L. R. Sinnige, *Z. physik. Chem.* 67, p. 432, 1909; 69, p. 102, 1909. E. Cohen, K. Inouye and C. Euwen, *ibid.* 75, p. 257, 1911. These authors give a critical résumé of earlier work along this line.

TABLE 132.

ABSORPTION OF GASES BY LIQUIDS.*

Temperature Centigrade. t	ABSORPTION COEFFICIENTS, a_t, FOR GASES IN WATER.						
	Carbon dioxide. CO_2	Carbon monoxide. CO	Hydrogen. H	Nitrogen. N	Nitric oxide. NO	Nitrous oxide. N_2O	Oxygen. O
0	1.797	0.0354	0.02110	0.02399	0.0738	1.048	0.04925
5	1.450	.0315	.02022	.02134	.0646	0.8778	.04335
10	1.185	.0282	.01944	.01918	.0571	0.7377	.03852
15	1.002	.0254	.01875	.01742	.0515	0.6294	.03456
20	0.901	.0232	.01809	.01599	.0471	0.5443	.03137
25	0.772	.0214	.01745	.01481	.0432	–	.02874
30	–	.0200	.01690	.01370	.0400	–	.02646
40	0.506	.0177	.01644	.01195	.0351	–	.02316
50	–	.0161	.01608	.01074	.0315	–	.02080
100	0.244	.0141	.01600	.01011	.0263	–	.01690

Temperature Centigrade. t	Air.	Ammonia. NH_3	Chlorine. Cl	Ethylene. C_2H_4	Methane. CH_4	Hydrogen sulphide. H_2S	Sulphur dioxide. SO_2
0	0.02471	1174.6	3.036	0.2563	0.05473	4.371	79.79
5	.02179	971.5	2.808	.2153	.04889	3.965	67.48
10	.01953	840.2	2.585	.1837	.04367	3.586	56.65
15	.01795	756.0	2.388	.1615	.03903	3.233	47.28
20	.01704	683.1	2.156	.1488	.03499	2.905	39.37
25	–	610.8	1.950	–	.02542	2.604	32.79

Temperature Centigrade. t	ABSORPTION COEFFICIENTS, a_t, FOR GASES IN ALCOHOL, C_2H_5OH.								
	Carbon dioxide. CO_2	Ethylene. C_2H_4	Methane. CH_4	Hydrogen. H	Nitrogen. N	Nitric oxide. NO	Nitrous oxide. N_2O	Hydrogen sulphide. H_2S	Sulphur dioxide. SO_2
0	4.329	3.595	0.5226	0.0692	0.1263	0.3161	4.190	17.89	328.6
5	3.891	3.323	.5086	.0685	.1241	.2998	3.838	14.78	251.7
10	3.514	3.086	.4953	.0679	.1228	.2861	3.525	11.99	190.3
15	3.199	2.882	.4828	.0673	.1214	.2748	3.215	9.54	144.5
20	2.946	2.713	.4710	.0667	.1204	.2659	3.015	7.41	114.5
25	2.756	2.578	.4598	.0662	.1196	.2595	2.819	5.62	99.8

* This table contains the volumes of different gases, supposed measured at 0° C. and 76 centimeters' pressure, which unit volume of the liquid named will absorb at atmospheric pressure and the temperature stated in the first column. The numbers tabulated are commonly called the absorption coefficients for the gases in water, or in alcohol, at the temperature t and under one atmosphere of pressure. The table has been compiled from data published by Bohr & Bock, Bunsen, Carius, Dittmar, Hamberg, Henrick, Pagliano & Emo, Raoult, Schönfeld, Setschenow, and Winkler. The numbers are in many cases averages from several of these authorities.

NOTE. — The effect of increase of pressure is generally to increase the absorption coefficient. The following is approximately the magnitude of the effect in the case of ammonia in alcohol at a temperature of 23° C.:

$$\begin{cases} P = 45 \text{ cms.} & 50 \text{ cms.} \quad 55 \text{ cms.} \quad 60 \text{ cms.} \quad 65 \text{ cms.} \\ a_{23} = 69 & 74 \quad\quad 79 \quad\quad 84 \quad\quad 88 \end{cases}$$

According to Setschenow the effect of varying the pressure from 45 to 85 centimeters in the case of carbonic acid in water is very small.

CAPILLARITY.—SURFACE TENSION OF LIQUIDS.*

TABLE 133.—Water and Alcohol in Contact with Air.

Temp. C.	Surface tension in dynes per centimeter.		Temp. C.	Surface tension in dynes per centimeter.		Temp. C.	Surface tension in dynes per centimeter.
	Water.	Ethyl alcohol.		Water.	Ethyl alcohol.		Water.
0°	75.6	23.5	40°	70.0	20.0	80°	64.3
5	74.9	23.1	45	69.3	19.5	85	63.6
10	74.2	22.6	50	68.6	19.1	90	62.9
15	73.5	22.2	55	67.8	18.6	95	62.2
20	72.8	21.7	60	67.1	18.2	100	61.5
25	72.1	21.3	65	66.4	17.8	–	–
30	71.4	20.8	70	65.7	17.3	–	–
35	70.7	20.4	75	65.0	16.9	–	–

TABLE 134.—Miscellaneous Liquids in Contact with Air.

Liquid.	Temp. C.°	Surface tension in dynes per centimeter.	Authority.
Aceton	16.8	23.3	Ramsay-Shields.
Acetic acid . . .	17.0	30.2	Average of various.
Amyl alcohol . .	15.0	24.8	"
Benzole	15.0	28.8	"
Butyric acid . .	15.0	28.7	"
Carbon disulphide	20.0	30.5	Quincke.
Chloroform . .	20.0	28.3	Average of various.
Ether	20.0	18.4	"
Glycerine . . .	17.0	63.14	Hall.
Hexane	0.0	21.2	Schiff.
"	68.0	14.2	"
Mercury	18.0	520.0	Average of various.
Methyl alcohol .	15.0	24.7	"
Olive oil	20.0	34.7	"
Petroleum . . .	20.0	25.9	Magie.
Propyl alcohol .	5.8	25.9	Schiff.
" " . .	97.1	18.0	"
Toluol	15.0	29.1	"
"	109.8	18.9	"
Turpentine . . .	21.0	28.5	Average of various.

TABLE 135.—Solutions of Salts in Water.†

Salt in solution.	Density.	Temp. C.°	Tension in dynes per cm.
$BaCl_2$	1.2820	15–16	81.8
"	1.0497	15–16	77.5
$CaCl_2$	1.3511	19	95.0
"	1.2773	19	90.2
HCl	1.1190	20	73.6
"	1.0887	20	74.5
"	1.0242	20	75.3
KCl	1.1699	15–16	82.8
"	1.1011	15–16	80.1
"	1.0463	15–16	78.2
$MgCl_2$	1.2338	15–16	90.1
"	1.1694	15–16	85.2
"	1.0362	15–16	78.0
NaCl	1.1932	20	85.8
"	1.1074	20	80.5
"	1.0360	20	77.6
NH_4Cl	1.0758	16	84.3
"	1.0535	16	81.7
"	1.0281	16	78.8
$SrCl_2$	1.3114	15–16	85.6
"	1.1204	15–16	79.4
"	1.0567	15–16	77.8
K_2CO_3	1.3575	15–16	90.9
"	1.1576	15–16	81.8
"	1.0400	15–16	77.5
Na_2CO_3	1.1329	14–15	79.3
"	1.0605	14–15	77.8
"	1.0283	14–15	77.2
KNO_3	1.1263	14	78.9
"	1.0466	14	77.6
$NaNO_3$	1.3022	12	83.5
"	1.1311	12	80.0
$CuSO_4$	1.1775	15–16	78.6
"	1.0276	15–16	77.0
H_2SO_4	1.8278	15	63.0?
"	1.4453	15	79.7
"	1.2636	15	79.7
K_2SO_4	1.0744	15–16	78.0
"	1.0360	15–16	77.4
$MgSO_4$	1.2744	15–16	83.2
"	1.0680	15–16	77.8
Mn_2SO_4	1.1119	15–16	79.1
"	1.0329	15–16	77.3
$ZnSO_4$	1.3981	15–16	83.3
"	1.2830	15–16	80.7
"	1.1039	15–16	77.8

---

* This determination of the capillary constants of liquids has been the subject of many careful experiments, but the results of the different experimenters, and even of the same observer when the method of measurement is changed, do not agree well together. The values here quoted can only be taken as approximations to the actual values for the liquids in a state of purity in contact with pure air. In the case of water the values given by Lord Rayleigh from the wave length of ripples (Phil. Mag. 1890) and by Hall from direct measurement of the tension of a flat film (Phil. Mag. 1893) have been preferred, and the temperature correction has been taken as 0.141 dyne per degree centigrade. The values for alcohol were derived from the experiments of Hall above referred to and the experiments on the effect of temperature made by Timberg (Wied. Ann. vol. 30).

The authority for a few of the other values given is quoted, but they are for the most part average values derived from a large number of results published by different experimenters.

† From Volkmann (Wied. Ann. vol. 17, p. 353).

TENSION OF LIQUIDS.

TABLE 136. — Surface Tension of Liquids.*

Liquid.	Specific gravity.	Surface tension in dynes per centimeter of liquid in contact with —		
		Air.	Water.	Mercury.
Water	1.0	75.0	0.0	(392)
Mercury	13.543	513.0	392.0	0
Bisulphide of carbon	1.2687	30.5	41.7	(387)
Chloroform	1.4878	(31.8)	26.8	(415)
Ethyl alcohol	0.7906	(24.1)	–	364
Olive oil	0.9136	34.6	18.6	317
Turpentine	0.8867	28.8	11.5	241
Petroleum	.7977	29.7	(28.9)	271
Hydrochloric acid	1.10	(72.9)	–	(392)
Hyposulphite of soda solution	1.1248	69.9	–	429

TABLE 137. — Surface Tension of Liquids at Solidifying Point.†

Substance.	Temperature of solidification. Cent.°	Surface tension in dynes per centimeter.	Substance.	Temperature of solidification. Cent.°	Surface tension in dynes per centimeter.
Platinum	2000	1691	Antimony	432	249
Gold	1200	1003	Borax	1000	216
Zinc	360	877	Carbonate of soda .	1000	210
Tin	230	599	Chloride of sodium .	–	116
Mercury	—40	588	Water	0	87.9‡
Lead	330	457	Selenium	217	71.8
Silver	1000	427	Sulphur	111	42.1
Bismuth	265	1390	Phosphorus	43	42.0
Potassium	58	371	Wax	68	34.1
Sodium	90	258			

TABLE 138. — Tension of Soap Films.

Elaborate measurements of the thickness of soap films have been made by Reinold and Rucker.‖ They find that a film of oleate of soda solution containing 1 of soap to 70 of water, and having 3 per cent of KNO$_3$ added to increase electrical conductivity, breaks at a thickness varying between 7.2 and 14.5 micro-millimeters, the average being 12.1 micro-millimeters. The film becomes black and apparently of nearly uniform thickness round the point where fracture begins. Outside the black patch there is the usual display of colors, and the thickness at these parts may be estimated from the colors of thin plates and the refractive index of the solution (*vide* Newton's rings, Table 222).

When the percentage of KNO$_3$ is diminished, the thickness of the black patch increases.

For example, KNO$_3$ = 3 1 0.5 0.0
Thickness = 12.4 13.5 14.5 22.1 micro-mm.

A similar variation was found in the other soaps.

It was also found that diminishing the proportion of soap in the solution, there being no KNO$_3$ dissolved, increased the thickness of the film.

1 part soap to 30 of water gave thickness 21.6 micro-mm.
1 part soap to 40 of water gave thickness 22.1 micro-mm.
1 part soap to 60 of water gave thickness 27.7 micro-mm.
1 part soap to 80 of water gave thickness 29.3 micro-mm.

---

* This table of tensions at the surface separating the liquid named in the first column and air, water or mercury as stated at the head of the last three columns, is from Quincke's experiments (Pogg. Ann. vol. 139, and Phil. Mag. 1871). The numbers given are the equivalent in dynes per centimeter of those obtained by Worthington from Quincke's results (Phil. Mag. vol. 20, 1885) with the exception of those in brackets, which were not corrected by Worthington; they are probably somewhat too high, for the reason stated by Worthington. The temperature was about 20° C.

† Quincke, "Pogg. Ann." vol. 135, p. 661.

‡ It will be observed that the value here given on the authority of Quincke is much higher than his subsequent measurements, as quoted above, give.

‖ "Proc. Roy. Soc." 1877, and "Phil. Trans. Roy. Soc." 1881, 1883, and 1893.

NOTE. — Quincke points out that substances may be divided into groups in each of which the ratio of the surface tension to the density is nearly constant. Thus, if this ratio for mercury be taken as unit, the ratio for the bromides and iodides is about a half: that of the nitrates, chlorides, sugars, and fats, as well as the metals, lead, bismuth, and antimony, about 1; that of water, the carbonates, sulphates, and probably phosphates, and the metals platinum, gold, silver, cadmium, tin, and copper, 2; that of zinc, iron, and palladium, 3; and that of sodium, 6.

VAPOR PRESSURES.

The vapor pressures here tabulated have been taken, with one exception, from Regnault's results. The vapor pressure of Pictet's fluid is given on his own authority. The pressures are in centimeters of mercury.

Temperature Cent.	Acetone. C_3H_6O	Benzol. C_6H_6	Carbon bisulphide. CS_2	Carbon tetrachloride. CCl_4	Chloroform. $CHCl_3$	Ethyl alcohol. C_2H_6O	Ethyl ether. $C_4H_{10}O$	Ethyl bromide. C_2H_5Br	Methyl alcohol. CH_4O	Turpentine. $C_{10}H_6$
—25°	–	–	–	–	–	–	–	4.41	.41	–
—20	–	.58	4.73	.98	–	.33	6.89	5.92	.63	–
—15	–	.88	6.16	1.35	–	.51	8.93	7.81	.93	–
—10	–	1.29	7.94	1.85	–	.65	11.47	10.15	1.35	–
—5	–	1.83	10.13	2.48	–	.91	14.61	13.06	1.92	–
0	–	2.53	12.79	3.29	5.97	1.27	18.44	16.56	2.68	.21
5	–	3.42	16.00	4.32	–	1.76	23.09	20.72	3.69	–
10	–	4.52	19.85	5.60	10.05	2.42	28.68	25.74	5.01	.29
15	–	5.89	24.41	7.17	–	3.30	35.36	31.69	6.71	–
20	17.96	7.56	29.80	9.10	16.05	4.45	43.28	38.70	8.87	.44
25	22.63	9.59	36.11	11.43	20.02	5.94	52.59	46.91	11.60	–
30	28.10	12.02	43.46	14.23	24.75	7.85	63.48	56.45	15.00	.69
35	34.52	14.93	51.97	17.55	30.35	10.29	76.12	67.49	19.20	–
40	42.01	18.36	61.75	21.48	36.93	13.37	90.70	80.19	24.35	1.08
45	50.75	22.41	72.95	26.08	44.60	17.22	107.42	94.73	30.61	–
50	62.29	27.14	85.71	31.44	53.50	21.99	126.48	111.28	38.17	1.70
55	72.59	32.64	100.16	37.63	63.77	27.86	148.11	130.03	47.22	–
60	86.05	39.01	116.45	44.74	75.54	35.02	172.50	151.19	57.99	2.65
65	101.43	46.34	134.75	52.87	88.97	43.69	199.89	174.95	70.73	–
70	118.94	54.74	155.21	62.11	104.21	54.11	230.49	201.51	85.71	4.06
75	138.76	64.32	177.99	72.57	121.42	66.55	264.54	231.07	103.21	–
80	161.10	75.19	203.25	84.33	140.76	81.29	302.28	263.86	123.85	6.13
85	186.18	87.46	231.17	97.51	162.41	98.64	343.95	300.06	147.09	–
90	214.17	101.27	261.91	112.23	186.52	118.93	389.83	339.89	174.17	9.06
95	245.28	116.75	296.63	128.69	213.28	142.51	440.18	383.55	205.17	–
100	279.73	134.01	332.51	146.71	242.85	169.75	495.33	431.23	240.51	13.11
105	317.70	153.18	372.72	166.72	275.40	201.04	555.62	483.12	280.63	–
110	359.40	174.44	416.41	188.74	311.10	236.76	621.46	539.40	325.96	18.60
115	405.00	197.82	463.74	212.91	350.10	277.34	693.33	600.24	376.98	–
120	454.69	223.54	514.88	239.37	392.57	323.17	771.92	665.80	434.18	25.70
125	508.62	251.71	569.97	268.24	438.66	374.69	–	736.22	498.05	–
130	566.97	282.43	629.16	299.69	488.51	432.30	–	811.65	569.13	34.90
135	629.87	315.85	692.59	333.86	542.25	496.42	–	892.19	647.93	–
140	697.44	352.07	760.40	370.90	600.02	567.46	–	977.96	733.71	46.40
145	–	391.21	832.69	411.00	661.92	645.80	–	–	830.89	–
150	–	433.37	909.59	454.31	728.06	731.84	–	–	936.13	60.50
155	–	478.65	–	501.02	798.53	825.92	–	–	–	68.60
160	–	527.14	–	551.31	873.42	–	–	–	–	77.50
165	–	568.30	–	605.38	952.78	–	–	–	–	–
170	–	634.07	–	663.44	–	–	–	–	–	–

TABLE 139 (*continued*).

VAPOR PRESSURES.

Temperature, Centigrade.	Ammonia. NH_3	Carbon dioxide. CO_2	Ethyl chloride. C_2H_5Cl	Ethyl iodide. C_2H_5I	Methyl chloride. CH_3Cl	Methylic ether. C_2H_6O	Nitrous oxide. N_2O	Pictet's fluid. $64SO_2 + 44CO_2$ by weight	Sulphur dioxide. SO_2	Hydrogen sulphide. H_2S
−30°	86.61	-	11.02	-	57.90	57.65	-	58.52	28.75	-
−25	110.43	1300.70	14.50	-	71.78	71.61	1569.49	67.64	37.38	374.93
−20	139.21	1514.24	18.75	-	88.32	88.20	1758.66	74.48	47.95	443.85
−15	173.65	1758.25	23.96	-	107.92	107.77	1968.43	89.68	60.79	519.65
−10	214.46	2034.02	30.21	-	130.96	130.66	2200.80	101.84	76.25	608.46
−5	264.42	2344.13	37.67	-	157.87	157.25	2457.92	121.60	94.69	706.60
0	318.33	2690.66	46.52	4.19	189.10	187.90	2742.10	139.08	116.51	820.63
5	383.03	3075.38	56.93	5.41	225.11	222.90	3055.86	167.20	142.11	949.08
10	457.40	3499.86	61.11	6.92	266.38	262.90	3401.91	193.80	171.95	1089.63
15	543.34	3964.69	83.26	8.76	313.41	307.98	3783.17	226.48	206.49	1244.79
20	638.78	4471.66	99.62	11.00	366.69	358.60	4202.79	258.40	246.20	1415.15
25	747.70	5020.73	118.42	13.69	426.74	415.10	4664.14	297.92	291.60	1601.24
30	870.10	5611.90	139.90	16.91	494.05	477.80	5170.85	338.20	343.18	1803.53
35	1007.02	6244.73	164.32	20.71	569.11	-	6335.98	383.80	401.48	2002.43
40	1159.53	6918.44	191.96	25.17	-	-	-	434.72	467.02	2258.25
45	1328.73	7631.46	223.07	30.38	-	-	-	478.80	540.35	2495.43
50	1515.83	-	257.94	36.40	-	-	-	521.36	622.00	2781.48
55	1721.98	-	266.84	43.32	-	-	-	-	712.50	3069.07
60	1948.21	-	340.05	51.22	-	-	-	-	812.38	3374.02
65	2196.51	-	387.85	-	-	-	-	-	922.14	3696.15
70	2467.55	-	440.50	-	-	-	-	-	-	4035.32
75	2763.00	-	498.27	-	-	-	-	-	-	-
80	3084.31	-	561.41	-	-	-	-	-	-	-
85	3433.09	-	630.16	-	-	-	-	-	-	-
90	3810.92	-	704.75	-	-	-	-	-	-	-
95	4219.57	-	785.39	-	-	-	-	-	-	-
100	4660.82	-	872.28	-	-	-	-	-	-	-

VAPOR PRESSURE.

TABLE 140. — Vapor Pressure of Ethyl Alcohol.*

Temp. C.	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
	Vapor pressure in millimeters of mercury at 0° C.									
0°	12.24	13.18	14.15	15.16	16.21	17.31	18.46	19.68	20.98	22.34
10	23.78	25.31	27.94	28.67	30.50	32.44	34.49	36.67	38.97	41.40
20	44.00	46.66	49.47	52.44	55.56	58.86	62.33	65.97	69.80	73.83
30	78.06	82.50	87.17	92.07	97.21	102.60	108.24	114.15	120.35	126.86
40	133.70	140.75	148.10	155.80	163.80	172.20	181.00	190.10	199.65	209.60
50	220.00	230.80	242.50	253.80	265.90	278.60	291.85	305.65	319.95	334.85
60	350.30	366.40	383.10	400.40	418.35	437.00	456.35	476.45	497.25	518.85
70	541.20	564.35	588.35	613.20	638.95	665.55	693.10	721.55	751.00	781.45

From the formula $\log p = a + b\alpha^t + c\beta^t$ Ramsay and Young obtain the following numbers.†

Temp. C.	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
	Vapor pressure in millimeters of mercury at 0° C.									
0°	12.24	23.73	43.97	78.11	133.42	219.82	350.21	540.91	811.81	1186.5
100	1692.3	2359.8	3223.0	4318.7	5686.6	7368.7	9409.9	11858.	14764.	18185.
200	22182.	26825.	32196.	38389.	45519.					

TABLE 141. — Vapor Pressure of Methyl Alcohol.‡

Temp. C.	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
	Vapor pressure in millimeters of mercury at 0° C.									
0°	29.97	31.6	33.6	35.6	37.8	40.2	42.6	45.2	47.9	50.8
10	53.8	57.0	60.3	63.8	67.5	71.4	75.5	79.8	84.3	89.0
20	94.0	99.2	104.7	110.4	116.5	122.7	129.3	136.2	143.4	151.0
30	158.9	167.1	175.7	184.7	194.1	203.9	214.1	224.7	235.8	247.4
40	259.4	271.9	285.0	298.5	312.6	327.3	342.5	358.3	374.7	391.7
50	409.4	427.7	446.6	466.3	486.6	507.7	529.5	552.0	575.3	599.4
60	624.3	650.0	676.5	703.8	732.0	761.1	791.1	822.0	–	–

---

* This table has been compiled from results published by Ramsay and Young (Jour. Chem. Soc. vol. 47, and Phil. Trans. Roy. Soc., 1886).

† In this formula $a = 5.0720301$; $\log b = \bar{2}.6406131$; $\log c = 0.6050854$; $\log \alpha = 0.003377538$; $\log \beta = \bar{1}.99682424$ (c is negative).

‡ Taken from a paper by Dittmar and Fawsitt (Trans. Roy. Soc. Edin. vol. 33).

Table 142.

VAPOR PRESSURE.*

Carbon Disulphide, Chlorobenzene, Bromobenzene, and Aniline.

Temp.	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
					(a) Carbon Disulphide.					
0°	127.90	133.85	140.05	146.45	153.10	160.00	167.15	174.60	182.25	190.20
10	198.45	207.00	215.80	224.95	234.40	244.15	254.25	264.65	275.40	286.55
20	298.05	309.90	322.10	334.70	347.70	361.10	374.95	389.20	403.90	419.00
30	434.60	450.65	467.15	484.15	501.65	519.65	538.15	557.15	576.75	596.85
40	617.50	638.70	660.50	682.90	705.90	729.50	753.75	778.60	804.10	830.25
					(b) Chlorobenzene.					
20°	8.65	9.14	9.66	10.21	10.79	11.40	12.04	12.71	13.42	14.17
30	14.95	15.77	16.63	17.53	18.47	19.45	20.48	21.56	22.69	23.87
40	25.10	26.38	27.72	29.12	30.58	32.10	33.69	35.35	37.08	38.88
50	40.75	42.69	44.72	46.84	49.05	51.35	53.74	56.22	58.79	61.45
60	64.20	67.06	70.03	73.11	76.30	79.60	83.02	86.56	90.22	94.00
70	97.90	101.95	106.10	110.41	114.85	119.45	124.20	129.10	134.15	139.40
80	144.80	150.30	156.05	161.95	168.00	174.25	181.70	187.30	194.10	201.15
90	208.35	215.80	223.45	231.30	239.35	247.70	256.20	265.00	274.00	283.25
100	292.75	302.50	312.50	322.80	333.35	344.15	355.25	366.65	378.30	390.25
110	402.55	415.10	427.95	441.15	454.65	468.50	482.65	497.20	512.05	527.25
120	542.80	558.70	575.05	591.70	608.75	626.15	643.95	662.15	680.75	699.65
130	718.95	738.65	758.80	–	–	–	–	–	–	–
					(c) Bromobenzene.					
40°	–	–	–	–	–	12.40	13.06	13.75	14.47	15.22
50	16.00	16.82	17.68	18.58	19.52	20.50	21.52	22.59	23.71	24.88
60	26.10	27.36	28.68	30.06	31.50	33.00	34.56	36.18	37.86	39.60
70	41.40	43.28	45.24	47.28	49.40	51.60	53.88	56.25	58.71	61.26
80	63.90	66.64	69.48	72.42	75.46	78.60	81.84	85.20	88.68	92.28
90	96.00	99.84	103.80	107.88	112.08	116.40	120.86	125.46	130.20	135.08
100	140.10	145.26	150.57	156.03	161.64	167.40	173.32	179.41	185.67	192.10
110	198.70	205.48	212.44	219.58	226.90	234.40	242.10	250.00	258.10	266.40
120	274.90	283.65	292.60	301.75	311.15	320.80	330.70	340.80	351.15	361.80
130	372.65	383.75	395.10	406.70	418.60	430.75	443.20	455.90	468.90	482.20
140	495.80	509.70	523.90	538.40	553.20	568.35	583.85	599.65	615.75	632.25
150	649.05	666.25	683.80	701.65	719.95	738.55	757.55	776.95	796.70	816.90
					(d) Aniline.					
80°	18.80	19.78	20.79	21.83	22.90	24.00	25.14	26.32	27.54	28.80
90	30.10	31.44	32.83	34.27	35.76	37.30	38.90	40.56	42.28	44.06
100	45.90	47.80	49.78	51.84	53.98	56.20	58.50	60.88	63.34	65.88
110	68.50	71.22	74.04	76.96	79.98	83.10	86.32	89.66	93.12	96.70
120	100.40	104.22	108.17	112.25	116.46	120.80	125.28	129.91	134.69	139.62
130	144.70	149.94	155.34	160.90	166.62	172.50	178.56	184.80	191.22	197.82
140	204.60	211.58	218.76	226.14	233.72	241.50	249.50	257.72	266.16	274.82
150	283.70	292.80	302.15	311.75	321.60	331.70	342.05	352.65	363.50	374.60
160	386.00	397.65	409.60	421.80	434.30	447.10	460.20	473.60	487.25	501.25
170	515.60	530.20	545.20	560.45	576.10	592.05	608.35	625.05	642.05	659.45
180	677.15	695.30	713.75	732.65	751.90	771.50	–	–	–	–

---

* These tables of vapor pressures are quoted from results published by Ramsay and Young (Jour. Chem. Soc. vol. 47). The tables are intended to give a series suitable for hot-jacket purposes.

TABLE 142 (*continued*).

VAPOR PRESSURE.

Methyl Salicylate, Bromonaphthaline, and Mercury.

Temp. C.	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
					(e) METHYL SALICYLATE.					
70°	2.40	2.58	2.77	2.97	3.18	3.40	3.62	3.85	4.09	4.34
80	4.60	4.87	5.15	5.44	5.74	6.05	6.37	6.70	7.05	7.42
90	7.80	8.20	8.62	9.06	9.52	9.95	10.44	10.95	11.48	12.03
100	12.60	13.20	13.82	14.47	15.15	15.85	16.58	17.34	18.13	18.95
110	19.80	20.68	21.60	22.55	23.53	24.55	25.61	26.71	27.85	29.03
120	30.25	31.52	32.84	34.21	35.63	37.10	38.67	40.24	41.84	43.54
130	45.30	47.12	49.01	50.96	52.97	55.05	57.20	59.43	61.73	64.10
140	66.55	69.08	71.69	74.38	77.15	80.00	82.94	85.97	89.09	92.30
150	95.60	99.00	102.50	106.10	109.80	113.60	117.51	121.53	125.66	129.90
160	134.25	138.72	143.31	148.03	152.88	157.85	162.95	168.19	173.56	179.06
170	184.70	190.48	196.41	202.49	208.72	215.10	221.65	228.30	235.15	242.15
180	249.35	256.70	264.20	271.90	279.75	287.80	296.00	304.48	313.05	321.85
190	330.85	340.05	349.45	359.05	368.85	378.90	389.15	399.60	410.30	421.20
200	432.35	443.75	455.35	467.25	479.35	491.70	504.35	517.25	530.40	543.80
210	557.50	571.45	585.70	600.25	615.05	630.15	645.55	661.25	677.25	693.60
220	710.10	727.05	744.35	761.90	779.85	798.10				
					(f) BROMONAPHTHALINE.					
110°	3.60	3.74	3.89	4.05	4.22	4.40	4.59	4.79	5.00	5.22
120	5.45	5.70	5.96	6.23	6.51	6.80	7.10	7.42	7.76	8.12
130	8.50	8.89	9.29	9.71	10.15	10.60	11.07	11.56	12.07	12.60
140	13.15	13.72	14.31	14.92	15.55	16.20	16.87	17.56	18.28	19.03
150	19.80	20.59	21.41	22.25	23.11	24.00	24.92	25.86	26.83	27.83
160	28.85	29.90	30.98	32.09	33.23	34.40	35.60	36.83	38.10	39.41
170	40.75	42.12	43.53	44.99	46.50	48.05	49.64	51.28	52.96	54.68
180	56.45	58.27	60.14	62.04	64.06	66.10	68.19	70.34	72.55	74.82
190	77.15	79.54	81.99	84.51	87.10	89.75	92.47	95.26	98.12	101.05
200	104.05	107.12	110.27	113.50	116.81	120.20	123.67	127.22	130.86	134.59
210	138.40	142.30	146.29	150.38	154.57	158.85	163.25	167.70	172.30	176.95
220	181.75	186.65	191.65	196.75	202.00	207.35	212.80	218.40	224.15	230.00
230	235.95	242.05	248.30	254.65	261.20	267.85	274.65	281.60	288.70	295.95
240	303.35	310.90	318.65	326.50	334.55	342.75	351.10	359.65	368.40	377.30
250	386.35	395.60	405.05	414.65	424.45	434.45	444.65	455.00	465.60	476.35
260	487.35	498.55	509.90	521.50	533.35	545.35	557.60	570.05	582.70	595.60
270	608.75	622.10	635.70	649.50	663.55	677.85	692.40	707.15	722.15	737.45
					(g) MERCURY.					
270°	123.92	126.97	130.08	133.26	136.50	139.81	143.18	146.61	150.12	153.70
280	157.35	161.07	164.86	168.73	172.67	176.79	180.88	185.05	189.30	193.63
290	198.04	202.53	207.10	211.76	216.50	221.33	226.25	231.25	236.34	241.53
300	246.81	252.18	257.65	263.21	268.87	274.63	280.48	286.43	292.49	298.66
310	304.93	311.30	317.78	324.37	331.08	337.89	344.81	351.85	359.00	366.28
320	373.67	381.18	388.81	396.56	404.43	412.44	420.58	428.83	437.22	445.75
330	454.41	463.20	472.12	481.19	490.40	499.74	509.22	518.85	528.63	538.56
340	548.64	558.87	569.25	579.78	590.48	601.33	612.34	623.51	634.85	646.36
350	658.03	669.86	681.86	694.04	706.40	718.94	731.65	744.54	757.61	770.87
360	784.31									

TABLE 143.

VAPOR PRESSURE OF SOLUTIONS OF SALTS IN WATER.*

The first column gives the chemical formula of the salt. The headings of the other columns give the number of gram-molecules of the salt in a liter of water. The numbers in these columns give the lowering of the vapor pressure produced by the salt at the temperature of boiling water under 76 centimeters barometric pressure.

Substance.	0.5	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10.0
$Al_2(SO_4)_3$	12.8	36.5							
$AlCl_3$	22.5	61.0	179.0	318.0					
$Ba(SO_3)_2$	6.6	15.4	34.4						
$Ba(OH)_2$	12.3	22.5	39.0						
$Ba(NO_3)_2$	13.5	27.0							
$Ba(ClO_3)_2$	15.8	33.3	70.5	108.2					
$BaCl_2$	16.4	36.7	77.6						
$BaBr_2$	16.8	38.8	91.4	150.0	204.7				
$Ca(SO_3)_2$	9.9	23.0	56.0	106.0					
$Ca(NO_3)_2$	16.4	34.8	74.6	139.3	161.7	205.4			
$CaCl_2$	17.0	39.8	95.3	166.6	241.5	319.5			
$CaBr_2$	17.7	44.2	105.8	191.0	283.3	368.5			
$CdSO_4$	4.1	8.9	18.1						
CdI_2	7.6	14.8	33.5	52.7					
$CdBr_2$	8.6	17.8	36.7	55.7	80.0				
$CdCl_2$	9.6	18.8	36.7	57.0	77.3	99.0			
$Cd(NO_3)_2$	15.9	36.1	78.0	122.2					
$Cd(ClO_3)_2$	17.5								
$CoSO_4$	5.5	10.7	22.9	45.5					
$CoCl_2$	15.0	34.8	83.0	136.0	186.4				
$Co(NO_3)_2$	17.3	39.2	89.0	152.0	218.7	282.0	332.0		
$FeSO_4$	5.8	10.7	24.0	42.4					
H_3BO_3	6.0	12.3	25.1	38.0	51.0				
H_3PO_4	6.6	14.0	28.6	45.2	62.0	81.5	103.0	146.9	189.5
H_3AsO_4	7.3	15.0	30.2	46.4	64.9				
H_2SO_4	12.9	26.5	62.8	104.0	148.0	198.4	247.0	343.2	
KH_2PO_4	10.2	19.5	33.3	47.8	60.5	73.1	85.2		
KNO_3	10.3	21.1	40.1	57.6	74.5	88.2	102.1	126.3	148.0
$KClO_3$	10.6	21.6	42.8	62.1	80.0				
$KBrO_3$	10.9	22.4	45.0						
$KHSO_4$	10.9	21.9	43.3	65.3	85.5	107.8	129.2	170.0	
KNO_2	11.1	22.8	44.8	67.0	90.0	110.5	130.7	167.0	198.8
$KClO_4$	11.5	22.3							
KCl	12.2	24.4	48.8	74.1	100.9	128.5	152.2		
$KHCO_2$	11.6	23.6	59.0	77.6	104.2	132.0	160.0	210.0	255.0
KI	12.5	25.3	52.2	82.6	112.2	141.5	171.8	225.5	278.5
$K_2C_2O_4$	13.9	28.3	59.8	94.2	131.0				
K_2WO_4	13.9	33.0	75.0	123.8	175.4	226.4			
K_2CO_3	14.4	31.0	68.3	105.5	152.0	209.0	258.5	350.0	
KOH	15.0	29.5	64.0	99.2	140.0	181.8	223.0	309.5	387.8
K_2CrO_4	16.2	29.5	60.0						
$LiNO_3$	12.2	25.9	55.7	88.9	122.2	155.1	188.0	253.4	309.2
$LiCl$	12.1	25.5	57.1	95.0	132.5	175.5	219.5	311.5	393.5
$LiBr$	12.2	26.2	60.0	97.0	140.0	186.3	241.5	341.5	438.0
Li_2SO_4	13.3	28.1	56.8	89.0					
$LiHSO_4$	12.8	27.0	57.0	93.0	130.0	168.0			
LiI	13.6	28.6	64.7	105.2	154.5	206.0	264.0	357.0	445.0
Li_2SiFl_6	15.4	34.0	70.0	106.0					
$LiOH$	15.9	37.4	78.1						
Li_2CrO_4	16.4	32.6	74.0	120.0	171.0				

---

* Compiled from a table by Tammann, "Mém. Ac. St. Petersb." 35, No. 9, 1887. See also Referate, "Zeit. f. Phys." ch. 2, 42, 1886.

TABLE 143 (*continued*).

VAPOR PRESSURE OF SOLUTIONS OF SALTS IN WATER.

Substance.	0.5	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10.0
$MgSO_4$	6.5	12.0	24.5	47.5					
$MgCl_2$	16.8	39.0	100.5	183.3	277.0	377.0			
$Mg(NO_3)_2$	17.6	42.0	101.0	174.8					
$MgBr_2$	17.9	44.0	115.8	205.3	298.5				
$MgH_2(SO_4)_2$	18.3	46.0	116.0						
$MnSO_4$	6.0	10.5	21.0						
$MnCl_2$	15.0	34.0	76.0	122.3	167.0	209.0			
NaH_2PO_4	10.5	20.0	36.5	51.7	66.8	82.0	96.5	126.7	157.1
$NaHSO_4$	10.9	22.1	47.3	75.0	100.2	126.1	148.5	189.7	231.4
$NaNO_3$	10.6	22.5	46.2	68.1	90.3	111.5	131.7	167.8	198.8
$NaClO_3$	10.5	23.0	48.4	73.5	98.5	123.3	147.5	196.5	223.5
$(NaPO_3)_6$	11.6								
$NaOH$	11.8	22.8	48.2	77.3	107.5	139.1	172.5	243.3	314.0
$NaNO_2$	11.6	24.4	50.0	75.0	98.2	122.5	146.5	189.0	226.2
$NaHPO_4$	12.1	23.5	43.0	60.0	78.7	99.8	122.1		
$NaHCO_2$	12.9	24.1	48.2	77.6	102.2	127.8	152.0	198.0	239.4
$NaSO_4$	12.6	25.0	48.9	74.2					
$NaCl$	12.3	25.2	52.1	80.0	111.0	143.0	176.5		
$NaBrO_3$	12.1	25.0	54.1	81.3	108.8	136.0			
$NaBr$	12.6	25.9	57.0	89.2	124.2	159.5	197.5	268.0	
NaI	12.1	25.6	60.2	99.5	136.7	177.5	221.0	301.5	370.0
$Na_4P_2O_7$	13.2	22.0							
Na_2CO_3	14.3	27.3	53.5	80.2	111.0				
$Na_2C_2O_4$	14.5	30.0	65.8	105.8	146.0				
Na_2WO_4	14.8	33.6	71.6	115.7	162.6				
Na_3PO_4	16.5	30.0	52.5						
$(NaPO_3)_3$	17.1	36.5							
NH_4NO_3	12.8	22.0	42.1	62.7	82.9	103.8	121.0	152.2	180.0
$(NH_4)_2SiFl_6$	11.5	25.0	44.5						
NH_4Cl	12.0	23.7	45.1	69.3	94.2	118.5	138.2	179.0	213.8
NH_4HSO_4	11.5	22.0	46.8	71.0	94.5	118.	139.0	181.2	218.0
$(NH_4)_2SO_4$	11.0	24.0	46.5	69.5	93.0	117.0	141.8		
NH_4Br	11.9	23.9	48.8	74.1	99.4	121.5	145.5	190.2	228.5
NH_4I	12.9	25.1	49.8	78.5	104.5	132.3	156.0	200.0	243.5
$NiSO_4$	5.0	10.2	21.5						
$NiCl_2$	16.1	37.0	86.7	147.0	212.8				
$Ni(NO_3)_2$	16.1	37.3	91.3	156.2	235.0				
$Pb(NO_3)_2$	12.3	23.5	45.0	63.0					
$Sr(SO_3)_2$	7.2	20.3	47.0						
$Sr(NO_3)_2$	15.8	31.0	64.0	97.4	131.4				
$SrCl_2$	16.8	38.8	91.4	156.8	223.3	281.5			
$SrBr_2$	17.8	42.0	101.1	179.0	267.0				
$ZnSO_4$	4.9	10.4	21.5	42.1	66.2				
$ZnCl_2$	9.2	18.7	46.2	75.0	107.0	153.0	195.0		
$Zn(NO_3)_2$	16.6	39.0	93.5	157.5	223.8				

PRESSURE OF SATURATED AQUEOUS VAPOR.

TABLE 144. — At Low Temperature. Over Ice.

Temperatures Centigrade.

	0	1	2	3	4	5	6	7	8	9
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
—60	0.008	0.007	0.005	0.004	0.003	0.003				
—50	.029	.026	.023	.021	.018	.016	0.014	0.012	0.010	0.009
—40	.094	.083	.074	.066	.059	.052	.047	.042	.037	.033
—30	.280	.252	.226	.203	.182	.163	.146	.131	.117	.105
—20	0.770	0.699	0.633	0.574	0.519	0.469	0.424	0.383	.345	.311
—10	1.947	1.780	1.627	1.486	1.356	1.237	1.127	1.026	0.933	0.848
— 0	4.579	4.215	3.879	3.566	3.277	3.009	2.762	2.533	2.322	2.127

Taken from Landolt-Börnstein, Physikalisch-Chemische Tabellen, 1912.

TABLE 145. — At Low Temperature. Over Water.

	0	1	2	3	4	5	6	7	8	9
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
—10	2.144	1.979	1.826	1.684	1.551	1.429	1.315			
— 0	4.579	4.255	3.952	3.669	3.404	3.158	2.928	2.712	2.509	2.321
+ 0	4.579	4.926	5.294	5.685	6.101	6.543	7.014	7.514	8.046	8.610

Taken from Landolt-Börnstein, Physikalisch-Chemische Tabellen, 1912.

TABLE 146. — 0° to 50° C. Hydrogen Scale.

Values interpolated between those given by Scheel and Heuse for every degree between 0° and 50° C. Annalen der Physik. (4), 31, p. 731, 1910.

	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
0°	4.579	4.613	4.647	4.681	4.715	4.750	4.785	4.820	4.855	4.890
1.	4.926	4.962	4.998	5.034	5.071	5.107	5.144	5.181	5.218	5.256
2.	5.294	5.332	5.370	5.408	5.447	5.486	5.525	5.564	5.604	5.644
3.	5.685	5.725	5.766	5.807	5.848	5.889	5.931	5.973	6.015	6.058
4.	6.101	6.144	6.187	6.230	6.274	6.318	6.363	6.408	6.453	6.498
5.	6.543	6.589	6.635	6.681	6.728	6.775	6.822	6.870	6.918	6.966
6.	7.014	7.063	7.112	7.171	7.210	7.260	7.310	7.361	6.412	7.463
7.	7.514	7.566	7.618	7.670	7.723	7.776	7.829	7.883	7.937	7.991
8.	8.046	8.101	8.156	8.212	8.268	8.324	8.381	8.438	8.495	8.552
9.	8.609	8.668	8.727	8.786	8.845	8.905	8.965	9.026	9.087	9.148
10.	9.210	9.272	9.334	9.396	9.459	9.522	9.586	9.650	9.715	9.780
11.	9.845	9.911	9.977	10.043	10.110	10.177	10.245	10.313	10.381	10.450
12.	10.519	10.589	10.659	10.729	10.800	10.871	10.943	11.015	11.087	11.160
13.	11.233	11.307	11.381	11.455	11.530	11.605	11.681	11.757	11.834	11.912
14.	11.989	12.067	12.146	12.225	12.304	12.384	12.464	12.545	12.626	12.708
15.	12.790	12.873	12.956	13.039	13.123	13.207	13.292	13.378	13.464	13.550
16.	13.637	13.724	13.812	13.900	13.989	14.078	14.168	14.258	14.350	14.441
17.	14.533	14.625	14.718	14.811	14.905	14.999	15.094	15.190	15.286	15.383
18.	15.480	15.578	15.676	15.775	15.874	15.974	16.074	16.175	16.276	16.378
19.	16.481	16.584	16.688	16.792	16.897	17.003	17.109	17.216	17.323	17.430
20.	17.539	17.648	17.757	17.867	17.977	18.088	18.200	18.313	18.426	18.540
21.	18.655	18.770	18.886	19.002	19.119	19.236	19.354	19.473	19.592	19.712
22.	19.832	19.953	20.075	20.197	20.320	20.444	20.569	20.694	20.820	20.947
23.	21.074	21.202	21.330	21.459	21.589	21.720	21.851	21.983	22.116	22.249
24.	22.383	22.518	22.654	22.790	22.927	23.065	23.203	23.342	23.482	23.622
25.	23.763	23.905	24.048	24.192	24.336	24.481	24.627	24.773	24.920	25.068

PRESSURE OF SATURATED AQUEOUS VAPOR.

TABLE 146 (*continued*). — 0° to 50° C. Hydrogen Scale.

	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
26°	25.217	25.367	25.517	25.668	25.820	25.972	26.125	26.279	26.434	26.590
27.	26.747	26.904	27.062	27.221	27.381	27.542	27.704	27.866	28.029	28.193
28.	28.358	28.524	28.690	28.857	29.025	29.194	29.364	29.535	29.707	29.879
29.	30.052	30.226	30.401	30.577	30.754	30.932	31.111	31.291	31.471	31.653
30.	31.834	32.017	32.201	32.386	32.572	32.759	32.947	33.135	33.324	33.514
31.	33.706	33.899	34.093	34.288	34.483	34.679	34.876	35.074	35.273	35.473
32.	35.674	35.876	36.079	36.283	36.488	36.694	36.901	37.109	37.318	37.529
33.	37.741	37.953	38.166	38.380	38.595	38.812	39.030	39.249	39.469	39.689
34.	39.911	40.134	40.358	40.583	40.809	41.036	41.264	41.493	41.723	41.955
35.	42.188	42.422	42.657	42.893	43.130	43.368	43.607	43.847	44.089	44.332
36.	44.577	44.82	45.06	45.30	45.55	45.80	46.05	46.30	46.56	46.82
37.	47.082	47.34	47.60	47.86	48.12	48.38	48.64	48.90	49.17	49.44
38.	49.708	49.98	50.25	50.52	50.79	51.06	51.33	51.60	51.88	52.16
39.	52.459	52.74	53.02	53.30	53.58	53.87	54.16	54.45	54.75	55.05
40.	55.341	55.63	55.93	56.23	56.53	56.83	57.13	57.43	57.74	58.05
41.	58.36	58.67	58.98	59.29	59.60	59.92	60.24	60.56	60.88	61.20
42.	61.52	61.84	62.16	62.49	62.82	63.15	63.48	63.81	64.14	64.48
43.	64.82	65.16	65.50	65.84	66.18	66.53	66.88	67.23	67.58	67.93
44.	68.28	68.63	68.99	69.35	69.71	70.07	70.43	70.79	71.16	71.53
45.	71.90	72.27	72.64	73.01	73.38	73.76	74.14	74.52	74.90	75.28
46.	75.67	76.06	76.45	76.84	77.23	77.62	78.02	78.42	78.82	79.22
47.	79.62	80.03	80.43	80.84	81.25	81.66	82.07	82.48	82.90	83.32
48.	83.74	84.16	84.59	85.02	85.45	85.88	86.31	86.74	87.17	87.61
49.	88.05	88.49	88.93	89.37	89.82	90.27	90.72	91.17	91.62	92.08

TABLE 147. 50° to 374° C. Hydrogen Scale.

	0	1	2	3	4	5	6	7	8	9
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
50°	92.54	97.24	102.13	107.24	112.56	118.11	123.89	129.90	136.16	142.68
60.	149.46	156.52	163.85	171.47	179.40	187.64	196.19	205.07	214.29	223.86
70.	233.79	244.11	254.82	265.91	277.41	289.32	301.65	314.42	327.64	341.32
80.	355.47	370.11	385.25	400.90	417.08	433.79	451.07	468.91	487.33	506.36
90.	526.00	546.27	567.19	588.77	611.04	634.01	657.69	682.11	707.29	733.24
100.	760.00	787.57	815.9	845.1	875.1	906.1	937.9	970.6	1004.3	1038.8
110.	1074.5	1111.1	1148.7	1187.4	1227.1	1267.9	1309.8	1352.8	1397.0	1442.4
120.	1488.9	1536.6	1585.7	1636.0	1687.5	1740.5	1794.7	1850.3	1907.3	1965.8
130.	2025.6	2086.9	2149.8	2214.0	2280.0	2347.5	2416.5	2487.3	2559.7	2633.8
140.	2709.5	2787.1	2866.4	2947.7	3030.5	3115.3	3202.1	3290.8	3381.3	3474.0
150.	3568.7	3665.3	3764.1	3864.9	3968.	4073.	4181.	4290.	4402.	4517.
160.	4633	4752	4874	4998	5124	5253	5384	5518	5655	5794
170.	5937	6081	6229	6379	6533	6689	6848	7010	7175	7343
180.	7514	7688	7866	8046	8230	8417	8608	8802	8999	9200
190.	9404	9612	9823	10038	10256	10479	10705	10934	11168	11406
200.	11647	11893	12143	12397	12654	12916	13183	13453	13728	14007
210.	14291	14578	14871	15167	15469	15774	16085	16401	16721	17046
220.	17376	17710	18049	18394	18743	19098	19458	19823	20193	20570
230.	20950	21336	21728	22125	22528	22936	23350	23770	24195	24626
240.	25064	25506	25956	26412	26873	27341	27815	28294	28780	29272
250.	29771	30276	30788	31308	31833	32364	32903	33448	34001	34561
260.	35127	35700	36280	36868	37463	38065	38675	39291	39915	40547
270.	41186	41832	42487	43150	43820	44498	45184	45879	46580	47290
280.	48011	48738	49474	50219	50972	51734	52506	53288	54079	54878
290.	55680	56500	57330	58170	59010	59860	60730	61610	62490	63390
300.	64290	65200	66120	67060	68000	68950	69910	70890	71870	72860
310.	73860	74880	75900	76940	77980	79040	80110	81180	82270	83370
320.	84480	85610	86750	87900	89050	90220	91400	92600	93820	95040
330.	96270	97510	98770	100040	101320	102610	103930	105250	106580	107930
340.	109300	110670	112050	113450	114870	116300	117750	119210	120680	122160
350.	123660	125170	126690	128230	129790	131370	132960	134560	136180	137820
360.	139480	141150	142850	144560	146300	148100	149900	151700	153500	155300
370.	157200	159100	161000	163000	164900					

Taken from Landolt-Börnstein Tables and based upon the following data: 50-70°, Nernst, Verh. d. D. Phys. Ges. 12, p. 565, 1910; 70-100°, Regnault, computed by Broch, 1881, improved by Wiebe, ZS. fur Instrum. 13, p. 329, 1893, also Tafeln für die Spannkraft des Wasserdampfes, Braunschweig, 1903; 100-374°, Holborn, Henning, Baumann, Annalen der Physik, 26, p. 833, 1908, 31, p. 945, 1910.

TABLE 148. — Weight in Grains of the Aqueous Vapor contained in a Cubic Foot of Saturated Air.*

Temp. °F.	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
—10	0.285	0.270	0.257	0.243	0.231	0.218	0.207	0.196	0.184	0.174
—0	0.481	0.457	0.434	0.411	0.389	0.370	0.350	0.332	0.316	0.300
+0	0.481	0.505	0.529	0.554	0.582	0.610	0.639	0.671	0.704	0.739
10	0.776	0.816	0.856	0.898	0.941	0.985	1.032	1.079	1.128	1.181
20	1.235	1.294	1.355	1.418	1.483	1.551	1.623	1.697	1.773	1.853
30	1.935	2.022	2.113	2.194	2.279	2.366	2.457	2.550	2.646	2.746
40	2.849	2.955	3.064	3.177	3.294	3.414	3.539	3.667	3.800	3.936
50	4.076	4.222	4.372	4.526	4.685	4.849	5.018	5.191	5.370	5.555
60	5.745	5.941	6.142	6.349	6.563	6.782	7.009	7.241	7.480	7.726
70	7.980	8.240	8.508	8.782	9.066	9.356	9.655	9.962	10.277	10.601
80	10.934	11.275	11.626	11.987	12.356	12.736	13.127	13.526	13.937	14.359
90	14.790	15.234	15.689	16.155	16.634	17.124	17.626	18.142	18.671	19.212
100	19.766	20.335	20.917	21.514	22.125	22.750	23.392	24.048	24.720	25.408
110	26.112	26.832	27.570	28.325	29.096	29.887	–	–	–	–

* See "Smithsonian Meteorological Tables," pp 132-133.

TABLE 149. — Weight in Grams of the Aqueous Vapor contained in a Cubic Meter of Saturated Air.

Temp. °C.	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
—20	0.892	0.810	0.737	0.673	0.613	0.557	0.505	0.457	0.413	0.373
—10	2.154	1.978	1.811	1.658	1.519	1.395	1.282	1.177	1.079	0.982
—0	4.835	4.468	4.130	3.813	3.518	3.244	2.988	2.752	2.537	2.340
+0	4.835	5.176	5.538	5.922	6.330	6.761	7.219	7.703	8.215	8.757
10	9.330	9.935	10.574	11.249	11.961	12.712	13.505	14.339	15.218	16.144
20	17.118	18.143	19.222	20.355	21.546	22.796	24.109	25.487	26.933	28.450
30	30.039	31.704	33.449	35.275	37.187	39.187	41.279	43.465	45.751	48.138

TABLE 150.

PRESSURE OF AQUEOUS VAPOR IN THE ATMOSPHERE.

This table gives the vapor pressure corresponding to various values of the difference $t - t_1$ between the readings of dry and wet bulb thermometers and the temperature t_1 of the wet bulb thermometer. The differences $t - t_1$ are given by two-degree steps in the top line, and t_1 by degrees in the first column. Temperatures in Centigrade degrees and Regnault's vapor pressures in millimeters of mercury are used throughout the table. The table was calculated for barometric pressure B equal to 76 centimeters, and a correction is given for each centimeter at the top of the columns.* Ventilating velocity of wet thermometer about 3 meters per second.

t_1	$t - t_1 = 0$	2	4	6	8	10	12	14	16	18	20	Difference per 1° of $t - t_1$
Corrections for B per centimeter.†		.013	.026	.040	.053	.066	.079	.092	.106	.119	.132	
—10	1.96	0.96										0.100
—9	2.14	1.14	0.14									0.100
—8	2.33	1.33	0.33									0.100
—7	2.53	1.53	0.53									0.100
—6	2.76	1.76	0.76									0.100
—5	3.01	2.01	1.00									0.100
—4	3.28	2.28	1.27	0.27								0.100
—3	3.57	2.57	1.56	0.56								0.100
—2	3.88	2.88	1.87	0.87								0.100
—1	4.22	3.22	2.21	1.21	0.21							0.100
0	4.60	3.60	2.59	1.59	0.59							0.100
1	4.94	3.93	2.92	1.92	0.92							0.100
2	5.30	4.29	3.29	2.28	1.28	0.27						0.100
3	5.69	4.68	3.68	2.67	1.66	0.66						0.101
4	6.10	5.09	4.09	3.08	2.07	1.06	0.05					0.101
5	6.53	5.52	4.51	3.50	2.49	1.48	0.48					0.101
6	7.00	5.99	4.98	3.97	2.96	1.95	0.94					0.101
7	7.49	6.48	5.47	4.45	3.44	2.43	1.42	0.41				0.101
8	8.02	7.01	5.99	4.98	3.97	2.96	1.94	0.93				0.101
9	8.57	7.56	6.54	5.53	4.51	3.50	2.49	1.48	0.46			0.101
10	9.17	8.16	7.14	6.12	5.11	4.09	3.08	2.07	1.06	0.05		0.101
11	9.79	8.77	7.76	6.74	5.73	4.71	3.69	2.68	1.66	0.64		0.102
12	10.46	9.44	8.43	7.41	6.39	5.37	4.36	3.34	2.32	1.30	0.28	0.102
13	11.16	10.14	9.12	8.10	7.09	6.07	5.05	4.03	3.01	1.99	0.97	0.102
14	11.91	10.89	9.87	8.85	7.83	6.81	5.79	4.77	3.71	2.69	1.67	0.102
15	12.70	11.68	10.66	9.64	8.62	7.60	6.58	5.56	4.54	3.52	2.50	0.102
16	13.54	12.52	11.50	10.47	9.45	8.43	7.41	6.39	5.37	4.35	3.33	0.102
17	14.42	13.40	12.37	11.35	10.33	9.31	8.28	7.26	6.24	5.22	4.20	0.102
18	15.36	14.34	13.31	12.29	11.26	10.24	9.21	8.19	7.17	6.15	5.13	0.102
19	16.35	15.33	14.30	13.27	12.25	11.22	10.20	9.17	8.15	7.13	6.11	0.102
20	17.39	16.37	15.34	14.31	13.28	12.26	11.23	10.21	9.18	8.15	7.12	0.103
21	18.50	17.47	16.45	15.42	14.39	13.36	12.33	11.31	10.28	9.25	8.22	0.103
22	19.66	18.63	17.60	16.57	15.54	14.51	13.48	12.46	11.43	10.40	9.37	0.103
23	20.89	19.86	18.83	17.80	16.77	15.74	14.71	13.68	12.66	11.63	10.60	0.103
24	22.18	21.15	20.12	19.09	18.05	17.02	15.99	14.96	13.94	12.91	11.88	0.103
25	23.55	22.52	21.49	20.45	19.43	18.39	17.36	16.33	15.30	14.27	13.24	0.103
26	24.99	23.96	22.92	21.89	20.86	19.82	18.79	17.76	16.73	15.70	14.67	0.103
27	26.51	25.48	24.44	23.40	22.37	21.34	20.30	19.27	18.24	17.21	16.18	0.103
28	28.10	27.07	26.03	24.99	23.96	22.92	21.89	20.85	19.82	18.79	17.76	0.103
29	29.78	28.75	27.71	26.67	25.63	24.59	23.56	22.52	21.49	20.46	19.43	0.103
30	31.55	30.51	29.47	28.43	27.40	26.36	25.32	24.29	23.25	22.22	21.18	0.104
31	33.41	32.37	31.33	30.29	29.25	28.22	27.18	26.14	25.10	24.07	23.03	0.104
32	35.36	34.32	33.28	32.24	31.21	30.17	29.13	28.09	27.05	26.01	24 97	0.104
33	37.41	36.37	35.33	34.29	33.25	32.22	31.18	30.14	29.10	28.06	27.02	0.104
34	39.57	38.53	37.48	36.44	35.40	34.36	33.32	32.28	31.24	30.20	29.16	0.104
35	41.83	40.79	39.74	38.70	37.66	36.62	35.58	34.54	33.50	32.46	31.42	0.104
36	44.20	43.16	42.11	41.07	40.03	38.99	37.95	36.90	35.86	34.82	33.78	0.104
37	46.69	45.65	44.60	43.56	42.52	41.48	40.44	39.39	38.35	37.31	36.27	0.104
38	49.30	48.26	47.21	46.17	45.13	44.08	43.04	41.99	40.95	39.91	38.87	0.104
39	52.04	51.00	49.95	48.91	47.86	46.82	45.77	44.73	43.68	42.64	41.59	0.105

Example.

$t - t_1 = 7.2$
$t_1 = 10.0$
$B = 74.5$
Tabular number $= 6.12 - 6 \times .101 = 5.51$
Correction for $B = 1.5 \times .048 \ldots = .07$
Hence we get $p \ldots = 5.58$

---

* The table was calculated from the formula $p = p_1 - 0.00066\,B\,(t - t_1)\,(1 + 0.00115\,t_1)$ (Ferrel, Annual Report U. S. Chief Signal Officer, 1886, App. 24).

† When B is less than 76 the correction is to be added, and when B is greater than 76 it is to be subtracted.

TABLE 151.

DEW-

The first column of this table gives the temperatures of the wet-bulb thermometer, and the top line the difference the table. The dew-points were computed for a barometric pressure of 76 centimeters. When the barometer differs and the resulting number added to or subtracted from the tabular number according as the barometer is below or

t_1	$t-t_1=1$	2	3	4	5	6	7	8
	Dew-points corresponding to the difference of temperature given in the above line and the wet-bulb thermometer reading given in first column.							
$\delta T/\delta B=$	.04	.11	.22	.49				
− 10	− 13.2	− 17.9						
− 9	12.0	16.0	− 22.0					
− 8	10.7	14.3	19.4					
− 7	9.5	12.7	17.1	− 24.0				
− 6	8.3	11.2	14.9	20.3				
$\delta T/\delta B=$	.03	.06	.11	.18	.31	.43		
− 5	− 7.1	− 9.7	− 12.9	− 17.5	− 24.5			
− 4	6.0	8.3	11.1	14.8	20.1			
− 3	4.8	6.9	9.4	12.6	16.8	− 23.4		
− 2	3.6	5.5	7.8	10.5	13.9	18.9		
− 1	2.5	4.2	6.2	8.5	11.5	15.4	− 21.0	
$\delta T/\delta B=$	.02	.04	.07	.10	.14	.19	.26	.38
0	− 1.3	− 2.9	− 4.8	− 6.8	− 9.3	− 12.3	− 16.5	− 22.9
1	0.3	1.7	3.5	5.3	7.6	10.2	13.5	18.3
2	+ 0.6	0.7	2.2	3.9	6.1	8.3	11.1	14.7
3	1.7	+ 0.2	1.0	2.6	4.6	6.4	8.9	11.9
4	2.8	1.4	0.0	1.3	3.1	4.7	6.9	9.4
$\delta T/\delta B=$	.02	.03	.05	.07	.09	.11	.14	.18
5	3.8	2.6	+ 1.2	− 0.1	− 1.6	− 3.2	− 5.0	− 7.1
6	4.9	3.7	2.5	+ 1.1	0.2	1.7	3.3	5.2
7	6.0	4.9	3.7	2.4	+ 1.1	0.3	1.8	3.4
8	7.0	6.0	4.9	3.7	2.5	+ 1.1	0.3	1.8
9	8.1	7.1	6.1	5.0	3.9	2.6	+ 1.2	0.1
$\delta T/\delta B=$	.01	.02	.03	.05	.06	.08	.10	.12
10	9.1	8.3	7.3	6.3	5.2	4.1	2.8	+ 1.5
11	10.2	9.3	8.4	7.5	6.5	5.5	4.3	3.1
12	11.2	10.4	9.6	8.7	7.8	6.8	5.8	4.7
13	12.3	11.5	10.7	9.9	9.1	8.2	7.2	6.2
14	13.3	12.6	11.9	11.1	10.3	9.0	8.6	7.6
$\delta T/\delta B=$	.01	.02	.03	.04	.05	.06	.07	.08
15	14.4	13.7	13.0	12.3	11.5	10.8	9.9	9.1
16	15.4	14.8	14.1	13.5	12.7	12.0	11.3	10.5
17	16.4	15.8	15.2	14.6	13.9	13.3	12.6	11.8
18	17.5	16.9	16.3	15.7	15.1	14.5	13.8	13.1
19	18.5	18.0	17.4	16.9	16.3	15.7	15.1	14.4
$\delta T/\delta B=$	.005	.01	.015	.02	.027	.033	.04	.05
20	19.5	19.0	18.5	18.0	17.4	16.9	16.3	15.7
21	20.5	20.1	19.6	19.1	18.6	18.1	17.5	17.0
22	21.6	21.1	20.7	20.2	19.7	19.2	18.7	18.2
23	22.6	22.2	21.7	21.3	20.8	20.4	19.9	19.4
24	23.6	23.2	22.8	22.4	22.0	21.5	21.1	20.6
$\delta T/\delta B=$	.005	.01	.015	.02	.025	.03	.035	.04
25	24.6	24.2	23.9	23.5	23.1	22.7	22.2	21.8
26	25.6	25.3	24.9	24.5	24.2	23.8	23.4	23.0
27	26.7	26.3	26.0	25.6	25.3	24.9	24.5	24.1
28	27.7	27.3	27.0	26.7	26.4	26.0	25.7	25.3
29	28.7	28.4	28.1	27.8	27.4	27.1	26.8	26.4
$\delta T/\delta B=$	.003	.006	.01	.013	.017	.019	.022	.026
30	29.7	29.4	29.1	28.8	28.5	28.2	27.9	27.6
31	30.7	30.5	30.2	29.9	29.6	29.3	29.0	28.7
32	31.7	31.5	31.2	30.9	30.7	30.4	30.1	29.8
33	32.8	32.5	32.2	32.0	31.7	31.5	31.2	30.9
34	33.8	33.5	33.3	33.0	32.8	32.5	32.3	32.0
$\delta T/\delta B=$	.003	.005	.008	.010	.013	.016	.019	.021
35	34.8	34.5	34.3	34.1	33.8	33.6	33.4	33.1
36	35.8	35.5	35.3	35.1	34.9	34.6	34.4	34.2
37	36.8	36.6	36.4	36.2	36.0	35.7	35.5	35.3
38	37.8	37.6	37.4	37.2	37.0	36.8	36.6	36.4
39	38.8	38.6	38.4	38.2	38.0	37.9	37.6	37.5

POINTS.

between the dry and the wet bulb, when the dew-point has the values given at corresponding points in the body of from 76 centimeters the corresponding numbers in the lines marked $\delta T/\delta B$ are to be multiplied by the difference, above 76. See examples. Thermometer ventilated at about 3 meters per sec.

Dew-points corresponding to the difference of temperature given in the above line and the wet-bulb thermometer reading given in first column.

EXAMPLES.

(1) Given $B=72$, $t_1=10$, $t-t_1=5$.
Then tabular number for $t_1=10$ and $t-t_1=5$ is 5.2
Also $76-72=4$ and $\delta T/\delta B=.06$.
∴ Correction $=0.06\times 4=$ 24
Hence the dew-point is 5.44

(2) Given $B=71.5$, $t_1=7$, $t-t_1=8$.
Then, as above, tabulated number $=$ . . . 3.4
$\delta T/\delta B=\frac{.18+.12}{2}=.15$
Correction $=0.15\times 4.5=$ 67
Dew-point $=$ 4.07

t_1	$t-t_1=9$	10	11	12	13	14	15
$\delta T/\delta B=$	.45	.67					
0							
1							
2	−20.0						
3	15.8	−22.2					
4	12.4	16.8					
$\delta T/\delta B=$	.23	.29	.37	.44	.54	.66	.72
5	−19.8	−13.1	−17.7				
6	7.4	10.1	13.4	−18.1			
7	5.3	7.6	10.1	13.5	−18.3		
8	3.3	5.2	7.4	10.1	13.5	−18.3	
9	1.6	3.2	5.1	7.2	9.9	13.1	−17.2
$\delta T/\delta B=$	.14	.17	.20	.22	.25	.29	.36
10	0.0	−1.3	−3.0	−4.7	−6.8	−9.4	−12.5
11	+1.8	+0.3	1.0	2.6	4.3	6.3	8.8
12	3.5	2.2	+0.8	0.6	2.1	3.7	5.7
13	5.1	3.9	2.7	+1.3	0.1	1.6	3.1
14	6.7	5.6	4.5	3.3	+1.9	+0.5	0.9
$\delta T/\delta B=$	.09	.11	.12	.14	.16	.18	.20
15	8.2	7.2	6.2	5.1	3.9	2.7	+1.3
16	9.6	8.7	7.8	6.8	5.8	4.7	3.5
17	11.0	10.2	9.4	8.5	7.5	6.5	5.5
18	12.4	11.7	10.9	10.1	9.2	8.3	7.4
19	13.8	13.1	12.4	11.6	10.8	10.0	9.1
$\delta T/\delta B=$	.06	.07	.08	.09	.10	.11	.13
20	15.1	14.5	13.8	13.1	12.4	11.6	10.8
21	16.4	15.8	15.2	14.5	13.9	13.2	12.5
22	17.6	17.1	16.5	15.9	15.3	14.7	14.0
23	18.9	18.4	17.9	17.3	16.8	16.2	15.7
24	20.1	19.6	19.2	18.7	18.1	17.6	17.0
$\delta T/\delta B=$	.045	.05	.06	.06	.07	.08	.09
25	21.4	20.9	20.4	20.0	19.5	19.0	18.5
26	22.6	22.1	21.7	21.3	20.8	20.3	19.9
27	23.7	23.4	22.9	22.5	22.1	21.7	21.2
28	24.9	24.5	24.2	23.8	23.4	23.0	22.6
29	26.1	25.7	25.4	25.0	24.6	24.2	23.9
$\delta T/\delta B=$	.031	.035	.041	.047	.053	.06	.07
30	27.2	26.9	26.6	26.2	25.9	25.5	25.2
31	28.4	28.1	27.8	27.4	27.1	26.8	26.4
32	29.5	29.2	28.9	28.6	28.3	28.0	27.7
33	30.7	30.4	30.1	29.8	29.5	29.2	28.9
34	31.8	31.5	31.2	30.9	30.7	30.4	30.1
$\delta T/\delta B=$	.024	.027	.029	.032	.037	.037	.04
35	32.9	32.6	32.4	32.1	31.8	31.6	31.4
36	34.0	33.7	33.5	33.3	33.0	32.8	32.5
37	35.1	34.9	34.6	34.4	34.2	33.9	33.7
38	36.2	35.9	35.7	35.5	35.3	35.1	34.8
39	37.3	37.1	36.8	36.6	36.4	36.2	36.0

RELATIVE HUMIDITY.*

This table gives the humidity of the air, for temperature *t* and dew-point *d* in Centigrade degrees, expressed in percentages of the saturation value for the temperature *t*.

Depression of the dew-point. *t* — *d*	Dew-point (*d*).					Depression of the dew-point. *t* — *d*	Dew-point (*d*).				
	— 10	0	+ 10	+ 20	+ 30		— 10	0	+ 10	+ 20	+ 30
C.						C.					
0°.0	100	100	100	100	100	**8°.0**	54	57	60	62	64
0.2	98	99	99	99	99	8.2	54	56	59	61	63
0.4	97	97	97	98	98	8.4	53	56	58	60	63
0.6	95	96	96	96	97	8.6	52	55	57	60	62
0.8	94	94	95	95	96	8.8	51	54	57	59	61
1.0	92	93	94	94	94	**9.0**	51	53	56	58	61
1.2	91	92	92	93	93	9.2	50	53	55	58	60
1.4	90	90	91	92	92	9.4	49	52	55	57	59
1.6	88	89	90	91	91	9.6	48	51	54	56	59
1.8	87	88	89	90	90	9.8	48	51	53	56	58
2.0	86	87	88	88	89	**10.0**	47	50	53	55	57
2.2	84	85	86	87	88	10.5	45	48	51	54	
2.4	83	84	85	86	87	11.0	44	47	49	52	
2.6	82	83	84	85	86	11.5	42	45	48	51	
2.8	80	82	83	84	85	12.0	41	44	47	49	
3.0	79	81	82	83	84	**12.0**	39	42	45	48	
3.2	78	80	81	82	83	13.0	38	41	44	46	
3.4	77	79	80	81	82	13.5	37	40	43	45	
3.6	76	77	79	80	82	14.0	35	38	41	44	
3.8	75	76	78	79	81	14.5	34	37	40	43	
4.0	73	75	77	78	80	**15.0**	33	36	39	42	
4.2	72	74	76	77	79	15.5	32	35	38	40	
4.4	71	73	75	77	78	16.0	31	34	37	39	
4.6	70	72	74	76	77	16.5	30	33	36	38	
4.8	69	71	73	75	76	17.0	29	32	35	37	
5.0	68	70	72	74	75	**17.5**	28	31	34	36	
5.2	67	69	71	73	75	18.0	27	30	33	35	
5.4	66	68	70	72	74	18.5	26	29	32	34	
5.6	65	67	69	71	73	19.0	25	28	31	33	
5.8	64	66	69	70	72	19.5	24	27	30	33	
6.0	63	66	68	70	71	**20.0**	24	26	29	32	
6.2	62	65	67	69	71	21.0	22	25	27		
6.4	61	64	66	68	70	22.0	21	23	26		
6.6	60	63	65	67	69	23.0	19	22	24		
6.8	60	62	64	66	68	24.0	18	21	23		
7.0	59	61	63	66	68	**25.0**	17	19	22		
7.2	58	60	63	65	67	26.0	16	18	21		
7.4	57	60	62	64	66	27.0	15	17	20		
7.6	56	59	61	63	65	28.0	14	16	19		
7.8	55	58	60	63	65	29.0	13	15	18		
8.0	54	57	60	62	64	**30.0**	12	14	17		

---

* Abridged from Table 45 of "Smithsonian Meteorological Tables."

TABLE 153.

VALUES OF 0.378*e*.*

This table gives the humidity term 0.378*e*, which occurs in the equation $\delta = \delta_0 \frac{h}{760} = \delta_0 \frac{B - 0.378e}{760}$ for the calculation of the density of air containing aqueous vapor at pressure *e* ; δ_0 is the density of dry air at normal temperature and barometric pressure, *B* the observed barometric pressure, and $h = B - 0.378e$, the pressure corrected for humidity. For values of $\frac{h}{760}$ see Table 154. Temperatures are in degrees Centigrade, and pressures in millimeters of mercury.

Dew Point. °C.	*e* Vapor Pressure (ice).	0.378*e*.	Dew Point. °C.	*e* Vapor Pressure (water).	0.378*e*.	Dew Point. °C.	*e* Vapor Pressure (water).	0.378*e*.
−50	0.034	0.01	0	4.579	1.73	+30	31.555	11.93
45	.061	.02	+1	4.921	1.86	31	33.416	12.63
40	.105	.04	2	5.286	2.00	32	35.372	13.37
35	.173	.07	3	5.675	2.15	33	37.427	14.15
30	.292	.11	4	6.088	2.30	34	39.586	14.96
−25	0.484	0.18	5	6.528	2.47	35	41.853	15.82
24	.534	.20	6	6.997	2.65	36	44.23	16.72
23	.589	.22	7	7.494	2.83	37	46.73	17.66
22	.648	.24	8	8.023	3.03	38	49.35	18.65
21	.714	.27	9	8.584	3.24	39	52.09	19.69
−20	0.787	0.30	10	9.179	3.47	40	54.97	20.78
19	.868	.33	11	9.810	3.71	41	57.98	21.92
18	.955	.36	12	10.479	3.96	42	61.13	23.12
17	1.048	.40	13	11.187	4.23	43	64.43	24.35
16	1.148	.44	14	11.936	4.51	44	67.89	25.66
−15	1.257	0.48	15	12.728	4.81	45	71.50	27.02
14	1.375	.52	16	13.565	5.13	46	75.28	28.46
13	1.506	.57	17	14.450	5.46	47	79.23	29.95
12	1.650	.62	18	15.383	5.82	48	83.36	31.51
11	1.806	.68	19	16.367	6.19	49	87.67	33.14
−10	1.974	0.75	20	17.406	6.58	50	92.17	34.84
9	2.154	.81	21	18.503	6.99	51	96.87	36.62
8	2.347	.89	22	19.661	7.43	52	101.77	38.47
7	2.557	.97	23	20.883	7.90	53	106.88	40.40
6	2.785	1.05	24	22.178	8.38	54	112.21	42.42
−5	3.032	1.15	25	23.546	8.90	55	117.77	44.52
4	3.299	1.25	26	24.987	9.45	56	123.56	46.71
3	3.586	1.36	27	26.505	10.02	57	129.59	48.98
2	3.894	1.47	28	28.103	10.62	58	135.87	51.36
1	4.223	1.60	29	29.785	11.26	59	142.41	53.83
0	4.579	1.73	30	31.555	11.93	60	149.21	56.40

---

* This table is quoted from "Smithsonian Meteorological Tables," p. 225.

RELATIVE DENSITY OF MOIST AIR FOR DIFFERENT PRESSURES AND HUMIDITIES.

TABLE 154. — Values of $\frac{h}{760}$, from $h = 1$ to $h = 9$, for the Computation of Different Values of the Ratio of Actual to Normal Barometric Pressure.

This gives the density of moist air at pressure h in terms of the density of the same air at normal atmosphere pressure. When air contains moisture, as is usually the case with the atmosphere, we have the following equation for pressure term: $h = B - 0.378e$, where e is the vapor pressure, and B the corrected barometric pressure. When the necessary psychrometric observations are made the value of e may be taken from Table 150, and then $0.378e$ from Table 153, or the dew-point may be found and the value of $0.378e$ taken from Table 153.

h	$\frac{h}{760}$
1	0.0013158
2	.0026316
3	.0039474
4	0.0052632
5	.0065789
6	.0078947
7	0.0092105
8	.0105263
9	.0118421

EXAMPLES OF USE OF THE TABLE.

To find the value of $\frac{h}{760}$ when $h = 754.3$

$h = 700$	gives	.92105
50	"	.065789
4	"	.005263
.3	"	.000395
754.3		.992497

To find the value of $\frac{h}{760}$ when $h = 5.73$

$h = 5$	gives	.0065789
.7	"	.0009210
.03	"	.0000395
5.73		.0075394

TABLE 155. — Values of the logarithms of $\frac{h}{760}$ for values of h between 80 and 340.

Values from 8 to 80 may be got by subtracting 1 from the characteristic, and from 0.8 to 8 by subtracting 2 from the characteristic, and so on.

h	Values of $\log \frac{h}{760}$.									
	0	1	2	3	4	5	6	7	8	9
80	$\bar{1}$.02228	$\bar{1}$.02767	$\bar{1}$.03300	$\bar{1}$.03826	$\bar{1}$.04347	$\bar{1}$.04861	$\bar{1}$.05368	$\bar{1}$.05871	$\bar{1}$.06367	$\bar{1}$.06858
90	.07343	.07823	.08297	.08767	.09231	.09691	.10146	.10596	.11041	.11482
100	$\bar{1}$.11919	$\bar{1}$.12351	$\bar{1}$.12779	$\bar{1}$.13202	$\bar{1}$.13622	$\bar{1}$.14038	$\bar{1}$.14449	$\bar{1}$.14857	$\bar{1}$.15261	$\bar{1}$.15661
110	.16058	.16451	.16840	.17226	.17609	.17988	.18364	.18737	.19107	.19473
120	.19837	.20197	.20555	.20909	.21261	.21611	.21956	.22299	.22640	.22978
130	.23313	.23646	.23976	.24304	.24629	.24952	.25273	.25591	.25907	.26220
140	.26531	.26841	.27147	.27452	.27755	.28055	.28354	.28650	.28945	.29237
150	$\bar{1}$.29528	$\bar{1}$.29816	$\bar{1}$.30103	$\bar{1}$.30388	$\bar{1}$.30671	$\bar{1}$.30952	$\bar{1}$.31231	$\bar{1}$.31509	$\bar{1}$.31784	$\bar{1}$.32058
160	.32331	.32601	.32870	.33137	.33403	.33667	.33929	.34190	.34450	.34707
170	.34964	.35218	.35471	.35723	.35974	.36222	.36470	.36716	.36961	.37204
180	.37446	.37686	.37926	.38164	.38400	.38636	.38870	.39128	.39334	.39565
190	.39794	.40022	.40249	.40474	.40699	.40922	.41144	.41365	.41585	.41804
200	$\bar{1}$.42022	$\bar{1}$.42238	$\bar{1}$.42454	$\bar{1}$.42668	$\bar{1}$.42882	$\bar{1}$.43094	$\bar{1}$.43305	$\bar{1}$.43516	$\bar{1}$.43725	$\bar{1}$.43933
210	.44141	.44347	.44552	.44757	.44960	.45162	.45364	.45565	.45764	.45963
220	.46161	.46358	.46554	.46749	.46943	.47137	.47329	.47521	.47712	.47902
230	.48091	.48280	.48467	.48654	.48840	.49025	.49210	.49393	.49576	.49758
240	.49940	.50120	.50300	.50479	.50658	.50835	.51012	.51188	.51364	.51539
250	$\bar{1}$.51713	$\bar{1}$.51886	$\bar{1}$.52059	$\bar{1}$.52231	$\bar{1}$.52402	$\bar{1}$.52573	$\bar{1}$.52743	$\bar{1}$.52912	$\bar{1}$.53081	$\bar{1}$.53249
260	.53416	.53583	.53749	.53914	.54079	.54243	.54407	.54570	.54732	.54894
270	.55055	.55216	.55376	.55535	.55694	.55852	.56010	.56167	.56323	.56479
280	.56634	.56789	.56944	.57097	.57250	.57403	.57555	.57707	.57858	.58008
290	.58158	.58308	.58457	.58605	.58753	.58901	.59048	.59194	.59340	.59486
300	$\bar{1}$.59631	$\bar{1}$.59775	$\bar{1}$.59919	$\bar{1}$.60063	$\bar{1}$.60206	$\bar{1}$.60349	$\bar{1}$.60491	$\bar{1}$.60632	$\bar{1}$.60774	$\bar{1}$.60914
310	.61055	.61195	.61334	.61473	.61611	.61750	.61887	.62025	.62161	.62298
320	.62434	.62569	.62704	.62839	.62973	.63107	.63240	.63373	.63506	.63638
330	.63770	.63901	.64032	.64163	.64293	.64423	.64553	.64682	.64810	.64939
340	.65067	.65194	.65321	.65448	.65574	.65701	.65826	.65952	.66077	.66201

DENSITY OF AIR.

Values of logarithms of $\frac{h}{760}$ for values of h between 350 and 800.

h	Values of log $\frac{h}{760}$.									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
350	$\bar{1}$.66325	$\bar{1}$.66449	$\bar{1}$.66573	$\bar{1}$.66696	$\bar{1}$.66819	$\bar{1}$.66941	$\bar{1}$.67064	$\bar{1}$.67185	$\bar{1}$.67307	$\bar{1}$.67428
360	.67549	.67669	.67790	.67909	.68029	.68148	.68267	.68385	.68503	.68621
370	.68739	.68856	.68973	.69090	.69206	.69322	.69437	.69553	.69668	.69783
380	.69897	.70011	.70125	.70239	.70352	.70465	.70577	.70690	.70802	.70914
390	.71025	.71136	.71247	.71358	.71468	.71578	.71688	.71798	.71907	.72016
400	$\bar{1}$.72125	$\bar{1}$.72233	$\bar{1}$.72341	$\bar{1}$.72449	$\bar{1}$.72557	$\bar{1}$.72664	$\bar{1}$.72771	$\bar{1}$.72878	$\bar{1}$.72985	$\bar{1}$.73091
410	.73197	.73303	.73408	.73514	.73619	.73723	.73828	.73932	.74036	.74140
420	.74244	.74347	.74450	.74553	.74655	.74758	.74860	.74961	.75063	.75164
430	.75265	.75366	.75467	.75567	.75668	.75768	.75867	.75967	.76066	.76165
440	.76264	.76362	.76461	.76559	.76657	.76755	.76852	.76949	.77046	.77143
450	$\bar{1}$.77240	$\bar{1}$.77336	$\bar{1}$.77432	$\bar{1}$.77528	$\bar{1}$.77624	$\bar{1}$.77720	$\bar{1}$.77815	$\bar{1}$.77910	$\bar{1}$.78005	$\bar{1}$.78100
460	.78194	.78289	.78383	.78477	.78570	.78664	.78757	.78850	.78943	.79036
470	.79128	.79221	.79313	.79405	.79496	.79588	.79679	.79770	.79861	.79952
480	.80043	.80133	.80223	.80313	.80403	.80493	.80582	.80672	.80761	.80850
490	.80938	.81027	.81115	.81203	.81291	.81379	.81467	.81554	.81642	.81729
500	$\bar{1}$.81816	$\bar{1}$.81902	$\bar{1}$.81989	$\bar{1}$.82075	$\bar{1}$.82162	$\bar{1}$.82248	$\bar{1}$.82334	$\bar{1}$.82419	$\bar{1}$.82505	$\bar{1}$.82590
510	.82676	.82761	.82846	.82930	.83015	.83099	.83184	.83268	.83352	.83435
520	.83519	.83602	.83686	.83769	.83852	.83935	.84017	.84100	.84182	.84264
530	.84346	.84428	.84510	.84591	.84673	.84754	.84835	.84916	.84997	.85076
540	.85158	.85238	.85319	.85399	.85479	.85558	.85638	.85717	.85797	.85876
550	$\bar{1}$.85955	$\bar{1}$.86034	$\bar{1}$.86113	$\bar{1}$.86191	$\bar{1}$.86270	$\bar{1}$.86348	$\bar{1}$.86426	$\bar{1}$.86504	$\bar{1}$.86582	$\bar{1}$.86660
560	.86737	.86815	.86892	.86969	.87047	.87123	.87200	.87277	.87353	.87430
570	.87506	.87582	.87658	.87734	.87810	.87885	.87961	.88036	.88111	.88186
580	.88261	.88336	.88411	.88486	.88560	.88634	.88708	.88782	.88856	.88930
590	.89004	.89077	.89151	.89224	.89297	.89370	.89443	.89516	.89589	.89661
600	$\bar{1}$.89734	$\bar{1}$.89806	$\bar{1}$.89878	$\bar{1}$.89950	$\bar{1}$.90022	$\bar{1}$.90094	$\bar{1}$.90166	$\bar{1}$.90238	$\bar{1}$.90309	$\bar{1}$.90380
610	.90452	.90523	.90594	.90665	.90735	.90806	.90877	.90947	.91017	.91088
620	.91158	.91228	.91298	.91367	.91437	.91507	.91576	.91645	.91715	.91784
630	.91853	.91922	.91990	.92059	.92128	.92196	.92264	.92333	.92401	.92469
640	.92537	.92604	.92672	.92740	.92807	.92875	.92942	.93009	.93076	.93143
650	$\bar{1}$.93210	$\bar{1}$.93277	$\bar{1}$.93343	$\bar{1}$.93410	$\bar{1}$.93476	$\bar{1}$.93543	$\bar{1}$.93609	$\bar{1}$.93675	$\bar{1}$.93741	$\bar{1}$.93807
660	.93873	.93939	.94004	.94070	.94135	.94201	.94266	.94331	.94396	.94461
670	.94526	.94591	.94656	.94720	.94785	.94849	.94913	.94978	.95042	.95106
680	.95170	.95233	.95297	.95361	.95424	.95488	.95551	.95614	.95677	.95741
690	.95804	.95866	.95929	.95992	.96055	.96117	.96180	.96242	.96304	.96366
700	$\bar{1}$.96428	$\bar{1}$.96490	$\bar{1}$.96552	$\bar{1}$.96614	$\bar{1}$.96676	$\bar{1}$.96738	$\bar{1}$.96799	$\bar{1}$.96861	$\bar{1}$.96922	$\bar{1}$.96983
710	.97044	.97106	.97167	.97228	.97288	.97349	.97410	.97471	.97531	.97592
720	.97652	.97712	.97772	.97832	.97892	.97951	.98012	.98072	.98132	.98191
730	.98251	.98310	.98370	.98429	.98488	.98547	.98606	.98665	.98724	.98783
740	.98842	.98900	.98959	.99018	.99076	.99134	.99193	.99251	.99309	.99367
750	$\bar{1}$.99425	$\bar{1}$.99483	$\bar{1}$.99540	$\bar{1}$.99598	$\bar{1}$.99656	$\bar{1}$.99713	$\bar{1}$.99771	$\bar{1}$.99828	$\bar{1}$.99886	$\bar{1}$.99942
760	0.00000	0.00057	0.00114	0.00171	0.00228	0.00285	0.00342	0.00398	0.00455	0.00511
770	.00568	.00624	.00680	.00737	.00793	.00849	.00905	.00961	.01017	.01072
780	.01128	.01184	.01239	.01295	.01350	.01406	.01461	.01516	.01571	.01626
790	.01681	.01736	.01791	.01846	.01901	.01955	.02010	.02064	.02119	.02173

TABLE 156.

VOLUME OF CASES.

Values of $1 + .00367\,t$.

The quantity $1 + .00367\,t$ gives for a gas the volume at t° when the pressure is kept constant, or the pressure at t° when the volume is kept constant, in terms of the volume or the pressure at 0°.

(a) This part of the table gives the values of $1 + .00367\,t$ for values of t between 0° and 10° C. by tenths of a degree.

(b) This part gives the values of $1 + .00367\,t$ for values of t between —90° and + 1990° C. by 10° steps.

These two parts serve to give any intermediate value to one tenth of a degree by a simple computation as follows: — In the (*b*) table find the number corresponding to the nearest lower temperature, and to this number add the decimal part of the number in the (*a*) table which corresponds to the difference between the nearest temperature in the (*b*) table and the actual temperature. For example, let the temperature be 682°.2:

We have for 680 in table (*b*) the number	3.49560
And for 2.2 in table (*a*) the decimal	.00807
Hence the number for 682.2 is	3.50367

(c) This part gives the logarithms of $1 + .00367\,t$ for values of t between —49° and + 399° C. by degrees.

(d) This part gives the logarithms of $1 + .00367\,t$ for values of t between 400° and 1990° C. by 10° steps.

(a) Values of $1 + .00367\,t$ for Values of t between 0° and 10° C. by Tenths of a Degree.

t	0.0	0.1	0.2	0.3	0.4
0	1.00000	1.00037	1.00073	1.00110	1.00147
1	.00367	.00404	.00440	.00477	.00514
2	.00734	.00771	.00807	.00844	.00881
3	.01101	.01138	.01174	.01211	.01248
4	.01468	.01505	.01541	.01578	.01615
5	1.01835	1.01872	1.01908	1.01945	1.01982
6	.02202	.02239	.02275	.02312	.02349
7	.02569	.02606	.02642	.02679	.02716
8	.02936	.02973	.03009	.03046	.03083
9	.03303	.03340	.03376	.03413	.03450

t	0.5	0.6	0.7	0.8	0.9
0	1.00184	1.00220	1.00257	1.00294	1.00330
1	.00550	.00587	.00624	.00661	.00697
2	.00918	.00954	.00991	.01028	.01064
3	.01284	.01321	.01358	.01395	.01431
4	.01652	.01688	.01725	.01762	.01798
5	1.02018	1.02055	1.02092	1.02129	1.02165
6	.02386	.02422	.02459	.02496	.02532
7	.02752	.02789	.02826	.02863	.02899
8	.03120	.03156	.03193	.03290	.03266
9	.03486	.03523	.03560	.03597	.03633

VOLUME OF GASES.

(b) Values of $1 + .00367t$ for Values of t between $-90°$ and $+1990°$ C. by 10° Steps.

t	00	10	20	30	40	50	60	70	80	90
−000	1.00000	0.96330	0.92660	0.88990	0.85320	0.81650	0.77980	0.74310	0.70640	0.66970
+000	1.00000	1.03670	1.07340	1.11010	1.14680	1.18350	1.22020	1.25690	1.29360	1.33030
100	1.36700	1.40370	1.44040	1.47710	1.51380	1.55050	1.58720	1.62390	1.66060	1.69730
200	1.73400	1.77070	1.80740	1.84410	1.88080	1.91750	1.95420	1.99090	2.02760	2.06430
300	2.10100	2.13770	2.17440	2.21110	2.24780	2.28450	2.32120	2.35790	2.39460	2.43130
400	2.46800	2.50470	2.54140	2.57810	2.61480	2.65150	2.68820	2.72490	2.76160	2.79830
500	2.83500	2.87170	2.90840	2.94510	2.98180	3.01850	3.05520	3.09190	3.12860	3.16530
600	3.20200	3.23870	3.27540	3.31210	3.34880	3.38550	3.42220	3.45890	3.49560	3.53230
700	3.56900	3.60570	3.64240	3.67910	3.71580	3.75250	3.78920	3.82590	3.86260	3.89930
800	3.93600	3.97270	4.00940	4.04610	4.08280	4.11950	4.15620	4.19290	4.22960	4.26630
900	4.30300	4.33970	4.37640	4.41310	4.44980	4.48650	4.52320	4.55990	4.59660	4.63330
1000	4.67000	4.70670	4.74340	4.78010	4.81680	4.85350	4.89020	4.92690	4.96360	5.00030
1100	5.03700	5.07370	5.11040	5.14710	5.18380	5.22050	5.25720	5.29390	5.33060	5.36730
1200	5.40400	5.44070	5.47740	5.51410	5.55080	5.58750	5.62420	5.66090	5.69760	5.73430
1300	5.77100	5.80770	5.84440	5.88110	5.91780	5.95450	5.99120	6.02790	6.06460	6.10130
1400	6.13800	6.17470	6.21140	6.24810	6.28480	6.32150	6.35820	6.39490	6.43160	6.46830
1500	6.50500	6.54170	6.57840	6.61510	6.65180	6.68850	6.72520	6.76190	6.79860	6.83530
1600	6.87200	6.90870	6.94540	6.98210	7.01880	7.05550	7.09220	7.12890	7.16560	7.20230
1700	7.23900	7.27570	7.31240	7.34910	7.38580	7.42250	7.45920	7.49590	7.53260	7.56930
1800	7.60600	7.64270	7.67940	7.71610	7.75280	7.78950	7.82620	7.86290	7.89960	7.93630
1900	7.97300	8.00970	8.04640	8.08310	8.11980	8.15650	8.19320	8.22990	8.26660	8.30330
2000	8.34000	8.37670	8.41340	8.45010	8.48680	8.52350	8.56020	8.59690	8.63360	8.67030

VOLUME OF

(c) Logarithms of 1 + .00367 t for Values

t	0	1	2	3	4	Mean diff. per degree.
— 40	$\bar{1}$ 931051	$\bar{1}$.929179	$\bar{1}$.927299	$\bar{1}$.925410	$\bar{1}$.923513	**1884**
— 30	.949341	.947546	.945744	.943934	.942117	1805
— 20	.966892	.965169	.963438	.961701	.959957	1733
—10	.983762	.982104	.980440	.978769	.977092	1667
— 0	0.000000	.998403	.996801	.995192	.993577	1605
+ 0	0.000000	0.001591	0.003176	0.004755	0.006329	**1582**
10	.015653	.017188	.018717	.020241	.021760	1526
20	.030762	.032244	.033721	.035193	.036661	1474
30	.045362	.046796	.048224	.049648	.051068	1426
40	.059488	.060875	.062259	.063637	.065012	1381
50	0.073168	0.074513	0.075853	0.077190	0.078522	**1335**
60	.086431	.087735	.089036	.090332	.091624	1299
70	.099301	.100567	.101829	.103088	.104344	1259
80	.111800	.113030	.114257	.115481	.116701	1226
90	.123950	.125146	.126339	.127529	.128716	1191
100	0.135768	0.136933	0.138094	0.139252	0.140408	**1158**
110	.147274	.248408	.149539	.150667	.151793	1129
120	.158483	.159588	.160691	.161790	.162887	1101
130	.169410	.170488	.171563	.172635	.173705	1074
140	.180068	.181120	.182169	.183216	.184260	1048
150	0.190472	0.191498	0.192523	0.193545	0.194564	**1023**
160	.200632	.201635	.202635	.203634	.204630	1000
170	.210559	.211540	.212518	.213494	.214468	976
180	.220265	.221224	.222180	.223135	.224087	956
190	.229759	.230697	.231633	.232567	.233499	935
200	0.239049	0.239967	0.240884	0.241798	0.242710	**916**
210	.248145	.249044	.249942	.250837	.251731	897
220	.257054	.257935	.258814	.259692	.260567	878
230	.265784	.266648	.267510	.268370	.269228	861
240	.274343	.275189	.276034	.276877	.277719	844
250	0.282735	0.283566	0.284395	0.285222	0.286048	**828**
260	.290969	.291784	.292597	.293409	.294219	813
270	.299049	.299849	.300648	.301445	.302240	798
280	.306982	.307768	.308552	.309334	.310115	784
290	.314773	.315544	.316314	.317083	.317850	769
300	0.322426	0.323184	0.323941	0.324696	0.325450	**756**
310	.329947	.330692	.331435	.332178	.332919	743
320	.337339	.338072	.338803	.339533	.340262	730
330	.344608	.345329	.346048	.346766	.347482	719
340	.351758	.352466	.353174	.353880	.354585	707
350	0.358791	0.359488	0.360184	0.360879	0.361573	**696**
360	.365713	.366399	.367084	.367768	.368451	684
370	.372525	.373201	.373875	.374549	.375221	674
380	.379233	.379898	.380562	.381225	.381887	664
390	.385439	.386494	.387148	.387801	.388453	654

GASES.

of *t* between —49° and +399° C. by Degrees.

t	5	6	7	8	9	Mean diff. per degree.
—40	$\bar{1}$.921608	$\bar{1}$.919695	$\bar{1}$.917773	$\bar{1}$.915843	$\bar{1}$.913904	**1926**
—30	.940292	.938460	.936619	.934771	.932915	1845
—20	.958205	.956447	.954681	.952909	.951129	1771
—10	.975409	.973719	.972022	.970319	.968609	1699
—0	.991957	.990330	.988697	.987058	.985413	1636
+0	0.007897	0.009459	0.011016	0.012567	0.014113	**1554**
10	.023273	.024781	.026284	.027782	.029274	1500
20	.038123	.039581	.041034	.042481	.043924	1450
30	.052482	.053893	.055298	.056699	.058096	1402
40	.066382	.067748	.069109	.070466	.071819	1359
50	0.079847	0.081174	0.082495	0.083811	0.085123	**1315**
60	.092914	.094198	.095486	.096765	.098031	1281
70	.105595	.106843	.108088	.109329	.110566	1243
80	.117917	.119130	.120340	.121547	.122750	1210
90	.129899	.131079	.132256	.133430	.134601	1175
100	0.141559	0.142708	0.143854	0.144997	0.146137	**1144**
110	.152915	.154034	.155151	.156264	.157375	1115
120	.163981	.164072	.166161	.167246	.168330	1087
130	.174772	.175836	.176898	.177958	.179014	1060
140	.185301	.186340	.187377	.188411	.189443	1035
150	0.195581	0.196596	0.197608	0.198619	0.199626	**1011**
160	.205624	.206615	.207605	.208592	.209577	988
170	.215439	.216409	.217376	.218341	.219304	966
180	.225038	.225986	.226932	.227876	.228819	946
190	.234429	.235357	.236283	.237207	.238129	925
200	0.243621	0.244529	0.245436	0.246341	0.247244	**906**
210	.252623	.253512	.254400	.255287	.256172	887
220	.261441	.262313	.263184	.264052	.264919	870
230	.270085	.270940	.271793	.272644	.273494	853
240	.278559	.279398	.280234	.281070	.281903	836
250	0.286872	0.287694	0.288515	0.289326	0.290153	**820**
260	.295028	.295835	.296640	.297445	.298248	805
270	.303034	.303827	.304618	.305407	.306196	790
280	.310895	.311673	.312450	.313226	.314000	776
290	.318616	.319381	.320144	.320906	.321667	763
300	0.326203	0.326954	0.327704	0.328453	0.329201	**750**
310	.333659	.334397	.335135	.335871	.336606	737
320	.340989	.341715	.342441	.343164	.343887	724
330	.348198	.348912	.349624	.350337	.351048	713
340	.355289	.355991	.356693	.357394	.358093	701
350	0.362266	0.362957	0.363648	0.364337	0.365025	**690**
360	.369132	.369813	.370493	.371171	.371849	678
370	.375892	.376562	.377232	.377900	.378567	668
380	.382548	.383208	.383868	.384525	.385183	658
390	.389104	.389754	.390403	.391052	.391699	648

VOLUME OF GASES.

(d) Logarithms of 1 + .00367 *t* for Values of *t* between 400° and 1990° C. by 10° Steps.

t	00	10	20	30	40
400	0.392345	0.398756	0.405073	0.411300	0.417439
500	0.452553	0.458139	0.463654	0.469100	0.474479
600	.505421	.510371	.515264	.520103	.524889
700	.552547	.556990	.561388	.565742	.570052
800	.595055	.599086	.603079	.607037	.610958
900	.633771	.637460	.641117	.644744	.648341
1000	0.669317	0.672717	0.676090	0.679437	0.682759
1100	.702172	.705325	.708455	.711563	.714648
1200	.732715	.735655	.738575	.741475	.744356
1300	.761251	.764004	.766740	.769459	.772160
1400	.788027	.790616	.793190	.795748	.798292
1500	0.813247	0.815691	0.818120	0.820536	0.822939
1600	.837083	.839396	.841697	.843986	.846263
1700	.859679	.861875	.864060	.866234	.868398
1800	.881156	.883247	.885327	.887398	.889459
1900	.901622	.903616	.905602	.907578	.909545

t	50	60	70	80	90
400	0.423492	0.429462	0.435351	0.441161	0.446894
500	0.479791	0.485040	0.490225	0.495350	0.500415
600	.529623	.534305	.538938	.543522	.548058
700	.574321	.578548	.582734	.586880	.590987
800	.614845	.618696	.622515	.626299	.630051
900	.651908	.655446	.658955	.662437	.665890
1000	0.686055	0.689327	0.692574	0.695797	0.698996
1100	.717712	.720755	.723776	.726776	.729756
1200	.747218	.750061	.752886	.755692	.758480
1300	.774845	.777514	.780166	.782802	.785422
1400	.800820	.803334	.805834	.808319	.810790
1500	0.825329	0.827705	0.830069	0.832420	0.834758
1600	.848528	.850781	.853023	.855253	.857471
1700	.870550	.872692	.874824	.876945	.879056
1800	.891510	.893551	.895583	.897605	.899618
1900	.911504	.913454	.915395	.917327	.919251

DETERMINATION OF HEIGHTS BY THE BAROMETER.

Formula of Babinet: $Z = C \dfrac{B_0 - B}{B_0 + B}$.

C (in feet) $= 52494 \left[1 + \dfrac{t_0 + t - 64}{900}\right]$ English measures.

C (in meters) $= 16000 \left[1 + \dfrac{2(t_0 + t)}{1000}\right]$ metric measures.

In which Z = difference of height of two stations in feet or meters.

B_0, B = barometric readings at the lower and upper stations respectively, corrected for all sources of instrumental error.

t_0, t = air temperatures at the lower and upper stations respectively.

Values of C.

ENGLISH MEASURES.

$\frac{1}{2}(t_0+t)$.	C	Log C
Fahr.	Feet.	
10°	49928	4.69834
15	50511	.70339
20	51094	4.70837
25	51677	.71330
30	52261	4.71818
35	52844	.72300
40	53428	4.72777
45	54011	.73248
50	54595	4.73715
55	55178	.74177
60	55761	4.74633
65	56344	.75085
70	56927	4.75532
75	57511	.75975
80	58094	4.76413
85	58677	.76847
90	59260	4.77276
95	59844	.77702
100	60427	4.78123

METRIC MEASURES.

$\frac{1}{2}(t_0+t)$.	C	Log C
Cent.	Meters.	
—10°	15360	4.18639
—8	15488	.19000
—6	15616	.19357
—4	15744	.19712
—2	15872	.20063
0	16000	4.20412
+2	16128	.20758
4	16256	.21101
6	16384	.21442
8	16512	.21780
10	16640	4.22115
12	16768	.22448
14	16896	.22778
16	17024	.23106
18	17152	.23431
20	17280	4.23754
22	17408	.24075
24	17536	.24393
26	17664	.24709
28	17792	.25022
30	17920	4.25334
32	18048	.25643
34	18176	.25950
36	18304	.26255

Values only approximate. Not good for great altitudes. A more accurate formula with corresponding tables may be found in Smithsonian Meteorological Tables, 3 revised ed. 1906.

TABLE 158.

BAROMETRIC

Barometric pressures corresponding to different
This table is useful when a boiling-point apparatus is used

(a) Common Measure.*

Temp. ° F.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
185	17.06	17.09	17.13	17.17	17.20	17.24	17.28	17.32	17.35	17.39
186	17.42	17.47	17.51	17.54	17.58	17.62	17.66	17.70	17.74	17.77
187	17.81	17.85	17.89	17.93	17.97	18.01	18.05	18.08	18.12	18.16
188	18.20	18.24	18.28	18.32	18.36	18.40	18.44	18.48	18.52	18.56
189	18.60	18.64	18.68	18.72	18.76	18.80	18.84	18.88	18.92	18.96
190	19.00	19.04	19.08	19.12	19.16	19.21	19.25	19.29	19.33	19.37
191	19.41	19.45	19.49	19.54	19.58	19.62	19.66	19.70	19.75	19.79
192	19.83	19.87	19.91	19.96	20.00	20.04	20.08	20.13	20.17	20.21
193	20.26	20.30	20.34	20.38	20.43	20.47	20.51	20.56	20.60	20.64
194	20.68	20.73	20.78	20.82	20.86	20.91	20.95	20.99	21.04	21.08
195	21.13	21.17	21.22	21.26	21.31	21.35	21.40	21.44	21.48	21.53
196	21.58	21.62	21.67	21.71	21.76	21.80	21.85	21.90	21.94	21.99
197	22.03	22.08	22.13	22.17	22.22	22.27	22.31	22.36	22.41	22.45
198	22.50	22.55	22.59	22.64	22.69	22.73	22.78	22.83	22.88	22.92
199	22.97	23.02	23.07	23.12	23.16	23.21	23.26	23.31	23.36	23.40
200	23.45	23.50	23.55	23.60	23.65	23.70	23.75	23.79	23.84	23.89
201	23.94	23.99	24.04	24.09	24.14	24.19	24.24	24.29	24.34	24.39
202	24.44	24.49	24.54	24.59	24.64	24.69	24.74	24.79	24.85	24.90
203	24.95	25.00	25.05	25.10	25.15	25.20	25.26	25.31	25.36	25.41
204	25.46	25.52	25.57	25.62	25.67	25.72	25.78	25.83	25.88	25.94
205	25.99	26.04	26.09	26.15	26.20	26.25	26.31	26.36	26.41	26.47
206	26.52	26.58	26.63	26.68	26.74	26.79	26.85	26.90	26.96	27.01
207	27.06	27.12	27.17	27.23	27.28	27.34	27.39	27.45	27.51	27.56
208	27.62	27.67	27.73	27.78	27.84	27.90	27.95	28.01	28.07	28.12
209	28.18	28.24	28.29	28.35	28.41	28.46	28.52	28.58	28.63	28.69
210	28.75	28.81	28.87	28.92	28.98	29.04	29.10	29.16	29.21	29.27
211	29.33	29.39	29.45	29.51	29.57	29.63	29.68	29.74	29.80	29.86
212	29.92	29.98	30.04	30.10	30.16	30.22	30.28	30.34	30.40	30.46

* Pressures in inches of mercury

The values at the lower temperatures are perhaps ½% too low. Table (b) is based on more recent data (1913).

PRESSURES.

temperatures of the boiling-point of water.
in place of the barometer for the determination of heights.

(b) Metric Measure.*

Temp. ° C.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
80°	355.5	356.9	358.4	359.8	361.3	362.7	364.2	365.7	367.1	368.6
81	370.1	371.6	373.1	374.6	376.1	377.6	379.1	380.6	382.2	383.7
82	385.2	386.8	388.3	389.9	391.4	393.0	394.6	396.2	397.7	399.3
83	400.9	402.5	404.1	405.7	407.3	408.9	410.5	412.2	413.8	415.4
84	417.1	418.7	420.4	422.0	423.7	425.4	427.0	428.7	430.4	432.1
85	433.8	435.5	437.2	438.9	440.6	442.4	444.1	445.8	447.6	449.3
86	451.1	452.8	454.6	456.4	458.1	459.9	461.7	463.5	465.3	467.1
87	468.9	470.7	472.5	474.4	476.2	478.0	479.9	481.7	483.6	485.5
88	487.3	489.2	491.1	493.0	494.9	496.8	498.7	500.6	502.5	504.4
89	506.4	508.3	510.2	512.2	514.1	516.1	518.1	520.0	522.0	524.0
90	526.0	528.0	530.0	532.0	534.0	536.0	538.1	540.1	542.2	544.2
91	546.3	548.3	550.4	552.5	554.6	556.6	558.7	560.8	563.0	565.1
92	567.2	569.3	571.4	573.6	575.7	577.9	580.1	582.2	584.4	586.6
93	588.8	591.0	593.2	595.4	597.6	599.8	602.0	604.3	606.5	608.8
94	611.0	613.3	615.6	617.8	620.1	622.4	624.7	627.0	629.4	631.7
95	634.0	636.3	638.7	641.0	643.4	645.8	648.1	650.5	652.9	655.3
96	657.7	660.1	662.5	664.9	667.4	669.8	672.2	674.7	677.2	679.6
97	682.1	684.6	687.1	689.6	692.1	694.6	697.1	699.6	702.2	704.7
98	707.3	709.8	712.4	715.0	717.6	720.2	722.8	725.4	728.0	730.6
99	733.2	735.9	738.5	741.2	743.8	746.5	749.2	751.9	754.6	757.3
100	760.0	762.7	765.4	768.2	770.9	773.7	776.4	779.2	782.0	784.8

* Pressure in millimeters of mercury.

STANDARD WAVE-LENGTHS.

TABLE 159. — Absolute Wave-length of Red Cadmium Line in Air, 760 mm. Pressure, 15° C.

6438.4722	Michelson, Travaux et Mém. du Bur. intern. des Poids et Mesures, 11, 1895.
6438.4700	Michelson, corrected by Benoit, Fabry, Perot, C. R. 144, 1082, 1907.
6438.4696	(accepted primary standard) Benoit, Fabry, Perot, C. R. 144, 1082, 1907.

TABLE 160. — International Secondary Standards. Iron Arc Lines.

Adopted as secondary standards at the International Union for Coöperation in Solar Research (transactions, 1910). Means of measures of Fabry-Buisson (1), Pfund (2), and Eversheim (3). Referred to primary standard = Cd. line, λ = 6438.4696 Ångströms (serving to define an Ångström). 760 mm., 15° C. Iron rods, 7 mm. diam. length of arc, 6 mm.; 6 amp. for λ greater than 4000 Ångströms, 4 amp. for lesser wave-lengths; continuous current, + pole above the —, 220 volts; source of light, 2 mm. at arc's center. Lines adopted in 1910.

Wave-length.	Wave-length.	Wave-length.	Wave-length.	Wave-length.	Wave-length.	Wave-length.
4282.408	4547.853	4789.657	5083.344	5405.780	5615.661	6230.734
4315.089	4592.658	4878.225	5110.415	5434.527	5658.836	6265.145
4375.934	4602.947	4903.325	5167.492	5455.614	5763.013	6318.028
4427.314	4647.439	4919.007	5192.363	5497.522	6027.059	6335.341
4466.556	4691.417	5001.881	5232.957	5506.784	6065.492	6393.612
4494.572	4707.288	5012.073	5266.569	5569.633	6137.701	6430.859
4531.155	4736.786	5049.827	5371.495	5586.772	6191.568	6494.993

TABLE 161. — International Secondary Standards. Iron Arc Lines.

Adopted in 1913. (4) Means of measures of Fabry-Buisson, Pfund, Burns and Eversheim.

Wave-length.	Wave-length.	Wave-length.	Wave-length.	Wave-length.	Wave-length.	Wave-length.
3370.789	3606.682	3753.615	3906.482	4076.642	4233.615	6750.250
3399.337	3640.392	3805.346	3907.937	4118.552	5709.396	5857.759 Ni
3485.345	3676.313	3843.261	3935.818	4134.685	6546.250	5892.882 Ni
3513.821	3677.629	3850.820	3977.746	4147.676	6592.928	
3556.881	3724.380	3865.527	4021.872	4191.443	6678.004	

(1) Astrophysical Journal, 28, p. 169, 1908; (2) Ditto, 28, p. 197, 1908; (3) Annalen der Physik, 30, p. 815, 1909. See also Eversheim, *ibid.* 36, p. 1071, 1911; Buisson et Fabry, *ibid.* 38, p. 245, 1912; (4) Astrophysical Journal, 39, p. 93, 1914.

TABLE 162. — Some of the Stronger Lines of Some of the Elements.

Barium .	5535.7	Helium .	5875.8	Magnesium	5167.5	Sodium .	5890.2
Cæsium .	4555.4	" . .	5876.2	" . .	5172.9	" . .	5896.2
" .	4593.3	Hydrogen	4101.8	" . .	5183.8	Strontium	4607.5
Calcium .	5589.0	" . .	4340.7	Mercury .	5461.0	" . .	5481.2
Cadmium	4799.9	" . .	4861.5	Potassium .	7668.5	" . .	6408.6
" . .	5085.8	" . .	6563.0	" . .	7701.9	Thallium.	5350.6
" . .	6438.5	Lithium .	6708.2	Rubidium .	6298.7		

TABLE 163.

STANDARD SOLAR WAVE-LENGTHS. ROWLAND'S VALUES.

Wave-lengths are in Ångström units (10^{-7} mm.), in air at 20° C and 76 cm. of mercury pressure. The intensities run from 1, just clearly visible on the map, to 1000 for the H and K lines; below 1 in order of faintness to 0000 as the lines are more and more difficult to see. This table contains only the lines above 5.

N indicates a line not clearly defined, probably an undissolved multiple line; **s**, a faded appearing line; **d**, a double. In the "substance" column, where two or more elements are given, the line is compound; the order in which they are given indicates the portion of the line due to each element; when the solar line is too strong to be due wholly to the element given, it is represented, **-Fe**, for example; when commas separate the elements instead of a dash, the metallic lines coincide with the same part of the solar line, **Fe, Cr**, for example.

Capital letters next the wave-length numbers are the ordinary designations of the lines. **A** indicates atmospheric lines, **(wv)**, due to water vapor, **(O)**, due to Oxygen.

Wave-length.	Substance.	Intensity.	Wave-length.	Substance.	Intensity.	Wave-length.	Substance.	Intensity.
3037.510s	Fe	10 N	3372.947	Ti–Pd	10 d?	3533.345	Fe	6
3047.725s	Fe	20 N	3380.722	Ni	6 N	3536.709	Fe	7
3053.530s	–	7 d?	3414.911	Ni	15	3541.237	Fe	7
3054.429	Mn, Ni	10	3423.848	Ni	7	3542.232	Fe	6
3057.552s	Ti, Fe	20	3433.715	Ni, Cr	8 d?	3555.079	Fe	9
3059.212s	Fe	20	3440.762s } O	Fe	20	3558.672s	Fe	8
3067.369s	Fe	8	3441.155s }	Fe	15	3565.535s	Fe	20
3073.091	Ti, –	6 Nd?	3442.118	Mn	6	3566.522	Ni	10
3078.769s	Ti, –	8 d?	3444.020s	Fe	8 N	3570.273s	Fe	20
3088.145s	Ti	7 d?	3446.406	Ni	15	3572.014	Ni	6
3134.230s	Ni, Fe	8	3449.583	Co	6 d?	3572.712	Se, –	6
3188.656	–, Fe	6 d?	3453.039	Ni	6 d?	3578.832	Cr	10
3236.703s	Ti	7 N	3458.601	Ni	8	3581.349s	Fe	30
3239.170	Ti	7	3461.801	Ni	8	3584.800	Fe	6
3242.125	Ti, –	8	3462.950	Co	6	3585.105	Fe	6
3243.189	–, Ni	6	3466.015s	Fe	6	3585.479	Fe	7
3247.688s	Cu	10	3475.594s	Fe	10	3585.859	Fe	6
3256.021	Fe?	6	3476.849s	Fe	8	3587.130	Fe	8
3267.834s	V	6	3483.923	Ni	6 d?	3587.370	Co	7
3271.129	Fe	6	3485.493	Fe Co	6	3588.084	Ni	6
3271.791	Ti, Fe	6 d?	3490.733s	Fe	10 N	3593.636	Cr	9
3274.096s	Cu	10	3493.114	Ni	10 N	3594.784	Fe	6
3277.482	Co–Fe	7 d?	3497.982s	Fe	8	3597.854	Ni	8
3286.898	Fe	7 N	3500.996s	Ni	6 d?	3605.479s	Cr	7
3295.951s	Fe, Mn	6	3510.466	Ni	8	3606.838s	Fe	6
3302.510s	Na	6	3512.785	Co	6	3609.008s	Fe	20
3315.807	Ni	7 d?	3513.965s	Fe	7	3612.882	Ni	6 d?
3318.160s	Ti	6	3515.206	Ni	12	3617.934s	Fe	6
3320.391	Ni	7	3519.904	N	7	3618.919s	Fe	20
3336.820	Mg	8 N	3521.410s	Fe	8	3619.539	Ni	8
3349.597	Ti	7	3524.677	Ni	20	3621.612s	Fe	6
3361.327	Ti	8	3526.183	Fe	6	3622.147s	Fe	6
3365.908	Ni	6	3526.988	Co	6	3631.605s	Fe	15
3366.311	Ti, Ni	6 d?	3529.964	Fe–Co	6	3640.535s	Cr–Fe	6
3369.713	Fe, Ni	6	3533.156	Fe	6	3642.820	Ti	7

Corrections to reduce Rowland's wave-lengths to standards of Table 160 (the accepted standards, 1913). Temperature 15° C, pressure 760 mm.

The differences "(Fabry-Buisson-arc-iron) — (Rowland-solar-iron)" lines were plotted, a smooth curve drawn, and the following values obtained:

Wave-length	3000.	3100.	3200.	3300.	3400.	3500.	3600.	3700.
Correction	—.106	—.115	—.124	—.137	—.148	—.154	—.155	—.140

H. A. Rowland, "A preliminary table of solar-spectrum wave-lengths," Astrophysical Journal, 1–6, 1895–1897.

TABLE 163 (*continued*).

STANDARD SOLAR WAVE-LENGTHS. ROWLAND'S VALUES.

Wave-length.	Substance.	Intensity.	Wave-length.	Substance.	Intensity.	Wave-length.	Substance.	Intensity.
3647.988s	Fe	12	3826.027s	Fe	20	4045.975s	Fe	30
3651.247	Fe,–	6	3827.980	Fe	8	4055.701s	Mn	6
3651.614	Fe	7	3829.501s	Mg	10	4057.668	–	7
3676.457	Fe, Cr	6	3831.837	Ni	6	4063.759s	Fe	20
3680.069s	Fe	9	3832.450s	Mg	15	4068.137	Fe–Mn	6
3684.258s	Fe	7d ?	3834.364	Fe	10	4071.908s	Fe	15
3685.339	Ti	10d ?	3838.435s	Mg–C	25	4077.885s	Sr	8
3686.141	Ti–Fe	6	3840.580s	Fe–C	8	4102.000Hδ	H, In	40N
3687.610s	Fe	6	3841.195	Fe–Mn	10	4121.477s	Cr–Co	6d ?
3689.614	Fe	6	3845.606	C–Co	8d ?	4128.251	Ce–V,–	6d
3701.234	Fe	8	3850.118	Fe–Cr	10	4132.235	Fe–Co	10
3705.708s	Fe	9	3856.524s	Fe	8	4137.156	Fe	6
3706.175	Ca, Mn	6d ?	3857.805	Cr–C	6d ?	4140.089	Fe	6
3709.389s	Fe	8	3858.442	Ni	7	4144.038	Fe	15
3716.591s	Fe	7	3860.055s	Fe–C	20	4167.438	–	8
3720.084s	Fe	40	3865.674	Fe–C	7	4187.204	Fe	6
3722.692s	Ni	10	3872.639	Fe	6	4191.595	Fe	6
3724.526	Fe	6	3878.152	Fe–C	8	4202.198s	Fe	8
3732.545s	Co–Fe	6	3878.720	Fe	7Nd ?	4226.904sg	Ca	20 d?
3733.469s	Fe–	7d ?	3886.434s	Fe	15	4233.772	Fe	6
3735.014s	Fe	40	3887.196	Fe	7	4236.112	Fe	8
3737.281s	Fe	30	3894.211	–	8d	4250.287s	Fe	8
3738.466	–	6	3895.803	Fe	7	4250.945s	Fe	8
3743.508	Fe–Ti	6	3899.850	Fe	8	4254.505s	Cr	8
3745.717s	Fe	8	3903.090	Cr, Fe, Mo	10	4260.640s	Fe	10
3746.058s	Fe	6	3904.023	–	8d	4271.934s	Fe	15
3748.408s	Fe	10	3905.660s	Si	12	4274.958s	Cr	7d ?
3749.631s	Fe	20	3906.628	Fe	10	4308.081sG	Fe	6
3753.732	Fe–Ti	6d ?	3920.410	Fe	10	4325.939s	Fe	8
3758.375s	Fe	15	3923.054	Fe	12d ?	4340.634Hγ	H	20N
3759.447	Ti	12d ?	3928.075s	Fe	8	4376.107s	Fe	6
3760.196	Fe	5	3930.450	Fe	8	4383.720s	Fe	15
3761.464	Ti	7	3933.523	–	8N	4404.927s	Fe	10
3763.945s	Fe	10	3933.825sK	Ca	1000	4415.293s	Fe	8
3765.689	Fe	6	3934.108	Co, V–Cr	8N	4442.510	Fe	6
3767.341s	Fe	8	3944.160s	Al	15	4447.892s	Fe	6
3775.717	Ni	7	3956.819	Fe	6	4494.738s	Fe	6
3783.674s	Ni	6	3957.177s	Fe–Ca	7d ?	4528.798	Fe	8
3788.046s	Fe	9	3961.674s	Al	20	4534.139	Ti–Co	6
3795.147s	Fe	8	3968.350	–, Zr	6N	4549.808	Ti–Co	6d ?
3798.655s	Fe	6	3968.625sH	Ca	700	4554.211s	Ba	8
3799.693s	Fe	7	3968.886	–	6N	4572.156s	Ti–	6
3805.486s	Fe	6	3969.413	Fe	10	4603.126	Fe	6
3806.865	Mn–Fe	8d ?	3974.904	Co–Fe	6d ?	4629.521s	Ti–Co	6
3807.293	Ni	6	3977.891s	Fe	6	4679.027s	Fe	6
3807.681	V–Fe	6	3986.903s	–	6	4703.177s	Mg	10
3814.698	–	8	4005.408	Fe	7	4714.599s	Ni	6
3815.987s	Fe	15	4030.918s	Mn	10d?	4736.963	Fe	6
3820.586sL	Fe–C	25	4033.224s	Mn	8d ?	4754.225s	Mn	7
3824.591	Fe	6	4034.644s	Mn	6d	4783.613s	Mn	6

Corrections to reduce Rowland's wave-lengths to standards of Table 160 (the accepted standards, 1913). Temperature 15° C, pressure 760 mm. :

Wave-length	3600.	3700.	3800.	3900.	4000.	4100.	4200.	4300.	4400.	4500.	4600.	4700.	4800.
Correction	–.155	–.140	–.141	–.144	– 148	–.152	–.156	–.161	– 167	–.172	–.176	–.179	–.179.

STANDARD SOLAR WAVE-LENGTHS. ROWLAND'S VALUES.

Wave-length.	Substance.	Intensity.	Wave-length.	Substance.	Intensity.	Wave-length.	Substance.	Intensity.
4861.527sF	H	30	5948.765s	Si	6	6563.045sC	H	40
4890.948s	Fe	6	5985.040s	Fe	6	6593.161s	Fe	6
4891.683	Fe	8	6003.239s	Fe	6	6867.457sB	A(O)	6d?
4919.174s	Fe	6	6008.785s	Fe	6	6868.336 }s	A(O)	6
4920.685	Fe	10	6013.715s	Mn	6	6868.478 }	A(O)	6
4957.785s	Fe	8	6016.861s	Mn	6	6869.142s	A(O)	7
5050.008s	Fe	6	6022.016s	Mn	6	6869.353s	A(O)	6
5167.497sb$_4$	Mg	15	6024.281s	Fe	7	6870.116 }s	A(O)	7 }d
5171.778s	Fe	6	6065.709s	Fe	7	6870.249 }	A(O)	7 }
5172.856sb$_2$	Mg	20	6102.392s	Fe	6	6871.180s	A(O)	8
5183.791sb$_1$	Mg	30	6102.937s	Ca	9	6871.532s	A(O)	10
5233.122s	Fe	7	6108.334s	Ni	6	6872.486s	A(O)	11
5266.738s	Fe	6	6122.434s	Ca	10	6873.080s	A(O)	12
5269.723sE	Fe	8d?	6136.829s	Fe	8	6874.037s	A(O)	12
5283.802s	Fe	6	6137.915	Fe	7	6874.899s	A(O)	13
5324.373s	Fe	7	6141.938s	Fe, Ba	7	6875.830s	A(O)	13
5328.236	Fe	8d?	6155.350	–	7	6876.958s	A(O)	13
5340.121	Fe	6	6162.390s	Ca	15	6877.882s	A(O)	12
5341.213	Fe	7	6169.249s	Ca	6	6879.288s	A(O)	12
5367.669s	Fe	6	6169.778s	Ca	7	6880.172s	A(O)	6
5370.166s	Fe	6	6170.730	Fe–Ni	6	6884.076s	A(O)	10
5383.578s	Fe	6	6191.393s	Ni	6	6886.000s	A(O)	11
5397.344s	Fe	7d?	6191.779s	Fe	9	6886.990s	A(O)	12
5405.989s	Fe	6	6200.527s	Fe	6	6889.192s	A(O)	13
5424.290s	Fe	6	6213.644s	Fe	6	6890.151s	A(O)	14
5429.911	Fe	6d?	6219.494s	Fe	6	6892.618s	A(O)	14
5447.130s	Fe	6d?	6230.943s	V–Fe	8	6893.560s	A(O)	15
5528.641s	Mg	8	6246.535s	Fe	8	6896.289s	A(O)	14
5569.848	Fe	6	6252.773s	–Fe	7	6897.208s	A(O)	15
5573.075	Fe	6	6256.572s	Ni–Fe	6	6900.199s	A(O)	14
5586.991	Fe	7	6301.718	Fe	7	6901.117s	A(O)	15
5588.985s	Ca	6	6318.239	Fe	6	6904.362s	A(O)	14
5615.877s	Fe	6	6335.554	Fe	6	6905.271s	A(O)	14
5688.436s	Na	6	6337 048	Fe	7	6908.783s	A(O)	13
5711.313s	Mg	6	6358.898	Fe	6	6909.676s	A(O)	13
5763.218s	Fe	6	6393.820s	Fe	7	6913.448s	A(O)	11
5857.674s	Ca	8	6400.217s	Fe	8	6914.337s	A(O)	11
5862.582s	Fe	6	6411.865s	Fe	7	6918.370s	A(O)	9
5890.186sD$_2$	Na	30	6421.570s	Fe	7	6919.250s	A(O)	9
5896.155 D$_1$	Na	20	6439.293s	Ca	8	6923.553s	A(O)	9
5901.682s	A(wv)	6	6450.033s	Ca	6	6924.427s	A(O)	9
5914.430s	–, A(wv)	6	6494.004s	Ca	6	7191.755	A, –	6N
5919.860s	A(wv)	7	6495.213	Fe	8	7206.692	–, A	6
5930.406s	Fe	6	6546.479s	Ti–Fe	6			

Corrections to reduce Rowland's wave-lengths to standards of Table 160 (the accepted standards, 1913). Temperature 15° C, pressure 760 mm.:

Wave-length	4800.	4900.	5000.	5100.	5200.	5300.	5400.	5500.	5600.	5700.	5800.
Correction	—.179	—.176	—.173	—.170	—.166	—.172	—.212	—.217	—.218	—.213	—.209

Wave-length	5800.	5900.	6000.	6100.	6200.	6300.	6400.	6500.	6600.	6700.	6800.
Correction	—.209	—.209	—.213	—.214	—.213	—.210	—.209	—.210.			

TABLE 164.

TERTIARY STANDARD WAVE-LENGTHS. IRON ARC LINES.

For arc conditions see Table 160, p. 172. For lines of group *c* class 5 for best results the slit should be at right angles to the arc at its middle point and the current should be reversed several times during the exposure.

Wave-lengths.	Class.	Intensity.	Wave-lengths.	Class.	Intensity.	Wave-lengths.	Class.	Intensity.
*2781.840		4	4337.052	b3	5	5332.909	a4	2
*2806.985		7	4369.777	b3	3	5341.032	a4	5
*2831.559		3	4415.128	b1	8r	5365.404	a1	2
*2858.341		3	4443.198	b3	3	5405.780	a	6
*2901.382		4	4461.658	a3	4	5434.528	a	6
*2926.584		5	4489.746	a3	3	5473.913	a	4
*2986.460		3	4528.620	c4	7	5497.521	a	4
*3000.453		4	4619.297	c4	4	5501.471	a	4
*3053.070		4	4786.811	c4	3	5506.784	a	3
*3100.838		2	4871.331	c5	8	‡5535.419	a	2
*3154.202		4	4890.769	c5	7	5563.612	b	3
*3217.389		4	4924.773	a	3	5975.352	b	2
*3257.603		4	4939.685	a	3	6027.059	b	3
*3307.238		4	4973.113	a	2	6065.495	b	4
*3347.932		4	4994.133	a	3	6136.624	b	5
*3389.748		3	5041.076	a	3	6157.734	b	4
*3476.705		5	5041.760	a	4	6165.370	b	3
*3506.502		5	5051.641	a	4	6173.345	b	4
*3553.741		5	5079.227	a	3	6200.323	b	4
*3617.789		6	5079.743	a	3	6213.441	b	5
*3659.521		5	5098.702	a	4	6219.290	b	5
*3705.567		6R	5123.729	a	4	6252.567	b	6
*3749.487		8R	5127.366	a	3	6254.269	b	4
*3820.430		8R	5150.846	a	4	6265.145	b	5
*3859.913		7R	5151.917	a	3	6297.802	b	4
*3922.917		6R	5194.950	a	5	6335.342	b	6
*3956.682		6	5202.341	a	5	6430.859	b	5
*4009.718		5	5216.279	a	5	6494.992	b	6
*4062.451		4	5227.191	a4	8			
†4132.063	b1	7	5242.495	a	3			
†4175.639	b	4	5270.356	a4	8			
†4202.031	b1	7r	5328.043	a1	7			
†4250.791	b2	7	5328.537	a4	4			

* Measures of Burns. † Means of St. John and Burns.

‡ Means of St. John and Goos. Others are means of measures by all three. References: St. John and Ware, Astrophysical Journal, 36, 1912; 38, 1913; Burns, Z. f. wissen. Photog. 12, p. 207, 1913, J. de Phys. 1913, and unpublished data; Goos, Astrophysical Journal, 35, 1912; 37, 1913. The lines in the table have been selected from the many given in these references with a view to equal distribution and where possible of classes *a* and *b*.

For class and pressure shifts see Gale and Adams, Astrophysical Journal, 35, p. 10, 1912. Class *a:* "This involves the well-known flame lines (de Watteville, Phil. Trans. A 204, p. 139. 1904), i.e. the lines relatively strengthened in low-temperature sources, such as the flame of the arc, the low-current arc, and the electric furnace. (Astrophysical Journal, 24, p. 185, 1906, 30, p. 86, 1909, 34, p. 37, 1911, 35, p. 185, 1912.) The lines of this group in the yellow-green show small but definite pressure displacements, the mean being 0.0036 Ångström per atmosphere in the arc." Class *b:* "To this group many lines belong; in fact all the lines of moderate displacement under pressure are assigned to it for the present. These are bright and symmetrically widened under pressure, and show mean pressure displacements of 0.009 Ångström per atmosphere for the lines in the region λ 5975–6678 according to Gale and Adams. Group *c* contains lines showing much larger displacements. The numbers in the class column have the following meaning: 1, symmetrically reversed; 2, unsymmetrically reversed; 3, remain bright and fairly narrow under pressure; 4, remain bright and symmetrical under pressure but become wide and diffuse; 5, remain bright and are widened very unsymmetrically toward the red under pressure."

For further measures in International units see Kayser, Bericht über den gegenwärtigen Stand der Wellenlängenmessungen, International Union for Coöperation in Solar Research, 1913. For further spectroscopic data see Kayser's Handbuch der Spectroscopie.

WAVE-LENGTHS OF FRAUNHOFER LINES.

For convenience of reference the values of the wave-lengths corresponding to the Fraunhofer lines usually designated by the letters in the column headed "index letters," are here tabulated separately. The values are in ten millionths of a millimeter, on the supposition that the D line value is 5896.155. The table is for the most part taken from Rowland's table of standard wave-lengths.

Index Letter.	Line due to —	Wave-length in centimeters $\times 10^8$.	Index Letter.	Line due to—	Wave-length in centimeters $\times 10^8$.
A	O	7621.28*	G	Fe	4308.081
	O	7594.06*		Ca	4307.907
a	–	7164.725	g	Ca	4226.904
B	O	6870.182†	h or H_δ	H	4102.000
C or H_α	H	6563.045	H	Ca	3968.625
α	O	6278.303‡	K	Ca	3933.825
D_1	Na	5896.155	L	Fe	3820.586
D_2	Na	5890.186	M	Fe	3727.778
D_3	He	5875.985	N	Fe	3581.349
E_1	Fe	5270.558	O	Fe	3441.155
	Ca	5270.438	P	Fe	3361.327
E_2	Fe	5269.723	Q	Fe	3286.898
b_1	Mg	5183.791	R	Ca	3181.387
b_2	Mg	5172.856		Ca	3179.453
b_3	Fe	5169.220	S_1 S_2	Fe	3100.787
	Fe	5169.069		Fe	3100.430
b_4	Fe	5167.678		Fe	3100.046
	Mg	5167.497	s	Fe	3047.725
F or H_β	H	4861.527	T	Fe	3020.76
d	Fe	4383.721	t	Fe	2994.53
G′ or H_γ	H	4340.634	U	Fe	2947.99
f	Fe	4325.939			

* The two lines here given for A are stated by Rowland to be: the first, a line "beginning at the head of A, outside edge;" the second, a "single line beginning at the tail of A."

† The principal line in the head of B.

‡ Chief line in the α group.

See Table 163, Rowland's Solar Wave-lengths (foot of page) for correction to reduce these values to standard system of wave-lengths, Table 160.

TABLE 166.—Photometric Standards.

No primary photometric standard has been generally adopted by the various governments. In Germany the Hefner lamp is most used; in England the Pentane lamp and sperm candles are used; in France the Carcel lamp is preferred; in America the Pentane and Hefner lamps are used to some extent, but candles are more largely employed in gas photometry. For the photometry of electric lamps, and generally in accurate photometric work, electric lamps, standardized at a national standardizing institution, are commonly employed.

The "International candle" is the name recently employed to designate the value of the candle as maintained by coöperative effort between the national laboratories of England, France, and America; and the value of various photometric units in terms of this international candle is given in the following table (taken from Circular No. 15 of the Bureau of Standards).

1 International Candle = 1 Pentane Candle.
1 International Candle = 1 Bougie Decimale.
1 International Candle = 1 American Candle.
1 International Candle = 1.11 Hefner Unit.
1 International Candle = 0.104 Carcel Unit.

Therefore 1 Hefner Unit = 0.90 International Candle.

The values of the flame standards most commonly used are as follows:

1. Standard Pentane Lamp, burning pentane	10.0 candles.
2. Standard Hefner Lamp, burning amyl acetate	0.9 candles.
3. Standard Carcel Lamp, burning colza oil	9.6 candles.
4. Standard English Sperm Candle, approximately	1.0 candles.

Slight differences in candle power are found in different lamps, even when made as accurately as possible to the same specifications. Hence these so-called primary standards should be themselves standardized.

TABLE 167.—Intrinsic Brightness of Various Light Sources.

	Barrows.	Ives & Luckiesh.		National Electric Lamp Association.
	C. P. per Sq. In. of surface of light.	C. P. per Sq. In. of surface of light.	C. P. per Sq. Mm. of surface of light.	C. P. per Sq. In. of surface of light.
Sun at Zenith	600,000	–	–	600,000
Crater, carbon arc	200,000	84,000	130.	200,000
Open carbon arc	10,000–50,000	–	–	10,000–50,000
Flaming arc	5,000	–	–	5,000
Magnetite arc	–	4,000	6.2	–
Nernst Glower	800–1,000	(115v.6 amp. d.c.) 3,010	4.7	(1.5 w.p.c.) 2,200
Tungsten incandescent, 1.15 w. p. c.	–	–	–	1,000
Tungsten incandescent, 1.25 w. p. c.	1,000	1,000	1.64	875
Tantalum incandescent, 2.0 w. p. c.	750	580	0.9	750
Graphitized carbon filament, 2.5 w. p. c.	625	750	1.2	625
Carbon incandescent, 3.1 w. p. c. .	480	485	0.75	480
Carbon incandescent, 3.5 w. p. c. .	375	400	0.63	375
Carbon incandescent, 4.0 w. p. c. .	300	325	0.50	–
Inclosed carbon arc (d. c.) . .	100–500	–	–	100–500
Inclosed carbon arc (a. c.) . .	–	–	–	75–200
Acetylene flame (1 ft. burner) . .	75–100	53.0	0.082	75–100
Acetylene flame (¼ ft. burner) .	–	33.0	0.057	–
Welsbach mantle	20–25	31.9	0.048	20–50
Welsbach (mesh)	–	56.0	0.067	–
Cooper Hewitt mercury vapor lamp	16.7	14.9	0.023	17
Kerosene flame	4–8	9.0	0.014	3–8
Candle flame	3–4	–	–	3–4
Gas flame (fish tail)	3–8	2.7	0.004	3–8
Frosted incandescent lamp . .	4–8	–	–	2–5
Moore carbon-dioxide tube lamp .	0.6	–	–	0.3–1.75

Taken from *Data*, 1911.

TABLE 168.—Visibility of White Lights.

Range.	Candle Power.	
	1	2
1 sea-mile = 1855 meters	0.47	0.41
2 " "	1.9	1.6
5 " "	11.8	10.

[1] Paterson and Dudding. [2] Deutsche Seewarte.

The energy falling on 1 sq. cm. at 1m. from a candle is about 4 ergs per sec. (Rayleigh, about 8 according to Ångström.)

TABLE 169.

EFFICIENCY OF VARIOUS ELECTRIC LIGHTS.

	Amperes.	Terminal Watts.	Lumens.	Kw-hours for 100,000 Lumen-hours.	Total cost per 100,000 Lumen-hours at 10 cts. per Kw-hour.
Regenerative d.-c., series arc	5.5	385	11,670	3.3	0.339
Regenerative d.-c., multiple arc	5.5	605	11,670	5.18	0.527
Magnetite d.-c., series arc	6.6	528	7,370	7.16	0.729
Flame arc, d.-c., inclined electrodes	10.0	550	8,640	6.37	0.837
Mercury arc, d.-c., multiple	3.5	385	4,400	15.92	0.89
Flame arc, d.-c., inclined electrodes	8.0	440	6,140	7.16	0.966
Flame arc, d.-c., vertical electrodes	8.0	440	6,140	7.16	0.966
Luminous arc, d.-c., multiple	6.6	726	7,370	9.85	0.988
Open arc, d.-c., series	9.6	480	5,025	9.55	1.079
Magnetite arc, d.-c., series	4.0	320	2,870	11.15	1.13
Flame arc, a.-c., vertical electrodes	10.0	467	5,340	8.75	1.275
Flame arc, a.-c., inclined electrodes	10.0	467	5,340	8.75	1.275
Open arc, d.-c., series	6.6	325	2,920	11.15	1.305
Tungsten series	6.6	75	626	12.0	1.384
Flame arc, a.-c., inclined electrodes	8.0	374	3,910	9.55	1.405
Inclosed arc, d.-c., series	6.6	475	3,315	14.32	1.459
Luminous arc, d.-c., multiple	4.0	440	2,870	15.32	1.547
Tungsten, multiple	0.545	60	475	12.6	1.55
Nernst, a.-c., 3-glower	1.87	414	2,160	19.2	1.88
Nernst, d.-c., 3-glower	1.87	414	2,160	19.2	1.90
Inclosed arc, a.-c., series	7.5	480	2,410	19.9	2.05
Inclosed arc, a.-c., series	6.6	425	2,020	21.3	2.193
Tantalum, d.-c., multiple	—	40	199	21.1	2.31
Tantalum, a.-c., multiple	—	40	199	21.1	2.504
Carbon, 3.1 w. p. c., multiple	—	49.6	166	29.9	3.24
Carbon, 3.5 w. p. c., series	6.6	210	626	33.6	3.47
Carbon, 3.5 w. p. c., multiple	—	56	166	33.7	3.50
Inclosed arc, d.-c., multiple	5.0	550	1,535	35.8	3.66
Inclosed arc, d.-c., multiple	3.5	385	1,030	37.4	3.84
Inclosed arc, a.-c., multiple	6.0	430	1,124	38.3	3.94
Inclosed arc, a.-c., multiple	4.0	285	688	41.4	4.265

Paper by Prof. J. M. Bryant and Mr. H. G. Hake, Engineering Experiment Station, University of Illinois.

SENSITIVENESS OF THE EYE TO RADIATION.

(Compiled from Nutting, Bulletin of the Bureau of Standards.)

Radiation is easily visible to most eyes from 0.330μ in the violet to 0.770μ in the red. At low intensities approaching threshold values (rod vision) the maximum of spectral sensibility lies in the green at about 0.510μ for 90% of all persons. At higher intensities with the establishment of cone vision the maximum shifts towards the yellow at least as far as 0.560μ.

TABLE 170. — Variation of the Sensitiveness of the Eye with the Wave-length at Low Intensities (near Threshold Values). König.

λ	.410	.430	.450	.470	.490	.510	.530	.550	.570	.590	.610
Mean sensitiveness	0.02	0.06	0.23	0.49	0.81	1.00	0.81	0.49	0.22	0.077	0.026

TABLE 171. — Variation of Sensitiveness to Radiation of Greater Intensities.

The sensibility is approximately proportional to the intensity over a wide range. The ratio of optical- to radiation-intensity increases more rapidly for the red than for the blue or green (Purkinje phenomenon).

The intensity is given for the spectrum at 0.535μ (green).

Intensity (metre-candles) =	.00024	.00225	.0360	.575	2.30	9.22	36.9	147.6	590.4
Ratio to preceding step =	-	9.38	16	16	4	4	4	4	4
Wave-length, λ.	Sensitiveness.								
0.430μ	.081	.093	.127	.128	.114	.114	–	–	–
.450	.33	.30	.29	.31	.23	.175	.16	–	–
.470	.63	.59	.54	.58	.51	.29	.26	.23	–
.490	.96	(.89)	(.76)	(.89)	(.83)	.50	.45	.38	.35
.505	1.00	1.00	1.00	1.00	.99	(.76)	.66	.61	.54
.520	.88	.86	.86	.94	.99	(.85)	.85	.85	.82
.535	.61	.62	.63	.72	.91	(.98)	.98	.99	.98
.555	.26	.30	.34	.41	.62	.84	.93	.97	.98
.575	.074	.102	.122	.168	(.39)	(.63)	(.76)	(.82)	(.84)
.590	.025	.034	.054	.091	.27	.49	.61	.68	.69
.605	.008	.012	.024	.056	.173	.35	(.45)	.54	.55
.625	.004	.004	.011	.027	.098	.20	.27	.35	.35
.650	.000	.000	.003	.007	.025	.060	.085	.122	.133
.670	.000	.000	.001	.002	.007	.017	.025	.030	.030
λ, maximum sensitiveness	.503	.504	.504	.508	.513	.530	.541	.543	.544

TABLE 172. — Sensibility to Small Differences in Intensity measured as a Fraction of the Whole.

λ =	.670	.605	.575	.505	.470	.430	White
I_0 in m. c. =	0.060	0.0056	0.0029	0.00017	0.00012	0.00012	0.00072
I	δI : I König's data, measures from one normal person only.						
1,000,000	–	–	–	–	–	–	.036
200,000	–	.042	–	–	–	–	.027
100,000	–	.024	.032	–	–	–	.019
50,000	.021	.025	.026	–	–	–	.017
20,000	.016	.018	.020	.019	–	–	.017
10,000	.016	.016	.018	.018	–	–	.018
5,000	.018	.016	.017	.016	–	–	.018
2,000	.016	.018	.018	.017	.018	–	.018
1,000	.017	.020	.018	.018	.017	.018	.018
500	.020	.021	.018	.019	.018	.021	.019
200	.022	.022	.022	.022	.021	.024	.022
100	.029	.028	.027	.024	.022	.025	.030
50	.038	.038	.032	.025	.025	.027	.032
10	.065	.061	.058	.036	.037	.040	.048
5	.092	.103	.089	.049	.046	.049	.059
1	.258	.212	.170	.080	.088	.074	.123
0.5	.376	.276	.21	.091	.096	.097	.188
0.10	–	–	.40	.133	.138	.137	.377
0.05	–	–	–	.183	.185	.154	.484
0.01	–	–	–	.271	.289	.249	–
0.005	–	–	–	.325	.300	.312	–

The sensibility to small differences in intensity is independent of the intensity (Fechner's law). About 0.016 for moderate intensities. Greater for extreme values.

It is independent of wave-length, extremes excepted (König's law).

Sensibility to slight differences in wave-length has two pronounced maxima (one in the yellow, one in the green) and two slight maxima (extreme blue, extreme red).

The visual sensation as a function of the time approaches a constant value with the lapse of time. With blue light there seems to be a pronounced maximum at 0.07 sec., with red a slight one at 0.12 seconds, with green the sensation rises steadily to its final value. For lower intensities these max. occur later.

An intensity of 500 metre-candles is about that on a horizontal plane on a cloudy day.

TABLE 173. — The Solar Constant.

Solar constant (amount of energy falling at normal incidence on one square centimeter per minute on body at earth's mean distance) = 1.932 calories = mean 696 determinations 1902—12. Apparently subject to variations, usually within the range of 7 per cent, and occurring irregularly in periods of a week or ten days.

Computed effective temperature of the sun: from form of black-body curves, 6000° to 7000° Absolute; from λmax. = 2930 and max. = 0.470μ, 6230°; from total radiation, $J = 76.8 \text{x} 10^{-12} \times T^4$, 5830°.

TABLE 174. — Solar spectrum energy (arbitrary units) and its transmission by the earth's atmosphere.

Values computed from $e_m = e_0 a^m$, where e_m is the intensity of solar energy after transmission through a mass of air m; m is unity when the sun is in the zenith, and approximately = sec. zenith distance for other positions (see table 180); e_0 = the energy which would have been observed had there been no absorbing atmosphere; a is the fractional amount observed when the sun is in the zenith.

Wave-length. μ	Transmission coefficients, a.				Intensity Solar Energy. Arbitrary Units.										
	Wash-ington.	Mount Wilson.	Mount Whitney.	One mile nearer earth.		Mount Whitney.	Mount Wilson.				Washington.				
					m = 0	m = 1	m = 1	2	4	6	m = 1	2	3	4	6
0.30	—	(.460)	(.550)	—	54	30	25	11	2	1	—	—	—	—	—
.32	—	.520	.615	—	111	68	58	30	8	2	—	—	—	—	—
.34	—	.580	.692	—	232	160	135	78	26	9	—	—	—	—	—
.36	—	.635	.741	—	302	224	192	122	49	20	—	—	—	—	—
.38	(.380)	.676	.784	.562	354	278	239	162	74	34	134	51	19	7	3
.40	.560	.729	.809	.768	414	335	302	220	117	62	232	130	73	41	13
.46	.690	.832	.887	.829	618	548	514	428	296	205	426	294	203	140	67
.50	.733	.862	.919	.850	606	557	522	450	334	248	441	323	237	174	94
.60	.779	.900	.940	.866	504	474	454	409	331	268	393	306	238	185	112
.70	.858	.950	.964	.903	364	351	346	329	297	268	312	268	230	197	145
.80	.886	.970	.976	.915	266	260	258	250	235	221	236	209	185	164	145
1.00	.922	.980	.975	.941	166	162	163	160	154	147	153	141	130	120	102
1.50	.938	.976*	.965	.961	63	61	61*	60*	57*	55*	59	55	52	49	43
2.00	.912	.970*	.932	.940	25	23	24*	23*	21*	19*	23	21	19	17	14

Transmission coefficients are for period when there was apparently no volcanic dust in the air.
*Possibly too high because of increased humidity towards noon.

TABLE 175. — The intensity of Solar Radiation in different sections of the spectrum, ultra-violet, visual infra-red. Calories.

Wave-length.				Mount Whitney.					Mount Wilson.				Washington.			
μ		μ		m = 0	m = 1	2	3	4	m = 1	2	3	4	m = 1	2	3	4
0.00	to	0.45		.31	.25	.19	.16	.13	.23	.16	.12	.09	.13	.06	.04	.02
0.45	to	0.70		.71	.67	.62	.58	.54	.65	.57	.51	.45	.53	.40	.30	.24
0.70	to	∞		.91	.87	.85	.82	.80	.69	.68	.66	.63	.69	.62	.57	.53
0.00	to	∞		1.93	1.78	1.66	1.56	1.47	1.57	1.42	1.28	1.17	1.35	1.08	.90	.79

TABLE 176. — Distribution of brightness (Radiation) over the Solar Disk.

(These observations extend over only a small portion of a sun-spot cycle.)

Wave-length.		μ 0 323	μ 0.386	μ 0.433	μ 0.456	μ 0.481	μ 0.501	μ 0.534	μ 0.604	μ 0.670	μ 0.699	μ 0.866	μ 1.031	μ 1.225	μ 1.655	μ 2.097
Fraction Radius.	0.00	144	338	456	515	511	489	463	399	333	307	174	111	77.6	39.5	14.0
	0.40	128	312	423	486	483	463	440	382	320	295	169	108	75.7	38.9	13.8
	0.55	120	289	395	455	456	437	417	365	308	284	163	105.5	73.8	38.2	13.6
	0.65	112	267	368	428	430	414	396	348	295	273	159	103	72.2	37.6	13.4
	0.75	99	240	333	390	394	380	366	326	281	258	152	99	69.8	36.7	13.1
	0.825	86	214	296	351	358	347	337	304	262	243	145	94.5	67.1	35.7	12.8
	0.875	76	188	266	317	324	323	312	284	247	229	138	90.5	64.7	34.7	12.5
	0.92	64	163	233	277	290	286	281	259	227	212	130	86	61.6	33.6	12.2
	0.95	49	141	205	242	255	254	254	237	210	195	122	81	58.7	32.3	11.7

Taken from vols. II and III and unpublished data of the Astrophysical Observatory of the Smithsonian Institution. Schwartzchild and Villiger: Astrophysical Journal, 23, 1906.

ATMOSPHERIC TRANSPARENCY AND SOLAR RADIATION.

TABLE 177.—Transmission of Radiation Through Moist and Dry Air.

This table gives the wave-length, λ; a the transmission of radiation by dry air above Mount Wilson (altitude = 1730 m. barometer, 620 mm.) for a body in the zenith; finally a correction factor, a_w, due to such a quantity of aqueous vapor in the air that if condensed it would form a layer 1 cm. thick. Except in the bands of selective absorption due to the air, a agrees very closely with what would be expected from purely molecular scattering. a_w is very much smaller than would be correspondingly expected, due possibly to the formation of ions by the ultra-violet light from the sun. The transmission varies from day to day. However, values for clear days computed as follows agree within a per cent or two of those observed when the altitude of the place is such that the effect due to dust may be neglected, e. g. for altitudes greater than 1000 meters. If B = the barometric pressure in mm., w, the amount of precipitable water in cm., then $a_B = a^{\frac{B}{620}} a_w^w$. w is best determined spectroscopically (Astrophysical Journal, 35, p. 149, 1912, 37, p. 359, 1913) otherwise by formula derived from Hann, $w = 2.3 e_w 10^{-\frac{h}{22000}}$, e_w being the vapor pressure in cm. at the station, h, the altitude in meters.

λ (μ)	.360	.384	.413	.452	.503	.535	.574	.624	.653	.720	.986	1.74
a	(.660)	.713	.783	.840	.885	.898	.905	.929	.938	.970	.986	.990
a_w	.950	.960	.965	.967	.977	.980	.974	.978	.985	.988	.990	.990

Fowle, Astrophysical Journal, 38, 1913.

TABLE 178.—Brightness of (radiation from) Sky at Mt. Wilson (1730 m.) and Flint Island (sea level).

Zenith dist. of zone		0–15°	15–35°	35–50°	50–60°	60–70°	70–80°	80–90°	–	Sun.
10^8 × mean ratio sky/sun	Mt. Wilson	1500*	400	520	610	660	700	720	–	–
" "	Flint Island	115	122	128	150	185	210	460	–	–
Ditto × area of zone	Mt. Wilson	51.0	58.8	91.5	87.2	104.3	117.6	125.3	–	636
" " "	Flint Island	3.9	17.9	22.5	21.4	29.2	35.3	80.0	–	210
Altitude of sun		–	–	5°	15°	25°	35°	47½°	65°	82½°
Sun's brightness, cal. per cm.² per min.		–	–	.533	.900	1.233	1.358	1.413	1.496	1.521
Ditto on horizontal surface		–	–	.046	.233	.524	.780	1.041	1.355	1.507
Mean brightness on normal surface sky × 10^8/sun		–	–	423	403	.385	365	346	326	310
Total sky radiation on horizontal cal. per cm.² per m.		–	–	.056	.110	.162	.189	.205	.226	.240
Total sun + sky, ditto		–	–	.102	.343	.686	.969	1.246	1.581	1.747

* Includes allowance for bright region near sun. For the dates upon which the observation of the upper portion of table were taken, the mean ratios of total radiation sky/sun, for equal angular areas, at normal incidence, at the island and on the mountain, respectively, were 636×10^{-8} and 210×10^{-8}, on a horizontal surface, 305×10^{-8} and 77×10^{-8}; for the whole sky, at normal incidence, 0.57 and 0.20; on a horizontal surface 0.27 and 0.07. Annals of the Astrophysical Observatory of the Smithsonian Institution, vols. II and III, and unpublished researches (Abbot).

TABLE 179.—Relative Distribution in Normal Spectrum of Sunlight and Sky-light at Mount Wilson.

Zenith distance about 50°.

	μ	μ	μ	μ	μ	μ	C	D	b	F
Place in Spectrum	0.422	0.457	0.491	0.566	0.614	0.660				
Intensity Sunlight	186	232	227	211	191	166				
Intensity Sky-light	1194	986	701	395	231	174				
Ratio at Mt. Wilson	642	425	309	187	121	105	102	143	246	316
Ratio computed by Rayleigh	–	–	–	–	–	–	102	164	258	328
Ratio observed by Rayleigh	–	–	–	–	–	–	102	168	291	369

TABLE 180.—Air Masses.

See Table 174 for definition. Besides values derived from the pure secant formula, the table contains those derived from various other more complex formula, taking into account the curvature of the earth, refraction, etc. The most recent is that of Bemporad.

Zenith Dist.	0°	20°	40°	60°	70°	75°	80°	85°	88°
Secant	1.00	1.064	1.305	2.000	2.924	3.864	5.76	11.47	28.7
Forbes	1.00	1.065	1.306	1.995	2.902	3.809	5.57	10.22	18.9
Bouguer	1.00	1.064	1.305	1.990	2.900	3.805	5.56	10.20	19.0
Laplace	1.00	–	–	1.993	2.899	–	5.56	10.20	18.8
Bemporad	1.00	–	–	1.995	2.904	–	5.60	10.39	19.8

The Laplace and Bemporad values, Lindholm, Nova Acta R. Soc. Upsal. 3, 1913; the others, Radau's Actinometric, 1877.

RELATIVE INTENSITY OF SOLAR RADIATION.

TABLE 181.—Mean intensity J for 24 hours of solar radiation on a horizontal surface at the top of the atmosphere and the solar radiation A, in terms of the solar radiation, A_0, at earth's mean distance from the sun.

Date.	Motion of the sun in longitude.	RELATIVE MEAN VERTICAL INTENSITY $\left(\frac{J}{A_0}\right)$.										$\frac{A}{A_0}$.
		LATITUDE NORTH.										
		0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	
Jan. 1	0°.99	0.303	0.265	0.220	0.169	0.117	0.066	0.018				1.0335
Feb. 1	31.54	.312	.282	.244	.200	.150	.100	.048	0.006			1.0288
Mar. 1	59.14	.320	.303	.279	.245	.204	.158	.108	.056	0.013		1.0173
Apr. 1	89.70	.317	.319	.312	.295	.269	.235	.195	.148	.101	0.082	1.0009
May 1	119.29	.303	.318	.330	.329	.320	.302	.278	.253	.255	.259	0.9841
June 1	149.82	.287	.315	.334	.345	.349	.345	.337	.344	.360	.366	0.9714
July 1	179.39	.283	.312	.333	.347	.352	.351	.345	.356	.373	.379	0.9666
Aug. 1	209.94	.294	.316	.330	.334	.330	.318	.300	.282	.295	.300	0.9709
Sept. 1	240.50	.310	.318	.316	.305	.285	.256	.220	.180	.139	.140	0.9828
Oct. 1	270.07	.317	.308	.289	.261	.225	.183	.135	.084	.065		0.9995
Nov. 1	300.63	.312	.286	.251	.211	.164	.114	.063	.018			1.0164
Dec. 1	330.19	.304	.267	.224	.175	.124	.072	.024				1.0288
Year....		0.305	0.301	0.289	0.268	0.241	0.209	0.173	0.144	0.133	0.126	

TABLE 182.—Mean Monthly and Yearly Temperatures.

Mean temperatures of a few selected American stations, also of a station of very high, one of very low and one of very small, range of temperature.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1 Hebron-Rama (Labr.)	−20.7	−20.9	−15.6	− 6.9	+ 0.2	+ 4.5	+ 7.6	+ 8.0	+ 4.5	− 0.8	− 6.2	−16.2	− 5.2
2 Winnipeg (Canada) .	−21.6	−18.8	−11.0	+ 1.9	+10.9	+17.1	+18.9	+17.6	+11.6	+ 4.1	− 7.6	−15.7	+ 0.6
3 Montreal . . .	−10.9	− 9.1	− 4.3	+ 4.8	+12.6	+18.3	+20.5	+19.3	+14.7	+ 7.8	− 0.2	− 7.1	+ 5.5
4 Boston . . .	− 2.8	− 2.2	+ 1.2	+ 7.3	+13.6	+19.1	+21.8	+20.6	+16.9	+11.1	+ 4.8	− 0.5	+ 9.2
5 Chicago . . .	− 4.8	− 2.9	+ 1.2	+ 7.9	+13.4	+19.7	+22.2	+21.6	+17.9	+11.1	+ 3.6	− 1.5	+ 9.1
6 Denver . . .	− 2.1	+ 0.1	+ 3.8	+ 8.3	+13.6	+19.1	+22.1	+21.2	+16.6	+10.3	+ 3.3	0.0	+ 9.7
7 Washington . .	+ 0.7	+ 2.1	+ 5.2	+11.7	+17.7	+22.9	+24.9	+23.7	+19.9	+13.4	+ 6.9	+ 2.3	+12.6
8 Pikes Peak . . .	−16.4	−15.6	−13.4	−10.4	− 5.3	+ 0.4	+ 4.5	+ 3.6	− 0.3	− 5.8	−11.8	−14.4	− 7.1
9 St. Louis . . .	− 0.8	+ 1.7	+ 6.2	+13.4	+18.8	+24.0	+26.0	+24.9	+20.8	+14.2	+ 6.4	+ 2.0	+13.1
10 San Francisco . .	+10.1	+10.9	+12.0	+12.6	+13.7	+14.7	+14.6	+14.8	+15.8	+15.2	+13.5	+10.8	+13.2
11 Yuma	+12.3	+14.9	+18.1	+21.0	+25.1	+29.4	+33.1	+32.6	+29.1	+22.8	+16.6	+13.3	+22.3
12 New Orleans . .	+12.1	+14.5	+16.7	+20.6	+23.7	+26.8	+27.9	+27 5	+25.7	+21.0	+15.9	+13.1	+20.4
13 Massaua . . .	+25.6	+26.0	+27.1	+29.0	+31.1	+33.5	+34.8	+34.7	+33.3	+31.7	+29.0	+27.0	+30.3
14 Ft. Conger (Greenl'd)	−39.0	−40.1	−33.5	−25.3	−10.0	+ 0.4	+ 2.8	+ 1.0	− 9.0	−22.7	−30.9	−33.4	−20.0
15 Werchojansk . .	−51.0	−45.3	−32.5	−13.7	+ 2.0	+12.3	+15.5	+10.1	+ 2.5	−15.0	−37.8	−47.0	−16.7
16 Batavia . . .	+25.3	+25.4	+25.8	+26.3	+26.4	+26.0	+25.7	+25.9	+26.3	+26.4	+26.2	+25.6	+25.9

Lat., Long., Alt. respectively: (1) +58°.5, 63°.0 W, —; (2) +49.9, 97.1 W, 233m.; (3) +45.5, 73.6 W, 57m.; (4) +42.3, 71.1 W, 38m.; (5) +41.9, 87.6 W, 251m.; (6) +39.7, 105.0 W, 1613m.; (7) +38.9, 77.0 W, 34m.; (8) +38.8, 105.0 W, 4308m.; (9) +38.6, 90.2 W, 173m.; (10) +37.8, 122.5 W, 47m.; (11) +32.7, 114.6 W, 43m.; (12) +30.0, 90.1 W, 16m.; (13) +15.6, 37.5 E, 9m.; (14) +81.7, 64.7 W., —; (15) +67.6, 133.8 E, 140m.; (16) −6.2, 106.8 E, 7m.

Taken from Hann's Lehrbuch der Meteorologie, 2'nd edition, which see for further data.

TABLE 183. — Glasses Made by Schott and Gen, Jena.

The following constants are for glasses made by Schott and Gen, Jena: n_A, n_C, n_D, n_F, n_G, are the indices of refraction in air for A=0.7682μ, C=0.6563μ, D=0.5893, F=0.4861, G′=0.4341. $v=(n_D-1)/(n_F-n_C)$. Ultra-violet indices: Simon, Wied. Ann. 53, 1894. Infra-red: Rubens, Wied. Ann. 45, 1892. Table is revised from Landolt, Börnstein and Meyerhoffer, Kayser, Handbuch der Spectroscopie, and Schott and Gen's list No. 751, 1909. See also Hovestadt's "Jena Glass."

	Catalogue Type =	O 546	O 381	O 184	O 102	O 165	S 57
	Designation =	Zinc-Crown.	Higher Dispersion Crown.	Light Silicate Flint.	Heavy Silicate Flint.	Heavy Silicate Flint.	Heaviest Silicate Flint.
	Melting Number =	1092	1151	451	469	500	163
	v =	60.7	51.8	41.1	33.7	27.6	22.2
Kind of Light and Wave-length.	Cd 0.2763μ	1.56759	-	-	-	-	-
	Cd .2837	1.56372	-	-	-	-	-
	Cd .2980	1.55723	1.57093	1.65397	-	-	-
	Cd .3403	1.54369	1.55262	1.63320	1.71968	1.85487	-
	Cd .3610	1.53897	1.54664	1.61388	1.70536	1.83263	-
	H .4340μ	1.52788	1.53312	1.59355	1.67561	1.78800	1.94493
	H .4861	1.52299	1.52715	1.58515	1.66367	1.77091	1.91890
	Na .5893	1.51698	1.52002	1.57524	1.64985	1.75130	1.88995
	H .6563	1.51446	1.51712	1.57119	1.64440	1.74368	1.87893
	K .7682	1.51143	1.51368	1.56669	1.63820	1.73530	1.86702
	.800μ	1.5103	1.5131	1.5659	1.6373	1.7339	1.8650
	1.200	1.5048	1.5069	1.5585	1.6277	1.7215	1.8481
	1.600	1.5008	1.5024	1.5535	1.6217	1.7151	1.8396
	2.000	1.4967	1.4973	1.5487	1.6171	1.7104	1.8316
	2.400	-	-	1.5440	1.6131	-	1.8286

Percentage composition of the above glasses:

O 546, SiO_2, 65.4; K_2O, 15.0; Na_2O, 5.0; BaO, 9.6; ZnO, 2.0; Mn_2O_3, 0.1; As_2O_3, 0.4; B_2O_3, 2.5.
O 381, SiO_2, 68.7; PbO, 13.3; Na_2O, 15.7; ZnO, 2.0; MnO_2, 0.1; As_2O_5, 0.2.
O 184, SiO_2, 53.7; PbO, 36.0; K_2O, 8.3; Na_2O, 1.0; Mn_2O_3, 0.06; As_2O_3, 0.3.
O 102, SiO_2, 40.0; PbO, 52.6; K_2O, 6.5; Na_2O, 0.5; Mn_2O_3, 0.09; As_2O_5, 0.3.
O 165, SiO_2, 29.26; PbO, 67.5; K_2O, 3.0; Mn_2O_3, 0.04; As_2O_3, 0.2.
S 57, SiO_2, 21.9; PbO, 78.0; As_2O_5, 0.1.

TABLE 184. — Jena Glasses.

No. and Type of Jena Glass.	n_D for D	n_F-n_C	$v=\frac{n_D-1}{n_F-n_C}$	n_D-n_A	n_F-n_D	$n_{G'}-n_F$	Specific Weight.
O 225 Light phosphate crown . .	1.5159	.00737	70.0	.00485	.00515	.00407	2.58
O 802 Boro-silicate crown	1.4967	0765	64.9	0504	0534	0423	2.38
UV 3199 Ultra-violet crown . . .	1.5035	0781	64.4	0514	0546	0432	2.41
O 227 Barium-silicate crown . . .	1.5399	0909	59.4	0582	0639	0514	2.73
O 114 Soft-silicate crown	1.5151	0910	56.6	0577	0642	0521	2.55
O 608 High-dispersion crown . .	1.5149	0943	54.6	0595	0666	0543	2.60
UV 3248 Ultra-violet flint	1.5332	0964	55.4	0611	0680	0553	2.75
O 381 High-dispersion crown . .	1.5262	1026	51.3	0644	0727	0596	2.70
O 602 Baryt light flint	1.5676	1072	53.0	0675	0759	0618	3.12
S 389 Borate flint	1.5686	1102	51.6	0712	0775	0629	2.83
O 726 Extra light flint	1.5398	1142	47.3	0711	0810	0669	2.87
O 154 Ordinary light flint	1.5710	1327	43.0	0819	0943	0791	3.16
O 184 " " "	1.5900	1438	41.1	0882	1022	0861	3.28
O 748 Baryt flint	1.6235	1599	39.1	9965	1142	0965	3.67
O 102 Heavy flint	1.6489	1919	33.8	1152	1372	1180	3.87
O 41 " "	1.7174	2434	29.5	1439	1749	1521	4.49
O 165 " "	1.7541	2743	27.5	1607	1974	1730	4.78
S 386 Heavy flint	1.9170	4289	21.4	2451	3109	2808	6.01
S 57 Heaviest flint	1.9626	4882	19.7	2767	3547	3252	6.33

TABLE 185. — Change of Indices of Refraction for 1° C in Units of the Fifth Decimal Place.

No. and Designation.	Mean Temp.	C	D	F	G′	$\frac{-\Delta n}{n}100$
S 57 Heavy silicate flint . . .	58.8°	1.204	1.447	2.090	2.810	0.0166
O 154 Light silicate flint . . .	58.4	0.225	0.261	0.334	0.407	0.0078
O 327 Baryt flint light	58.3	—0.008	0.014	0.080	0.137	0.0079
O 225 Light phosphate crown .	58.1	—0.202	—0.190	—0.168	—0.142	0.0049

Pulfrich, Wied. Ann. 45, p. 609, 1892.

TABLE 186. — Index of Refraction of Rock Salt in Air.

λ(μ).	n.	Observer.	λ(μ).	n.	Observer.	λ(μ).	n.	Observer.
0.185409	1.89348	M	0.88396	1.534011	L	5.8932	1.516014	P
.204470	1.76964	"	.972298	1.532532	"	"	1.515553	L
.291368	1.61325	"	.98220	1.532435	P	6.4825	1.513628	P
.358702	1.57932	"	1.036758	1.531762	L	"	1.513467	L
.441587	1.55962	"	1.1786	1.530372	P	7.0718	1.511062	P
.486149	1.55338	"	"	1.530374	L	7.6611	1.508318	"
"	1.553406	L	1.555137	1.528211	"	7.9558	1.506804	"
"	1.553399	P	1.7680	1.527440	P	8.8398	1.502035	"
.58902	1.544340	L	"	1.527441	L	10.0184	1.494722	"
.58932	1.544313	P	2.073516	1.526554	"	11.7864	1.481816	"
.656304	1.540672	P	2.35728	1.525863	P	12.9650	1.471720	"
"	1.540702	L	"	1.525849	L	14.1436	1.460547	"
.706548	1.538633	P	2.9466	1.524534	P	14.7330	1.454404	"
.766529	1.536712	P	3.5359	1.523173	"	15.3223	1.447494	"
.76824	1.53666	M	4.1252	1.521648	P	15.9116	1.441032	"
.78576	1.536138	P	"	1.521625	L	20.57	1.3735	RN
.88396	1.534011	P	5.0092	1.518978	P	22.3	1.340	"

$$n^2=a^2+\frac{M_1}{\lambda^2-\lambda_1{}^2}+\frac{M_2}{\lambda^2-\lambda_2{}^2}-k\lambda^2-h\lambda^4 \text{ or }=b^2+\frac{M_1}{\lambda^2-\lambda_1{}^2}+\frac{M_2}{\lambda^2-\lambda_2{}^2}-\frac{M_3}{\lambda_3{}^2-\lambda^2}$$

where $a^2=2.330165$ $\lambda_2{}^2=0.02547414$ $b^2=5.680137$
$M_1=0.01278685$ $k=0.0009285837$ $M_3=12059.95$
$\lambda_1{}^2=0.0148500$ $h=0.000000286086$ $\lambda_3{}^2=3600.$ (P)
$M_2=0.005343924$

TABLE 187. — Change of Index of Refraction for 1° C in Units of the 5th Decimal Place.

0.202μ	+3.134	Mi	0.441μ	−3.425	Mi	C line	−3.749	Pl	0.760μ	−3.73	L
.210	+1.570	"	.508	−3.517	"	D "	−3.739	"	1.368	−3.88	L
.224	−0.187	"	.643	−3.636	"	F "	−3.648	"	1.88	−3.85	L
.298	−2.727	"				G′ "	−3.585	"	4.3	−3.82	L

L Annals of the Astrophysical Observatory of the Smithsonian Institution, Vol. I, 1900.
M Martens, Ann. d. Phys. 6, 1901, 8, 1902.
Mi Micheli, Ann. d. Phys. 7, 1902.
P Paschen, Wied. Ann. 26, 1908.
Pl Pulfrich, Wied. Ann. 45, 1892.
RN Rubens and Nichols, Wied. Ann. 60, 1897.

TABLE 188. — Index of Refraction of Silvine (Potassium Chloride) in Air.

λ(μ).	n	Observer.	λ(μ).	n.	Observer.	λ(μ).	n.	Observer.
0.185409	1.82710	M	1.1786	1.478311	P	8.2505	1.462726	P
.200090	1.71870	"	"	1.47824	W	"	1.46276	W
.21946	1.64745	"	1.7680	1.475890	P	8.8398	1.460858	P
.257317	1.58125	"	"	1.47589	W	"	1.46092	W
.281640	1.55836	"	2.35728	1.474751	P	10.0184	1.45672	P
.308227	1.54136	"	2.9466	1.473834	"	"	1.45673	W
.358702	1.52115	"	"	1.47394	W	11.786	1.44919	P
.394415	1.51219	"	3.5359	1.473049	P	"	1.44941	W
.467832	1.50044	"	"	1.47304	W	12.965	1.44346	P
.508606	1.49620	"	4.7146	1.471122	P	"	1.44385	W
.58933	1.49044	P	"	1.47129	W	14.144	1.43722	P
.67082	1.48669	M	5.3039	1.470013	P	15.912	1.42617	"
.78576	1.483282	P	"	1.47001	W	17.680	1.41403	"
.88398	1.481422	P	5.8932	1.468804	P	20.60	1.3882	RN
.98220	1.480084	"	"	1.46880	W	22.5	1.369	"

$$n^2=a^2+\frac{M_1}{\lambda^2-\lambda_1{}^2}+\frac{M_2}{\lambda^2-\lambda_2{}^2}-k\lambda^2-h\lambda^4 \text{ or }=b^2+\frac{M_1}{\lambda^2-\lambda_1{}^2}+\frac{M_2}{\lambda^2-\lambda_2{}^2}+\frac{M_3}{\lambda_3{}^2-\lambda^2}$$

$a^2=2.174967$ $\lambda_2{}^2=0.0255550$ $b^2=3.866619$
$M_1=0.008344206$ $k=0.000513495$ $M_3=5569.715$
$\lambda_1{}^2=0.0119082$ $h=0.000000167587$ $\lambda_3{}^2=3292.47$ (P)
$M_2=0.00698382$

W Weller, see Paschen's article. Other references as under Table 187, above.

TABLES 189-192.

INDEX OF REFRACTION.

TABLE 189. — Index of Refraction of Fluorite in Air.

λ (μ)	n	Observer	λ (μ)	n	Observer	λ (μ)	n	Observer.
0.1856	1.50940	S	1 4733	1.42641	P	4.1252	1.40855	P
.19881	1.49629	"	1.5715	1.42596	"	4.4199	1.40559	"
.21441	1.48462	"	1.6206	1.42582	"	4.7146	1.40238	"
.22045	1.47762	"	1.7680	1.42507	"	5.0092	1.39898	"
.25713	1.46476	"	1.9153	1.42437	"	5.3036	1.39529	"
.32525	1.44987	"	1.9644	1.42413	"	5.5985	1.39142	"
.34555	1.44697	"	2.0626	1.42359	"	5.8932	1.38719	"
.39681	1.44214	"	2.1608	1.42308	"	6.4825	1.37819	"
.48607	1.43713	P	2.2100	1.42288	"	7.0718	1.36805	"
.58930	1.43393	P	2.3573	1.42199	"	7.6612	1 35680	"
.65618	1.43257	S	2.5537	1.42088	"	8.2505	1.34444	"
.68671	1.43200	"	2.6519	1.42016	"	8.8398	1.33079	"
.71836	1.43157	"	2.7502	1.41971	"	9.4291	1.31612	"
.76040	1.43101	"	2.9466	1.41826	"	51.2	3.47	RA
.8840	1.42982	P	3.1430	1.41707	"	61.1	2.66	"
1.1786	1.42787	"	3.2413	1.41612	"	∞	2.63	S
1.3756	1.42690	"	3 5359	1.41379	"	References under Table 173.		
1.4733	1.42641	"	3.8306	1.41120	"			

$$n^2 = a^2 + \frac{M_1}{\lambda^2 - \lambda_1^2} - e\lambda^2 - f\lambda^4 \text{ or} = b^2 + \frac{M_2}{\lambda^2 - \lambda_v^2} + \frac{M_3}{\lambda^2 - \lambda_r^2}$$

where $a^2 = 2.03882$ $f = 0.000002916$ $M_3 = 5114.65$

$M_1 = 0.0062183$ $b^2 = 6.09651$ $\lambda_r^2 = 1260.56$

$\lambda_1^2 = 0.007706$ $M_2 = 0.0061386$ $\lambda_v = 0.0940\mu$

$e = 0.0031999$ $\lambda_v^2 = 0.00884$ $\lambda_r = 35.5\mu$ (P)

TABLE 190. — Change of Index of Refraction for 1° C in Units of the 5th Decimal Place.

C line, —1.220; D, —1.206; F, —1.170; G, —1.142. (Pl)

TABLE 191. — Index of Refraction of Iceland Spar ($CaCO_3$) in Air.

λ (μ)	n_o	n_e	Observer.	λ (μ)	n_o	n_e	Observer.	λ (μ)	n_o	n_e	Observer.
0.198	–	1.5780	M	0.508	1.6653	1.4896	M	0.991	1.6438	1.4802	C
.200	1.9028	1.5765	"	.533	1.6628	1.4884	"	1.229	1.6393	1.4787	"
.208	1.8673	1.5664	"	.589	1.6584	1.4864	"	1.307	1.6379	1.4783	"
.226	1.8130	1.5492	–	.643	1.6550	1.4849	"	1.497	1.6346	1.4774	"
.298	1.7230	1.5151	C	.656	1.6544	1.4846	"	1.682	1.6313	–	"
.340	1.7008	1.5056	M	.670	1.6537	1.4843	"	1.749	–	1.4764	"
.361	1.6932	1.5022	C	.760	1.6500	1.4826	–	1.849	1.6280	–	"
.410	1.6802	1.4964	–	.768	1.6497	1.4826	M	1.908	–	1.4757	"
.434	1.6755	1.4943	M	.801	1.6487	1.4822	C	2.172	1.6210	–	"
.486	1.6678	1.4907	"	.905	1.6458	1.4810	"	2.324	–	1.4739	"

C Carvallo, J. de Phys. (3), 9, 1900.
M Martens, Ann. der Phys. (4) 6, 1901, 8, 1902.
P Paschen, Wied. Ann. 56, 1895.
Pl Pulfrich, Wied. Ann 45, 1892.
RA Rubens-Aschkinass, Wied. Ann. 67, 1899.
S Starke, Wied. Ann. 60, 1897.

TABLE 192. — Index of Refraction of Nitroso-dimethyl-aniline. (Wood.)

λ	n	λ	n	λ	n	λ	n	λ	n
0.497	2.140	0.525	1.945	0.584	1.815	0.636	1.647	0.713	1.718
.500	2.114	.536	1.909	.602	1.796	.647	1.758	.730	1.713
.506	2.074	.546	1.879	.611	1.783	.659	1.750	.749	1.709
.508	2.025	.557	1.857	.620	1.778	.669	1.743	.763	1.697
.516	1.985	.569	1.834	.627	1.769	.696	1.723		

Nitroso-dimethyl-aniline has enormous dispersion in yellow and green, metallic absorption in violet. See Wood, Phil. Mag 1903.

INDEX OF REFRACTION.

TABLE 193. — Index of Refraction of Quartz (SiO_2).

Wave-length.	Index Ordinary Ray.	Index Extraordinary Ray.	Temperature ° C.	Wave-length.	Index Ordinary Ray.	Index Extraordinary Ray.	Temperature ° C.
0.185	1.67582	1.68999	18	0.656	1.54189	1.55091	18
.193	.65997	.67343	"	.686	.54099	.54998	"
.198	.65090	.66397	"	.760	.53917	.54811	"
.206	.64038	.65300	"	1.160	.5329	Rubens.	–
.214	.63041	.64264	"	.969	.5216		–
.219	.62494	.63698	"	2.327	.5156		–
.231	.61399	.62560	"	.84	.5039		–
.257	.59622	.60712	"	3.18	.4944		–
.274	.58752	.59811	"	.63	.4799		–
.340	.56748	.57738	"	.96	.4679		–
.396	.55815	.56771	"	4.20	.4569		–
.410	.55650	.56600	"	5.0	.417		–
.486	.54968	.55896	"	6.45	.274		–
0.598	1.54424	1.55334	"	7.0	1.167		–

Except Rubens' values, — means from various authorities.

TABLE 194. — Indices of Refraction for various Alums.*

R	Density.	Temp. C.°	Index of refraction for the Fraunhofer lines.							
			a	B	C	D	E	b	F	G
Aluminium Alums. $RAl(SO_4)_2+12H_2O$.†										
Na	1.667	17–28	1.43492	1.43563	1.43653	1.43884	1.44185	1.44231	1.44412	1.44804
$NH_3(CH_3)$	1.568	7–17	.45013	.45062	.45177	.45410	.45691	.45749	.45941	.46363
K	1.735	14–15	.45226	.45303	.45398	.45645	.45934	.45996	.46181	.46609
Rb	1.852	7–21	.45232	.45328	.45417	.45660	.45955	.45999	.46192	.46618
Cs	1.961	15–25	.45437	.45517	.45618	.45856	.46141	.46203	.46386	.46821
NH_4	1.631	15–20	.45509	.45599	.45693	.45939	.46234	.46288	.46481	.46923
Tl	2.329	10–23	.49226	.49317	.49443	.49748	.50128	.50209	.50463	.51076
Chrome Alums. $RCr(SO_4)_2+12H_2O$.†										
Cs	2.043	6–12	1.47627	1.47732	1.47836	1.48100	1.48434	1.48491	1.48723	1.49280
K	1.817	6–17	.47642	.47738	.47865	.48137	.48459	.48513	.48753	.49309
Rb	1.946	12–17	.47660	.47756	.47868	.48151	.48486	.48522	.48775	.49323
NH_4	1.719	7–18	.47911	.48014	.48125	.48418	.48744	.48794	.49040	.49594
Tl	2.386	9–25	.51692	.51798	.51923	.52280	.52704	.52787	.53082	.53808
Iron Alums. $RFe(SO_4)_2+12H_2O$.†										
K	1.806	7–11	1.47639	1.47706	1.47837	1.48169	1.48580	1.48670	1.48939	1.49605
Rb	1.916	7–20	.47700	.47770	.47894	.48234	.48654	.48712	.49003	.49700
Cs	2.061	20–24	.47825	.47921	.48042	.48378	.48797	.48867	.49136	.49838
NH_4	1.713	7–20	.47927	.48029	.48150	.48482	.48921	.48993	.49286	.49980
Tl	2.385	15–17	.51674	.51790	.51943	.52365	.52859	.52946	.53284	.54112

---

[*] According to the experiments of Soret (Arch. d. Sc. Phys. Nat. Genève, 1884, 1888, and Comptes Rendus, 1885).

[†] *R* stands for the different bases given in the first column.

For other alums see reference on Landolt-Börnstein-Roth Tabellen.

TABLE 195.

INDEX OF REFRACTION.

Various Monorefringent or Optically Isotropic Solids.

Substance.	Line of Spectrum.	Index of Refraction.	Authority.
Agate (light color)	red	1.5374	De Senarmont.
Albite glass	D	1.4890	Larsen, 1909.
Ammonium chloride	D	1.6422	Grailich.
Anorthite glass	D	1.5755	Larsen, 1909.
Arsenite	D	1.755	DesCloiseaux.
Barium nitrate	D	1.5716	Fock.
Bell metal	D	1.0052	Beer.
Blende	Li	2.34165	Ramsay.
	Na	2.36923	
	Tl	2.40069	
Boric acid	C	1.46245	Bedson and Carleton Williams.
	D	1.46303	
	F	1.47024	
Borax (vitrified)	C	1.51222	
	D	1.51484	
	F	1.52068	
Camphor	D	1.532	Kohlrausch.
		1.5462	Mulheims.
Diamond (colorless)	red	2.414	DesCloiseaux.
	green	2.428	
Diamond (brown)	B	2.46062	Schrauf.
	D	2.46986	
	E	2.47902	
Ebonite	D	1.6	Ayrton & Perry.
Fuchsin	A	2.03	Means.
	B	2.19	
	C	2.33	
	G	1.97	
	H	1.32	
Garnet (different varieties)	D	1.74 to 1.90	Various.
Gum arabic	red	1.480	Jamin.
" "	"	1.514	Wollaston.
Lime CaO	D	1.832	Wright, 1909.
Magnesium oxide	D	1.734	Wright, 1909.
Obsidian	D	1.482 to 1.496	Various.
Opal	D	1.406 1.450	"
Pitch	red	1.531	Wollaston.
Potassium bromide	D	1.5593	Topsöe and Christiansen.
" chlorstannate	"	1.6574	
" iodide	"	1.6666	
Phosphorus	"	2.1442	Gladstone & Dale.
Resins: Aloes	red	1.619	Jamin.
Canada balsam	"	1.528	Wollaston.
Colophony	"	1.548	Jamin.
Copal	"	1.528	"
Mastic	"	1.535	Wollaston.
Peru balsam	D	1.593	Baden Powell.
Selenium, vitreous	A	2.612	Wood.
	B	2.680	
	C	2.729	
	D	2.93	
Silver bromide	D	2.253	Wernicke.
Silver chloride	"	2.061	
Silver iodide	"	2.182	
Sodium chlorate	"	1.5150	Dussaud.
Spinel	"	1.7155	DesCloiseaux.
Strontium nitrate	"	1.5667	Fock.

TABLE 196.

INDEX OF REFRACTION.

Uniaxial Crystals.

Substance.	Line of spectrum.	Index of refraction.		Authority.
		Ordinary ray.	Extraordinary ray.	
Alunite (alum stone)	D	1.573	1.592	Levy & Lacroix.
Ammonium arseniate	red	1.577	1.524	De Senarmont.
Anatase	D	2.5354	2.4959	Schrauf.
Apatite	D	1.6390	1.6345	“
Benzil	D	1.6588	1.6784	DesCloiseaux.
Beryl	D	1.589 to 1.570	1.582 to 1.566	Various.
Brucite	D	1.560	1.581	Kohlrausch.
Calomel	D	1.9732	2.6559	Dufet.
Cinnabar	red	2.854	3.199	DesCloiseaux
Corundum (ruby, sapphire, etc.)	red	1.767 to 1.769	1.759 1.762	“
Dioptase	green	1.667	1.723	“
Dolomite	D	1.667 to 1.696	1.506 to 1.512	Various.
Emerald (pure)	green	1.584	1.578	DesCloiseaux.
Gehlenite	D	1.666	1.661	Wright, 1908.
Greenockite	D	2.506	2.529	Merwin, 1912.
Ice at — 8° C.	D	1.309	1.313	Meyer.
Idocrase	D	1.719 to 1.722	1.717 to 1.720	DesCloiseaux.
Ivory	D	1.539	1.541	Kohlrausch.
Magnesite	D	1.717	1.515	Mallard.
Nephelite	D	1.541	1.537	Bowen, 1912.
Potassium arseniate	red	1.564	1.515	DesCloiseaux.
“ “	red	1.493	1.501	De Senarmont.
Rutil	D	2.6158	2.9029	Bärwald.
Silver (red ore)	red	3.084	2.881	Fizeau.
Sodium arseniate	D	1.459	1.467	Baker.
“ nitrate	D	1.587	1.336	Schrauf.
“ phosphate	D	1.446	2.452	Dufet.
Strychnine sulphate	D	1.614	1.519	Martin.
Tin stone	D	1.997	2.093	Grubenman.
Tourmaline (colorless)	D	1.637	1.619	Heusser.
“ (different colors)	D	1.633 to 1.650	1.616 to 1.625	Jeroféjew.
Wurtzite	D	2.356	2.378	Merwin, 1912.
Zircon (hyacinth)	red	1.92	1.97	De Senarmont.
“ “	D	1.924	1.968	Sanger.

TABLE 197.

BIAXIAL CRYSTALS.

Substance.	Line of spectrum.	Index of Refraction.			Authority.
		Minimum.	Intermediate.	Maximum.	
Amphibole	D	1.633	1.642	1.657	Lévy-Lacroix.
Andalusite	red	1.632	1.638	1.643	Lévy-Lacroix.
Anemousite	D	1.5549	1.5587	1.5634	Wright 1910.
Anglesite	D	1.8771	1.8823	1.8936	Arzruni.
Anhydrite	D	1.5693	1.5752	1.6130	Mülheims.
Anorthite	D	1.576	1.583	1.589	Bowen 1912
Antipyrin	D	1.5697	1.6935	1.7324	Liweh.
Aragonite	D	1.5301	1.6816	1.6859	Rudberg.
Axinite	red	1.6720	1.6779	1.6810	DesCloiseaux.
Barite	D	1.636	1.637	1.648	Various.
Borax	D	1.4467	1.4694	1.4724	Dufet.
Carnegeite	D	1.509	——	1.514	Bowen 1912.
Copper sulphate . .	D	1.5140	1.5368	1.5433	Kohlrausch.
Gypsum	D	1.5208	1.5228	1.5298	Mülheims.
Hillebrandite . . .	D	1.605	——	1.612	Wright 1908.
Magnesium Carbonate	D	1.495	1.501	1.526	Genth, Penfield.
Magnesium Sulphate .	D	1.432	1.455	1.460	Means.
Mica (muscovite) . .	D	1.5601	1.5936	1.5977	Pulfrich.
Olivine	D	1.661	1.678	1.697	DesCloiseaux.
Orthoclase	D	1.5190	1.5237	1.5260	"
Potassium bichromate .	D	1.7202	1.7380	1.8197	Dufet.
" nitrate .	D	1.3346	1.5056	1.5064	Schrauf.
" sulphate .	D	1.4932	1.4946	1.4980	Topsöe & Christiansen.
Spurrite	D	1.640	1.674	1.679	Wright 1908.
Sugar (Cane) . .	D	1.5397	1.5667	1.5716	Calderon
Sulphur (rhombic) .	D	1.9505	2.0383	2.2405	Schrauf.
Topaz (Brazilian) .	D	1.6294	1.6308	1.6375	Mülheims.
Topaz (different kinds)	D	1.638 to 1.613	1.631 to 1.616	1.637 to 1.623	Various.
Wallastonite . . .	D	1.620	1.632	1.634	Means.
Zinc sulphate . . .	D	1.4568	1.4801	1.4836	Topsöe & Christiansen.

Table 198.

INDEX OF REFRACTION.

Indices of Refraction relative to Air for Solutions of Salts and Acids.

Substance.	Density.	Temp. C.	Indices of refraction for spectrum lines.					Authority.
			C	D	F	H_γ	H	
(a) Solutions in Water.								
Ammonium chloride	1.067	27°.05	1.37703	1.37936	1.38473	–	1.39336	Willigen.
" "	.025	29.75	.34850	.35050	.35515	–	.36243	"
Calcium chloride .	.398	25.65	.44000	.44279	.44938	–	.46001	"
" "	.215	22.9	.39411	.39652	.40206	–	.41078	"
" "	.143	25.8	.37152	.37369	.37876	–	.38666	"
Hydrochloric acid .	1.166	20.75	1.40817	1.41109	1.41774	–	1.42816	"
Nitric acid	.359	18.75	.39893	.40181	.40857	–	.41961	"
Potash (caustic) . .	.416	11.0	.40052	.40281	.40808	–	.41637	Fraunhofer.
Potassium chloride .	normal	solution	.34087	.34278	.34719	1.35049	–	Bender.
" "	double	normal	.34982	.35179	.35645	.35994	–	"
" "	triple	normal	.35831	.36029	.36512	.36890	–	"
Soda (caustic) . .	1.376	21.6	1.41071	1.41334	1.41936	–	1.42872	Willigen.
Sodium chloride . .	.189	18.07	.37562	.37789	.38322	1.38746	–	Schutt.
" "	.109	18.07	.35751	.35959	.36442	.36823	–	"
" "	.035	18.07	.34000	.34191	.34628	.34969	–	"
Sodium nitrate . .	1.358	22.8	1.38283	1.38535	1.39134	–	1.40121	Willigen.
Sulphuric acid . .	.811	18.3	.43444	.43669	.44168	–	.44883	"
" "	.632	18.3	.42227	.42466	.42967	–	.43694	"
" "	.221	18.3	.36793	.37009	.37468	–	.38158	"
" "	.028	18.3	.33663	.33862	.34285	–	.34938	"
Zinc chloride . . .	1.359	26.6	1.39977	1.40222	1.40797	–	1.41738	"
" " . . .	.209	26.4	.37292	.37515	.38026	–	.38845	"
(b) Solutions in Ethyl Alcohol.								
Ethyl alcohol . . .	0.789	25.5	1.35791	1.35971	1.36395	–	1.37094	Willigen.
" "	.932	27.6	.35372	.35556	.35986	–	.36662	"
Fuchsin (nearly saturated)	–	16.0	.3918	.398	.361	–	.3759	Kundt.
Cyanin (saturated) .	–	16.0	.3831	–	.3705	–	.3821	"

Note. — Cyanin in chloroform also acts anomalously; for example, Sieben gives for a 4.5 per cent. solution $\mu_A = 1.4593$, $\mu_B = 1.4695$, μ_F(green) $= 1.4514$, μ_G (blue) $= 1.4554$. For a 9.9 per cent. solution he gives $\mu_A = 1.4902$, μ_F(green) $= 1.4497$, μ_G(blue) $= 1.4597$.

(c) Solutions of Potassium Permanganate in Water.*

Wave-length in cms. × 10⁶.	Spectrum line.	Index for 1 % sol.	Index for 2 % sol.	Index for 3 % sol.	Index for 4 % sol.	Wave-length in cms. × 10⁶.	Spectrum line.	Index for 1 % sol.	Index for 2 % sol.	Index for 3 % sol.	Index for 4 % sol.
68.7	B	1.3328	1.3342	–	1.3382	51.6	–	1.3368	1.3385	–	–
65.6	C	.3335	.3348	1.3365	.3391	50.0	–	.3374	.3383	1.3386	1.3404
61.7	–	.3343	.3365	.3381	.3410	48.6	F	.3377	–	–	.3408
59.4	–	.3354	.3373	.3393	.3426	48.0	–	.3381	.3395	.3398	.3413
58.9	D	.3353	.3372	–	.3426	46.4	–	.3397	.3402	.3414	.3423
56.8	–	.3362	.3387	.3412	.3445	44.7	–	.3407	.3421	.3426	.3439
55.3	–	.3366	.3395	.3417	.3438	43.4	–	.3417	–	–	.3452
52.7	E	.3363	–	–	–	42.3	–	.3431	.3442	.3457	.3468
52.2	–	.3362	.3377	.3388	–	–	–	–	–	–	–

* According to Christiansen.

TABLE 199.

INDEX OF REFRACTION.

Indices of Refraction of Liquids relative to Air.

Substance.	Temp. C.	Index of refraction for spectrum lines.					Authority.
		C	D	F	H_γ	H	
Acetone	10°	1.3626	1.3646	1.3694	1.3732	–	Korten.
Almond oil . . .	0	.4755	.4782	.4847	–	–	Olds.
Analin *	20	.5993	.5863	.6041	.6204	–	Weegmann.
Aniseed oil . . .	21.4	.5410	.5475	.5647	–	–	Willigen.
" " . . .	15.1	.5508	.5572	.5743	–	1.6084	Baden Powell.
Benzene †	10	1.4983	1.5029	1.5148	–	1.5355	Gladstone.
"	21.5	.4934	.4979	.5095	–	.5304	"
Bitter almond oil .	20	.5391	–	.5623	.5775	–	Landolt.
Bromnaphtalin . .	20	.6495	.6582	.6819	.7041	.7289	Walter.
Carbon disulphide ‡	0	1.6336	1.6433	1.6688	1.6920	1.7175	Ketteler.
" "	20	.6182	.6276	.6523	.6748	.6994	"
" "	10	.6250	.6344	.6592	–	.7078	Gladstone.
" "	19	.6189	.6284	.6352	–	.7010	Dufet.
Cassia oil	10	.6007	.6104	.6389	–	.7039	Baden Powell.
" "	22.5	.5930	.6026	.6314	–	.6985	" "
Chinolin	20	1.6094	1.6171	1.6361	1.6497	–	Gladstone.
Chloroform . . .	10	.4466	.4490	.4555	–	.4661	Gladstone & Dale.
" . . .	30	–	.4397	–	–	.4561	" "
" . . .	20	.4437	.4462	.4525	–	–	Lorenz.
Cinnamon oil . .	23.5	.6077	.6188	.6508	–	–	Willigen.
Ether	15	1.3554	1.3566	1.3606	–	1.3683	Gladstone & Dale.
"	15	.3573	.3594	.3641	–	.3713	Kundt.
Ethyl alcohol . .	0	.3677	.3695	.3739	.3773	–	Korten.
" " . .	10	.3636	.3654	.3698	.3732	–	"
" " . .	20	.3596	.3614	.3657	.3690	–	"
" " . .	15	.3621	.3638	.3683	–	.3751	Gladstone & Dale.
Glycerine	20	1.4706	–	1.4784	1.4828	–	Landolt.
Methyl alcohol . .	15	.3308	1.3326	.3362	–	.3421	Baden Powell.
Olive oil	0	.4738	.4763	.4825	–	–	Olds.
Rock oil	0	.4345	.4573	.4644	–	–	"
Turpentine oil . .	10.6	1.4715	1.4744	1.4817	–	1.4939	Fraunhofer.
" " . .	20.7	.4692	.4721	.4793	–	.4913	Willigen.
Toluene	20	.4911	.4955	.5070	.5170	–	Bruhl.
Water §	20	.3312	.3330	.3372	.3404	.3435	Means.

* Weegmann gives $\mu_D = 1.59668 - .000518\,t$. Knops gives $\mu_F = 1.61500 - .00056\,t$.

† Weegmann gives $\mu_D = 1.51474 - .000665\,t$. Knops gives $\mu_D = 1.51399 - .000644\,t$.

‡ Wüllner gives $\mu_C = 1.63407 - .00078\,t$; $\mu_F = 1.66908 - .00082\,t$; $\mu_h = 1.69215 - .00085\,t$.

§ Dufet gives $\mu_D = 1.33397 - 10^{-7}(125\,t + 20.6\,t^2 - .000435\,t^3 - .00115\,t^4)$ between 0° and 50°; and nearly the same variation with temperature was found by Ruhlmann, namely, $\mu_D = 1.33373 - 10^{-7}(20.14\,t^2 + .000494\,t^4)$.

TABLE 200.

INDEX OF REFRACTION.

Indices of Refraction of Gases and Vapors.

A formula was given by Biot and Arago expressing the dependence of the index of refraction of a gas on pressure and temperature. More recent experiments confirm their conclusions. The formula is $n_t - 1 = \frac{n_0 - 1}{1 + at} \cdot \frac{p}{760}$, where n_t is the index of refraction for temperature t, n_0 for temperature zero, a the coefficient of expansion of the gas with temperature, and p the pressure of the gas in millimeters of mercury.

(a) Indices of refraction.

Spectrum line.	10^3 (n–1) Air.	Spectrum line.	10^3 (n–1) Air.	Wave-length.	(n–1) 10^3. Air.	O.	N.	H.
				μ				
A	.2905	M	.2993	.4861	.2951	.2734	.3012	.1406
B	.2911	N	.3003	.5461	.2936	.2717	.2998	.1397
C	.2914	O	.3015	.5790	.2930	.2710	—	.1393
D	.2922	P	3023	.6563	.2919	.2698	.2982	.1387
E	.2933	Q	.3031	.4360	.2971	.2743	CO_2	.1418
F	.2943	R	.3043	.5462	.2937	.2704	.4506	.1397
G	.2962	S	.3053	.6709	.2918	.2683	.4471	.1385
H	.2978	T	.3064	6.709	.2881	.2643	.4804	.1361
K	.2980	U	.3075	8.678	.2888	.2650	.4579	.1361
L	.2987			First 4, Cuthbertsons; the rest, Koch, 1909.				

(b) The following are compiled mostly from a table published by Brühl (Zeits. für Phys. Chem. vol. 7, pp. 25–27). The numbers are from the results of experiments by Biot and Arago, Dulong, Jamin, Ketteler, Lorenz, Mascart, Chappius, Rayleigh, and Rivière and Prytz. When the number given rests on the authority of one observer the name of that observer is given. The values are for 0° Centigrade and 760 mm. pressure.

Substance.	Kind of light.	Indices of refraction and authority.	Substance.	Kind of light.	Indices of refraction and authority.
Acetone	D	1.001079–1.001100	Hydrogen	white	1.000138–1.000143
Ammonia	white	1.000381–1.000385	"	D	1.000132 Burton.
"	D	1.000373–1.000379	Hydrogen sulphide	D	1.000644 Dulong.
Argon	D	1.000281 Rayleigh.		D	1.000623 Mascart.
Benzol	D	1.001700–1.001823	Methane	white	1.000443 Dulong.
Bromine	D	1.001132 Mascart.	"	D	1.000444 Mascart.
Carbon dioxide	white	1.000449–1.000450	Methyl alcohol	D	1.000549–1.000623
" "	D	1.000448–1.000454	Methyl ether	D	1.000891 Mascart.
Carbon disulphide	white	1.001500 Dulong.	Nitric oxide	white	1.000303 Dulong.
	D	1.001478–1.001485	" "	D	1.000297 Mascart.
Carbon monoxide	white	1.000340 Dulong.	Nitrogen	white	1.000295–1.000300
	white	1.000335 Mascart.	"	D	1.000296–1.000298
Chlorine	white	1.000772 Dulong.	Nitrous oxide	white	1.000503–1.000507
"	D	1.000773 Mascart.	" "	D	1.000516 Mascart.
Chloroform	D	1.001436–1.001464	Oxygen	white	1.000272–1.000280
Cyanogen	white	1.000834 Dulong.	"	D	1.000271–1.000272
"	D	1.000784–1.000825	Pentane	D	1.001711 Mascart.
Ethyl alcohol	D	1.000871–1.000885	Sulphur dioxide	white	1.000665 Dulong.
Ethyl ether	D	1.001521–1.001544	" "	D	1.000686 Ketteler.
Helium	D	1.000036 Ramsay.	Water	white	1.000261 Jamin.
Hydrochloric acid	white	1.000449 Mascart.	"	D	1.000249–1.000259
	D	1.000447 "			

MEDIA FOR DETERMINATIONS OF REFRACTIVE INDICES WITH THE MICROSCOPE.

TABLE 201.—Liquids, n_D (0.589μ) = 1.74 to 1.87.

In 100 parts of methylene iodide at 20° C. the number of parts of the various substances indicated in the following table can be dissolved, forming saturated solutions having the permanent refractive indices specified. When ready for use the liquids can be mixed by means of a dropper to give intermediate refractions. Commercial iodoform (CHI_3) powder is not suitable, but crystals from a solution of the powder in ether may be used, or the crystalized product may be bought. A fragment of tin in the liquids containing the SnI_4 will prevent discoloration.

CHI_3.	SnI_4.	AsI_3.	SbI_3.	S.	n_{na} at 20°.
			12		1.764
	25				1.783
	25		12		1.806
	30			6	1.820
	27	13	7		1.826
40	27	16			1.842
	31	14	8	10	1.853
35	31	16	8	10	1.868

TABLE 202.—Resin-like Substances, n_D (0.589μ) = 1.68 to 2.10.

Piperine, one of the least expensive of the alkaloids, can be obtained very pure in straw-colored crystals. When melted it dissolves the tri-iodides of arsenic and antimony very freely. The solutions are fluid at slightly above 100° and when cold, resin-like. A solution containing 3 parts antimony iodide to one part of arsenic iodide with varying proportions of piperine is easier to manipulate than one containing either iodide alone. The following table gives the necessary data concerning the composition and refractive indices for sodium light. In preparing, the constituents, in powder of about 1 mm. grain, should be weighed out and then fused *over*, not *in*, a low flame. Three-inch test tubes are suitable.

Per cent Iodides.	00.	10.	20.	30.	40.	50.	60.	70.	80.
Index of refraction	1.683	1.700	1.725	1.756	1.794	1.840	1.897	1.968	2.050

TABLE 203.—Permanent Standard Resinous Media, n_D (0.589μ) = 1.546 to 1.682.

Any proportions of piperine and rosin form a homogeneous fusion which cools to a transparent resinous mass. The following table shows the refractive indices of various mixtures. On account of the strong dispersion of piperine the refractive indices of minerals apparently matched with those of mixtures rich in this constituent are 0.005 to 0.01 too low. To correct this error a screen made of a thin film of 7 per cent antimony iodide and 93 per cent piperine should be used over the eye-piece. Any amber-colored rosin in lumps is suitable.

Per cent Rosin.	00.	10.	20.	30.	40.	50.	60.	70.	80.	90.	100.
Index of refraction	1.683	1.670	1.657	1.643	1.631	1.618	1.604	1.590	1.575	1.560	1.544

All taken from Merwin, Jour. Wash. Acad. of Sc. 3, p. 35, 1913.

TABLES 204-205.

OPTICAL CONSTANTS OF METALS.

TABLE 204.

Two constants are required to characterize a metal optically, the refractive index, *n*, and the absorption index, *k*, the latter of which has the following significance: the amplitude of a wave after travelling one wave-length, λ^1 measured in the metal, is reduced in the ratio[1] $1 : e^{-2\pi k}$ or for any distance *d*, $1 : e^{-\frac{2\pi dk}{\lambda^1}}$; for the same wave-length measured in air this ratio becomes $1 : e^{-\frac{2\pi dnk}{\lambda^1}}$. *nk* is sometimes called the extinction coefficient. Plane polarized light reflected from a polished metal surface is in general elliptically polarized because of the relative change in phase between the two rectangular components vibrating in and perpendicular to the plane of incidence. For a certain angle, $\bar{\phi}$ (principal incidence) the change is 90° and if the plane polarized incident beam has a certain azimuth $\bar{\psi}$ (Principal azimuth) circularly polarized light results. Approximately, (Drude, Annalen der Physik, 36, p. 546, 1889),

$$k = \tan 2\bar{\psi}\,(1 - \cot^2\bar{\phi}) \text{ and } n = \frac{\sin\bar{\phi}\tan\bar{\phi}}{(1+k^2)^{\frac{1}{2}}}\,(1 + \tfrac{1}{2}\cot^2\bar{\phi}).$$

For rougher approximations the factor in parentheses may be omitted. R = computed percentage reflection.

TABLE 205.

(The points have been so selected that a smooth curve drawn through them very closely indicates the characteristics of the metal.)

Metal.	λ	$\bar{\phi}$	$\bar{\psi}$	Computed.				Authority.
				n	k	nk	R	
	μ						%	
Cobalt	0.231	64°31′	29°39	1.10	1.30	1.43	32.	Minor.
	.275	70 22	29 59	1.41	1.52	2.14	46.	"
	.500	77 5	31 53	1.93	1.93	3.72	66.	"
	.650	79 0	31 25	2.35	1.87	4.40	69.	Ingersoll.
	1.00	81 45	29 6	3.63	1.58	5.73	73.	"
	1.50	83 21	26 18	5.22	1.29	6.73	75.	"
	2.25	83 48	26 5	5.65	1.27	7.18	76.	"
Copper	.231	65 57	26 14	1.39	1.05	1.45	29.	Minor.
	.347	65 6	28 16	1.19	1.23	1.47	32.	"
	.500	70 44	33 46	1.10	2.13	2.34	56.	"
	.650	74 16	41 30	0.44	7.4	3.26	86.	Ingersoll.
	.870	78 40	42 30	0.35	11.0	3.85	91.	"
	1.75	84 4	42 30	0.83	11.4	9.46	96.	"
	2.25	85 13	42 30	1.03	11.4	11.7	97.	"
	4.00	87 20	42 30	1.87	11.4	21.3		Först.-Fréed.
	5.50	88 00	41 50	3.16	9.0	28.4		" "
Gold	1.00	81 45	44 00	0.24	28.0	6.7		" "
	2.00	85 30	43 56	0.47	26.7	12.5		" "
	3.00	87 05	43 50	0.80	24.5	19.6		" "
	5.00	88 15	43 25	1.81	18.1	33.		" "
Iridium	1.00	82 10	29 15	3.85	1.60	6.2		" "
	2.00	83 10	29 40	4.30	1.66	7.1		" "
	3.00	81 40	30 40	3.33	1.79	6.0		" "
	5.00	79 00	32 20	2 27	2.03	4.6		" "
Nickel	0.420	72 20	31 42	1.41	1.79	2.53	54.	Tool.
	0.589	76 1	31 41	1.79	1.86	3.33	62.	Drude.
	0.750	78 45	32 6	2.19	1.99	4.36	70.	Ingersoll.
	1.00	80 33	32 2	2.63	2.00	5.26	74.	"
	2.25	84 21	33 30	3.95	2.33	9.20	85.	"
Platinum	1.00	75 30	37 00	1.14	3.25	3.7		Först.-Fréed.
	2.00	74 30	39 50	0.70	5.06	3.5		" "
	3.00	73 50	41 00	0.52	6.52	3.4		" "
	5.00	72 00	42 10	0.34	9.01	3.1		" "
Silver	0.226	62 41	22 16	1.41	0.75	1.11	18.	Minor.
	.293	63 14	18 56	1.57	0.62	0.97	17.	"
	.316	52 28	15 38	1.13	0.38	0.43	4.	"
	.332	52 1	37 2	0.41	1.61	0.65	32.	"
	.395	66 36	43 6	0.16	12.32	1.91	87.	"
	.500	72 31	43 29	0.17	17.1	2.94	93.	"
	.589	75 35	43 47	0.18	20.6	3.64	95.	"
	.750	79 26	44 6	0.17	30.7	5.16	97.	Ingersoll.
	1.00	82 0	44 2	0.24	29.0	6.96	98.	"
	1.50	84 42	43 48	0.45	23.7	10.7	98.	'
	2.25	86 18	43 34	0.77	19.9	15.4	99.	"
	3.00	87 10	42 40	1.65	12.2	20.1		Först.-Fréed.
	4.50	88 20	41 10	4.49	7.42	33.3		" "
Steel	0.226	66 51	28 17	1.30	1.26	1.64	35.	Minor.
	.257	68 35	28 45	1.38	1.35	1.86	40.	"
	.325	69 57	30 9	1.37	1.53	2.09	45.	"
	.500	75 47	29 2	2.09	1.50	3.14	57.	"
	.650	77 48	27 9	2.70	1.33	3.59	59.	Ingersoll.
	1.50	81 48	28 51	3.71	1.55	5.75	73.	"
	2.25	83 22	30 36	4.14	1.79	7.41	80.	"

Drude, Annalen der Physik und Chemie, 39, p. 481, 1890; 42, p. 186, 1891; 64, p. 159, 1898. Minor, Annalen der Physik, 10, p. 581, 1903. Tool, Physical Review, 31, p. 1, 1910. Ingersoll, Astrophysical Journal, 32, p. 265, 1910; Försterling and Fréedericksz, Annalen der Physik, 40, p. 201, 1913.

TABLES 206-207.

OPTICAL CONSTANTS OF METALS.

TABLE 206.

Metal.	λ.	n.	k.	R.	Ref.
	μ				
Al.*	0.589	1.44	5.32	83	1
Sb.*	.589	3.04	4.94	70	1
Bi.†‡	white	2.26	–	–	2
Cd.*	.589	1.13	5.01	85	1
Cr.*	.579	2.97	4.85	70	3
Cb.*	.579	1.80	2.11	41	3
Au.†	.257	0.92	1.14	28	4
	.441	1.18	1.85	42	4
	.589	0.47	2.83	82	4
I. crys.	.589	3.34	0.57	30	4
Ir.*	.579	2.13	4.87	75	3
Fe.§	.257	1.01	0.88	16	4
	.441	1.28	1.37	28	4
	.589	1.51	1.63	33	4
Pb.*	.589	2.01	3.48	62	1
Mg.*	.589	0.37	4.42	93	1
Mn.*	.579	2.49	3.89	64	3
Hg. (liq.)	.326	0.68	2.26	66	4
	.441	1.01	3.42	74	4
	.589	1.62	4.41	75	4
	.668	1.72	4.70	77	4
Pd.*	.579	1.62	3.41	65	3
Pt.†	.257	1.17	1.65	37	4
	.441	1.94	3.16	58	4
	.589	2.63	3.54	59	4
	.668	2.91	3.66	59	4
Ni.*	.275	1.09	1.16	24	4
	.441	1.16	1.23	25	4
	.589	1.30	1.97	43	4
	μ				
Rh.*	0.579	1.54	4.67	78	3
Se.‡	.400	2.94	2.31	44	5
	.490	3.12	1.49	35	5
	.589	2.93	0.45	25	5
	.760	2.60	0.06	20	5
Si.*	.589	4.18	0.09	38	6
	1.25	3.67	0.08	33	6
	2.25	3.53	0.08	31	6
Na. (liq.)	.589	.004	2.61	99	1
Ta.*	.579	2.05	2.31	44	3
Sn.*	.589	1.48	5.25	82	1
W.*	.579	2.76	2.71	49	3
V.*	.579	3.03	3.51	58	3
Zn.*	.257	0.55	0.61	20	4
	.441	0.93	3.19	73	4
	.589	1.93	4.66	74	4
	.668	2.62	5.08	73	4

λ = wave-length, n = refraction index.
k = absorption index, R = reflection.

(1) Drude, see Table 205; (2) Kundt, prism used, Ann. der Physik und Chemie, 34, p. 477, 36, p. 824, 1889; (3) v. Wartenberg, Verh. deutsch. Physik. Ges. 12, p. 105, 1910; (4) Meier, Annales der Physik, 10, p. 581, 1903; (5) Wood, Phil. Mag. (6), 3, 607, 1902; (6) Ingersoll, *see* Table 205.

* solid, † electrolytic, ‡ prism, § deposited as film in vacuo.

TABLE 207.—Reflecting Power of Metals.

Wave-length	Al.	Sb.	Cd.	Co.	Graph-ite.	Ir.	Mg.	Mo.	Pd.	Rh.	Si.	Ta.	Te.	Sn.	W	Va.	Zn.
μ	Per cents.																
.5	–	–	–	–	22	–	72	46	–	76	34	38	–	–	49	57	–
.6	–	53	–	–	24	–	73	48	–	77	32	45	49	–	51	58	–
.8	–	54	–	–	25	–	74	52	–	81	29	64	48	–	56	60	–
1.0	71	55	72	67	27	78	74	58	72	84	28	78	50	54	62	61	80
2.0	82	60	87	72	35	87	77	82	81	91	28	90	52	61	85	69	92
4.0	92	68	96	81	48	94	84	90	88	92	28	93	57	72	93	79	97
7.0	96	71	98	93	54	95	91	93	94	94	28	94	68	81	95	88	98
10.0	98	72	98	97	59	96	–	94	97	95	28	–	–	84	96	–	98
12.0	98	–	99	97	–	96	–	95	97	–	–	95	–	85	96	–	99

Coblentz, Bulletin Bureau of Standards, 2, p. 457, 1906, 7, p. 197, 1911. The surfaces of some of the samples were not perfect so that the corresponding values have less weight. The methods for polishing the various metals are described in the original articles.

According to Fresnel the amount of light reflected by the surface of a transparent medium $= \frac{1}{2}(A + B) = \frac{1}{2}\left\{ \frac{\sin^2(i-r)}{\sin^2(i+r)} + \frac{\tan^2(i-r)}{\tan^2(i+r)} \right\}$; A is the amount polarized in the plane of incidence; B is that polarized perpendicular to this; i and r are the angles of incidence and refraction.

TABLE 208. — Light reflected when $i = 0°$ or Incident Light is Normal to Surface.

n.	$\frac{1}{2}(A+B)$.	n.	$\frac{1}{2}(A+B)$.	n.	$\frac{1}{2}(A+B)$.	n.	$\frac{1}{2}(A+B)$.
1.00	0.00	1.4	2.78	2.0	11.11	5.	44.44
1.02	0.01	1.5	4.00	2.25	14.06	5.83	50.00
1.05	0.06	1.6	5.33	2.5	18.37	10.	66.67
1.1	0.23	1.7	6.72	2.75	22.89	100.	96.08
1.2	0.83	1.8	8.16	3.	25.00	∞	100.00
1.3	1.70	1.9	9.63	4.	36.00		

TABLE 209. — Light reflected when n is near Unity or equals $1 + dn$.

i.	A.	B.	$\frac{1}{2}(A+B)$.	$\frac{A-B}{A+B}$.*
0°	1.000	1.000	1.000	0.0
5	1.015	.985	1.000	1.5
10	1.063	.939	1.001	6.2
15	1.149	.862	1.005	14.3
20	1.282	.752	1.017	26.0
25	1.482	.612	1.047	41.5
30	1.778	.444	1.111	60.0
35	2.221	.260	1.240	79.1
40	2.904	.088	1.496	94.5
45	4.000	.000	2.000	100.0
50	5.857	.176	3.016	94.5
55	9.239	1.081	5.160	79.1
60	16.000	4.000	10.000	60.0
65	31.346	12.952	22.149	41.5
70	73.079	42.884	57.981	26.0
75	222.85	167.16	195.00	14.3
80	1099.85	971.21	1035.53	6.2
85	17330.64	16808.08	17069.36	1.5
90	∞	∞	∞	0.0

TABLE 210. — Light reflected when $n = 1.55$.

i.	r.	A.	B.	dA.†	dB.†	$\frac{1}{2}(A+B)$.	$\frac{A-B}{A+B}$.*
° ′	° ′						
0	0 0.0	4.65	4.65	0.130	0.130	4.65	0.0
5	3 13.4	4.70	4.61	.131	.129	4.65	1.0
10	6 25.9	4.84	4.47	.135	.126	4.66	4.0
15	9 36.7	5.09	4.24	.141	.121	4.66	9.1
20	12 44.8	5.45	3.92	.150	.114	4.68	16.4
25	15 49.3	5.95	3.50	.161	.105	4.73	25.9
30	18 49.1	6.64	3.00	.175	.094	4.82	37.8
35	21 43.1	7.55	2.40	.191	.081	4.98	51.7
40	24 30.0	8.77	1.75	.210	.066	5.26	66.7
45	27 8.5	10.38	1.08	.233	.049	5.73	81.2
50	29 37.1	12.54	0.46	.263	.027	6.50	92.9
55	31 54.2	15.43	0.05	.303	.007	7.74	99.3
60	33 58.1	19.35	0.12	.342	−.013	9.73	98.8
65	35 47.0	24.69	1.13	.375	−.032	12.91	91.2
70	37 19.1	31.99	4.00	.400	−.050	18.00	77.7
75	38 32.9	42.00	10.38	.410	−.060	26.19	61.8
80	39 26.8	55.74	23.34	.370	−.069	39 54	41.0
82 30	39 45.9	64.41	34.04	.320	−.067	49.22	30.8
85 0	39 59.6	74.52	49.03	.250	−.061	61.77	20.6
86 0	40 3.6	79.02	56.62	.209	−.055	67.82	16.5
87 0	40 6.7	83.80	65.32	.163	−.046	74.56	12.4
88 0	40 8.9	88.88	75.31	.118	−.036	82.10	8.3
89 0	40 10.2	94.28	86.79	.063	−.022	90.54	4.1
90 0	40 10.7	100.00	100.00	.000	−.000	100.00	0.0

Angle of total polarization = 57° 10′.3, A = 16.99.

* This column gives the degree of polarization

† Columns 5 and 6 furnish a means of determining A and B for other values of n. They represent the change in these quantities for a change of n of 0.01.

Taken from E. C. Pickering's "Applications of Fresnel's Formula for the Reflection of Light."

TABLES 211-212.

REFLECTION OF METALS.

TABLE 211. — Perpendicular Incidence and Reflection.

The numbers give the per cents of the incident radiation reflected.

Wave-length, μ.	Silver-backed Glass.	Mercury-backed Glass.	Mach's Magnalium. $69Al+31Mg$.	Brandes-Schünemann Alloy. $32Cu+34Sn+29Ni+5Fe$.	Ross' Speculum Metal. $68.2Cu+31.8Sn$.	Nickel. *Electrolytically Deposited.*	Copper. *Electrolytically Deposited.*	Steel. *Untempered.*	Copper. *Commercially Pure.*	Platinum. *Electrolytically Deposited.*	Gold. *Electrolytically Deposited.*	Brass. *(Trowbridge).*	Silver. *Chemically Deposited.*
.251	-	-	67.0	35.8	29.9	37.8	-	32.9	25.9	33.8	38.8	-	34.1
.288	-	-	70.6	37.1	37.7	42.7	-	35.0	24.3	38.8	34.0	-	21.2
.305	-	-	72.2	37.2	41.7	44.2	-	37.2	25.3	39.8	31.8	-	9.1
.316	-	-	-	-	-	-	-	-	-	-	-	-	4.2
.326	-	-	75.5	39.3	-	45.2	-	40.3	24.9	41.4	28.6	-	14.6
.338	-	-	-	-	-	46.5	-	-	-	-	-	-	55.5
.357	-	-	81.2	43.3	51.0	48.8	-	45.0	27.3	43.4	27.9	-	74.5
.385	-	-	83.9	44.3	53.1	49.6	-	47.8	28.6	45.4	27.1	-	81.4
.420	-	-	83.3	47.2	56.4	56.6	-	51.9	32.7	51.8	29.3	-	86.6
.450	85.7	72.8	83.4	49.2	60.0	59.4	48.8	54.4	37.0	54.7	33.1	-	90.5
.500	86.6	70.9	83.3	49.3	63.2	60.8	53.3	54.8	43.7	58.4	47.0	-	91.3
.550	88.2	71.2	82.7	48.3	64.0	62.6	59.5	54.9	47.7	61.1	74.0	-	92.7
.600	88.1	69.9	83.0	47.5	64.3	64.9	83.5	55.4	71.8	64.2	84.4	-	92.6
.650	89.1	71.5	82.7	51.5	65.4	66.6	89.0	56.4	80.0	66.5	88.9	-	94.7
.700	89.6	72.8	83.3	54.9	66.8	68.8	90.7	57.6	83.1	69.0	92.3	-	95.4
.800	-	-	84.3	63.1	-	69.6	-	58.0	88.6	70.3	94.9	-	96.8
1.0	-	-	84.1	69.8	70.5	72.0	-	63.1	90.1	72.9	-	-	97.0
1.5	-	-	85.1	79.1	75.0	78.6	-	70.8	93.8	77.7	97.3	-	98.2
2.0	-	-	86.7	82.3	80.4	83.5	-	76.7	95.5	80.6	96.8	91.0	97.8
3.0	-	-	87.4	85.4	86.2	88.7	-	83.0	97.1	88.8	-	93.7	98.1
4.0	-	-	88.7	87.1	88.5	91.1	-	87.8	97.3	91.5	96.9	95.7	98.5
5.0	-	-	89.0	87.3	89.1	94.4	-	89.0	97.9	93.5	97.0	95.9	98.1
7.0	-	-	90.0	88.6	90.1	94.3	-	92.9	98.3	95.5	98.3	97.0	98.5
9.0	-	-	90.6	90.3	92.2	95.6	-	92.9	98.4	95.4	98.0	97.8	98.7
11.0	-	-	90.7	90.2	92.9	95.9	-	94.0	98.4	95.6	98.3	96.6	98.8
14.0	-	-	92.2	90.3	93.6	97.2	-	96.0	97.9	96.4	97.9	-	98.3

Based upon the work of Hagen and Rubens, Ann. der Phys. (1) 352, 1900; (8) 1, 1902; (11) 873, 1903. Taken partly from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.

TABLE 212. — Percentage Diffuse Reflection from Miscellaneous Substances.

Wave-length μ	Lamp-blacks.					Pt. black electrol.	Green leaves.	Lead oxide.	Al. oxide.	Zinc oxide.	White Paper.	Lead carbonate.	Asphalt.	Black velvet.	Black felt.	Red brick.
	Paint.	Rosin.	Sperm candle.	Acetylene	Camphor.											
*.60	3.2						25.	52.	84.	82.		89.	15.	1.8	14.	30.
*.95	3.4	1.3	1.1	0.6	1.3	1.1			88.	86.	75.	93.			21.	
4.4	3.2	1.3	.9	.8	1.2	1.4		51.	21.	8.	18.	29.		3.7		
8.8	3.8		1.3	1.2	1.6	2.1		26.	2.	3.	5.	11.		2.7		12.
24.0	4.4	3.0	4.0	2.1	5.7	4.2		10.	6.	5.		7.				

*Not monochromatic (max.) means from Coblentz, J. Franklin Inst. 1912. Bulletin Bureau of Standards, 9, p. 283, 1912, contains many other materials.

TRANSMISSIBILITY FOR RADIATION OF JENA GLASSES.

TABLE 213.

Coefficients, a, in the formula $I_t = I_0 a^t$, where I_0 is the Intensity before, and I_t after, transmission through the thickness t, expressed in centimeters. Deduced from observations by Müller, Vogel, and Rubens as quoted in Hovestadt's Jena Glass (English translation).

Type of Glass.	Coefficient of transmission, a.									
λ =	.375 μ	390 μ	.400 μ	.434 μ	.436 μ	.455 μ	.477 μ	.503 μ	.580 μ	.677 μ
O 340, Ord. light flint	.388	.456	.614	.569	.680	.834	.880	.880	.878	.939
O 102, H'vy silicate flint	–	.025	.463	.502	.566	.663	.700	.782	.828	.794
O 93, Ord. " "	–	–	–	–	.714	.807	.899	.871	.903	.943
O 203, " " crown	.583	.583	.695	.667	.806	.822	.860	.872	.872	.903
O 598, (Crown)	–	–	–	–	.797	.770	.771	.776	.818	.860

λ =	0.7 μ	0.95 μ	1.1 μ	1.4 μ	1.7 μ	2.0 μ	2.3 μ	2.5 μ	2.7 μ	2.9 μ	3.1 μ
S 204, Borate crown	1.00	.99	.94	.90	.85	.81	.69	.43	.29	.18	–
S 179, Med. phosp. cr.	–	.98	.95	.90	.84	.67	.49	.87	.18	–	–
O 1143, Dense, bor. sil. cr.	.98	–	.97	–	.95	.93	.90	.84	.71	.47	.27
O 1092, Crown	.99	.96	.95	.99	.99	.91	.82	.71	60	.48	.29
O 1151, "	.98	–	.99	.99	.98	.94	.90	.79	.75	.45	.32
O 451, Light flint	1.00	–	.99	–	.98	.95	.92	.84	.78	.54	.34
O 469, Heavy "	1.00	–	.98	–	.99	.98	.98	.97	.90	.66	.50
O 500, " "	1.00	–	1.00	–	1.00	–	1.00	.99	.92	.74	.53
S 163, " "	1.00	–	.98	–	.99	–	.99	–	.94	.78	.60

TABLE 214.

Note: With the following data, t must be expressed in millimeters; i. e. the figures as given give the transmissions for thickness of 1 mm.

No. and Type of Glass.	Wave-length in μ.												
	Visible Spectrum.							Ultra-violet Spectrum.					
	.644 μ	.578 μ	.546 μ	.509 μ	.480 μ	.436 μ	.405 μ	.384 μ	.361 μ	.340 μ	.332 μ	.309 μ	.280 μ
F 3815 Dark neutral	.35	.35	.37	.35	.34	.30	.15	.06					
F 4512 Red filter	.94	.05											
F 2745 Copper ruby	.72	.39	.47	.47	.45	.43	.43						
F 4313 Dark yellow	.98	.97	.93	.83	.09								
F 4351 Yellow	.98	.97	.96	.93	.44	.15							
F 4937 Bright yellow	1.0	1.0	1.0	.99	.74	.40	.31	.28	.22	.18	.14	.06	
F 4930 Green filter	.17	.50	.64	.62	.44								
F 3873 Blue filter	–	–	–	.18	.50	.73	.69	.59	.36	.10			
F 3654 Cobalt glass, transparent for outer red	–	–	–	.15	.44	.85	1.0	1.0	1.0	1.0	1.0	.58	
F 3653 Blue, ultraviolet	–	–	–	–	.11	.65	1.0	1.0	1.0	1.0	1.0	.81	.18
F 3728 Didymium, str'g bands	.99	.72	.99	.96	.95	.96	.99	.99	.89	.89	.77	.54	

This and the following table are taken from Jenaer Glas für die Optik, Liste 751, 1909

TABLE 215. — Transmissibility of Jena Ultra-violet Glasses.

No. and Type of Glass.	Thickness.	0.397 μ	0.383 μ	0.361 μ	0.346 μ	0.325 μ	0.309 μ	0.280 μ
UV 3199 Ultra-violet	1 mm.	1.00	1.00	1.00	1.00	1.00	0.95	0.56
" "	2 mm.	0.99	0.99	0.99	0.97	0.90	0.57	
" "	1 dm.	0.95	0.95	0.89	0.70	0.36		
UV 3248 "	1 mm.	1.00	1.00	1.00	1.00	0.98	0.91	0.35
" "	2 mm.	0.98	0.98	0.98	0.92	0.78	0.38	
" "	1 dm.	0.96	0.87	0.79	0.45	0.08		

TABLE 216.

TRANSMISSIBILITY FOR RADIATION.

Transmissibility of the Various Substances of Tables 166 to 175.

Alum: Ordinary alum (crystal) absorbs the infra-red.
Metallic reflection at 9.05μ and 30 to 40μ.

Rock-salt: Rubens and Trowbridge (Wied. Ann. 65, 1898) give the following transparencies for a 1 cm. thick plate in %:

λ	9	10	12	13	14	15	16	17	18	19	20.7	23.7μ
%	99.5	99.5	99.3	97.6	93.1	84.6	66.1	51.6	27.5	9.6	0.6	0.

Pflüger (Phys. Zt. 5. 1904) gives the following for the ultra-violet, same thickness: 280μμ, 95.5%; 231, 86%; 210, 77%; 186, 70%.
Metallic reflection at 0.110μ, 0.156, 51.2, and 87μ.

Sylvine: Transparency of a 1 cm. thick plate (Trowbridge, Wied. Ann. 60, 1897).

λ	9	10	11	12	13	14	15	16	17	18	19	20.7	23.7μ
%	100.	98.8	99.0	99.5	99.5	97.5	95.4	93.6	92.	86.	76.	58.	15.

Metallic reflection at 0.114μ, 0.161, 61.1, 100.

Fluorite: Very transparent for the ultra-violet nearly to 0.1μ.
Rubens and Trowbridge give the following for a 1 cm. plate (Wied. Ann. 60, 1897):

λ	8μ	9	10	11	12μ
%	84.4	54.3	16.4	1.0	0

Metallic reflection at 24μ, 31.6, 40μ.

Iceland Spar: Merritt (Wied. Ann. 55, 1895) gives the following values of k in the formula $i = i_0 e^{-kd}$ (d in cm.):
For the ordinary ray:

λ	1.02	1.45	1.72	2.07	2.11	2.30	2.44	2.53	2.60	2.65	2.74μ
k	0.0	0.0	0.03	0.13	0.74	1.92	3.00	1.92	1.21	1.74	2.36

λ	2.83	2.90	2.95	3.04	3.30	3.47	3.62	3.80	3.98	4.35	4.52	4.83μ
k	1.32	0.70	1.80	4.71	22.7	19.4	9.6	18.6	∞	6.6	14.3	6.1

For the extraordinary ray:

λ	2.49	2.87	3.00	3.28	3.38	3.59	3.76	3.90	4.02	4.41	4.67μ
k	0.14	0.08	0.43	1.32	0.89	1.79	2.04	1.17	0.89	1.07	2.40

λ	4.91	5.04	5.34	5.50μ
k	1.25	2.13	4.41	12.8

Quartz: Very transparent to the ultra-violet; Pflüger gets the following transmission values for a plate 1 cm. thick: at 0.222μ, 94.2%; 0.214, 92; 0.203, 83.6; 0.186, 67.2%.
Merritt (Wied. Ann. 55, 1895) gives the following values for k (see formula under Iceland Spar):
For the ordinary ray:

λ	2.72	2.83	2.95	3.07	3.17	3.38	3.67	3.82	3.96	4.12	4.50μ
k	0.20	0.47	0.57	0.31	0.20	0.15	1.26	1.61	2.04	3.41	7.30

For the extraordinary ray:

λ	2.74	2.89	3.00	3.08	3.26	3.43	3.52	3.59	3.64	3.74	3.91	4.19	4.36μ
k	0.0	0.11	0.33	0.26	0.11	0.51	0.76	1.88	1.83	1.62	2.22	3.35	8.0

For $\lambda > 7$ μ, becomes opaque, metallic reflection at 8.50μ, 9.02, 20.75–24.4μ, then transparent again.

The above are taken from Kayser's "Handbuch der Spectroscopie," vol. iii.

TABLES 217-218.

TRANSMISSIBILITY OF RADIATION.

TABLE 217. — Color Screens.

The following light-filters are quoted from Landolt's "Das optische Drehungsvermögen, etc." 1898. Although only the potassium salt does not keep well it is perhaps safer to use freshly prepared solutions.

Color.	Thickness. mm.	Water solutions of	Grammes of substance in 100 c.cm.	Optical centre of band. μ	Transmission.
Red	20	Crystal-violet, 5BO	0.005	0.6659	begins about 0.718μ. ends sharp at 0.639μ.
"	20	Potassium monochromate	10.		
Yellow	20	Nickel-sulphate, $NiSO_4$.7aq.	30.	0.5919	0.614–0.574μ,
"	15	Potassium monochromate	10.		
"	15	Potassium permanganate	0.025		
Green	20	Copper chloride, $CuCl_2$.2aq.	60.	0.5330	0.540–0.505μ
"	20	Potassium monochromate	10.		
Bright blue	20	Double-green, SF	0.02	0.4885	0.526–0.494 and 0.494–0.458μ
	20	Copper-sulphate, $CuSO_4$.5aq.	15.		
Dark blue	20	Crystal-violet, 5BO	0.005	0.4482	0.478–0.410μ
	20	Copper sulphate, $CuSO_4$.5aq.	15.		

TABLE 218. — Color Screens.

The following list is condensed from Wood's Physical Optics :

Methyl violet, 4R· (Berlin Anilin Fabrik) very dilute, and nitroso-dimethyl-aniline transmits 0.365μ. Methyl violet + chinin-sulphate (separate solutions), the violet solution made strong enough to blot out 0.4359μ, transmits 0.4047 and 0.4048, also faintly 0.3984.

Cobalt glass + aesculin solution transmits 0.4359μ.

Guinea green B extra (Berlin) + chinin sulphate transmits 0.4916μ.

Neptune green (Bayer, Elberfeld) + chrysoidine. Dilute the latter enough to just transmit 0.5790 and 0.5461 ; then add the Neptune green until the yellow lines disappear.

Chrysoidine + eosine transmits 0.5790μ. The former should be dilute and the eosine added until the green line disappears.

Silver chemically deposited on a quartz plate is practically opaque except to the ultra-violet region 0.3160–0.3260 where 90% of the energy passes through. The film should be of such thickness that a window backed by a brilliantly lighted sky is barely visible.

In the following those marked with a * are transparent to a more or less degree to the ultra-violet:

* Cobalt chloride: solution in water, — absorbs 0.50–.53μ; addition of $CaCl_2$ widens the band to 0.47–.50. It is exceedingly transparent to the ultra-violet down to 0.20. If dissolved in methyl alcohol + water, absorbs 0.50–.53 and everything below 0.35. In methyl alcohol alone 0.485–0.555 and below 0.40μ.

Copper chloride: in ethyl alcohol absorbs above 0.585 and below 0.535 ; in alcohol + 50% water, above 0.595 and below 0.37μ.

Neodymium salts are useful combined with other media, sharpening the edges of the absorption bands. In solution with bichromate of potash, transmits 0.535–.565 and above 0.60μ, the bands very sharp (a useful screen for photographing with a visually corrected objective).

Praesodymium salts: three strong bands at 0.482, .468, .444. In strong solutions they fuse into a sharp band at 0.435–.485μ. Absorption below 0.34.

Picric acid absorbs 0.36–.42μ, depending on the concentration.

Potassium chromate absorbs 0.40–.35, 0.30–.24, transmits 0.23μ.

* Potassium permanganate: absorbs 0.555–.50, transmits all the ultra-violet.

Chromium chloride: absorbs above 0.57, between 0.50 and .39, and below 0.33μ. These limits vary with the concentration.

Aesculin: absorbs below 0.363μ, very useful for removing the ultra-violet.

* Nitroso-dimethyl-aniline: very dilute aqueous solution absorbs 0.49–.37 and transmits all the ultra-violet.

Very dense cobalt glass + dense ruby glass or a strong potassium bichromate solution cuts off everything below 0.70 and transmits freely the red.

Iodine: saturated solution in CS_2 is opaque to the visible and transparent to the infra-red.

TRANSMISSIBILITY OF RADIATION.

TABLE 219. — Color Screens. Jena Glasses.

	Kind of Glass.	Maker's No.	Color.	Region Transmitted.	Thickness. mm.
1	Copper-ruby . .	2728	Deep red	Only red to 0.6μ	1.7
1a	Gold-ruby . . .	459^{III}	Red	Red, yellow; in thin layers also blue and violet.	
2	Uranium . . .	454^{III}	Bright yellow . . .	Red, yellow, green to E_b; in thin layer also blue	16.
2a	"	455^{III}	Bright yellow, fluoresces.		
3	Nickel	440^{III}	Bright yellow-brown	Red, yellow, green (weakened), blue (very weakened)	11.
4	Chromium . .	414^{III}	Yellow-green . . .	Yellowish-green	10.
4a	"	433^{III}	Greenish-yellow . .	Red, green; from 0.65–.50μ . . .	5.
4b	Green copper . .	431^{III}	Green	Green, yellow, some red and blue .	2–3
5	Chromium . . .	432^{III}	Yellow-green . . .	Yellowish-green, some red . . .	2.5
6	Copper chromium	436^{III}	Grass-green . . .	Green	5.
7	Green-filter . .	437^{III}	Dark green	Green (in thin sheets some blue) .	5.
8	" " . . .	438^{III}	" "	Green	
10	Copper	2742	Blue, as $CuSO_4$ . .	Green, blue, violet	5–12
11	Blue-violet . .	447^{III}	Blue, as cobalt glass	Blue, violet	5.
"	" " . . .	"	" " " " .	Blue, violet, blue-green (weakened), *no red*	2–5
12	Cobalt	424^{III}	Blue	Blue, violet, extreme red	4–5
13	Nickel	450^{III}	Dark violet	Violet (G–H), extreme red . . .	6.
14	Violet	452^{III}	" "	Violet (G–H), some weakened . .	7.
15	Gray	444^{III}	Gray, no recognizable color	All parts of the spectrum weakened	0.1–8
16	"	445^{III}			0.1–3

See "Über Farbgläser für wissenschaftliche und technische Zwecke," by Zsigmondy, Z. für Instrumentenkunde, 21, 1901 (from which the above table is taken), and "Über Jenenser Lichtfilter," by Grebe, same volume.

(The following notes are quoted from Everett's translation of the above in the English edition of Hovestadt's "Jena Glass.")

Division of the spectrum into complementary colors:

1st by 2728 (deep red) and 2742 (blue, like copper sulphate).
2nd by 454^{III} (bright yellow) and 447^{III} (blue, like cobalt glass).
3rd by 433^{III} (greenish-yellow) and 424^{III} (blue).

Thicknesses necessary in above: 2728, 1.6–1.7 mm.; 2742, 5; 454^{III}, 16; 447^{III}, 1.5–2.0; 433^{III}, 2.5–3.5; 424^{III}, 3 mm.

Three-fold division into red, green and blue (with violet):

2728, 1.7 mm.; 414^{III}, 10 mm.; 447^{III}, 1.5 mm., or by
2728, 1.7 mm.; 436^{III}, 2.6 mm.; 447^{III}, 1.8 mm.

Grebe found the three following glasses specially suited for the additive methods of three-color projection:

2745, red; 438^{III}, green; 447^{III}, blue violet;

corresponding closely to Young's three elementary color sensations.

Most of the Jena glasses can be supplied to order, but the absorption bands vary somewhat in different meltings.

See also "Atlas of Absorption Spectra," Uhler and Wood, Carnegie Institution Publications, 1907.

TABLE 219a. — Water Vapor.

Values of a in $I = I_0 e^{ad}$, d in c. m. I_0; I, intensity before and after transmission.

Wave-length μ,	.186	.193	.200	.210	.220	.230	.240	.260	.300	.415
a	.0688	.0165	.009	.0061	.0057	.0034	.0032	.0025	.0015	.00035
Wave-length μ,	.430	.450	.487	.500	.550	.600	.650	.779	.865	.945
a	.00023	.0002	.0001	.0002	.0003	.0016	.0025	.272	.296	.538

First 9: Kreusler, Drud. Ann. 6, 1901,; next Ewan, Proc. R. Soc. 57, 1894, Aschkinass, Wied Ann. 55, 1895; last 3, Nichols, Phys. Rev. 1, 1.
See Rubens, Ladenburg. Verh. D. Phys. Ges. 1911, for extinction coefs., reflective power and index of refraction, 1 μ to 18 μ.

TABLE 220. — Tartaric Acid ; Camphor ; Santonin ; Santonic Acid; Cane Sugar.

A few examples are here given showing the effect of wave-length on the rotation of the plane of polarization. The rotations are for a thickness of one decimeter of the solution. The examples are quoted from Landolt & Börnstein's "Phys. Chem. Tab." The following symbols are used :—

p = number grams of the active substance in 100 grams of the solution.
c = " " solvent " " " "
q = " " active " " cubic centimeter "

Right-handed rotation is marked +, left-handed —.

Line of spectrum.	Wave-length according to Angström in cms. × 10⁶.	Tartaric acid,* CuH_6O_6, dissolved in water. q = 50 to 95, temp. = 24° C.	Camphor,* $C_{10}H_{16}O$, dissolved in alcohol. q = 50 to 95, temp. = 22.9° C.	Santonin,† $C_{15}H_{18}O_3$, dissolved in chloroform. q = 75 to 96.5, temp. = 20° C.
B	68.67			$-140^\circ.1 + 0.2085\,q$
C	65.62	$+2^\circ.748 + 0.09446\,q$	$38^\circ.549 - 0.0852\,q$	$-149.3 + 0.1555\,q$
D	58.92	$+1.950 + 0.13030\,q$	$51.945 - 0.0964\,q$	$-202.7 + 0.3086\,q$
E	52.69	$+0.153 + 0.17514\,q$	$74.331 - 0.1343\,q$	$-285.6 + 0.5820\,q$
b₁	51.83	– –	– –	$-302.38 + 0.6557\,q$
b₂	51.72	$-0.832 + 0.19147\,q$	$79.348 - 0.1451\,q$	– –
F	48.61	$-3.598 + 0.23977\,q$	$99.601 - 0.1912\,q$	$-365.55 + 0.8284\,q$
e	43.83	$-9.657 + 0.31437\,q$	$149.696 - 0.2346\,q$	$-534.98 + 1.5240\,q$

Line of spectrum.	Wave-length according to Angström in cms. × 10⁶.	Santonin,† $C_{15}H_{18}O_3$, * dissolved in alcohol. c = 1.782. temp. = 20° C.	Santonin,† $C_{15}H_{18}O_3$, dissolved in alcohol. c = 4.046. temp. = 20° C.	Santonin,† $C_{15}H_{18}O_3$, dissolved in chloroform c = 3.1–30.5. temp. = 20° C.	Santonic acid,† $C_{15}H_{20}O_4$, dissolved in chloroform. c = 27.192. temp. = 20° C.	Cane sugar,‡ $C_{12}H_{22}O_{11}$, dissolved in water. p = 10 to 30.
B	68.67	— 110.4°	442°	484°	— 49°	47°.56
C	65.62	— 118.8	504	549	— 57	52.70
D	58.92	— 161.0	693	754	— 74	60.41
E	52.69	— 222.6	991	1088	— 105	84.56
b₁	51.83	— 237.1	1053	1148	— 112	–
b₂	51.72	–	–	–	–	87.88
F	48.61	— 261.7	1323	1444	— 137	101.18
e	43.83	— 380.0	2011	2201	— 197	–
G	43.07	–	–	–	–	131.96
g	42.26	–	2381	2610	— 230	–

* Arndtsen, "Ann. Chim. Phys." (3) 54, 1858.
† Narini, "R. Acc. dei Lincei," (3) 13, 1882.
‡ Stefan, "Sitzb. d. Wien. Akad." 52, 1865.

TABLE 221. — Sodium Chlorate; Quartz.

Sodium chlorate (Guye, C. R. 108, 1889).				Quartz (Soret & Sarasin, Arch. de Gen. 1882, or C. R. 95, 1882).*					
Spectrum line.	Wave-length.	Temp. C.	Rotation per mm.	Spectrum line.	Wave-length.	Rotation per mm.	Spectrum line.	Wave-length.	Rotation per mm.
α	71.769	15°.0	2°.068	A	76.04	12°.668	Cd₉	36.090	63°.628
B	67.889	17.4	2.318	a	71.836	14.304	N	35.818	64.459
C	65.073	20.6	2.599	B	68.671	15.746	Cd₁₀	34.655	69.454
D	59.085	18.3	3.104				O	34.406	70.587
E	53.233	16.0	3.841	C	65.621	17.318			
F	48.912	11.9	4.587	D₁	58.951	21.684	Cd₁₁	34.015	72.448
G	45.532	10.1	5.331	D₂	58.891	21.727	P	33.600	74.571
G	42.834	14.5	6.005				Q	32.858	78.579
H	40.714	13.3	6.754	E	52.691	27.543	Cd₁₂	32.470	80.459
L	38.412	14.0	7.654	F	48.607	32.773			
M	37.352	10.7	8.100	G	43.072	42.604	R	31.798	84.972
N	35.818	12.9	8.861				Cd₁₇	27.467	121.052
P	33.931	12.1	9.801	h	41.012	47.481	Cd₁₈	25.713	143.266
Q	32.341	11.9	10.787	H	39.681	51.193	Cd₂₃	23.125	190.426
R	30.645	13.1	11.921	K	39.333	52.155			
T	29.918	12.8	12.424				Cd₂₄	22.645	201.824
Cd₁₇	28.270	12.2	13.426	L	38.196	55.625	Cd₂₅	21.935	220.731
Cd₁₈	25.038	11.6	14.965	M	37.262	58.894	Cd₂₆	21.431	235.972

* The paper is quoted from a paper by Ketteler in "Wied. Ann." vol. 21, p. 444. The wave-lengths are for the Fraunhofer lines, Angström's values for the ultra violet sun, and Cornu's values for the cadmium lines.

TABLE 222.

NEWTON'S RINGS.

Newton's Table of Colors.

The following table gives the thickness in millionths of an inch, according to Newton, of a plate of air, water, and glass corresponding to the different colors in successive rings commonly called colors of the first, second, third, etc., orders.

Order.	Color for reflected light.	Color for transmitted light.	Thickness in millionths of an inch for — Air.	Water.	Glass.
I.	Very black	—	0.5	0.4	0.2
	Black . .	White . .	1.0	0.75	0.9
	Beginning of black .	—	2.0	1.5	1.3
	Blue . .	Yellowish red . .	2.4	1.8	1.5
	White . .	Black . .	5.2	3.9	3.4
	Yellow . .	Violet .	7.1	5.3	4.6
	Orange .	—	8.0	6.0	4.2
	Red . . .	Blue . .	9.0	6.7	5.8
II.	Violet . .	White .	11.2	3.4	7.2
	Indigo . .	—	12.8	9.6	8.4
	Blue . .	Yellow .	14.0	10.5	9.0
	Green . .	Red . .	15.1	11.3	9.7
	Yellow . .	Violet .	16.3	12.2	10.4
	Orange .	—	17.2	13.0	11.3
	Bright red	Blue . .	18.2	13.7	11.8
	Scarlet . .	—	19.7	14.7	12.7
III.	Purple . .	Green .	21.0	15.7	13.5
	Indigo . .	—	21.1	17.6	14.2
	Blue . .	Yellow .	23.2	17.5	15.1
	Green . .	Red . .	25.2	18.6	16.2
	Yellow . .	Bluish green	27.1	20.3	17.5
	Red . . .	—	29.0	21.7	18.7
	Bluish red	—	32.0	24.0	20.7
IV.	Bluish green .	—	24.0	25.5	22.0
	Green . .	Red .	35.3	26.5	22.7
	Yellowish green .	—	36.0	27.0	23.2
	Red . . .	Bluish green	40.3	30.2	26.0
V.	Greenish blue . .	Red .	46.0	34.5	39.7
	Red . . .	—	52.5	39.4	34.0
VI.	Greenish blue . .	—	58.7	46	38.0
	Red . . .	—	65.0	48.7	42.0
VII.	Greenish blue . .	—	72.0	53.2	45.8
	Reddish white .	—	71.0	57.7	49.4

The above table has been several times revised both as to the colors and the numerical values. Professors Reinold and Rucker, in their investigations on the measurement of the thickness of soap films, found it necessary to make new determinations. They give a shorter series of colors, as they found difficulty in distinguishing slight differences of shade, but divide each color into ten parts and tabulate the variation of thickness in terms of the tenth of a color band. The position in the band at which the thickness is given and the order of color are indicated by numerical subscripts. For example: $R_{1\,5}$ indicates the red of the first order and the fifth tenth from the edge furthest from the red edge of the spectrum. The thicknesses are in millionths of a centimeter.

Order.	Color.	Position.	Thickness.
I.	Red * .	$R_{1\,5}$	28.4
II.	Violet .	$V_{2\,5}$	30.5
	Blue . .	$B_{2\,5}$	35.3
	Green .	$G_{2\,5}$	40.9
	Yellow *	$Y_{2\,5}$	45.4
	Orange *	$O_{2\,5}$	49.1
	Red . .	$R_{2\,5}$	52.2
III.	Purple .	$P_{3\,5}$	55.9
	Blue . .	$B_{3\,0}$	57.7
	Blue * .	$B_{3\,5}$	60.3
	Green .	$G_{3\,5}$	65.6
	Yellow *	$Y_{3\,5}$	71.0
	Red * .	$R_{3\,5}$	76.5
	Bluish red * .	$BR_{3\,5}$	81.5
IV.	Green .	$G_{4\,0}$	84.1
	" .	$G_{4\,5}$	89.3
	Yellow green *	$YG_{4\,5}$	96.4
	Red * .	$R_{4\,5}$	105.2
V.	Green .	$G_{5\,0}$	111.9
	Green *.	$G_{5\,5}$	118.8
	Red . .	$R_{5\,0}$	126.0
	Red * .	$R_{5\,5}$	133.5
VI.	Green .	$G_{6\,0}$	141.0
	Green *	$G_{6\,5}$	147.9
	Red . .	$R_{6\,0}$	154.8
	Red * .	$R_{6\,5}$	162.7
VII.	Green .	$G_{7\,0}$	170.5
	Green *.	$G_{7\,5}$	178.7
	Red . .	$R_{7\,0}$	186.9
	Red * .	$R_{7\,5}$	193.6
VIII.	Green .	$G_{8\,0}$	200.4
	Red . .	$R_{8\,0}$	211.5

* The colors marked are the same as the corresponding colors in Newton's table.

TABLE 223.

CONDUCTIVITY FOR HEAT.

The coefficient k is the quantity of heat in small calories which is transmitted per second through a plate one centimeter thick per square centimeter of its surface when the difference of temperature between the two faces of the plate is one degree Centigrade. The coefficient k is found to vary with the absolute temperature of the plate, and is expressed approximately by the equation $k_t = k_0 [1 + \alpha (t - t_0)]$. k_0 is the resistance at t_0, the lower temperature of the bracketed pairs in the table, k_t that at temperature t and α is a constant.

Substance.	t	k_t	α	Authority.
Aluminum	18	0.480	.00030	2
	100	.492		
Antimony	0	.0442	—.001041	1
	100	.0396		
Bismuth	18	.0194	—.0021	2
	100	.0161		
Brass (yellow)	0	.2041	.002445	1
	100	.2540		
" (red)	0	.2460	.001492	1
	100	.2827		
Cadmium	18	.222	—.00038	2
	100	.215		
Constantin 60Cu+40Ni	18	.5402	.00227	2
	100	.6405		
Copper	18	.918	—.00013	2
	100	.908		
German silver	0	.0700	.002670	1
	100	.0887		
Iron (cast)	18	.108	—.0001	2
	100	.108		
" (wrought)	18	.144	—.0001	2
	100	.142		
Lead	18	.083	—.0001	2
	100	.076		
Mercury	0	.0148	.0055	4
	50	.0189		
Magnesium	0–100	.3760	-	1
Manganin 84Cu+4Ni+12Mn	18	.5186	+.0026	2
	100	.6310		
Nickel	18	.1420	-	2
Palladium	18	.1683	-	2
Platinum	18	.1664	+.00051	2
	100	.1733		
Steel (hard)	-	.0620	-	5
" (soft)	-	.1110	-	5
Silver	18	1.006	—.00017	2
	100	.992		
Tin	0	.1528	—.000687	1
	100	.1423		
Wood's alloy	-	.0319	-	4
Zinc	18	.2653	—.00016	2
	100	.2619		
Concrete (cinder)	-	.00081	-	-
" (stone)	-	.0022	-	3

Substance.	t	k_t	Authority.
Carborundum	-	.00050	1
Slate	-	.0036	1
Soil dry	-	.00033	11
" wet	-	.0016	11
Diatomic earth	-	.00013	12
Fire-brick	-	.00028	12
Granite from	-	.00510	6
to	-	.00550	
Lime	-	.00029	12
Magnesia from	-	.00016	12
to	-	.00045	
Marbles, limestone, calcite, compact dolomite from	-	.00470	6
to	-	.00560	
Micaceous flagstone:			
along cleavage	-	.00632	6
across cleavage	-	.00441	6
Paraffine	-	.00014	8
	0	.00023	9
	100	.00168	9
Pasteboard	-	.00045	8
Plaster of Paris	-	.00070	11
" " " powder	-	.0026	11
Quartz	-	.00036	12
Sand (white dry)	-	.00093	6
Sandstone and hard grit (dry) from	-	.00545	6
to	-	.00565	
Sawdust	-	.00012	8
Serpentine (Cornwall red)	-	.00441	6
Slate:			
along cleavage from	-	.00550	6
to	-	.00650	
across cleavage from	-	.00315	6
to	-	.00360	
Snow, compact layers	-	.00051	7
Strawboard	-	.00033	8
Vulcanite	-	.00087	10
Vulcanized rubber (soft) from	-	.00034	6
to	-	.00054	6
Wax (bees)	-	.00009	8
Wood, fir:			
parallel to axis	-	.00030	8
perpendicular to axis	-	.00009	8

1 Lorenz.
2 J + D*.
3 Norton.
4 H. F. Weber.
5 Kohlrausch.
6 H. L: & D.†
7 Hjeltström.
8 G. Forbes.
9 R. Weber.
10 Stefan.
11 Lees-Chorlton.
12 Hutton-Blard.

---

* Jaeger and Diesselhorst.

† Herschel, Lebour, and Dunn (British Association Committee).

TABLE 224.

THERMAL CONDUCTIVITIES AT HIGH TEMPERATURES.

Material.	Authority.	Temperature Centigrade Degrees.	Thermal Conductivity Calories per sec. per deg. C. per cm. cube.	
Nickel	Angell[1]	300	.126	
		400	.117	
		600	.088	
		700	.069	
		800	.068	
		1000	.064	
		1200	.058	
Aluminum	Angell[1]	100	.49	
		200	.55	
		300	.64	
		400	.76	
		600	1.01	
Iron	Hering	100 – 727	.202	
		100 – 912	.184	
		100 – 1245	.191	
Copper	Hering	100 – 197	1.043	
		100 – 268	.969	
		100 – 370	.931	
		100 – 541	.902	
		100 – 837	.858	
Graphite (Artificial)	Hering	100 – 390	.338	
		100 – 546	.324	
		100 – 720	.306	
		100 – 914	.291	
	Hansen[2]	30 – 2830	.162	
		2800 – 3200	.002	
			maximum.	minimum.
		90 – 110	.55	.45
		180 – 220	.44	.34
		350 – 450	.35	.26
		500 – 700	.31	.22
Amorphous Carbon	Hansen[2]	37 – 163	.028	.003
		170 – 330	.027	.004
		240 – 523	.020	.003
		283 – 597	.011	.004
	Hering	100 – 360	.089	
		100 – 751	.124	
		100 – 842	.129	
Graphite brick	Wologdine	300 – 700	.024	
Carborundum brick	"	150 – 1200	.0032 to .027	
Magnesia brick	"	50 – 1130	.0027 to .0072	
Gas retort brick	"	100 – 1125	.0038	
Building and terra cotta	"	15 – 1100	.0018 to .0038	
Silica brick	"	100 – 1000	.002 to .0033	
Stoneware mixtures	"	70 – 1000	.0029 to .0053	
Porcelain (Sèvres)	"	165 – 1055	.0039 to .0047	
Fire clay brick	"	125 – 1220	.0032 to .0054	
Limestone	Poole[3]	40	.0046 to .0057	
		100	.0039 to .0049	
		350	.0032 to .0035	
Granite	Poole[3]	100	.0045 to .0050	
		200	.0043 to .0097	
		500	.0040	

Angell, Phys. Rev. 33, p. 421, 1911; Clement, Egy, Eng. Exp. Univers. of Ill., Bul. 36, 1909; Dewey, Progressive Age, 27, p. 772, 1909; Hering, Trans. Am. Inst. Elect. Eng. 1910; Poole, Phil. Mag. 24, p. 45, 1912; Wologdine, Bull. Soc. Encouragement, 111, p. 879, 1909; Electroch. and Met. Ind. 7, pp. 383, 433, 1909; Woolson, Eng. News, 58, p. 166, 1907; heat transmission by concretes. Actual values not given; Hansen, Trans. Amer. Electrochem. Soc. 16, p. 329, 1909; Richards, Met. and Chem. Eng. 11, p. 575, 1913.

[1] Taken from Angell's curves.
[2] Values calculated from results expressed in other units. The max. and min. do not relate to variability in material, but to possible errors in the method.
[3] Taken from Poole's curves.

CONDUCTIVITY FOR HEAT.

TABLE 225. — Various Substances.

Substance.	t o	k_t	Authority.
Asbestos paper	–	.00043	5
Blotting paper	–	.00015	5
Carbon	0	.000405	1
Portland cement	–	.00071	5
Cork	0	.000717	1
Cotton wool	0	.000043	1
Cotton pressed	–	.000033	1
Chalk	–	.002000	2
Ebonite	49	.000370	2
Felt	0	.000087	1
Flannel (dry)	0	.00012	1
Glass, from	–	.0011	3
Glass, to	–	.0023	
Horn	–	.000087	1
Haircloth	–	.000042	1
Ice	–	.00223	1
Ice	–	.00568	4
Leather, cow-hide	–	.00042	5
" chamois	–	.00015	5
Linen	–	.00021	5
Silk	–	.000095	5
Caen stone (building limestone)	–	.00433	2
Calc's sandstone (freestone)	–	.00211	2

1 G. Forbes.
2 H., L., & D.*
3 Various.
4 Neumann.
5 Lees-Chorlton.

TABLE 226. — Water and Salt Solutions.

Substance.	Density.	t o	k_t	Authority.
Water	–	–	.002	1
"	–	0	.00120	2
"	–	9–15	.00136	2
"	–	4	.00129	3
"	–	30	.00157	4
"	–	18	.00124	5
Solutions in water.				
$CuSO_4$	1.160	4.4	.00118	2
KCl	1.026	13	.00116	4
NaCl	$33\frac{1}{3}$%	10–18	.00267	6
H_2SO_4	1.054	20.5	.00126	5
"	1.100	20.5	.00128	5
"	1.180	21	.00130	5
$ZnSO_4$	1.134	4.5	.00118	2
"	1.136	4.5	.00115	2

1 Bottomley.
2 H. F. Weber.
3 Wachsmuth.
4 Graetz.
5 Chree.
6 Winkelmann.

TABLE 227. — Organic Liquids.

Substance.	t o	k_t ×1000	a	Authority.
Acetic acid	9–15	.472	–	1
Alcohols: amyl	9–15	.328	–	1
ethyl	9–15	.423	–	1
methyl	9–15	.495	–	1
Benzole	5	.333	–	1
Carbon disulphide	9–15	.343	–	1
Chloroform	9–15	.288	–	1
Ether	9–15	.303	–	1
Glycerine	9–15	.637	0.12	2
Oils: olive	–	.395	–	3
castor	–	.425	–	3
petroleum	13	.355	0.011	2
turpentine	13	.325	0.0067	2
Vaseline	–	.44	–	4

1 H. F. Weber.
2 Graetz.
3 Wachsmuth.
4 Lees.

TABLE 228. — Gases.

Substance.	t o	k_t ×10000	a	Authority.
Air	0	.568	.00190	1
Argon	0	.389	.00260	2
Ammonia	0	.458	.00548	1
Carbon monoxide	0	.499	–	1
" dioxide	0	.307	–	1
Ethylene	0	.395	.00445	1
Helium	0	3.39	.00318	2
Hydrogen	0	3.27	.00175	1
Methane	7–8	.647	–	1
Nitrogen	7–8	.524	–	1
Nitrous oxide	7–8	.350	.00446	1
Oxygen	7–8	.563	–	1

1 Winkelmann.
2 Schwarze.

---

* Herschel, Lebour, and Dunn (British Association Committee).

TABLE 229.

DIFFUSIVITIES.

The diffusivity of a substance = $h^2 = k/c\rho$, where k is the conductivity for heat, c the specific heat and ρ the density. (Kelvin.) The values are mostly for room temperatures, about 18° C.

Material.	Diffusivity.	Material.	Diffusivity.
Aluminum	0.826	Coal	0.002
Antimony	.139	Concrete (cinder)	.0032
Bismuth	.0678	" (stone)	.0058
Brass (yellow)	.339	" (light slag)	.006
Cadmium	.467	Cork (ground)	.0017
Copper	1.133	Ebonite	.0010
Gold	1.182	Glass (ordinary)	.0057
Iron (wrought, also mild steel)	0.173	Granite	.0155
Iron (cast, also 1% carbon steel)	.121	Ice	.0112
Lead	.237	Limestone	.0092
Magnesium	.883	Marble (white)	.0090
Mercury	.0327	Paraffin	.00098
Nickel	.152	Rock material (earth aver.)	.0118
Palladium	.240	" " (crustal rocks)	.0064
Platinum	.243	Sandstone	.0133
Silver	1.737	Snow (fresh)	.0033
Tin	0.407	Soil (clay or sand, slightly damp)	.005
Zinc	.402	Soil (very dry)	.0031
Air	.179	Water	.0014
Asbestos (loose)	.0035	Wood (pine, cross grain)	.00068
Brick (average fire)	.0074	" (" with ")	.0023
" (" building)	.0050		

Taken from "An Introduction to the Mathematical Theory of Heat Conduction," Ingersoll and Zobel, 1913.

HEAT OF COMBUSTION.

Heat of combustion of some common organic compounds.
Products of combustion, CO_2 or SO_2 and water, which is assumed to be in a state of vapor.

Substance.	Small calories per gram of substance.	Authority.
Acetylene	11923	Thomsen.
Alcohols: Amyl	8958	Favre and Silbermann.
Ethyl	7183	" " "
Methyl	5307	" " "
Benzene	9977	Stohmann, Kleber, and Langbein.
Coals: Bituminous	7400–8500	Various.
Anthracite	7800	Average of various.
Lignite	6900	" " "
Coke	7000	" " "
Carbon disulphide	3244	Berthelot.
Dynamite, 75%	1290	Roux and Sarran.
Gas: Coal gas	5800–11000	Mahler.
Illuminating	5200–5500	Various.
Methane	13063	Favre and Silbermann.
Naphthalene	9618–9793	Various.
Gunpowder	720–750	"
Oils: Lard	9200–9400	"
Olive	9328–9442	Stohmann.
Petroleum, Am. crude	11094	Mahler.
" " refined	11045	"
" Russian	10800	"
Woods: Beech with 12.9% H_2O	4168	Gottlieb.
Birch " 11.83 "	4207	"
Oak " 13.3 "	3990	"
Pine " 12.17 "	4422	"

TABLE 231.

HEAT VALUES AND ANALYSES OF VARIOUS TYPES OF FUEL.

(a) Coals.

Coal.		Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Hydrogen	Carbon.	Nitrogen.	Oxygen.	Calories per gram.	B. T. U.'s per pound.
Lignite	Low grade . .	38.81	25.48	27.29	8.42	.97	7.09	37.45	.50	45.57	3526	6347
	High grade . .	33.38	27.44	29.62	9.56	.94	6.77	41.31	.67	40.75	3994	7189
Sub-bituminous	Low grade .	22.71	34.78	36.60	5.91	.29	6.14	52.54	1.03	34.09	5115	9207
	High grade .	15.54	33.03	46.06	5.37	.58	5.89	60.08	1.05	27.03	5865	10557
Bituminous	Low grade .	11.44	33.93	43.92	10.71	4.94	5.39	60.06	1.02	17.88	6088	10958
	High grade	3.42	34.36	58.83	3.39	.58	5.25	77.98	1.29	11.51	7852	14134
Semi-bituminous	Low grade .	2.7	14.5	75.5	7.3	.99	4.58	80.65	1.82	4.66	7845	14121
	High grade .	3.26	14.57	78.20	3.97	.54	4.76	84.62	1.02	5.09	8166	14699
Semi-anthracite. . . .		2.07	9.81	78.82	9.30	1.74	3.62	80.28	1.47	3.59	7612	13702
Anthracite	Low grade .	2.76	2.48	82.07	12.69	.54	2.23	79.22	.68	4.64	6987	12577
	High grade	3.33	3.27	84.28	9.12	.60	3.08	81.35	.79	5.06	7417	13351

(b) Peats (air dried).

From	Vol. Hydro-Carbon.	Fixed Carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calories per gram.	B.T.U.'s per pound.
Franklin Co., N. Y.	67.10	28.99	3.91	.15	5.93	57.17	1.48	31.36	5726	10307
Sawyer Co., Wis.	56.54	27.92	15.54	.29	4.71	51.00	1.92	26.54	4867	8761

(c) Liquid Fuels.

Fuel.	Specific Gravity at 15° C.	Calories per gram.	British Thermal Units per pound.
Petroleum ether	.684–.694	12210–12220	21978–21996
Gasoline	.710–.730	11100–11400	19980–20520
Kerosene	.790–.800	11000–11200	19800–20160
Fuel oils, heavy petroleum or refinery residue.	.960–.970	10200–10500	18360–18900
Alcohol, fuel or denatured with 7–9 per cent water and denaturing material . . .	.8196–.8202	6440–6470	11592–11646

Table compiled by U. S. Geological Survey.

TABLE 232.

CHEMICAL AND PHYSICAL PROPERTIES OF FIVE DIFFERENT CLASSES OF EXPLOSIVES.

Explosive.	Specific gravity.	Number of large calories developed by 1 kilogram of the explosive.	Pressure developed in own volume after elimination of surface influence.	Unit disruptive charge by ballistic pendulum.	Rate of detonation. Cartridges 1¼ in. diam.	Duration of flame from 100 grams of explosive.	Length of flame from 100 grams.	Cartridge 1¼ in. transmitted explosion at a distance of	Products of combustion from 200 grams; gaseous, solid, and liquid, respectively.	Ignition occurred in 4% fire damp & coal dust mixture with
			Kg. per sq. cm.	Grams.	Meters per second.	Milliseconds.	Inches.	Inches.	Grams.	Grams.
(A) Forty-per-cent nitroglycerin dynamite	1.22	1221.4	8235	227*	4688	.358	24.63	12	88.4 79.7 14.5	25
(B) FFF black blasting powder	1.25	789.4	4817	374† 458*	469.4‡	925.	54.32	–	154.4 126.9 4.1‖	25
(C) Permissible explosive; nitroglycerin class	1.10	760.5	5912	301*	3008	.471	27.79	4	103.9 65.1 15.4	1000
(D) Permissible explosive; ammonium nitrate class	0.97	992.8	7300	279*	3438§	.483	25.68	1	89.8 27.5 75.5	800
(E) Permissible explosive; hydrated class	1.54	610.6	6597	434*	2479	.338	17.49	3	86.1 56.0 33.0	Over 1000

Chemical Analyses.

(A)	Moisture	0.91
	Nitroglycerin	39.68
	Sodium nitrate	42.46
	Wood pulp	13.58
	Calcium carbonate	3.37
(B)	Moisture	0.80
	Sodium nitrate	70.57
	Charcoal	17.74
	Sulphur	10.89
(C)	Moisture	7.89
	Nitroglycerin	24.02
	Sodium nitrate	36.25
	Wood pulp and crude fibre from grains	9.20
	Starch	21.31
	Calcium carbonate	0.97
	Magnesium "	0.36
(D)	Moisture	0.23
	Ammonium nitrate	83.10
	Sulphur	0.46
	Starch	2.61
	Wood pulp	1.89
	Poisonous matter	2.54
	Manganese peroxide	2.64
	Sand	6.53
(E)	Moisture	2.34
	Nitroglycerin	30.85
	Ammonium nitrate	9.94
	Sand	1.75
	Coal	11.98
	Clay	7.64
	Ammonium sulphate	8.96
	Zinc sulphate (7HO)	6.89
	Potassium sulphate	19.65

---

* One pound of clay tamping used. † Two pounds of clay tamping used. ‡ Rate of burning.
§ Cartridges 1¾ in. diam. ‖ For 300 grammes.

Compiled from U. S. Geological Survey Results, — "Investigation of Explosives for use in Coal Mines, 1909."

TABLE 233.

Heat of combination of elements and compounds expressed in units, such that when unit mass of the substance is units, which will be raised in temperature

Substance.	Combined with oxygen forms —	Heat units.	Combined with chlorine forms —	Heat units.	Combined with sulphur forms —	Heat units.	Authority.
Calcium	CaO	3284	$CaCl_2$	4255	CaS	2300	1
Carbon — Diamond	CO_2	7859	–	–	–	–	2
" "	CO	2141	–	–	–	–	3
" — Graphite	CO_2	7796	–	–	–	–	3
Chlorine	Cl_2O	—254	–	–	–	–	1
Copper	Cu_2O	321	CuCl	520	–	–	1
"	CuO	585	$CuCl_2$	819	CuS	158	1
"	"	593	–	–	–	–	4
Hydrogen*	H_2O	34154	HCl	22000	H_2S	2250	3
"	"	34800	–	–	–	–	5
"	"	34417	–	–	–	–	6
Iron	FeO	1353	$FeCl_2$	1464	$FeSH_2O$	428	3
"	–	–	$FeCl_3$	1714	–	–	3
Iodine	I_2O_5	177	–	–	–	–	1
Lead	PbO	243	$PbCl_2$	400	PbS	98	1
Magnesium	MgO	6077	$MgCl_2$	6291	MgS	3191	1
Manganese	$MnOH_2O$	1721	$MnCl_2$	2042	$MnSH_2O_2$	841	1
Mercury	Hg_2O	105	HgCl	206	–	–	1
"	HgO	153	$HgCl_2$	310	HgS	84	1
Nitrogen*	N_2O	—654	–	–	–	–	1
"	NO	—1541	–	–	–	–	1
"	NO_2	—143	–	–	–	–	1
Phosphorus (red)	P_2O_5	5272	–	–	–	–	1
" (yellow)	"	5747	–	–	–	–	7
" "	"	5964	–	–	–	–	1
Potassium	K_2O	1745	KCl	2705	K_2S	1312	8
Silver	Ag_2O	27	AgCl	271	Ag_2S	24	1
Sodium	Na_2O	3293	NaCl	4243	Na_2S	1900	8
Sulphur	SO_2	2241	–	–	–	–	1
"	"	2165	–	–	–	–	2
Tin	SnO	573	$SnCl_2$	690	–	–	4
"	–	–	$SnCl_4$	1089	–	–	7
Zinc	ZnO	1185	–	–	–	–	4
"	"	1314	$ZnCl_2$	1495	–	–	1

Substance.	Combined with $S + O_4$ to form —	Heat units.	Combined with $N + O_3$ to form —	Heat units.	Combined with $C + O_3$ to form —	Heat units.	Authority.
Calcium	$CaSO_4$	7997	$Ca(NO_3)_2$	5080	$CaCO_3$	6730	1
Copper	$CuSO_4$	2887	$Cu(NO_3)_2$	1304	–	–	1
Hydrogen	H_2SO_4	96450	HNO_3	41500	–	–	1
Iron	$FeSO_4$	4208	$Fe(NO_3)_2$	2134	–	–	1
Lead	$PbSO_4$	1047	$Pb(NO_3)_2$	512	$PbCO_3$	814	1
Magnesium	$MgSO_4$	12596	–	–	–	–	1
Mercury	–	–	–	–	–	–	1
Potassium	K_2SO_4	4416	KNO_3	3061	K_2CO_3	3583	1
Silver	Ag_2SO_4	776	$AgNO_3$	266	Ag_2CO_3	561	1
Sodium	Na_2SO_4	7119	$NaNO_3$	4834	Na_2CO_3	5841	1
Zinc	$ZnSO_4$	3538	–	–	–	–	1

AUTHORITIES.

1 Thomsen.
2 Berthelot.
3 Favre and Silbermann.
4 Joule.
5 Hess.
6 Average of seven different.
7 Andrews.
8 Woods.

---

* Combustion at constant pressure.

COMBINATION.

caused to combine with oxygen or the negative radical, the numbers indicate the amount of water, in the same from 0° to 1° C. by the addition of that heat.

Substance.	In dilute solutions.						Authority.
	Forms —	Heat units.	Forms —	Heat units.	Forms —	Heat units.	
Calcium	$CaOH_2O$	3734	$CaCl_2H_2O$	4690	$CaS + H_2O$	2457	1
Carbon — Diamond	–	–	–	–	–	–	2
" "	–	–	–	–	–	–	3
" — Graphite	–	–	–	–	–	–	3
Chlorine	–	–	–	–	–	–	1
Copper	–	–	–	–	–	–	1
"	–	–	–	–	–	–	1
"	–	–	–	–	–	–	4
Hydrogen	–	–	–	–	–	–	3
"	–	–	–	–	–	–	5
"	–	–	–	–	–	–	6
Iron	$FeO + H_2O$	1220*	$FeCl_2 + H_2O$	1785	–	–	3
"	–	–	$FeCl_3$	2280	–	–	3
Iodine	–	–	–	–	–	–	1
Lead	–	–	$PbCl_2$	368	–	–	1
Magnesium	MgO_2H_2	9050 †	$MgCl_2$	7779	MgS	4784	1
Manganese	–	–	$MnCl_2$	2327	–	–	1
Mercury	–	–	–	–	–	–	1
"	–	–	$HgCl_2$	299	–	–	1
Nitrogen	–	–	–	–	–	–	1
"	–	–	–	–	–	–	1
"	–	–	–	–	–	–	1
Phosphorus (red)	–	–	–	–	–	–	1
" (yellow)	–	–	–	–	–	–	7
" "	–	–	–	–	–	–	1
Potassium	K_2O	2110*	KCl	2592	K_2S	1451	8
Silver	–	–	–	–	–	–	1
Sodium	Na_2O	3375	NaCl	4190	Na_2S	2260	8
Sulphur	–	–	–	–	–	–	1
"	–	–	–	–	–	–	2
Tin	–	–	$SnCl_2$	691	–	–	7
"	–	–	$SnCl_4$	1344	–	–	7
Zinc	–	–	–	–	–	–	4
"	–	–	$ZnCl_2$	1735	–	–	1

Substance.	In dilute solutions.						Authority.
	Forms —	Heat units.	Forms —	Heat units.	Forms —	Heat units.	
Calcium	–	–	$Ca(NO_3)_2$	5175	–	–	1
Copper	$CuSO_4$	3150	$Cu(NO_3)_2$	1310	–	–	1
Hydrogen	H_2SO_4	105300	HNO_3	24550	–	–	1
Iron	$FeSO_4$	4210	$Fe(NO_3)_3$	2134	–	–	1
Lead	–	–	$Pb(NO_3)_2$	475	–	–	1
Magnesium	$MgSO_4$	13420	$Mg(NO_3)_2$	8595	–	–	1
Mercury	–	–	$Hg(NO_3)_2$	335	–	–	1
Potassium	K_2SO_4	4324	KNO_3	2860	–	–	1
Silver	Ag_2SO_4	753	$AgNO_3$	216	–	–	1
Sodium	Na_2SO_4	7160	$NaNO_3$	4620	Na_2CO_3	5995	1
Zinc	$ZnSO_4$	3820	$Zn(NO_3)_2$	2035	–	–	1

AUTHORITIES.

1 Thomsen.
2 Berthelot.
3 Favre and Silbermann.
4 Joule.
5 Hess.
6 Average of seven different.
7 Andrews.
8 Woods.

* Thomsen.

† Total heat from elements.

TABLE 234.

LATENT HEAT OF VAPORIZATION.

The temperature of vaporization in degrees Centigrade is indicated by *T*; the latent heat in large calories per kilogram or in small calories or therms per gram by *H*; the total heat from 0° C, in the same units by *H'*. The pressure is that due to the vapor at the temperature *T*.

Substance.	Formula.	*T*	*H*	*H'*	Authority.
Acetic acid	$C_2H_4O_2$	118°	84.9	-	Ogier.
Air	-	-	50.97	-	Fenner-Richtmyer.
Alcohol: Amyl	$C_5H_{12}O$	131	120	-	Schall.
Ethyl	C_2H_6O	78.1	205	255	Wirtz.
"	"	0	236	236	Regnault.
"	"	50	-	264	"
"	"	100	-	267	"
"	"	150	-	285	"
Methyl	CH_4O	64.5	2.67	307	Wirtz.
"	"	0	289	289	Ramsay and Young.
"	"	50	-	274	" " "
"	"	100	-	246	" " "
"	"	150	-	206	" " "
"	"	200	-	152	" " "
"	"	238.5	-	44.2	" " "
Ammonia	NH_3	7.8	294.2	-	Regnault.
"	"	11	291.3	-	"
"	"	16	297.4	-	"
"	"	17	296.5	-	"
Benzene	C_6H_6	80.1	92.9	127.9	Wirtz.
Bromine	Br	61	45.6	-	Andrews.
Carbon dioxide, solid	CO_2	-	-	138.7	Favre.
" " liquid	"	—25	72.23	-	Cailletet and Mathias.
" " "	"	0	57.48	-	" " "
" " "	"	12.35	44.97	-	Mathias.
" " "	"	22.04	31.8	-	"
" " "	"	29.85	14.4	-	"
" " "	"	30.82	3.72	-	"
" disulphide	CS_2	46.1	83.8	94.8	Wirtz.
" "	"	0	90	90	Regnault.
" "	"	100	-	100.5	"
" "	"	140	-	102.4	"
Chloroform	$CHCl_3$	60.9	58.5	72.8	Wirtz.
Ether	$C_4H_{10}O$	34.5	88.4	107	"
"	"	34.9	90.5	-	Andrews.
"	"	0	94	94	Regnault.
"	"	50	-	115.1	"
"	"	120	-	140	"
Iodine	I	-	23.95	-	Favre and Silbermann.
Mercury	Hg	357	65	-	Mean.
Nitrogen	N	—195.6	47.65	-	Alt.
Oxygen	O	—182.9	50.97	-	"
Sulphur dioxide	SO_2	0	91.2	-	Cailletet and Mathias.
" "	"	30	80.5	-	" " "
" "	"	65	68.4	-	" " "
Turpentine	$C_{10}H_{16}$	159.3	74.04	-	Brix.
Water	H_2O	100	535.9	-	Andrews.
"	"	100	-	637	Regnault.

LATENT HEAT OF VAPORIZATION.*

Substance, formula, and temperature.	l = total heat from fluid at 0° to vapor at t°. r = latent heat at t°.	Authority.
Acetone, C_3H_6O, — 3° to 147°.	$l = 140.5 + 0.36644\,t - 0.000516\,t^2$ $l = 139.9 + 0.23356\,t + 0.00055358\,t^2$ $r = 139.9 - 0.27287\,t + 0.0001571\,t^2$	Regnault. Winkelmann. "
Benzol, C_6H_6, 7° to 215°.	$l = 109.0 + 0.24429\,t - 0.0001315\,t^2$	Regnault.
Carbon dioxide, CO_2, — 25° to 31°.	$r^2 = 118.485\,(31 - t) - 0.4707\,(31 - t^2)$	Cailletet and Mathias.
Carbon disulphide, CS_2, — 6° to 143°.	$l = 90.0 + 0.14601\,t - 0.000412\,t^2$ $l = 89.5 + 0.16993\,t - 0.0010161\,t^2 + 0.000003424\,t^3$ $r = 89.5 - 0.06530\,t - 0.0010976\,t^2 + 0.000003424\,t^3$	Regnault. Winkelmann. "
Carbon tetrachloride, CCl_4, 8° to 163°.	$l = 52.0 + 0.14625\,t - 0.000172\,t^2$ $l = 51.9 + 0.17867\,t - 0.0009599\,t^2 + 0.000003733\,t^3$ $r = 51.9 - 0.01931\,t - 0.0010505\,t^2 + 0.000003733\,t^3$	Regnault. Winkelmann. "
Chloroform, $CHCl_3$, — 5° to 159°.	$l = 67.0 + 0.1375\,t$ $l = 67.0 + 0.14716\,t - 0.0000937\,t^2$ $r = 67.0 - 0.08519\,t - 0.0001444\,t^2$	Regnault. Winkelmann. "
Nitrogen, N.	$r = 68.85 - 0.2736\,T$	Alt.
Nitrous oxide, N_2O, — 20° to 36°.	$r^2 = 131.75\,(36.4 - t) - 0.928\,(36.4 - t)^2$	Cailletet and Mathias.
Oxygen, O.	$r = 60.67 - 0.2080\,T$	Alt.
Sulphur dioxide, SO_2, 0° to 60°.	$r = 91.87 - 0.3842\,t - 0.000340\,t^2$	Mathias.
Water, H_2O.	$r = 94.210\,(365 - t)^{0.31249}$, 30° — 100° $r = 538.46 - 0.6422\,(t - 100) - 0.000833\,(t - 100)^2$, 100°–180° $r = 539.66 - 0.718\,(t - 100)$, 120°–180°	Henning. "

---

* Quoted from Landolt & Börnstein's "Phys. Chem. Tab."

TABLE 235.

LATENT HEAT OF FUSION.

This table contains the latent heat of fusion of a number of solid substances in large calories per kilogram or small calories or therms per gram. It has been compiled principally from Landolt and Börnstein's tables. *C* indicates the composition, *T* the temperature Centigrade, and *H* the latent heat.

Substance.	*C*	*T*	*H*	Authority.
Alloys: $30.5Pb + 69.5Sn$	$PbSn_4$	183	17.	Spring.
$36.9Pb + 63.1Sn$	$PbSn_3$	179	15.5	"
$63.7Pb + 36.3Sn$	$PbSn$	177.5	11.6	"
$77.8Pb + 22.2Sn$	Pb_2Sn	176.5	9.54	"
Britannia metal, $9Sn + 1Pb$	-	236	28.0*	Ledebur.
Rose's alloy, $24Pb + 27.3Sn + 48.7Bi$	-	98.8	6.85	Mazzotto.
Wood's alloy $\left\{\begin{matrix} 25.8Pb + 14.7Sn \\ + 52.4Bi + 7Cd \end{matrix}\right\}$	-	75.5	8.40	"
Aluminum	Al	658.	76.8	Glaser.
Ammonia	NH_3	—75.	108.	Massol.
Benzole	C_6H_6	5.4	30.6	Mean.
Bromine	Br	—7.3	16.2	Regnault.
Bismuth	Bi	268	12.64	Person.
Cadmium	Cd	320.7	13.66	"
Calcium chloride	$CaCl_2 + 6H_2O$	28.5	40.7	"
Copper	Cu	1083	42.	Mean.
Iron, Gray cast	-	-	23.	Gruner.
" White "	-	-	33.	"
" Slag	-	-	50.	"
Iodine	I	-	11.71	Favre and Silbermann.
Ice	H_2O	0	79.63	Dickinson, Harper, Osborne.†
"	"	0	79.59	Smith.‡
" (from sea-water)	H_2O + 3.535 of solids	—8.7	54.0	Petterson.
Lead	Pb	327	5.36	Mean.
Mercury	Hg	—39	2.82	Person.
Naphthalene	$C_{10}H_8$	79.87	35.62	Pickering.
Nickel	Ni	1435	4.64	Pionchon.
Palladium	Pd	1545	36.3	Violle.
Phosphorus	P	44.2	4.97	Petterson.
Platinum	Pt	1755	27.2	Violle.
Potassium	K	62	15.7	Joannis.
Potassium nitrate	KNO_3	333.5	48.9	Person.
Phenol	C_6H_6O	25.37	24.93	Petterson.
Paraffin	-	52.40	35.10	Batelli.
Silver	Ag	961	21.07	Person.
Sodium	Na	97	31.7	Joannis.
" nitrate	$NaNO_3$	305.8	64.87	"
" phosphate	$Na_2HPO_4 + 12H_2O$	36.1	66.8	"
Spermaceti	-	43.9	36.98	Batelli.
Sulphur	S	115	9.37	Person.
Tin	Sn	232	14.0	Mean.
Wax (bees)	-	61.8	42.3	"
Zinc	Zn	419	28.13	"

---

* Total heat from 0° C.

† U. S. Bureau of Standards, 1913, in terms of 15° calorie.

‡ 1903, based on electrical measurements, assuming mechanical equivalent = 4.187, and in terms of the value of the international volt in use after 1911.

TABLE 236.

MELTING-POINTS OF THE CHEMICAL ELEMENTS.

The metals in **heavier type** are often used as standards.

The melting-points are reduced as far as possible to a common temperature scale which is the one used by the United States Bureau of Standards in certifying pyrometers. This scale is defined in terms of Wien's law with C_2 taken as 14500, and on which the melting-point of platinum is 1755° C (Nernst and Wartenburg, 1751; Waidner and Burgess, 1753; Holborn and Valentiner, 1770; see C. R. 148, p. 1177, 1909). Above 1100° C, the temperatures are expressed to the nearest 5° C. Temperatures above the platinum point may be uncertain by over 50° C.

Element.	Melting-point.	Remarks.
Aluminum	**658 ± 1**	Most samples give 657 or less (Burgess).
Antimony	**630 ± 1**	"Kahlbaum" purity.
Argon	— 188	Ramsay-Travers.
Arsenic	500	
Barium	850	(Guntz.)
Beryllium	< Ag	
Bismuth	270	Adjusted.
Boron	> 2000 < 2500	Weintraub.
Bromine	— 7.3	
Cadmium	321	Range: 320.7–320.9.
Cæsium	26	Range: 26.37–25.3
Calcium	805	Adjusted.
Chlorine	— 102	(Olszewski.)
Carbon	(>3500)	Sublimes.
Cerium	645	
Chromium	>1520	Burgess-Waltenberg
Cobalt	1478	Burgess-Waltenberg
Copper	**1083 ± 3**	Mean, Holborn-Day, Day-Clement.
Erbium		
Fluorine	— 223	(Moissan - Dewar.)
Gallium	30.1	
Germanium	< Ag	
Gold	**1063 ± 3**	Adjusted.
Hydrogen	— 259	
Indium	155	(Thiel.)
Iodine	114	Range: 112–115.
Iridium	2290	Mendenhall Ingersoll.
Iron	**1530**	Burgess-Waltenberg.
Krypton	— 169	(Ramsay).
Lanthanum	810	(Muthmann-Weiss.)
Lead	**327 ± 0.5**	
Lithium	186	(Kahlbaum.)
Magnesium	651	(Grube) in clay crucibles, 635.
Manganese	1260	Burgess-Waltenberg
Mercury	— 38.7	
Molybdenum	2535	Mendenhall-Forsythe
Neodymium	840	(Muthmann-Weiss.)
Neon	— 252	
Nickel	**1452**	Day, Sosman, Burgess, Waltenberg.
Niobium	1950	v. Bolton.
Nitrogen	— 211	(Fischer-Alt.)
Osmium	About 2700	(Waidner - Burgess, unpublished.)
Oxygen	— 230?	
Palladium	**1545 ± 15**	(Waidner-Burgess, Nernst-Wartenburg.)
Phosphorus	44.2	
Platinum	**1755 ± 20**	See Note.
Potassium	62.3	
Præsodymium	940	(Muthmann-Weiss.)
Rhodium	1910	(Mendenhall-Ingersoll.)
Rubidium	38.5	
Ruthenium	1900?	
Samarium	1300–1400	(Muthmann-Weiss.)
Selenium	217	Saunders.
Silicon	1420	Adjusted.
Silver	**961 ± 1**	Adjusted.
Sodium	97	
Strontium		Between Ca and Ba?
Sulphur	113.5–119.5	Various forms. See Landolt-Börnstein.
Tantalum	2800	Adjusted from Waidner-Burgess = 2910.
Tellurium	451	Adjusted.
Thallium	302	
Thorium	>1700<Pt	v. Wartenburg.
Tin	**231.9 ± .2**	
Titanium	1795	Burgess-Waltenberg.
Tungsten	2950	Mean, Waidner-Burgess and Wartenburg.
Uranium	Near Mo	Moissan.
Vanadium	1720	Burgess-Waltenberg.
Xenon	— 140	Ramsay.
Zinc	419 ± 0.5	
Zirconium	> Si	Troost.

TABLE 237.

BOILING-POINTS OF THE CHEMICAL ELEMENTS.

Element.	Range.	Boiling-point.	Observer; Remarks.
	°	°	
Aluminum	–	1800.	Greenwood, Ch. News, 100, 1909.
Antimony	–	1440.	" " " " "
Argon	–	—186.1	Ramsay-Travers, Z. Phys. Ch. 38, 1901.
Arsenic	449–450	–	Gray, sublimes, Conechy.
"	–	>360.	Black, sublimes, Engel, C. R. 96, 1883.
"	280–310	–	Yellow, sublimes.
Barium	–	–	Boils in vacuo, Guntz, 1903.
Bismuth	1420–1435	1430.	Barus, 1894; Greenwood, l. c.
Boron	–	–	Volatilizes without melting in electric arc.
Bromine	59–63	61.1	Thorpe, 1880; van der Plaats, 1886.
Cadmium	–	778.	Berthelot, 1902.
Cæsium	–	670.	Ruff-Johannsen.
Carbon	–	3600.	Computed, Violle, C. R. 120, 1895.
"	–	–	Volatilizes without melting in electric oven, Moisson.
Chlorine	–	—33.6	Regnault, 1863.
Chromium	–	2200.	Greenwood, Ch. News, 100, 1909.
Copper	2100–2310	2310.	" l. c.
Fluorine	–	—187.	Moisson-Dewar, C. R. 136, 1903.
Helium	–	—267.	Computed, Tracers Ch. News, 86, 1902.
Hydrogen	—252.5–252.8	—252.6	Mean.
Iodine	–	> 200.	
Iron	–	2450.	Greenwood, l. c.
Krypton	–	—151.7	Ramsay, Ch. News, 87, 1903.
Lead	–	1525.	Greenwood, l. c.
Lithium	–	1400.	Ruff-Johannsen, Ch. Ber. 38, 1905.
Magnesium	–	1120.	Greenwood, l. c.
Manganese	–	1900.	" "
Mercury	–	357.	Crafts; Regnault.
Neon	–	—239.	Dewar, 1901.
Nitrogen	—195.7–194.4	—195.	Mean.
Oxygen	—182.5–182.9	—182.7	"
Ozone	–	—119.	Troost, C. R. 126, 1898.
Phosphorus	287–290	288.	
Potassium	667–757	712.	Perman; Ruff-Johannsen.
Rubidium	–	696.	Ruff-Johannsen.
Selenium	664–694	690.	
Silver	–	1955.	Greenwood, l. c.
Sodium	742–757	750.	Perman; Ruff-Johannsen.
Sulphur	444.7–445	444.7	Mean.
Tellurium	–	1390.	Deville-Troost, C. R. 91, 1880.
Thallium	–	1280.	v. Wartenberg, 25 Anorg. Ch. 56, 1908.
Tin	–	2270.	Greenwood, l. c.
Xenon	–	—109.1	Ramsay, Z. Phys. Ch. 44, 1903.
Zinc	916–942	930.	

Table 238.

DENSITIES AND MELTING AND BOILING POINTS. INORGANIC COMPOUNDS.

Substance.	Chemical Formula.	Density about 20° C.	Melting-point C.	Authority.	Boiling-point C.	Pressure mm.	Authority.
Aluminum chloride	$AlCl_3$	–	190.	1	183°	752	1
“ nitrate	$Al(NO_3)_3+9H_2O$	–	72.8	2	–	–	–
Aluminum oxide	Al_2O_3	4.00	2020	11	–	–	–
Ammonia	NH_3	–	—75.	3	—33.5	760	7
Ammonium nitrate	NH_4NO_3	1.72	165.	–	–	–	–
“ sulphate	$(NH_4)_2SO_4$	1.77	140.	4	–	–	–
“ phosphite	$NH_4H_2PO_3$	–	123.	5	–	–	–
Antimony trichloride	$SbCl_3$	3.06	73.	–	223.	760	–
“ pentachloride	$SbCl_5$	2.35	3.	11	102.	68	14
Arsenic trichloride	$AsCl_3$	2.20	—18.	8	130.2	760	23
Arseniетted hydrogen	AsH_3	–	—113.5	6	—54.8	“	6
Barium chloride	$BaCl_2.2H_2O$	3.10	113.	9	–	–	–
“ nitrate	$Ba(NO_3)_2$	3.24	575.	24	–	–	–
“ perchlorate	$Ba(ClO_4)_2$	–	505.	10	–	–	–
Bismuth trichloride	$BiCl_3$	4.56	232.5	–	440.	760	–
Boric acid	H_3BO_3	1.46	185.	–	–	–	–
“ anhydride	B_2O_3	1.79	577.	–	–	–	–
Borax (sodium borate)	$Na_2B_4O_7$	1.69	561+	9	–	–	–
Cadmium chloride	$CdCl_2$	4.05	560.	25	900.±	–	9
“ nitrate	$Cd(NO_3)_2+4H_2O$	2.45	59.5	2	132.	760	4
Calcium chloride	$CaCl_2$	2.26	774.	–	–	–	–
“ “	$CaCl_2+6H_2O$	1.68	29.6	–	–	–	–
“ nitrate	$Ca(NO_3)_2$	2.36	499.	24	–	–	–
“ “	$Ca(NO_3)_2+4H_2O$	1.82	42.3	26	–	–	–
Carbon tetrachloride	CCl_4	1.59	—24.	22	76.7	760	23
“ trichloride	C_2Cl_6	1.63	184.	–	–	–	–
“ monoxide	CO	–	—207.	6	—190.	760	6
“ dioxide	CO_2	–	—57.	3	—80.	subl.	–
“ disulphide	CS_2	1.26	—110.	13	46.2	760	–
Chloric acid	$HClO_4+H_2O$	1.81	50.	15	–	–	–
Chlorine dioxide	ClO_2	–	—76.	3	9.9	731	21
Chrome alum	$KCr(SO_4)_2+12H_2O$	1.83	89.	16	–	–	–
“ nitrate	$Cr_2(NO_3)_6+18H_2O$	–	37.	2	170.	760	2
Cobalt sulphate	$CoSO_4$	3.53	97.	16	–	–	–
Cupric chloride	$CuCl_2$	3.05	498.	9	–	–	–
Cuprous “	Cu_2Cl_2	3.7	421.	–	1000.±	760	9
Cupric nitrate	$Cu(NO_3)_2+3H_2O$	2.05	114.5	2	170.	760	2
Hydrobromic acid	HBr	–	—86.7	3	—68.7	“	–
Hydrochloric “	HCl	–	—111.3	17	—83.1	755	17
Hydrofluoric “	HFl	.99	—92.3	6	—36.7	“	17
Hydriodic “	HI	–	—51.3	17	—35.7	760	–
Hydrogen peroxide	H_2O_2	1.5	—2.	18	80.2	47	20
“ phosphide	PH_3	–	—132.5	6	–	–	–
“ sulphide	H_2S	–	—86.	3	—62.	–	–
Iron chloride	$FeCl_3$	2.80	301.	–	–	–	–
“ nitrate	$Fe(NO_3)_3+9H_2O$	1.68	47.2	2	–	–	–
“ sulphate	$FeSO_4+7H_2O$	1.90	64.	16	–	–	–
Lead chloride	$PbCl_2$	5.8	500.	9	900.±	760	–
“ metaphosphate	$Pb(PO_3)_2$	–	800.	9	–	–	–
Magnesium chloride	$MgCl_2$	2.18	708.	9	–	–	–
“ nitrate	$Mg(NO_3)_2+6H_2O$	1.46	90.	2	143.	760	2
“ sulphate	$MgSO_4+5H_2O$	1.68	150.	16	–	–	–
Manganese chloride	$MnCl_2+4H_2O$	2.01	87.5	19	106.	760	19
“ nitrate	$Mn(NO_3)_2+6H_2O$	1.82	26.	2	129.	“	2
“ sulphate	$MnSO_4+5H_2O$	2.09	54.	16	–	–	–
Mercurous chloride	Hg_2Cl_2	7.10	450±	–	–	–	–
Mercuric chloride	$HgCl_2$	5.42	282.	–	305.	–	–

1, Friedel and Crafts; 2, Ordway; 3, Faraday; 4, Marchand; 5, Amat; 6, Olszweski; 7, Gibbs; 8, Baskerville; 9, Carnelly: 10, Carnelly and O'Shea; 11, Ruff; 13, Wroblewski and Olszewski; 14, Anschütz; 15, Roscoe; 16, Tilden; 17, Ladenburg; 18, Staedel; 19, Clarke, "Const. of Nature"; 20, Bruhl; 21, Schacherl; 22, Tamman; 23, Thorpe; 24, Ramsay; 25, Lorenz; 26, Morgan.

Table 238 (*continued*).

DENSITIES AND MELTING- AND BOILING-POINTS.
INORGANIC COMPOUNDS.

Substance.	Chemical Formula.	Density about 20° C.	Melting-point C.	Authority.	Boiling-point C.	Pressure mm.	Authority.
Nickel carbonyl	NiC_4O_4	1.32	—25.	1	43°	760	–
“ nitrate	$Ni(NO_3)_2 + 6H_2O$	2.05	56.7	2	136.7	“	2
“ oxide	NiO	6.69	–	–	–	–	–
“ sulphate	$NiSO_4 + 7H_2O$	1.98	99.	3	–	–	–
Nitric acid	HNO_3	1.52	—42.	4	86.	760	16
“ anhydride	N_2O_5	1.64	30.	5	48.	“	9
“ oxide*	NO	–	—155.	–	—153.	“	6
“ peroxide	N_2O_4	–	—10.1	8	24.	760	–
Nitrous anhydride	N_2O_3	–	—82.	7	0.±	“	–
“ oxide	N_2O	–	—102.4	8	—89.8	“	8
Phosphoric acid (ortho)	H_3PO_4	1.88	40.±	–	–	–	–
Phosphorous acid	H_3PO_3	1.65	72.	–	–	–	–
Phosphorus trichloride	PCl_3	1.61	—111.8	10	76.	760	19
“ oxychloride	$POCl_3$	1.68	+1.3	–	108.	“	–
“ disulphide	P_3S_6	–	297.	12	–	“	–
“ pentasulphide	P_2S_5	–	275.	13	522.	“	–
“ sesquisulphide	P_4S_3	2.10	168.	–	400.	“	–
“ trisulphide	P_2S_3	–	290.±	14	490.	“	25
Potassium carbonate	K_2CO_3	2.29	840.±	–	–	–	–
“ chlorate	$KClO_3$	2.34	372.	15	–	–	–
“ chromate	K_2CrO_4	2.72	975.	17	–	–	–
“ cyanide	KCN	1.52	–	–	–	–	–
“ perchlorate	$KClO_4$	2.52	610.	15	–	–	–
“ chloride	KCl	1.99	801.	–	–	–	–
“ nitrate	KNO_3	2.10	341.	–	–	–	–
“ acid phosphate	KH_2PO_4	2.34	96.	3	–	–	–
“ acid sulphate	$KHSO_4$	2.35	205.	–	–	–	–
Silver chloride	$AgCl$	5.56	451.	15	–	–	–
“ nitrate	$AgNO_3$	4.35	208.7	–	–	–	–
“ perchlorate	$AgClO_4$	–	486.	18	–	–	–
“ phosphate	Ag_3PO_4	6.37	849.	15	–	–	–
“ metaphosphate	$AgPO_3$	–	482.	15	–	–	–
“ sulphate	Ag_2SO_4	5.45	655.±	–	–	–	–
Sodium chloride	$NaCl$	2.17	800.	11	–	–	–
“ hydroxide	$NaOH$	2.1	318.	27	–	–	–
“ nitrate	$NaNO_3$	2.26	315.	–	–	–	–
“ chlorate	$NaClO_3$	2.48	248.	28	–	–	–
“ perchlorate	$NaClO_4$	–	482.	18	–	–	–
“ carbonate	Na_2CO_3	2.48	852.	–	–	–	–
“ “	$Na_2CO_3 + 10H_2O$	1.46	34.	3	–	–	–
“ phosphate	$Na_2HPO_4 + 12H_2O$	1.54	38.	–	–	–	–
“ metaphosphate	$NaPO_3$	2.48	617.	15	–	–	–
“ pyrophosphate	$Na_4P_2O_7$	2.45	970.	30	–	–	–
“ phosphite	$(H_2NaPO_3)_2 + 5H_2O$	–	42.	20	–	–	–
“ sulphate	Na_2SO_4	2.67	884.	11	–	–	–
“ “	$Na_2SO_4 + 10H_2O$	1.46	32.38	17	–	–	–
“ hyposulphite	$Na_2S_2O_3 + 5H_2O$	1.73	48.16	–	–	–	–
Sulphur dioxide	SO_2	–	—76.	–	—10.	760	–
Sulphuric acid	H_2SO_4	1.83	10.4	21	338.	“	22
“ “	$12H_2SO_4 + H_2O$	–	—0.5	22	–	–	–
“ “	$H_2SO_4 + H_2O$	–	8.5	–	–	–	–
“ “ (pyro)	$H_2S_2O_7$	–	35.	22	–	–	–
Sulphur trioxide	SO_3	1.91	15.	–	46.2	760	–
Tin, stannic chloride	$SnCl_4$	2.28	—33.	23	114.	“	19
“ stannous “	$SnCl_2$	–	250.	24	605.	“	–
Zinc chloride	$ZnCl_2$	2.91	365.	29	710.	“	–
“ “	$ZnCl_2 + 3H_2O$	–	6.5	26	–	–	–
“ nitrate	$Zn(NO_3)_2 + 6H_2O$	2.06	36.4	3	131.	760	2
“ sulphate	$ZnSO_4 + 7H_2O$	2.02	50.	3	–	–	–

1, Mond, Langer, Quincke; 2, Ordway; 3, Tilden; 4, Erdmann; 5, R. Weber; 6, Olszewski; 7, Birhaus; 8, Ramsay; 9, Deville; 10, Wroblewski; 11, Day, Sosman, White; 12, Ramme; 13, Meyer; 14, Lemoine; 15, Carnelly; 16, Mitscherlich; 17, LeChatelier; 18, Carnelly, O'Shea; 19, Thorpe; 20, Amat; 21, Mendelejeff; 22, Marignac; 23, Besson; 24, Clarke, "Const. of Nature"; 25, Isambert; 26, Mylius; 27, Hevesy; 28, Retgers; 29, Grünauer; 30, Richards and others.

* Under pressure 138 mm. mercury.

TABLE 239. — Effect of Pressure on Melting-Point.

Substance.	Melting-point at 1 kg/sq. cm.	Highest experimental pressure : kg/sq. cm.	dt/dp at 1 kg/sq. cm.	Δ t. (observed) for 1000 kg/sq. cm.	Reference.
Hg	−38.85	12000	0.00511	5.1*	1
K	59.7	2800	.0136	13.8	2
Na	97.4	2800	.0082	8.2	2
Sn	231.9	2000	.00317	3.17	3
Bi	270.9	2000	−0.00344	−3.44	3
Cd	320.9	2000	0.00609	6.09	3
Pb	327.4	2000	.00777	7.77	3

* Δ t (observed) for 10000 kg/sq. cm. is 50.8°.

References. — 1. P. W. Bridgman, "Proc. Am. Acad." 47, pp. 391–96, 416–19, 1911.
2. G. Tammann, "Kristallisieren und Schmelzen," Leipzig, 1903, pp. 98–99.
3. J. Johnston and L. H. Adams, "Am. J. Sci." 31, p. 516, 1911.

A large number of organic substances, selected on account of their low melting-points, have also been investigated: by Tammann, *loc. cit.*; G. A. Hulett, "Z. Physik. Chem." 28, p. 629, 1899; F. Körber, *ibid.*, 82, p. 45, 1913; E. A. Block, *ibid.*, 82, p. 403, 1913. The results for water are given in the following table.

TABLE 240. — Effect of Pressure on the Freezing-Point of Water (Bridgman*).

Pressure†: kg/sq. cm.	Freezing-point.	Phases in Equilibrium.
1	0.0	Ice I — liquid.
1000	−8.8	"
2000	−20.15	"
2115	−22.0	Ice I — ice III — liquid (triple point).
3000	−18.40	Ice III — liquid.
3530	−17.0	Ice III — ice V — liquid (triple point).
4000	−13.7	Ice V — liquid.
6000	−1.6	"
6380	+0.16	Ice V — ice VI — liquid (triple point).
8000	12.8	Ice VI — liquid.
12000	37.9	"
16000	57.2	"
20000	73.6	"

* P. W. Bridgman, "Proc. Am. Acad." p. 47, 441–558, 1912.
† 1 atm. = 1.033 kg/sq. cm.

TABLE 241. — Melting-point of Mixtures.

Metals.	Melting-points, C°.											Reference.
	Percentage of metal in second column.											
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100 %	
Pb. Sn.	326	295	276	262	240	220	190	185	200	216	232	1
Bi.	322	290	-	-	179	145	126	168	205	-	268	7
Te.	322	710	790	880	917	760	600	480	410	425	446	8
Ag.	328	460	545	590	620	650	705	775	840	905	959	9
Na.	-	360	420	400	370	330	290	250	200	130	96	13
Cu.	326	870	920	925	945	950	955	985	1005	1020	1084	2
Sb.	326	250	275	330	395	440	490	525	560	600	632	16
Al. Sb.	650	750	840	925	945	950	970	1000	1040	1010	632	17
Cu.	650	630	600	560	540	580	610	755	930	1055	1084	18
Au.	655	675	740	800	855	915	970	1025	1055	675	1062	10
Ag.	650	625	615	600	590	580	575	570	650	750	954	17
Zn.	654	640	620	600	580	560	530	510	475	425	419	11
Fe.	653	860	1015	1110	1145	1145	1220	1315	1425	1500	1515	3
Sn.	650	645	635	625	620	605	590	570	560	540	232	17
Sb. Bi.	632	610	590	575	555	540	520	470	405	330	268	16
Ag.	630	595	570	545	520	500	505	545	680	850	959	9
Sn.	622	600	570	525	480	430	395	350	310	255	232	19
Zn.	632	555	510	540	570	565	540	525	510	470	419	17
Ni. Sn.	1455	1380	1290	1200	1235	1290	1305	1230	1060	800	232	17
Na. Bi.	96	425	520	590	645	690	720	730	715	570	268	13
Cd.	96	125	185	245	285	325	330	340	360	390	322	13
Cd. Ag.	322	420	520	610	700	760	805	850	895	940	954	17
Tl.	321	300	285	270	262	258	245	230	210	235	302	14
Zn.	322	280	270	295	313	327	340	355	370	390	419	11
Au. Cu.	1063	910	890	895	905	925	975	1000	1025	1060	1084	4
Ag.	1064	1062	1061	1058	1054	1049	1039	1025	1006	982	963	5
Pt.	1075	1125	1190	1250	1320	1380	1455	1530	1610	1685	1775	20
K. Na.	62	17.5	—10	—3.5	5	11	26	41	58	77	97.5	15
Hg.	–	-	-	–	–	90	110	135	162	265	–	13
Tl.	62.5	133	165	188	205	215	220	240	280	305	301	14
Cu. Ni.	1080	1180	1240	1290	1320	1335	1380	1410	1430	1440	1455	17
Ag.	1082	1035	990	945	910	870	830	788	814	875	960	9
Sn.	1084	1005	890	755	725	680	630	580	530	440	232	12
Zn.	1084	1040	995	930	900	880	820	780	700	580	419	6
Ag. Zn.	959	850	755	705	690	660	630	610	570	505	419	11
Sn.	959	870	750	630	550	495	450	420	375	300	232	9
Na. Hg.	96.5	90	80	70	60	45	22	55	95	215	–	13

1 Means, Landolt-Börnstein-Roth Tabellen.
2 Friedrich-Leroux, Metal. 4, 1907.
3 Gwyer, Zs. Anorg. Ch. 57, 1908.
4 Means, L.-B.-R. Tabellen.
5 Roberts-Austen Chem. News, 87, 2, 1903.
6 Shepherd J. ph. ch. 8, 1904.
7 Kapp, Diss., Königsberg, 1901.
8 Fay and Gilson, Trans. Am. Inst. Min. Eng. Nov. 1901.
9 Heycock and Neville, Phil. Trans. 189A, 1897.
10 " " " " " 194A, 201, 1900.
11 Heycock and Neville, J. Chem. Soc. 71, 1897.
12 " " " Phil. Trans. 202A, 1, 1903.
13 Kurnakow, Z. Anorg. Chem. 23, 439, 1900.
14 " " " " 30, 86, 1902.
15 " " " " 30, 109, 1902.
16 Roland-Gosselin, Bul. Soc. d'Encour. (5) 1, 1896.
17 Gautier, " " " (5) 1, "
18 Le Chatelier, " " " (4) 10, 573, 1895.
19 Reinders, Z. Anorg. Chem. 25, 113, 1896.
20 Erhard and Schertel, Jahrb. Berg-u. Hüttenw. Sachsen. 1879, 17.

TABLE 242. — Alloy of Lead, Tin, and Bismuth.

	Per cent.									
Lead	32.0	25.8	25.0	43.0	33.3	10.7	50.0	35.8	20.0	70.9
Tin	15.5	19.8	15.0	14.0	33.3	23.1	33.0	52.1	60.0	9.1
Bismuth	52.5	54.4	60.0	43.0	33.3	66.2	17.0	12.1	20.0	20.0
Solidification at	96°	101°	125°	128°	145°	148°	161°	181°	182°	234°

Charpy, Soc. d'Encours, Paris, 1901.

TABLE 243. — Low Melting-point Alloy.

	Per cent.						
Cadmium	10.8	10.2	14.8	13.1	6.2	7.1	6.7
Tin	14.2	14.3	7.0	13.8	9.4	–	-
Lead	24.9	25.1	26.0	24.3	34.4	39.7	43.4
Bismuth	50.1	50.4	52.2	48.8	50.0	53.2	49.9
Solidification at	65.5°	67.5°	68.5°	68.5°	76.5°	89.5°	95°

Drewitz, Diss. Rostock, 1902.

All compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.

Table 244.

DENSITIES, MELTING-POINTS, AND BOILING-POINTS OF SOME ORGANIC COMPOUNDS.

N.B. — The data in this table refer only to normal compounds.

Substance.	Formula	Temp. ° C.	Density.	Melting-point	Boiling-point.	Authority.
(a) Paraffin Series: C_nH_{2n+2}.						
Methane*	CH_4	—164.	0.415	—184	—165.	Olszewski, Young.
Ethane†	C_2H_6	0	.446	—171.4	—93.	Ladenburg, "
Propane	C_3H_8	0	.536	—195	—45.	Young, Hainlen.
Butane	C_4H_{10}	0	.60	–	1.	Butlerow, Young.
Pentane	C_5H_{12}	0	.647	–	36.3	Thorpe, Young.
Hexane	C_6H_{14}	17.	.663	–	69.	Schorlemmer.
Heptane	C_7H_{16}	0	.701	–	98.4	Thorpe, Young.
Octane	C_8H_{18}	0	.719	–	125.5	" "
Nonane	C_9H_{20}	0	.733	—51.	150.	Krafft.
Decane	$C_{10}H_{22}$	0	.745	—31.	173.	"
Undecane	$C_{11}H_{24}$	0	.756	—26.	195.	"
Dodecane	$C_{12}H_{26}$	0	.765	—12.	214.	"
Tridecane	$C_{13}H_{28}$	0	.771	—6.	234.	"
Tetradecane	$C_{14}H_{30}$	4.	.775	5.	252.	"
Pentadecane	$C_{15}H_{32}$	10.	.776	10.	270.	"
Hexadecane	$C_{16}H_{34}$	18.	.775	18.	287.	"
Heptadecane	$C_{17}H_{36}$	22.	.777	22.	303.	"
Octadecane	$C_{18}H_{38}$	28.	.777	28.	317.	"
Nonadecane	$C_{19}H_{40}$	32.	.777	32.	330.	"
Eicosane	$C_{20}H_{42}$	37.	.778	37.	121.§	"
Heneicosane	$C_{21}H_{44}$	40.	.778	40.	129.§	"
Docosane	$C_{22}H_{46}$	44.	.778	44.	136.5§	"
Tricosane	$C_{23}H_{48}$	48.	.779	48.	142.5§	"
Tetracosane	$C_{24}H_{50}$	51.	.779	51.	243.‡	"
Heptacosane	$C_{27}H_{56}$	60.	.780	60.	172.§	"
Pentriacontane	$C_{31}H_{64}$	68.	.781	68.	199.§	"
Dicetyl	$C_{32}H_{66}$	70.	.781	70.	205.§	"
Penta-tria-contane	$C_{35}H_{72}$	75.	.782	75.	331.‡	"
(b) Olefines, or the Ethylene Series: C_nH_{2n}.						
Ethylene	C_2H_4	–	0.610	—169.	—103.	Wroblewski or Olszewski.
Propylene	C_3H_6	–	–	–	—50.2	Ladenburg, Krügel.
Butylene	C_4H_8	—13.5	.635	–	1.	Sieben.
Amylene	C_5H_{10}	–	–	–	36.	Wagner or Saytzeff.
Hexylene	C_6H_{12}	0	.76	–	69.	Wreden or Znatowicz.
Heptylene	C_7H_{14}	19.5	.703	–	96.–99.	Morgan or Schorlemmer.
Octylene	C_8H_{16}	17.	.722	–	122.–123.	Möslinger.
Nonylene	C_9H_{18}	20.	.767	–	140.–142.	Beilstein, "Org. Chem."
Decylene	$C_{10}H_{20}$	–	–	–	175.	" " "
Undecylene	$C_{11}H_{22}$	20.	.773	–	196.–197.	" " "
Dodecylene	$C_{12}H_{24}$	—31.	.795	—31.	212.–214.	" " "
Tridecylene	$C_{13}H_{26}$	15.	.774	–	233.	Bernthsen.
Tetradecylene	$C_{14}H_{28}$	—12.	.794	—12.	127.‡	Krafft.
Pentadecylene	$C_{15}H_{30}$	–	.814	–	247.	Bernthsen.
Hexadecylene	$C_{16}H_{32}$	4.	.792	4.	155.‡	Krafft, Mendelejeff, etc.
Octadecylene	$C_{18}H_{36}$	18.	.791	18.	179.‡	Krafft.
Eicosylene	$C_{20}H_{40}$	0	.871	–	390.–400.	Beilstein, "Org. Chem."
Cerotene	$C_{27}H_{54}$	–	–	58.	–	Bernthsen.
Melene	$C_{30}H_{60}$	–	–	62.	–	"

* Liquid at —11.° C. and 180 atmospheres' pressure (Cailletet).
† " " + 4.° " " 46 " " "
‡ Boiling-point under 15 mm. pressure.
§ In vacuo.

DENSITIES, MELTING-POINTS, AND BOILING-POINTS OF SOME ORGANIC COMPOUNDS.

Substance.	Chemical formula.	Temp. C°.	Specific gravity.	Melting-point.	Boiling-point.	Authority.
(c) Acetylene Series : C_nH_{2n-2}.						
Acetylene	C_2H_2	-	-	−81.	−85.	Villard.
Allylene	C_3H_4	-	-	-	-	
Ethylacetylene	C_4H_6	-	-	-	+18.	Bruylants, Kutscheroff, and others.
Propylacetylene	C_5H_8	-	-	-	48.–50.	Bruylants, Taworski.
Butylacetylene	C_6H_{10}	-	-	-	68.–70.	Taworski.
Oenanthylidene	C_7H_{12}	-	-	-	100.–101.	Beilstein, and others.
Caprylidene	C_8H_{14}	0.	0.771	-	133.–134.	Behal.
Undecylidene	$C_{11}H_{20}$	-	-	-	210.–215.	Bruylants.
Dodecylidene	$C_{12}H_{22}$	−9.	.810	−9.	105.*	Krafft.
Tetradecylidene	$C_{14}H_{26}$	+6.5	.806	+6.5	134.*	"
Hexadecylidene	$C_{16}H_{30}$	20.	.804	20.	160.*	"
Octadecylidene	$C_{18}H_{34}$	30.	.802	30.	184.*	"
(d) Monatomic alcohols : $C_nH_{2n+1}OH$.						
Methyl alcohol	CH_3OH	0.	0.812	-	66.	
Ethyl alcohol	C_2H_5OH	0.	.806	−130.†	78.	
Propyl alcohol	C_3H_7OH	0.	.817	-	97.	From Zander, "Lieb. Ann." vol. 224, p. 85, and Krafft, "Ber." vol. 16, 1714, " 19, 2221, " 23, 2360, and also Wroblewski and Olszewski, "Monatshefte," vol. 4, p. 338.
Butyl alcohol	C_4H_9OH	0.	.823	-	117.	
Amyl alcohol	$C_5H_{11}OH$	0.	.829	-	138.	
Hexyl alcohol	$C_6H_{13}OH$	0.	.833	-	157.	
Heptyl alcohol	$C_7H_{15}OH$	0.	.836	-	176.	
Octyl alcohol	$C_8H_{17}OH$	0.	.839	-	195.	
Nonyl alcohol	$C_9H_{19}OH$	0.	.842	−5.	213.	
Decyl alcohol	$C_{10}H_{21}OH$	+7.	.839	+7.	231.	
Dodecyl alcohol	$C_{12}H_{25}OH$	24.	.831	24.	143.*	
Tetradecyl alcohol	$C_{14}H_{29}OH$	38.	.824	38.	167.*	
Hexadecyl alcohol	$C_{16}H_{33}OH$	50.	.818	50.	190.*	
Octadecyl alcohol	$C_{18}H_{37}OH$	59.	.813	59.	211.*	
(e) Alcoholic ethers : $C_nH_{2n+2}O$.						
Dimethyl ether	C_2H_6O	-	-	-	−23.6	Erlenmeyer, Kreichbaumer.
Diethyl ether	$C_4H_{10}O$	4.	0.731	−117	+34.6	Regnault, Olszewski.
Dipropyl ether	$C_6H_{14}O$	0.	.763	-	90.7	Zander and others.
Di-iso-propyl ether	$C_6H_{14}O$	0.	.743	-	69.	"
Di-n-butyl ether	$C_8H_{18}O$	0.	.784	-	141.	Lieben, Rossi, and others.
Di-sec-butyl ether	$C_8H_{18}O$	21.	.756	-	121.	Kessel.
Di-iso-butyl "	$C_8H_{18}O$	15.	.762	-	122.	Reboul.
Di-iso-amyl "	$C_{10}H_{22}O$	0.	.799	-	170.–175.	Wurtz.
Di-sec-hexyl "	$C_{12}H_{26}O$	-	-	-	203.–208.	Erlenmeyer and Wanklyn.
Di-norm-octyl "	$C_{16}H_{34}O$	17.	.805	-	280.–282.	Moslinger.
(f) Ethyl ethers : $C_nH_{2n+2}O$.						
Ethyl-methyl ether	C_3H_8O	0.	0.725	-	11.	Wurtz, Williamson.
" propyl "	$C_5H_{12}O$	20.	0.739	-	63.–64.	Chancel, Brühl.
" iso-propyl ether	$C_5H_{12}O$	0.	.745	-	54.	Markownikow.
" norm-butyl ether	$C_6H_{14}O$	0.	.769	-	92.	Lieben, Rossi.
" iso-butyl ether	$C_6H_{14}O$	-	.751	-	78.–80.	Wurtz.
" iso-amyl ether	$C_7H_{16}O$	18.	.764	-	112.	Williamson and others.
" norm-hexyl ether	$C_8H_{18}O$	-	-	-	134.–137.	Lieben, Janeczek.
" norm-heptyl ether	$C_9H_{20}O$	16.	.790	-	165.	Cross.
" norm-octyl ether	$C_{10}H_{22}O$	17.	.794	-	182.–184.	Moslinger.

* Boiling-point under 15 mm. pressure.

† Liquid at −11.° C. and 180 atmospheres' pressure (Cailletet).

DENSITIES, MELTING-POINTS, AND BOILING-POINTS OF SOME ORGANIC COMPOUNDS.

(g) Miscellaneous.

Substance.	Chemical formula.	Density and temperature.		Melting-point, C.	Boiling-point, C.	Authority.
Acetic Acid . .	CH_3COOH	1.115	0°	16.7	118.5	Young '09
Acetone	CH_3COCH_3	0.812	0°	—94.6	56.1	
Aldehyde . . .	C_2H_4O	0.806	0°	—120.	+20.8	
Aniline	$C_6H_5NH_2$	1.038	0°	—8.	183.9	
Beeswax		0.96±		62.		
Benzoic Acid . .	$C_7H_6O_2$	1.293	4	121.	249.	
Benzol	C_6H_6	0.879	20	5.58	80.2	Young
Benzophenone . .	$(C_6H_5)_2CO$	1.090	50	48.	305.9	Holborn-Henning
Butter		0.86-7		30.±		
Camphor . . .	$C_{10}H_{16}O$	0.99	10	176.	209.	
Carbolic Acid . .	C_6H_5OH	1.060	21	43.	182.	
Carbon bisulphide	CS_2	1.292	0	—110.	46.2	
" tetrachloride	CCl_4	1.582	21	—30.	76.7	Young
Chlorbenzene . .	C_6H_5Cl	1.111	15	—40.	132.	
Chloroform . . .	$CHCl_3$	1.257	0	—65.	61.2	
Cyanogen . . .	C_2N_2			—35.	—21.	
Ethyl bromide . .	C_2H_5Br	1.45	15	—117.	38.4	
,, chloride . .	C_2H_5Cl	0.918	8	—141.6	14.	
,, ether . . .	$C_4H_{10}O$	0.736	0	—118.	34.6	
,, iodide . .	C_2H_5I	1.944	14		72.	
Formic acid . .	$HCOOH$	1.242	0	8.6	100.8	
Gasolene		0.68±			70–90	
Glucose	$CHO(HCOH)_4CH_2OH$	1.56		146.		
Glycerine . . .	$C_3H_8O_3$	1.269	0	20.	290.	
Iodoform . . .	CHI_3	2.25	25	119.		
Lard				38.±		
Methyl chloride .	CH_3Cl	0.992	—24	—103.6	—24.1	
Methyl iodide . .	CH_3I	2.285	15	—64.	42.3	
Napthalene . . .	$C_6H_4 \cdot C_4H_4$	1.152	15	80.	218.0	Holborn-Henning
Nitrobenzol . . .	$C_6H_5O_2N$	1.212	7.5	5.	211.	
Nitroglycerine . .	$C_3H_5N_3O_9$	1.60				
Olive oil		0.92			300.±	
Oxalic acid . . .	$C_2H_2O_4 \cdot 2H_2O$	1.68		190.		
Paraffin wax, soft .				38–52	350–390	
" " hard				52–56	390–430	
Pyrogallol . . .	$C_6H_3(OH)_3$	1.46	40	133.	293.	
Spermaceti . . .				45.±		
Starch	$C_6H_{10}O_5$	1.56				
Sugar, cane . . .	$C_{12}H_{22}O_{11}$	1.588	20		160.	
Stearine	$(C_{18}H_{35}O_2)_3C_3H_5$	0.925	65			
Tartaric acid . .	$C_4H_6O_6$	1.754				
Tallow, beef . .				40–45		
" mutton .				44–45		
Toluene	$C_6H_5CH_3$	0.882	00	—92.	111.	
Xylene (o) . . .	$C_6H_4(CH_3)_2$	0.863	20	—28.	142.	
" (m) . . .	"	0.864	20	54.	140.	
" (p) . . .	"	0.861	20	15.	138.	

TABLE 245.

TRANSFORMATION AND MELTING TEMPERATURES OF LIME-ALUMINA-SILICA COMPOUNDS AND EUTECTIC MIXTURES.

The majority of these determinations are by G. A. Rankin. (Part unpublished.)

Substance.	% CaO	Al_2O_3	SiO_2	Transformation.	Temp.
$CaSiO_3$ . . .	48.2	—	51.8	Melting	1540° ±2°
$CaSiO_3$ . . .	48.2	—	51.8	α to β and reverse	1200 ±2
Ca_2SiO_4 . . .	65.	—	35.	Melting	2130 ±10
“ . . .	65.	—	35.	γ to β and reverse	675 ±5
“ . . .	65.	—	35.	β to α and reverse	1420 ±2
$Ca_3Si_2O_7$ . . .	58.2	—	41.8	Dissociation into Ca_2SiO_4 and liquid	1475 ±5
Ca_3SiO_5 . . .	73.6	—	26.4	Dissociation into Ca_2SiO_4 and CaO	1900 ±5
$Ca_3Al_2O_6$ . . .	62.2	37.8	—	Dissociation into CaO and liquid	1535 ±5
$Ca_5Al_6O_{14}$ . .	47.8	52.2	—	Melting	1455 ±5
$CaAl_2O_4$ . . .	35.4	64.6	—	Melting	1600 ±5
$Ca_3Al_{10}O_{18}$ . .	24.8	75.2	—	Melting	1720 ±10
Al_2SiO_5 . . .	—	62.8	37.1	Melting	1816 ±10
$CaAl_2Si_2O_8$ . .	20.1	36.6	43.3	Melting	1550 ±2
$Ca_2Al_2SiO_7$ . .	40.8	37.2	22.0	Melting	1590 ±2
$Ca_3Al_2SiO_8$ . .	50.9	30.9	18.2	Dissociation into Ca_2SiO_4+ $Ca_2Al_2SiO_7$ and liquid . .	1335 ±5

EUTECTICS.

Crystalline Phases.	% CaO	Al_2O_3	SiO_2	Melting Temp.
$CaSiO_3,SiO_2$	37.	—	63.	1436°
Ca,SiO_3 $3CaO,2SiO_2$	54.5	—	45.5	1455±
Ca,SiO_4 CaO.	67.5	—	32.5	2065±
Al_2SiO_5,SiO_2	—	13.	87.	1610
Al_2SiO_5,Al_2O_3	—	64.	36.	1810
$CaAl_2Si_2O_8$ $CaSiO_3$	34.1	18.6	47.3	1299
$CaAl_2Si_2O_8$ SiO_2	10.5	19.5	70.	1359
$CaAl_2Si_2O_8$ $SiO_2,CaSiO_3$	23.2	14.8	62.	1165
$Ca_2Al_2SiO_7$ Ca_2SiO_4	49.6	23.7	26.7	1545
Al_2O_3 $CaAl_2Si_2O_8$	19.3	39.3	41.4	1547
$CaAl_2Si_2O_8$ Al_2SiO_5,SiO_2	9.8	19.8	70.4	1345
$Ca_2Al_2SiO_7$ $Ca_3Al_{10}O_{18}$	35.	50.8	14.2	1552
$Ca_2Al_2SiO_7$ $CaAl_2O_4$	37.8	52.9	9.3	1512
$Ca_2Al_2SiO_7$ $CaAl_2O_4$ $Ca_3Al_{10}O_{18}$	37.5	53.2	9.3	1505
$CaAl_2Si_2O_8$ $Ca_2Al_2SiO_7$	30.2	36.8	33.	1385
$Ca_2Al_2SiO_7$ $Ca_3Si_2O_7$ $CaSiO_3$	47.2	11.8	41.	1310
$Ca_2Al_2SiO_7$ $CaSiO_3$	45.7	13.2	41.1	1316

EUTECTICS.

Crystalline Phases.	% CaO	Al_2O_3	SiO_2	Melting Temp.
$CaAl_2Si_2O_8$ $Ca_2Al_2SiO_7$ $CaSiO_3$	38.	20.	42.	1265°
$CaAl_2Si_2O_8$ $Ca_2Al_2SiO_7$ Al_2O_3	29.2	39.	31.8	1380
Ca_2SiO_4 $CaAl_2O_4$ $Ca_5Al_6O_{14}$	49.5	43.7	6.8	1335

QUINTUPLE POINTS.

Crystalline Phases.	% CaO	Al_2O_3	SiO_2	Melting Temp.
$Ca_2Al_2SiO_7$ Ca_3SiO_7 Ca_2SiO_4	48.2	11.9	39.9	1335
$Ca_2Al_2SiO_7$ Ca_2SiO_4 $CaAl_2O_4$	48.3	42.	9.7	1380
$CaAl_2Si_2O_8$ Al_2O_3 Al_2SiO_5	15.6	36.5	47.9	1512
$Ca_3Al_{10}O_{18}$ $Ca_2Al_2SiO_7$ Al_2O_3	31.2	44.5	24.3	1475

QUADRUPLE POINTS.

Crystalline Phases.	% CaO	Al_2O_3	SiO_2	Melting Temp.
$3CaO.2SiO_2$ $2CaO.SiO_2$	55.5	—	44.5	1475

The accuracy of the melting-points is 5 to 10 units. Geophysical Laboratory. See also Day and Sosman, Am. J. of Sc. xxxi, p. 341, 1911.

TABLE 246.

LOWERING OF FREEZING-POINTS BY SALTS IN SOLUTION.

In the first column is given the number of gram-molecules (anhydrous) dissolved in 1000 grams of water; the second contains the molecular lowering of the freezing-point; the freezing-point is therefore the product of these two columns. After the chemical formula is given the molecular weight, then a reference number.

g. mol. / 1000 g. H_2O	Molecular Lowering.
$Pb(NO_3)_2$, 331.0: 1, 2.	
0.000362	5.5°
.001204	5.30
.002805	5.17
.005570	4.97
.01737	4.69
.5015	2.99
$Ba(NO_3)_2$, 261.5: 1.	
0.000383	5.6°
.001259	5.28
.002681	5.23
.005422	5.13
.008352	5.04
$Cd(NO_3)_2$, 236.5: 3.	
0.00298	5.4°
.00689	5.25
.01997	5.18
.04873	5.15
$AgNO_3$, 167.0: 4, 5.	
0.1506	3.32°
.5001	2.96
.8645	2.87
1.749	2.27
2.953	1.85
3.856	1.64
0.0560	3.82
.1401	3.58
.3490	3.28
KNO_3, 101.9: 6, 7.	
0.0100	3.5
.0200	3.5
.0500	3.41
.100	3.31
.200	3.19
.250	3.08
.500	2.94
.750	2.81
1.000	2.66
$NaNO_3$, 85.09: 2, 6, 7.	
0.0100	3.6°
.0250	3.46
.0500	3.44
.2000	3.345
.500	3.24
.5015	3.30
1.000	3.15
1.0030	3.03
NH_4NO_3, 80.11: 6, 8.	
0.0100	3.6°
.0250	3.50
0.0500	3.47°
.1000	3.42
.2000	3.32
.500	3.26
1.000	3.14
$LiNO_3$, 69.07: 9.	
0.0398	3.4°
.1671	3.35
.4728	3.35
1.0164	3.49
$Al_2(SO_4)_3$, 342.4: 10.	
0.0131	5.6°
.0261	4.9
.0543	4.5
.1086	4.03
.217	3.83
$CdSO_4$, 208.5: 1, 11.	
0.000704	3.35°
.002685	3.05
.01151	2.69
.03120	2.42
.1473	2.13
.4129	1.80
.7501	1.76
1.253	1.86
K_2SO_4, 174.4: 3, 5, 6, 10, 12.	
0.00200	5.4°
.00398	5.3
.00865	4.9
.0200	4.76
.0500	4.60
.1000	4.32
.200	4.07
.454	3.87
$CuSO_4$, 159.7: 1, 4, 11.	
0.000286	3.3°
.000843	3.15
.002279	3.03
.006670	2.79
.01463	2.59
.1051	2.28
.2074	1.95
.4043	1.84
.8898	1.76
$MgSO_4$, 120.4: 1, 4, 11.	
0.000675	3.29
.002381	3.10
.01263	2.72
.0580	2.65
.2104	2.23
0.4978	2.02°
.8112	2.01
1.5233	2.28
$BaCl_2$, 208.3: 3, 6, 13.	
0.00200	5.5°
.00498	5.2
.0100	5.0
.0200	4.95
.04805	4.80
.100	4.69
.200	4.66
.500	4.82
.586	5.03
.750	5.21
$CdCl_2$, 183.3: 3, 14.	
0.00299	5.0°
.00690	4.8
.0200	4.64
.0541	4.11
.0818	3.93
.214	3.39
.429	3.03
.858	2.71
1.072	2.75
$CuCl_2$, 134.5: 9.	
0.0350	4.9°
.1337	4.81
.3380	4.92
.7149	5.32
$CoCl_2$, 129.9: 9.	
0.0276	5.0°
.1094	4.9
.2369	5.03
.4399	5.30
.538	5.5
$CaCl_2$, 111.0: 5, 13-16.	
0.0100	5.1°
.05028	4.85
.1006	4.79
.5077	5.33
.946	5.3
2.432	8.2
3.469	11.5
3.829	14.4
0.0478	5.2
.153	4.91
.331	5.15
.612	5.47
.998	6.34
$MgCl_2$, 95.26: 6, 14.	
0.0100	5.1°
.0500	4.98
.1500	4.96
.3000	5.186
.6099	5.69
KCl, 74.60: 9, 17-19.	
0.02910	3.54°
.05845	3.46
.112	3.43
.3139	3.41
.476	3.37
1.000	3.286
1.989	3.25
3.269	3.25
$NaCl$, 58.50: 3, 20, 12, 16.	
0.00399	3.7°
.01000	3.67
.0221	3.55
.04949	3.51
.1081	3.48
.2325	3.42
.4293	3.37
.700	3.43
NH_4Cl, 53.52: 6, 15.	
0.0100	3.6°
.0200	3.56
.0350	3.50
.1000	3.43
.2000	3.396
.4000	3.393
.7000	3.41
$LiCl$, 42.48: 9, 15.	
0.00992	3.7°
.0455	3.5
.09952	3.53
.2474	3.50
.5012	3.61
.7939	3.71
$BaBr_2$, 297.3: 14.	
0.100	5.1°
.150	4.9
.200	5.00
.500	5.18
$AlBr_3$, 267.0: 9.	
0.0078	1.4°
.0559	1.2
.1971	1.07
.4355	1.07

1 Hausrath, Ann. Phys. 9, 1902.
2 Leblanc-Noyes, Z. Phys. Ch. 6, 1890.
3 Jones, Z. Phys. Ch. 11, 1893.
4 Raoult, Z. Phys. Ch. 2, 1888.
5 Arrhenius, Z. Phys. Ch. 2, 1888.
6 Loomis, Wied. Ann. 57, 1896.
7 Jones, Am. Chem. J. 27, 1902.
8 Jones-Caldwell, Am. Chem. J. 25, 1901.
9 Biltz, Z. Phys. Ch. 40, 1902.
10 Jones-Mackay, Am. Chem. J. 19, 1897.
11 Kahlenberg, J. Phys. Ch. 5, 1901.
12 Abegg, Z. Phys. Ch. 20, 1896.
13 Jones-Getman, Am. Ch. J. 27, 1902.
14 Jones-Chambers, Am. Ch. J. 23, 1900.
15 Loomis, Wied. Ann. 60, 1897.
16 Roozeboom, Z. Phys. Ch. 4, 1889.
17 Raoult, Z. Phys. Ch. 27, 1898.
18 Roloff, Z. Phys. Ch. 18, 1895.
19 Kistiakowsky, Z. Phys. Ch. 6, 1890.
20 Loomis, Wied. Ann. 51, 1894.

Compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.

LOWERING OF FREEZING-POINTS BY SALTS IN SOLUTION (*continued*).

$\frac{\text{g. mol.}}{\text{1000 g. } H_2O}$	Molecular Lowering.
$CdBr_2$, 272.3: 3, 14.	
0.00324	5.1°
.00718	4.6
.03627	3.84
.0719	3.39
.1122	3.18
.220	2.96
.440	2.76
.800	2.59
$CuBr_2$, 223.5: 9.	
0.0242	5.1°
.0817	5.1
.2255	5.27
.6003	5.89
$CaBr_2$, 200.0: 14.	
0.0871	5.1°
.1742	5.18
.3484	5.30
.5226	5.64
$MgBr_2$, 184.28: 14.	
0.0517	5.4°
.103	5.16
.207	5.26
.517	5.85
KBr, 119.1: 9, 21.	
0.0305	3.61°
.1850	3.49
.6801	3.30
.250	3.78
.500	3.56
CdI_2, 366.1: 3, 5, 22.	
0.00210	4.5°
.00626	4.0
.02062	3.52
.04857	2.70
.1360	2.35
.333	2.13
.684	2.23
.888	2.51
KI, 166.0: 9, 2.	
0.0651	3.5°
.2782	3.50
.6030	3.42
1.003	3.37
SrI_2, 341.3: 22.	
0.054	5.1°
.108	5.2
.216	5.35
.327	5.52
NaOH, 40.06: 15.	
0.02002	3.45°
.05005	3.45
.1001	3.41
.2000	3.407
KOH, 56.16: 1, 15, 23.	
0.00352	3.60°
.00770	3.59
.02002	3.44
.05006	3.43
.1001	3.42
.2003	3.424
230	3.50
.465	3.57
CH_3OH, 32.03: 24, 25.	
0.0100	1.8°
.0301	1.82
.2018	1.811
1.046	1.86
3.41	1.88
6.200	1.944
C_2H_5OH, 46.04: 1, 12, 17, 24–27	
0.000402	1.67°
.004993	1.67
.0100	1.81
.02892	1.707
.0705	1.85
.1292	1.829
.2024	1.832
.5252	1.834
1.0891	1.826
1.760	1.83
3.901	1.92
7.91	2.02
11.11	2.12
18.76	1.81
0.0173	1.80
.0778	1.79
K_2CO_3, 138.30: 6	
0.0100	5.1°
.0200	4.93
.0500	4.71
.100	4.54
.200	4.39
Na_2CO_3, 106.10: 6.	
0.0100	5.1°
.0200	4.93
.0500	4.64
.1000	4.42
.2000	4.17
Na_2SO_3, 126.2: 28	
0.1044	4.51°
.3397	3.74
.7080	3.38
Na_2HPO_4, 142.1: 22, 29	
0.01001	5.0°
.02003	4.84
.05008	4.60
.1002	4.34
Na_2SiO_3, 122.5: 15.	
0.01052	6.4°
.05239	5.86
.1048	5.28
.2099	4.66
.5233	3.99
HCl, 36.46: 1–3, 6, 13, 18, 22.	
0.00305	3.68°
.00695	3.66
.0100	3.6
.01703	3.59
.0500	3.59
.1025	3.56
.2000	3.57
.3000	3.612
.464	3.68
.516	3.79
1.003	3.95
1.032	4.10
1.500	4.42
2.000	4.97
2.115	4.52
3.000	6.03
3.053	4.90
4.065	5.67
4.657	6.19
HNO_3, 63.05: 3, 13, 15	
0.02004	3.55°
.05015	3.50
.0510	3.71
.1004	3.48
.1059	3.53
.2015	3.45
.250	3.50
.500	3.62
1.000	3.80
2.000	4.17
3.000	4.64
H_3PO_2, 66.0: 29.	
0.1260	2.90°
.2542	2.75
.5171	2.59
1.071	2.45
HPO, 82 0: 4, 5.	
0.0745	3.0°
.1241	2.8
.2482	2.6
1.00	2.39
H_3PO_4, 98.0: 6, 22.	
0.0100	2.8°
.0200	2.68
.0500	2.49
.1000	2.36
.2000	2.25
0.472	2.20°
.944	2.27
1.620	2.60
$(COOH)_2$, 90.02: 4, 15.	
0.01002	3.3°
.02005	3.19
.05019	3.03
.1006	2.83
.2022	2.64
.366	2.56
.648	2.3
$C_3H_5(OH)_3$, 92.06: 24, 25.	
0.0200	1.86°
.1008	1.86
.2031	1.85
.535	1.91
2.40	1.98
5.24	2.13
$(C_2H_5)_2O$, 74.08: 24	
0.0100	1.6°
.0201	1.67
.1011	1.72
.2038	1.702
Dextrose, 180.1: 24, 30.	
0.0198	1.84°
.0470	1.85
.1326	1.87
.4076	1.894
1.102	1.921
Levulose, 180.1: 24, 25	
0.0201	1.87°
.2050	1.871
.554	2.01
1.384	2.32
2.77	3.04
CHO, 342.2: 1, 24, 26.	
0.000332	1.90°
.001410	1.87
.009978	1.86
.0201	1.88
.1305	1.88
H_2SO_4, 98.08: 13, 20, 31–33.	
0.00461	4.8°
.0100	4.49
.0200	4.32
.0461	4.10
.100	3.96
.200	3.85
.400	3.98
1.000	4.19
1.500	4.96
2.000	5.65
2.500	6.53

1–20 *See* page 217.
21 Sherrill, Z. Phys. Ch. 43, 1903.
22 Chambers-Frazer, Am. Ch. J. 23, 1900.
23 Noyes-Whitney, Z. Phys. Ch. 15, 1894.
24 Loomis, Z. Phys. Ch. 32, 1900.
25 Abegg, Z. Phys. Ch. 15, 1894.
26 Nernst-Abegg, Z. Phys. Ch. 15, 1894.
27 Pictet-Altschul, Z. Phys. Ch. 16, 1895.
28 Barth, Z. Phys. Ch. 9, 1892.
29 Petersen, Z. Phys. Ch. 11, 1893.
30 Roth, Z. Phys. Ch. 43, 1903.
31 Wildermann, Z. Phys. Ch. 15, 1894.
32 Jones-Carroll, Am. Ch. J. 28, 1902.
33 Jones-Murray, Am. Ch. J. 30, 1903.

TABLE 247.

RISE OF BOILING-POINT PRODUCED BY SALTS DISSOLVED IN WATER.*

This table gives the number of grams of the salt which, when dissolved in 100 grams of water, will raise the boiling-point by the amount stated in the headings of the different columns. The pressure is supposed to be 76 centimeters.

Salt.	1° C.	2°	3°	4°	5°	7°	10°	15°	20°	25°
$BaCl_2 + 2H_2O$	15.0	31.1	47.3	63.5	(71.6 gives 4°.5 rise of temp.)					
$CaCl_2$	6.0	11.5	16.5	21.0	25.0	32.0	41.5	55.5	69.0	84.5
$Ca(NO_3)_2 + 2H_2O$	12.0	25.5	39.5	53.5	68.5	101.0	152.5	240.0	331.5	443.5
KOH	4.7	9.3	13.6	17.4	20.5	26.4	34.5	47.0	57.5	67.3
$KC_2H_3O_2$	6.0	12.0	18.0	24.5	31.0	44.0	63.5	98.0	134.0	171.5
KCl	9.2	16.7	23.4	29.9	36.2	48.4	(57.4 gives a rise of 8°.5)			
K_2CO_3	11.5	22.5	32.0	40.0	47.5	60.5	78.5	103.5	127.5	152.5
$KClO_3$	13.2	27.8	44.6	62.2						
KI	15.0	30.0	45.0	60.0	74.0	99.5	134.	185.0	(220 gives 18°.5)	
KNO_3	15.2	31.0	47.5	64.5	82.0	120.5	188.5	338.5		
$K_2C_4H_4O_6 + \frac{1}{2}H_2O$	18.0	36.0	54.0	72.0	90.0	126.5	182.0	284.0		
$KNaC_4H_4O_6$	17.3	34.5	51.3	68.1	84.8	119.0	171.0	272.5	390.0	510.0
$KNaC_4H_4O_6 + 4H_2O$	25.0	53.5	84.0	118.0	157.0	266.0	554.0	5510.0		
$LiCl$	3.5	7.0	10.0	12.5	15.0	20.0	26.0	35.0	42.5	50.0
$LiCl + 2H_2O$	6.5	13.0	19.5	26.0	32.0	44.0	62.0	92.0	123.0	160.5
$MgCl_2 + 6H_2O$	11.0	22.0	33.0	44.0	55.0	77.0	110.0	170.0	241.0	334.5
$MgSO_4 + 7H_2O$	41.5	87.5	138.0	196.0	262.0					
$NaOH$	4.3	8.0	11.3	14.3	17.0	22.4	30.0	41.0	51.0	60.1
$NaCl$	6.6	12.4	17.2	21.5	25.5	33.5	(40.7 gives 8°.8 rise)			
$NaNO_3$	9.0	18.5	28.0	38.0	48.0	68.0	99.5	156.0	222.0	
$NaC_2H_3O_2 + 3H_2O$	14.9	30.0	46.1	62.5	79.7	118.1	194.0	480.0	6250.0	
$Na_2S_2O_3$	14.0	27.0	39.0	49.5	59.0	77.0	104.0	152.0	214.5	311.0
Na_2HPO_4	17.2	34.4	51.4	68.4	85.3					
$Na_2C_4H_4O_6 + 2H_2O$	21.4	44.4	68.2	93.9	121.3	183.0	(237.3 gives 8°.4 rise)			
$Na_2S_2O_3 + 5H_2O$	23.8	50.0	78.6	108.1	139.3	216.0	400.0	1765.0		
$Na_2CO_3 + 10H_2O$	34.1	86.7	177.6	369.4	1052.9					
$Na_2B_4O_7 + 10H_2O$	39.	93.2	254.2	898.5	(5555.5 gives 4°.5 rise)					
NH_4Cl	6.5	12.8	19.0	24.7	29.7	39.6	56.2	88.5		
NH_4NO_3	10.0	20.0	30.0	41.0	52.0	74.0	108.0	172.0	248.0	337.0
NH_4SO_4	15.4	30.1	44.2	58.0	71.8	99.1	(115.3 gives 108.2)			
$SrCl_2 + 6H_2O$	20.0	40.0	60.0	81.0	103.0	150.0	234.0	524.0		
$Sr(NO_3)_2$	24.0	45.0	63.6	81.4	97.6					
$C_4H_6O_6$	17.0	34.4	52.0	70.0	87.0	123.0	177.0	272.0	374.0	484.0
$C_2H_2O_4 + 2H_2O$	19.0	40.0	62.0	86.0	112.0	169.0	262.0	540.0	1316.0	50000.0
$C_6H_8O_7 + H_2O$	29.0	58.0	87.0	116.0	145.0	208.0	320.0	553.0	952.0	

Salt.	40°	60°	80°	100°	120°	140°	160°	180°	200°	240°
$CaCl_2$	137.5	222.0	314.0							
KOH	92.5	121.7	152.6	185.0	219.8	263.1	312.5	375.0	444.4	623.0
$NaOH$	93.5	150.8	230.0	345.0	526.3	800.0	1333.0	2353.0	6452.0	–
NH_4NO_3	682.0	1370.0	2400.0	4099.0	8547.0	∞				
$C_4H_6O_6$	980.0	3774.0	(infinity gives 170)							

---

* Compiled from a paper by Gerlach, "Zeit. f. Anal. Chem." vol. 26.

TABLE 248.

FREEZING MIXTURES.*

Column 1 gives the name of the principal refrigerating substance, *A* the proportion of that substance, *B* the proportion of a second substance named in the column, *C* the proportion of a third substance, *D* the temperature of the substances before mixture, *E* the temperature of the mixture, *F* the lowering of temperature, *G* the temperature when all snow is melted, when snow is used, and *H* the amount of heat absorbed in heat units (small calories when *A* is grams). Temperatures are in Centigrade degrees.

Substance.	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
$NaC_2H_3O_2$ (cryst.)	85	H_2O-100	-	10.7	— 4.7	15.4	-	-
NH_4Cl . . .	30	“ “	-	13.3	— 5.1	18.4	-	-
$NaNO_3$ . . .	75	“ “	-	13.2	— 5.3	18.5	-	-
$Na_2S_2O_3$ (cryst.) .	110	“ “	-	10.7	— 8.0	18.7	-	-
KI	140	“ “	-	10.8	— 11.7	22.5	-	-
$CaCl_2$ (cryst.) .	250	“ “	-	10.8	— 12.4	23.2	-	-
NH_4NO_3 . .	60	“ “	-	13.6	— 13.6	27.2	-	-
$(NH_4)_2SO_4$ . .	25	“ 50	NH_4NO_3-25	-	-	26.0	-	-
NH_4Cl . . .	25	“ “	“ “	-	-	22.0	-	-
$CaCl_2$ . . .	25	“ “	“ “	-	-	20.0	-	-
KNO_3 . . .	25	“ “	NH_4Cl-25	-	-	20.0	-	-
Na_2SO_4 . .	25	“ “	“ “	-	-	19.0	-	-
$NaNO_3$ . . .	25	“ “	“ “	-	-	17.0	-	-
K_2SO_4 . . .	10	Snow 100	-	— 1	— 1.9	0.9	-	
Na_2CO_3 (cryst.) .	20	“ “	-	— 1	— 2.0	1.0	-	-
KNO_3 . . .	13	“ “	-	— 1	— 2.85	1.85	-	-
$CaCl_2$ . . .	30	“ “	-	— 1	— 10.9	9.9	-	-
NH_4Cl . . .	25	“ “	-	— 1	— 15.4	14.4	-	-
NH_4NO_3	45	“ “	-	— 1	— 16.75	15.75	-	-
$NaNO_3$ . . .	50	“ “	-	— 1	— 17.75	16.75	-	-
NaCl . . .	33	“ “	-	— 1	— 21.3	20.3	-	-
$H_2SO_4 + H_2O$ (66.1 % H_2SO_4)	1	“ 1.097	-	— 1	— 37.0	36.0	— 37.0	0.0
	1	“ 1.26	-	— 1	— 36.0	35.0	— 30.2	17.0
	1	“ 1.38	-	— 1	— 35.0	34.0	— 25.0	27.0
	1	“ 2.52	-	— 1	— 30.0	29.0	— 12.4	133.0
	1	“ 4.32	-	— 1	— 25.0	24.0	— 7.0	273.0
	1	“ 7.92	-	— 1	— 20.0	19.0	— 3.1	553.0
	1	“ 13.08	-	— 1	— 16.0	15.0	— 2.1	967.0
$CaCl_2 + 6H_2O$	1	“ 0.35	-	0	-	-	0.0	52.1
	1	“ .49	-	0	-	-	— 19.7	49.5
	1	“ .61	-	0	-	-	— 39.0	40.3
	1	“ .70	-	0	-	-	— 54.9†	30.0
	1	“ .81	-	0	-	-	— 40.3	46.8
	1	“ 1.23	-	0	-	-	— 21.5	88.5
	1	“ 2.46	-	0	-	-	— 9.0	192.3
	1	“ 4.92	-	0	-	-	— 4.0	392.3
Alcohol at 4°	77	“ 73	-	0	— 30.0	-	-	-
	-	CO_2 solid	-	-	— 72.0	-	-	-
Chloroform . .	-	“ “	-	-	— 77.0	-	-	-
Ether . . .	-	“ “	-	-	— 77.0	-	-	-
Liquid SO_2 . .	-	“ “	-	-	— 82.0	-	-	-
NH_4NO_3 .	1	H_2O-.75	-	20	5.0	-	-	33.0
	1	“ .94	-	20	— 4.0	-	-	21.0
	1	“ “	-	10	— 4.0	-	-	34.0
	1	“ “	-	5	— 4.0	-	-	40.5
	1	Snow “	-	0	— 4.0	-	-	122.2
	1	H_2O-1.20	-	10	— 14.0	-	-	17.9
	1	Snow “	-	0	— 14.0	-	-	129.5
	1	H_2O-1.31	-	10	— 17.5†	-	-	10.6
	1	Snow “	-	0	— 17.5†	-	-	131.9
	1	H_2O-3.61	-	10	— 8.0	-	-	0.4
	1	Snow “	-	0	— 8.0	-	-	327.0

---

* Compiled from the results of Cailletet and Colardeau, Hammerl, Hanamann, Moritz, Pfanndler, Rudorf, and Tollinger.

† Lowest temperature obtained.

TABLE 249.

CRITICAL TEMPERATURES, PRESSURES, VOLUMES, AND DENSITIES OF GASES.*

θ = Critical temperature.
P = Critical pressure in atmospheres.
ϕ = Critical volume referred to volume at 0° and 76 centimeters pressure.
d = Critical density in grams per cubic centimeter.
a, b, Van der Waals constants in $\left(p+\frac{a^2}{v^2}\right)\left(v-b\right)=1+\alpha t$.

Substance.	θ	P	ϕ	d	a × 10⁵	b × 10⁶	Observer
Air	—140.0	39.0	-	-	257	1560	1
Alcohol (C_2H_6O)	243.6	62.76	0.00713	0.288	2407	3769	2
" (CH_4O)	239.95	78.5	-	-	1898	2992	3
Ammonia	130.0	15.0	-	-	798	1606	4
Argon	—117.4	52.9	-	-	259	1348	5
Benzol	288.5	47.9	-	0.305	3726	5370	3
Bromine	302.2	-	0.00605	1.18	1434	2020	6
Carbon dioxide	31.2	73.	0.0044	0.46	717	1908	-
" monoxide	—141.1	35.9	-	-	275	1683	7
" disulphide	277.7	78.1	-	-	2197	3227	8
Chloroform	260.0	54.9	-	-	2930	4450	9
Chlorine	141.0	83.9	-	-	1157	2259	4
"	146.0	93.5	-	-	1063	2050	10
Ether	197.0	35.77	0.01584	0.208	3496	6016	11
"	194.4	35.61	0.01344	0.262	3464	6002	3
Ethane	32.1	49.0	-	-	1074	2848	12
Ethylene	9.9	51.1	-	-	886	2533	-
Helium	<—268.0	-	-	-	5	700	13
Hydrogen	—240.8	14.	-	-	42	880	14
" chloride	51.25	86.0	-	-	692	1726	15
" "	52.3	86.0	-	0.61	697	1731	4
" sulphide	100.0	88.7	-	-	888	1926	1
Krypton	—62.5	54.3	-	-	462	1776	5
Methane	—81.8	54.9	-	-	376	1557	1
"	—95.5	50.0	-	-	357	1625	4
Neon	<—205.0	29.	-	-	-	-	5,13
Nitric oxide (NO)	—93.5	71.2	-	-	257	1160	1
Nitrogen	—146.0	35.0	-	0.44	259	1650	1
" monoxide (N_2O)	35.4	75.0	0.0048	0.41	720	1888	4,17
Oxygen	—118.0	50.0	-	0.6044	273	1420	1
Sulphur dioxide	155.4	78.9	0.00587	0.49	1316	2486	9,17
Water	358.1	-	0.001874	0.429	-	-	6
"	374.	217.5	-	-	1089	1362	16

(1) Olszewski, C. R. 98, 1884; 99, 1884; 100, 1885; Beibl. 14, 1890; Z. Phys. Ch. 16, 1893.
(2) Ramsay-Young, Tr. Roy. Soc. 177, 1886.
(3) Young, Phil. Mag. 1900.
(4) Dewar, Phil. Mag. 18, 1884; Ch. News, 84, 1901.
(5) Ramsay, Travers, Phil. Trans. 16, 17, 1901.
(6) Nadejdine, Beibl. 9, 1885.
(7) Wroblewski, Wied. Ann. 20, 1883; Stz. Wien. Ak. 91, 1885.
(8) Hannay, Pr. Roy. Soc. 32, 1882.
(9) Sajotschewsky, Beibl. 3, 1879.
(10) Knietsch, Lieb. Ann. 259, 1890.
(11) Batelli, Mem. Torino (2), 41, 1890.
(12) Cardozo, Arch. sc. phys. 30, 1910.
(13) Kamerlingh-onnes, Comno. Phys. tab. Leiden, 1908, 1909, Proc. Amst. 11, 1908, C. R. 147, 1908.
(14) Olszewski, Ann. Phys. 17, 1905.
(15) Ansdell, Chem. News, 41, 1880.
(16) Holborn, Baumann Ann. Phys. 31, 1910.
(17) Cailletet, C. R. 102, 1886; 104, 1887.

*Abridged for the most part from Landolt and Börnstein's "Phys. Chem. Tab."

TABLE 250.

LINEAR EXPANSION OF THE ELEMENTS.

In the heading of the columns t is the temperature or range of temperature; C is the coefficient of linear expansion; A_1 is the authority for C; M is the mean coefficient of expansion between 0° and 100° C.; α and β are the coefficients in the equation $l_t = l_0(1 + \alpha t + \beta t^2)$, where l_0 is the length at 0° C. and l_t the length at t° C.; A_2 is the authority for α, β, and M.

Substance.	t	$C \times 10^4$	A_1	$M \times 10^4$	$\alpha \times 10^4$	$\beta \times 10^6$	A_2
Aluminum	40	0.2313	1	0.2220	-	-	2
"	600	.3150	3				
"	—191 to +16	.1835	4	-	.23536	.00707	5
Antimony:							
Parallel to cryst. axis	40	.1692	1				
Perp. to axis	40	.0882	1				
Mean	40	.1152	1	.1056	.0923	.0132	6
Arsenic	40	.0559	1				
Bismuth:							
Parallel to axis	40	.1621	1				
Perp. to axis	40	.1208	1				
Mean	40	.1346	1	.1316	.1167	.0149	6
Cadmium	40	.3069	1	.3159	.2693	.0466	6
Carbon:							
Diamond	40	.0118	1				
Gas carbon	40	.0540	1				
Graphite	40	.0786	1		.0055	.0016	13
Anthracite	40	.2078	1				
Cobalt	40	.1236	1				
Copper	40	.1678	1	.1666	.1481	.0185	6
"	—191 to +16	.1409	4	-	.16070	.00403	5
Gold	40	.1443	1	.1470	.1358	.0112	6
Indium	40	.4170	1				
Iron:							
Soft	40	.1210	1				
Cast	40	.1061	1				
"	—191 to +16	.0850	4				
Wrought	—18 to 100	.1140	7	-	.11705	.005254	8
Steel	40	.1322	1	-	.09173	.008336	8
" annealed	40	.1095	1	.1089	.1038	.0052	9
Lead	40	.2924	1	.2709	.273	.0074	6
Magnesium	40	.2694	1				
Nickel	40	.1279	1	-	.13460	.003315	8
"	—191 to +16	.1012	4				
Osmium	40	.0657	1				
Palladium	40	.1176	1	-	.11670	.002187	8
Phosphorus	0–40	1.2530	10				
Platinum	40	0.0899	1	-	.08868	.001324	8
Potassium	0–50	.8300	11				
Rhodium	40	.0850	1				
Ruthenium	40	.0963	1				
Selenium	40	.3680	1	.6604	-	-	12
Silicon	40	.0763	1				
Silver	40	.1921	1	-	.18270	.004793	8
"	—191 to +16	.1704	4				
Sulphur:							
Cryst. mean	40	.6413	1	1.180	-	-	12
Tellurium	40	.1675	1	.3687	-	-	12
Thallium	40	.3021	1				
Tin	40	.2234	1	.2296	.2033	.0263	6
Zinc	40	.2918	1	.2976	.2741	.0234	6

1 Fizeau.
2 Calvert, Johnson and Lowe.
3 Chatelier.
4 Henning.
5 Dittenberger.
6 Matthiessen.
7 Andrews.
8 Holborn-Day.
9 Benoit.
10 Pisati and De Franchis.
11 Hagen.
12 Spring.
13 Day and Sosman.

The above table has been partly compiled from the results published by Fizeau, "Comptes Rendus," vol. 68, and Matthiessen, "Proc. Roy. Soc.," vol. 15.
The Holborn-Day and Day and Sosman data are for temperatures from 20° to 1000° C. The Dittenberger, 0° to 600° C.

LINEAR EXPANSION OF MISCELLANEOUS SUBSTANCES.

The coefficient of cubical expansion may be taken as three times the linear coefficient. t is the temperature or range of temperature, C the coefficient of expansion, and A the authority.

Substance.	t	$C \times 10^4$	A.
Brass:			
Cast	0–100	0.1875	1
Wire	"	0.1930	1
—	"	.1783–.193	2
$71.5Cu+27.7Zn+0.3Sn+0.5Pb$	40	0.1859	3
$71Cu+29Zn$	0–100	0.1906	4
Bronze:			
$3Cu+1Sn$	16.6–100	0.1844	5
" "	16.6–350	0.2116	5
" "	16.6–957	0.1737	5
$86.3Cu+9.7Sn+4Zn$	40	0.1782	3
$97.6Cu+2.2Sn+0.2P$ hard	0–80	0.1713	6
soft	"	0.1708	6
Caoutchouc	–	.657–.686	2
"	16.7–25.3	0.770	7
Constantine	4–29	0.1523	–
Ebonite	25.3–35.4	0.842	7
Fluor spar: CaF_2	0–100	0.1950	8
German silver	"	0.1836	8
Gold-platinum: $2Au+1Pt$	"	0.1523	4
Gold-copper: $2Au+1Cu$	"	0.1552	4
Glass:			
Tube	"	0.0833	1
"	"	0.0828	9
Plate	"	0.0891	10
Crown (mean)	"	0.0897	10
"	50–60	0.0954	11
Flint	"	0.0788	11
Jena thermometer 16^{III} normal	0–100	0.081	12
" 59^{III}	"	0.058	12
" "	−191 to +16	0.424	13
Gutta percha	20	1.983	14
Ice	−20 to −1	0.51	15
Iceland spar:			
Parallel to axis	0–80	0.2631	6
Perpendicular to axis	"	0.0544	6
Lead-tin (solder) $2Pb+1Sn$	0–100	0.2508	1
Magnalium	12–39	0.238	16
Marble	15–100	0.117	17
Paraffin	0–16	1.0662	18
"	16–38	1.3030	18
"	38–49	4.7707	18
Platinum-iridium $10Pt+1Ir$	40	0.0884	3

Substance.	t	$C \times 10^4$	A.
Platinum-silver: $1Pt+2Ag$	0–100	0.1523	4
Porcelain	20–790	0.0413	19
" Bayeux	1000–1400	0.0553	20
Quartz:			
Parallel to axis	0–80	0.0797	6
" " "	−190 to +16	.0521	21
Perpend. " "	0–80	0.1337	6
Quartz glass	−190 to +16	−.0026	13
Rock salt	40	0.4040	3
Speculum metal	0–100	0.1933	1
Topaz:			
Parallel to lesser horizontal axis	"	0.0832	8
Parallel to greater horizontal axis	"	0.0836	8
Parallel to vertical axis	"	0.0472	8
Tourmaline:			
Parallel to longitudinal axis	"	0.0937	8
Parallel to horizontal axis	"	0.0773	8
Type metal	16.6–254	0.1952	5
Vulcanite	0–18	0.6360	22
Wedgwood ware	0–100	0.0890	5
Wood:			
Parallel to fibre:			
Ash	"	0.0951	23
Beech	2–34	0.0257	24
Chestnut	"	0.0649	24
Elm	"	0.0565	24
Mahogany	"	0.0361	24
Maple	"	0.0638	24
Oak	"	0.0492	24
Pine	"	0.0541	24
Walnut	"	0.0658	24
Across the fibre:			
Beech	"	0.614	24
Chestnut	"	0.325	24
Elm	"	0.443	24
Mahogany	"	0.404	24
Maple	"	0.484	24
Oak	"	0.544	24
Pine	"	0.341	24
Walnut	"	0.484	24
Wax: White	10–26	2.300	25
"	26–31	3.120	25
"	31–43	4.860	25
"	43–57	15.227	25

1 Smeaton.
2 Various.
3 Fizeau.
4 Matthiessen.
5 Daniell.
6 Benoit.
7 Kohlrausch.
8 Pfaff.
9 Deluc.
10 Lavoisier and Laplace.
11 Pulfrich.
12 Schott.
13 Henning.
14 Russner.
15 Mean.
16 Stadthagen.
17 Fröhlich.
18 Rodwell.
19 Braun.
20 Deville and Troost.
21 Scheel.
22 Mayer.
23 Glatzel.
24 Villari.
25 Kopp.

TABLE 252.

CUBICAL EXPANSION OF SOLIDS.

If v_2 and v_1 are the volumes at t_2 and t_1 respectively, then $v_2 = v_1 (1 + C\Delta t)$, C being the coefficient of cubical expansion and Δt the temperature interval. Where only a single temperature is stated C represents the true coefficient of cubical expansion at that temperature.*

Substance.	t or Δt	$C \times 10^4$	Authority.
Antimony	0–100	0.3167	Matthiessen
Beryl	0–100	0.0105	Pfaff
Bismuth	0–100	0.3948	Matthiessen
Copper	0–100	0.4998	"
Diamond	40	0.0354	Fizeau
Emerald	40	0.0168	"
Galena	0–100	0.558	Pfaff
Glass, common tube	0–100	0.276	Regnault
" hard	0–100	0.214	"
" Jena, borosilicate 59 III	20–100	0.156	Scheel
" pure silica	0–80	0.0129	Chappuis
Gold	0–100	0.4411	Matthiessen
Ice	—20-—1	1.1250	Brunner
Iron	0–100	0.3550	Dulong and Petit
Lead	0–100	0.8399	Matthiessen
Paraffin	20	5.88	Russner
Platinum	0–100	0.265	Dulong and Petit
Porcelain, Berlin	20	0.0814	Chappuis and Harker
Potassium chloride	0–100	1.094	Playfair and Joule
" nitrate	0–100	1.967	" " "
" sulphate	20	1.0754	Tutton
Quartz	0–100	0.3840	Pfaff
Rock salt	50–60	1.2120	Pulfrich
Rubber	20	4.87	Russner
Silver	0–100	0.5831	Matthiessen
Sodium	20	2.1364	E. Hazen
Stearic acid	33.8–45.5	8.1	Kopp
Sulphur, native	13.2–50.3	2.23	"
Tin	0–100	0.6889	Matthiessen
Zinc	0–100	0.8928	"

---

* For tables of cubical expansion complete to 1876, see Clark's Constants of Nature, Smithsonian Collections, 289.

TABLE 253.

CUBICAL EXPANSION OF LIQUIDS.

If V_0 is the volume at 0° then at t° the expansion formula is $V_t = V_0(1 + \alpha t + \beta t^2 + \gamma t^3)$. The table gives values of α, β and γ and of C, the true coefficient of cubical expansion, at 20° for some liquids and solutions. Δt is the temperature range of the observation and A the authority.

Liquid.	Δt	$\alpha\ 10^3$	$\beta\ 10^6$	$\gamma\ 10^8$	$C\ 10^3$ at 20°	A
Acetic acid	16–107	1.0630	0.12636	1.0876	1.071	3
Acetone	0–54	1.3240	3.8090	—0.87983	1.487	3
Alcohol:						
Amyl	—15–80	8.9001	0.6573	1.18458	0.902	4a
Ethyl, 30% by vol. . .	18–39	0.2928	10.790	—11.87	–	6
" 50% " . .	0–39	0.7450	1.85	0.730	–	6
" 99.3% " . .	27–46	1.012	2.20	–	1.12	6
" 500 atmo. press. .	0–40	0.866	–	–	–	1
" 3000 " " .	0–40	0.524	–	–	–	1
Methyl	0–61	1.1342	1.3635	0.8741	1.199	5a
Benzol	11–81	1.17626	1.27776	0.80648	1.237	5a
Bromine	0–59	1.06218	1.87714	—0.30854	1.132	2
Calcium chloride:						
5.8% solution . . .	18–25	0.07878	4.2742	–	0.250	7
40.9% " . . .	17–24	0.42383	0.8571	–	0.458	7
Carbon disulphide . . .	—34–60	1.13980	1.37065	1.91225	1.218	4a
500 atmos. pressure .	0–50	0.940	–	–	–	1
3000 " " .	0–50	0.581	–	–	–	1
Carbon tetrachloride . .	0–76	1.18384	0.89881	1.35135	1.236	4b
Chloroform	0–63	1.10715	4.66473	—1.74328	1.273	4b
Ether	—15–38	1.51324	2.35918	4.00512	1.656	4a
Glycerine	–	0.4853	0.4895	–	0.505	8
Hydrochloric acid:						
33.2% solution	0–33	0.4460	0.215	–	0.455	9
Mercury	0–100	0.18182	0.0078	–	1.8186	13
Olive oil	–	0.6821	1.1405	—0.539	0.721	10
Pentane	0–33	1.4646	3.09319	1.6084	1.608	14
Potassium chloride:						
24.3% solution	16–25	0.2695	2.080	–	0.353	7
Phenol	36–157	0.8340	0.10732	0.4446	1.090	11
Petroleum:						
Density 0.8467	24–120	0.8994	1.396	–	0.955	12
Sodium chloride:						
20.6% solution	0–29	0 3640	1.237	–	0.414	9
Sodium sulphate:						
24% solution	11-40	0.3599	1.258	–	0.410	9
Sulphuric acid:						
10.9% solution	0–30	0.2835	2.580	–	0.387	9
100.0%	0–30	0.5758	—0.432	–	0.558	9
Turpentine	—9–106	0.9003	1.9595	—0.44998	0.973	5b
Water	0–33	—0.06427	8.5053	6.7900	0.207	13

AUTHORITIES.

1. Amagat: C. R. 105, p. 1120; 1887.
2. Thorpe: Proc. Roy. Soc. 24, p. 283; 1876.
3. Zander: Lieb. Ann. 225, p. 109; 1884.
4. Pierre: a. Lieb. Ann. 56, p. 139; 1845.
   b. Lieb. Ann. 80, p. 125; 1851.
5. Kopp: a. Lieb. Ann. 94, p. 257; 1855.
   b. Lieb. Ann. 93, p. 129; 1855.
6. Recknagel: Sitzber. bayr. Ak. p. 327, 2 Abt.; 1866.
7. Drecker: Wied. Ann. 34, p. 952; 1888.
8. Emo: Ber. Chem. Ges. 16, 1857; 1883.
9. Marignac: Lieb. Ann., Supp. VIII, p. 335; 1872.
10. Spring: Bull. Brux. (3) 3, p. 331; 1882.
11. Pinette: Lieb. Ann. 243, p. 32; 1888.
12. Frankenheim: Pogg. Ann. 72, p. 422; 1847.
13. Scheel: Wiss. Abh. Reichsanstalt, 4, p. 1; 1903.
14. Thorpe and Jones: J. Chem. Soc. 63, p. 273; 1893.

TABLE 254.

COEFFICIENTS OF THERMAL EXPANSION.

Coefficients of Expansion of Gases.

Pressures are given in centimeters of mercury.

Coefficient at Constant Volume.			
Substance.	Pressure cm.	Coefficient × 100.	Reference.
Air	.6	.37666	1
“	1.3	.37172	“
“	10.0	.36630	“
“	25.4	.36580	“
“	75.2	.36660	“
“ 0°–100°	100.1	.36744	2
“	76.0	.36650	3
“	200.0	.36903	“
“	2000.	.38866	“
“	10000.	.4100	“
Argon	51.7	.3668	4
Carbon dioxide	76.0	.36856	3
“ “	1.8	.36753	1
“ “	5.6	.36641	“
“ “	74.9	.37264	“
“ “ 0°–20°	51.8	.36985	2
“ “ 0°–40°	51.8	.36972	“
“ “ 0°–100°	51.8	.36981	“
“ “ 0°–20°	99.8	.37335	“
“ “ 0°–100°	99.8	.37262	“
“ “ 0°–100°	100.0	.37248	5
Carbon monoxide	76.	.36667	3
Helium	56.7	.3665	4
Hydrogen 16°–132°	.0077	.3328	6
“ 15°–132°	.025	.3623	“
“ 12°–185°	.47	.3656	“
“	.93	.37002	1
“	11.2	.36548	“
“	76.4	.36504	“
“ 0°–100°	100.0	.36626	2
Nitrogen 13°–132°	.06	.3021	6
“ 9°–133°	.53	.3290	“
“ 0°–20°	100.2	.36754	2
“ 0°–100°	100.2	.36744	“
“	76.	.36682	7
Oxygen 11°–132°	.007	.4161	6
“ 9°–132°	.25	.3984	“
“ 11°–132°	.51	.3831	“
“	1.9	.36683	8
“	18.5	.36690	“
“	75.9	.36681	“
Nitrous oxide	76.	.3676	3
Sulph’r dioxide SO_2	76.	.3845	“

Coefficient at Constant Pressure.			
Substance.	Pressure cm.	Coefficient × 100.	Reference.
Air	76.	.3671	3
“	257.	.3693	“
“ 0°–100°	100.1	.36728	2
Hydrogen 0°–100°	100.0	.36600	“
“	200 Atm.	.332	9
“	400 “	.295	“
“	600 “	.261	“
“	800 “	.242	“
Carbon dioxide	76.	.3710	3
“ “ 0°–20°	51.8	.37128	2
“ “ 0°–40°	51.8	.37100	“
“ “ 0°–100°	51.8	.37073	“
“ “ 0°–20°	99.8	.37602	“
“ “ 0°–100°	99.8	.37410	“
“ “ 0°–20°	137.7	.37972	“
“ “ 0°–100°	137.7	.37703	“
“ “ 0°–7.5°	2621.	.1097	6
“ “ 64°–100°	2621.	.6574	“
Carbon monoxide	76.	.3669	3
Nitrous oxide	76.	.3719	“
Sulphur dioxide	76.	.3903	“
“ “	98.	.3980	“
Water-vapor 0°–119°	76.	.4187	10
0°–141°	76.	.4189	“
0°–162°	76.	.4071	“
0°–200°	76.	.3938	“
0°–247°	76.	.3799	“

Thomson has given, Encyc. Brit. “Heat,” the following for the calculation of the expansion, E. between 0° and 100° C. Expansion is to be taken as the change of volume under constant pressure:

Hydrogen, $E = .3662(1 - .00049\,V/v)$,
Air, $E = .3662(1 - .0026\,V/v)$,
Oxygen, $E = .3662(1 - .0032\,V/v)$,
Nitrogen, $E = .3662(1 - .0031\,V/v)$,
CO_2 $E = 3662(1 - .0164\,V/v)$.

V/v is the ratio of the actual density of the gas at 0° C to what it would have at 0° C and 1 Atm. pressure.

1 Meleander, Wied. Beibl. 14, 1890; Wied. Ann. 47, 1892.
2 Chappuis, Trav. Mem. Bur. Intern. Wts. Meas. 13, 1903.
3 Regnault, Ann. chim. phys. (3) 5, 1842.
4 Keunen-Randall, Proc. R. Soc. 59, 1896.
5 Chappuis, Arch. sc. phys. (3), 18, 1892.
6 Baly-Ramsay, Phil. Mag. (5), 38, 1894.
7 Andrews, Proc. Roy. Soc. 24, 1876.
8 Meleander, Acta Soc. Fenn. 19, 1891.
9 Amagat, C. R. 111, 1890.
10 Hirn, Théorie méc. chaleur, 1862.

MECHANICAL EQUIVALENT OF HEAT.

TABLE 255.—Summary.

Taken from J. S. Ames, L'équivalent mécanique de la chaleur, Rapports présentés au congrès international du physique, Paris, 1900.

Name.	Method.	Scale.	Result.	Temp. °C.
Joule	Mechanical .	. . . .	4.173	16.5
Rowland . . .	Mechanical .	. . . .	4.195	10.
			4.187	15.
			4.181	20.
			4.176	25.
Reynolds-Morby .	Mechanical .	. . . .	4.1832	Mean-calory.
Griffiths	Electrical . . $\frac{E^2t}{R}$	Latimer-Clark = 1.4342v at 15°C. International Ohm	4.198	15.
			4.192	20.
			4.187	25.
Schuster-Gannon	Electrical Eit.	Latimer-Clark = 1.4340v. at 15° C., Elec. Chem. Equiv. Silver = 0.001118g	4.1905	19.1
Callendar-Barnes	Electrical Eit.	Latimer-Clark = 1.4342v. at 15° C.	4.179	40.

TABLE 256.—Reduced to Gram-calory at 20° C. (Nitrogen thermometer).

		*
Joule	4.169×10^7 ergs	4.169×10^7 ergs.
Rowland . . .	4.181 “ “	4.181 “ “
Griffiths	4.192 “ “	4.184 “ “
Schuster-Gannon	4.189 “ “	4.181 “ “
Callendar-Barnes	4.186 “ “	4.178 “ “

* Admitting an error of 1 part per 1000 in the electrical scale.

The mean of the last four then gives

1 small (20° C) calory = 4.181×10^7 ergs.

1 small (15° C) calory = 4.185×10^7 ergs assuming sp. ht. of water at 20° = 0.9990.

TABLE 257.—Conversion Factors for Units of Work.

	Joules Watts × sec. Volt-amp. per sec.	Small 15° Calories.	Ergs.	Kilo-gram-meters.	Foot-poundals.	Foot-pounds.
1 joule = 1 watt × second	1	0.2389	10^7	$\frac{1}{g^*}$	23.73	$\frac{23.73}{g\dagger}$
1 small 15° calory =	4.185	1	4.185×10^7	$\frac{4.185}{g^*}$	99.31	$\frac{99.31}{g\dagger}$
1 erg =	10^{-7}	0.2389×10^{-7}	1	$\frac{10^{-7}}{g^*}$	23.73×10^{-7}	$\frac{23.73}{g\dagger} \times 10^{-7}$
1 kilog.-meter =	g^*	$0.2389g^*$	$g^* \times 10^7$	1	$23.73g^*$	23.73
1 foot-poundal =	.04214	.01007	421400.	$\frac{.04214}{g^*}$	1	$\frac{1}{g\dagger}$
1 foot-pound =	$.04214g\dagger$	$.01007g\dagger$	$421400g\dagger$	.04214	$g\dagger$	1

* g = 9.80 m. per sec. per sec. at latitude 45°, sea level.
† g = 32.2 ft. per sec. per sec. “ “ “ “ “

TABLE 258.

SPECIFIC HEAT OF THE CHEMICAL ELEMENTS.

Element.	Range * of Temperature, ° C.	Specific heat.	Reference.	Element.	Range * of Temperature, ° C.	Specific heat.	Reference.
Aluminum	—250	0.1428	1	Iodine	9–98	0 0541	25
“	0	.2089	“	Iridium	—186–+18	.0282	26
“	100	.2226	“	“	18–100	.0323	“
“	250	.2382	“	Iron, cast	20–100	.1189	27
“	500	.2739	“	“ wrought	15–100	.1152	28
“	16–100	.2122	43	“ “	1000–1200	.1989	“
Antimony	15	.0489	2	“ “	500	.176	“
“	100	.0503	“	“ hard-drawn	0–18	.0986	29
“	200	.0520	“	“ “ “	20–100	.1146	“
Arsenic, gray	0–100	.0822	3	“	—185–+20	.0958	4
“ black	0–100	.0861	“	Lanthanum	0–100	.0448	15
Barium	—185–+20	.068	4	Lead	15	.0299	2
Bismuth	—186	.0284	5	“	100	.0311	“
“	0	.0301	6	“	300	.0338	“
“	75	.0309	“	“ fluid	to 310	.0356	30
“	20–100	.0302	7	“ “	“ 360	.0410	“
“ fluid	280–380	.0363	8	“	18–100	.03096	43
Boron	0–100	.307	9	“	16–256	.03191	“
Bromine, solid	—78–—20	.0843	10	Lithium	—100	.5997	31
“ fluid	13–45	.107	11	“	0	.7951	“
Cadmium	21	.0551	2	“	50	.9063	“
“	100	.0570	“	“	100	1.0407	“
“	200	.0594	“	“	190	1.3745	“
“	300	.0617	“	Magnesium	—185–+20	0.222	4
Cæsium	0–26	.0482	12	“	60	.2492	7
Calcium	—185–+20	.157	4	“	325	.3235	“
“	0–181	.170	13	“	625	.4352	“
Carbon, graphite	—50	.114	14	“	20–100	.2492	“
“ “	+11	.160	“	Manganese	60	.1211	“
“ “	977	.467	“	“	325	.1783	“
“ diamond	—50	.0635	“	“	20–100	.1211	“
“ “	+11	.113	“	“	—100	.0979	31
“ “	985	.459	“	“	0	.1072	“
Cerium	0–100	.0448	15	“	100	.1143	“
Chlorine, liquid	0–24	.2262	16	Mercury	—185–+20	.032	4
Chromium	—200	.0666	17	“	0	.03346	32
“	0	.1039	“	“	85	.0328	“
“	100	.1121	“	“	100	.03284	2
“	600	.1872	“	“	250	.03212	“
“	—185–+20	.086	4	Molybdenum	—185–+20	.062	4
Cobalt	500	.1452	18	“	60	.0647	7
“	1000	.204	“	“	475	.0750	“
“	—182–+15	.0822	19	“	20–100	.0647	“
“	15–100	.1030	“	Nickel	—185–+20	.092	4
Copper	17	.0924	2	“	100	.1128	18
“	100	.0942	“	“	300	.1403	“
“	15–238	.09510	43	“	500	.1299	“
“	900	.1259	20	“	1000	.1608	“
“	—181–+13	.0868	21	“	18–100	.109	26
“	23–100	.0940	“	Osmium	19–98	.0311	10
Gallium, liquid	to 113	.080	22	Palladium	—186–+18	.0528	26
“ solid	12–23	.079	22	“	0–100	.0592	24
Germanium	0–100	.0737	23	“	0–1265	.0714	“
Gold	—185–+20	.033	4	Phosphorus, red	0–51	.1829	33
“	0–100	.0316	24	“ yellow	13–36	.202	“
Indium	0–100	.0570	13	“ “	—186–+20	.178	4

See opposite page for References. See Table 260 for supplementary data.

* Where one temperature alone is given, the “true” specific heat is given; otherwise, the “mean” specific heat.

TABLES 258 (*continued*) -259.

SPECIFIC HEAT.

TABLE 258.—Specific Heat of the Chemical Elements (*continued*).

Element.	Range * of Temperature, °C.	Specific Heat.	Reference.
Platinum	−186–+18	0.0293	26
"	0–100	.0323	24
"	100	.0275	34
"	500	.0356	35
"	700	.0368	"
"	900	.0380	"
"	1100	.0390	"
"	1500	.0407	"
"	500	.0335	"
"	1100	.0358	"
"	1500	.0368	"
Potassium	−185–+20	.170	4
Rhodium	10–97	.0580	25
Ruthenium	0–100	.0611	13
Selenium	−188–+18	.068	36
Silicon	−185–+20	.123	4
"	−39.8	.1360	14
"	+57.1	.1833	"
"	232	.2029	"
Silver	−186–−79	.0496	26
"	−79–+18	.0544	"
"	0–100	.0559	13
"	23	.05498	2
"	100	.05663	"
"	500	.0581	34
"	17–507	.05987	43
"	800	.076	18
" fluid	907–1100	.0748	"
Sodium	−185–+20	.253	4
Sulphur	−188–+18	0.137	36
" rhombic	0–54	.1728	33
" monoclin	0–52	.1809	"
" liquid	119–147	.235	2
Tantalum	−185–+20	.033	4
"	1400	0.043	-
Tellurium	−188–+18	.047	36
" crys.	15–100	.0483	37
Thallium	−185–+20	.038	4
"	20–100	.0326	27
Thorium	0–100	.0276	38
Tin	−196–−79	.0486	26
"	−76–+18	.0518	"
" cast	21–109	.0551	30
" fluid	250	.05799	18
" "	1100	.0758	"
Titanium	−185–+20	.082	4
"	0–100	.1125	39
Tungsten	−185–+20	.036	4
"	0–100	.0336	40
"	1000	0.044	-
Uranium	0–98	.028	41
Vanadium	0–100	.1153	40
Zinc	−192–+20	.0836	27
"	20–100	.0931	"
"	0–100	.0935	13
"	100	.0951	2
"	300	.1040	"
Zirconium	0–100	.0660	42

1 Bontschew.
2 Naccari, Atti Torino, 23, 1887–88.
3 Wigand, Ann. d. Phys. (4) 22, 1907.
4 Nordmeyer-Bernouli, Verh. d. phys. Ges. 9, 1907; 10, 1908.
5 Giebe, Verh. d. phys. Ges. 5, 1903.
6 Lorenz, Wied. Ann. 13, 1881.
7 Stücker, Wien. Ber. 114, 1905.
8 Person, C. R. 23, 1846; Ann. d. chim. (3) 21, 1847; 24, 1848.
9 Moisson-Gautier, Ann. chim. phys. (7) 17, 1896.
10 Regnault, Ann. d. chim. (3) 26, 1849; 63, 1861.
11 Andrews, Pog. Ann. 75, 1848.
12 Eckardt-Graefe, Z. Anorg. Ch. 23, 1900.
13 Bunsen, Pogg. Ann. 141, 1870; Wied. Ann. 31, 1887.
14 Weber, Phil. Mag. (4) 49, 1875.
15 Hillebrand, Pog. Ann. 158, 1876.
16 Knietsch.
17 Adler, Beibl. 27, 1903.
18 Pionchon, C. R. 102–103, 1886.
19 Tilden, Phil. Trans. (A) 201, 1903.
20 Richards, Ch. News, 68, 1893.
21 Trowbridge, Science, 8, 1898.
22 Berthelot, Ann. d. chim. (5) 15, 1878.
23 Pettersson-Hedellius, J. Pract. Ch. 24, 1881.
24 Violle, C. R. 85, 1877; 87, 1878.
25 Regnault, Ann. d. chim. (2) 73, 1840; (3) 63, 1861.
26 Behn, Wied. Ann. 66, 1898; Ann. d. Phys. (4) 1, 1900.
27 Schmitz, Pr. Roy. Soc. 72, 1903.
28 Nichol, Phil. Mag. (5) 12, 1881.
29 Hill, Verh. d. phys. Ges. 3, 1901.
30 Spring, Bull. de Belg. (3) 11, 1886; 29, 1895.
31 Laemmel, Ann. d. Phys. (4) 16, 1905.
32 Barnes-Cooke, Phys. Rev. 16, 1903.
33 Wiegand, Fort. d. Phys. 1906.
34 Tilden, Pr. Roy. Soc. 66, 1900, 71, 1903; Phil. Trans. (A) 194, 1900; 201, 1903.
35 White, Phys. Rev. 28, 1909.
36 Dewar, Ch. News, 92, 1905.
37 Kopp, Phil. Trans. London, 155, 1865.
38 Nilson, C. R. 96, 1883.
39 Nilson-Pettersson, Zt. phys. Ch. 1, 1887.
40 Mache, Wien. Ber. 106, 1897.
41 Blümcke, Wied. Ann. 24, 1885.
42 Mixter-Dana, Lieb. Ann. 169, 1873.
43 Magnus, Ann. d. Phys. 31, 1910.

* When one temperature alone is given, the "true" specific heat is given; otherwise, the "mean" specific heat.

Compiled in part from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen

TABLE 259.—Specific Heat of Water and of Mercury.

Specific Heat of Water.							Specific Heat of Mercury.			
Temperature, °C.	Barnes.	Rowland.	Barnes-Regnault.	Temperature, °C.	Barnes	Barnes-Regnault.	Temperature, °C.	Specific Heat.	Temperature, °C.	Specific Heat.
−5	1.0155	–	–	60	0.9988	0.9994	0	0.03346	90	0.03277
0	1.0091	1.0070	1.0094	65	.9994	1.0004	5	.03340	100	.03269
+5	1.0050	1.0039	1.0053	70	1.0001	1.0015	10	.03335	110	.03262
10	1.0020	1.0016	1.0023	80	1.0014	1.0042	15	.03330	120	.03255
15	1.0000	1.0000	1.0003	90	1.0028	1.0070	20	.03325	130	.03248
20	0.9987	.9991	0.9990	100	1.0043	1.0101	25	.03320	140	.03241
25	.9978	.9989	.9981	120	–	1.0162	30	.03316	150	.0324
30	.9973	.9990	.9976	140	–	1.0223	35	.03312	170	.0322
35	.9971	.9997	.9974	160	–	1.0285	40	.03308	190	.0320
40	.9971	1.0006	.9974	180	–	1.0348	50	.03300	210	.0319
45	.9973	1.0018	.9976	200	–	1.0410	60	.03294	–	–
50	.9977	1.0031	.9980	220	–	1.0476	70	.03289	–	–
55	.9982	1.0045	.9985	–	–	–	80	.03284	–	–

Barnes's results: Phil. Trans. (A) 199, 1902; Phys. Rev. 15, 1902; 16, 1903. (H thermometer.)
Bousfield, Phil. Trans. A 211, p. 199, 1911. Barnes-Regnault's as revised by Peabody; Steam Tables.

The mercury data from 0° C to 80, Barnes-Cooke (H thermometer); from 90° to 140, mean of Winklemann, Naccari and Milthaler (air thermometer); above 140°, mean of Naccari and Milthaler.

TABLE 260. — Additional Specific Heats of the Chemical Elements.

Element.	Temperature.	Sp. Heat.	Reference.	Element.	Temperature.	Sp. Heat.	Reference.
Aluminum .	—240.6°	0.0092	1	Lithium . .	—191-—80	0.521	2
	—190.0	.0889	"		—78-0	.595	"
	—190-—82	.1466	2		—75-+19	.629	"
	—76-—1	.1962	"	Manganese .	—188-—79	.0820	4
	+16-+100	.2122	3		—79-+15	.1091	"
	+16-+304	.2250	"	Mercury, sol.	—77-—42	.0329	2
Boron . . .	—191-—78	.0707	2	" liq.	—36-—3	.0334	"
	—76-0	.1677	"	Potassium .	—191-—80	.1568	"
Bromine . .	—192-—80	.0702	4		—78-0	.1666	2
Carbon, graph.	—191-—79	.0573	2	Sodium . .	—191-—83	.243	"
	—76-0	.1255	"		—77-0	.276	"
—Ache. graph.	—244.0	.005	6	Zinc . . .	—190-—82	.0792	"
	—186.0	.027	"		—76-2	.0906	"
—Diamond .	—79-—3	.0720	2	Iron . . .	0-+200°	.1175	5
Copper . .	—249.5	.0035	1		0-+300	.1233	"
	—185.0	.0532	"		0-+400	.1282	"
	—190-—83	.0720	2		0-+500	.1338	"
	—76-0	.0878	"		0-+600	.1396	"
	+15-+238	.0951	3		0-+700	.1487	"
Iodine . . .	—90-+17	.0485	4		0-+800	.1597	"
	—191-—80	.0454	"		0-+900	.1644	"
Lead . . .	—77-—3	.0303	2		0-+1000	.1557	"
	+18-+100	.0310	3		0-+1100	.1534	"
	+16-+256	.0319	"				

1. Nernst, Lindemann, 1910, 1911.
2. Kosef, Ann. der Phys. 36, 1911.
3. Magnus, Ann. der Phys. 31, 1910.
4. Estreicher, Straniewski, 1912.
5. Harker — Proc. Phys. Soc., London, 19, p. 703, 1905. Fe = .01C, .02Si, .03S, .04P, trace Mn.

TABLE 261. — Mean Specific Heats of Quartz, Silica Glass, and Platinum from zero, C., to the temperature named.

The mean specific heats of quartz above 550° are here increased by the heat (2.3 calories) of the inversion at 575°. The accuracy is probably better than 2 per mille.

Interval.	Quartz.	Silica Glass.	Platinum.	Obs.—calculated for Pt.
0-100°	.1870	.1845	—	—
0-300°	.2169	.2124	.03283	.00000
0-500°	.2382	.2303	.03363	+.00012
0-550°	.2441	—	—	—
0-600°	.2520	—	—	—
0-700°	.2555	.2433	.03424	+.00005
0-900°	.2608	.2523	.03487	.00000
0-1100°	.2654	—	.03551	—.00004
0-1300°	—	—	.03620	—.00003

The results for Platinum follow the formula :

Sp. Heat = .03174 + .000 0034 θ very closely. If the formula were strictly correct the *true specific heat* at any temp. would be : .03174 +.000 006 8 θ, which is probably true to 1% as it is.

Determinations by W. P. White. Geographical Laboratory.

TABLE 262. — Specific Heat of Various Solids.*

Solid.	Temperature °C.	Specific Heat.	Authority.†
Alloys:			
Bell metal	15–98	0.0858	R
Brass, red	0	.08991	L
“ yellow	0	.08831	“
80 Cu+20 Sn	14–98	.0862	R
88.7 Cu+11.3 Al	20–100	.10432	Ln
German silver	0–100	.09464	T
Lipowitz alloy: 24.97 Pb + 10.13 Cd + 50.66 Bi +14.24 Sn	5–50	.0345	M
“ “	100–150	.0426	“
Rose's alloy: 27.5 Pb+48.9 Bi+23.6 Sn	—77–20	.0356	S
“ “	20–89	.0552	“
Wood's alloy: 25.85 Pb + 6.99 Cd + 52.43 Bi + 14.73 Sn	5–50	.0352	M
“ “ (fluid)	100–150	.0426	“
Miscellaneous alloys:			
17.5 Sb+29.9 Bi+18.7 Zn+33.9 Sn	20–99	.05657	R
37.1 Sb+62.9 Pb	10–98	.03880	“
39.9 Pb+60.1 Bi	16–99	.03165	P
“ “ (fluid)	144–358	.03500	“
63.7 Pb+36.3 Sn	12–99	.04073	R
46.7 Pb+53.3 Sn	10–99	.04507	“
63.8 Bi+36.2 Sn	20–99	.04001	“
46.9 Bi+53.1 Sn	20–99	.04504	“
Gas coal	20–1040	.3145	–
Glass, normal thermometer 16^{III}	19–100	.1988	W
“ French hard thermometer	–	.1869	Z
“ crown	10–50	.161	H M
“ flint	10–50	.117	“
Ice	—188-—252	.146	D
“	—78-—188	.285	“
“	—18-—78	.463	“
India rubber (Para)	?–100	.481	G-T
Paraffin	—20-+3	.3768	R W
“	—19-+20	.5251	“
“	0–20	.6939	“
“	35–40	.622	B
“ fluid	60–63	.712	“
Vulcanite	20–100	.3312	A M

TABLE 263. — Specific Heat of Various Liquids.*

Liquid.	Temperature °C.	Specific Heat.	Authority.	Liquid.	Temperature °C.	Specific Heat.	Authority.†
Alcohol, ethyl	—20	0.5053	R	Nitrobenzole	28	0.362	A
“ “	0	.548	“	Napthalene, $C_{10}H_8$	80–85	.396	B
“ “	40	.648	“	“	90–95	.409	“
“ methyl	5–10	.590	“	Oils: castor	–	.434	W
“ “	15–20	.601	“	citron	5.4	.438	H W
Anilin	15	.514	G	olive	6.6	.471	“
“	30	.520	“	sesame	–	.387	W
“	50	.529	“	turpentine	0	.411	R
Benzole, C_6H_6	10	.340	H-D	Petroleum	21–58	.511	Pa
“	40	.423	“	Toluol, C_6H_8	10	.364	H-D
“	65	.482	“	“	65	.490	“
Diphenylamine, $C_{12}H_{11}N$	53	.464	B	“	85	.534	“
“	65	.482	“	$CaCl_2$, sp. gr. 1.14	—15	.764	DMG
Ethyl ether	0	.529	R	“ “ “	0	.775	“
Glycerine	15–50	.576	E	“ “ “	+20	.787	“
Nitrobenzole	14	.350	A	“ “ 1.20	—20	.695	“

---

* These specific heat tables are compiled partly from more extended tables in Landolt-Börnstein-Meyerhoffer's Tables.

† For references see Table 263, page 242.

TABLE 263. — Specific Heat of Various Liquids.

Liquid.	Temperature °C.	Specific Heat.	Authority.	Liquid.	Temperature °C.	Specific Heat.	Authority.
$CaCl_2$, sp. gr. 1.20	0	0.712	DMG	$KOH + 30 H_2O$	18	0.876	TH
" " "	+20	.725	"	" + 100 "	18	.975	"
" " 1.26	—20	.651	"	$NaOH + 50 H_2O$	18	.942	"
" " "	0	.663	"	" + 100 "	18	.983	"
" " "	+20	.676	"	$NaCl + 10 H_2O$	18	.791	"
$CuSo_4 + 50 H_2O$	12–15	.848	Pa	" + 200 "	18	.978	"
" +200 "	12–14	.951	"	Sea water, sp. gr. 1.0043	17.5	.980	"
" +400 "	13–17	.975	"	" " " 1.0235	17.5	.938	"
$ZnSO_4 + 50 H_2O$	20–52	.842	Ma	" " " 1.0463	17.5	.903	"
" +200 "	20–52	.952	"				

A, Abbot.
AM, A. M. Mayer.
B, Batelli.
D, Dewar.
E, Emo.
G, Griffiths.
G-T, Gee and Terry.
DMG, Dickinson, Mueller, and George.
H-D, de Heen and Deruyts.
HM, H. Meyer.
L, Lorenz.
Ln, Luginen.
M, Mazotto.
Ma, Marignac.
P, Person.
Pa, Pagliani.
R, Regnault.
RW, R. W. Weber.
T, Tomlison.
S, Schüz.
Th, Thomsen.
W, Wachsmuth.
Wn, Winkelmann.
Z, Zouloff.

TABLE 264. — Specific Heat of Minerals and Rocks.

Substance.	Temperature ° C.	Specific Heat.	Reference.	Substance.	Temperature ° C.	Specific Heat.	Reference.
Andalusite	0–100	0.1684	1	Rock-salt	13–45	0.219	6
Anhydrite, $CaSO_4$	0–100	.1753	1	Serpentine	16–98	.2586	2
Apatite	15–99	.1903	2	Siderite	9–98	.1934	4
Asbestos	20–98	.195	3	Spinel	15–47	.194	6
Augite	20–98	.1931	3	Talc	20–98	.2092	3
Barite, $BaSO_4$	10–98	.1128	4	Topaz	0–100	.2097	1
Beryl	15–99	.1979	2	Wollastonite	19–51	.178	6
Borax, $Na_2B_4O_7$ fused	16–98	.2382	4	Zinc blende, ZnS	0–100	.1146	1
Calcspar, $CaCO_3$	0–50	.1877	1	Zircon	21–51	.132	6
" "	0–100	.2005	1	Rocks:			
" "	0–300	.2204	1	Basalt, fine, black	12–100	.1996	6
Casiderite, SnO_3	16–98	.0933	4	" " "	20–470	.199	9
Corundum	9–98	.1976	4	" " "	470–750	.243	9
Cryolite, $Al_2Fl_6.6NaF$	16–99	.2522	2	" " "	750–880	.626	9
Fluorite, CaF_2	15–99	.2154	4	" " "	880–1190	.323	9
Galena, PbS	0–100	.0466	5	Dolomite	20–98	.222	3
Garnet	16–100	.1758	2	Gneiss	17–99	.196	10
Hematite, Fe_2O_3	15–99	.1645	2	"	17–213	.214	10
Hornblende	20–98	.1952	3	Granite	12–100	.192	7
Hypersthene	20–98	.1914	3	Kaolin	20–98	.224	3
Labradorite	20–98	.1949	3	Lava, Aetna	23–100	.201	11
Magnetite	18–45	.156	6	" "	31–776	.259	11
Malachite, $Cu_2CO_4.H_2O$	15–99	.1763	2	" Kilauea	25–100	.197	11
Mica (Mg)	20–98	.2061	3	Limestone	15–100	.216	12
" (K)	20–98	.2080	3	Marble	0–100	.21	–
Oligoclase	20–98	.2048	3	Quartz sand	20–98	.191	3
Orthoclase	15–99	.1877	2	Sandstone	–	.22	–
Pyrites, copper	15–99	.1291	2				
Pyrolusite, MnO_2	17–48	.159	6				
Quartz, SiO_2	12–100	.188	7				
" "	0	.1737	8				
" "	350	.2786	8				
" "	400–1200	.305	8				

1 Lindner.
2 Oeberg.
3 Ulrich.
4 Regnault.
5 Tilden.
6 Kopp.
7 Joly.
8 Pionchon.
9 Roberts-Austen, Rücker.
10 R. Weber.
11 Bartoli.
12 Morano.

Compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.

TABLE 265.

SPECIFIC HEATS OF GASES AND VAPORS.

Substance.	Range of Temp. °C.	Sp. Ht. Constant Pressure.	Authority.	Range of Temp. °C.	Mean Ratio of Specific Heats. C_p/C_v.	Authority.
Acetone, C_3H_6O	26–110	0.3468	Wiedemann.			
“ “	27–179	0.3740	“			
“ “	129–233	0.4125	Regnault.			
Air	—30–+10	0.2377	“	5–14	1.4025	Lummer and Pringsheim.
“	0–100	0.2374	“			
“	0–200	0.2375	“			
“	20–440	0.2366	Holborn and Austin.			
“	20–630	0.2429				
“	20–800	0.2430	“			
Alcohol, C_2H_5OH	108–220	0.4534	Regnault.	53	1.133	Jaeger.
“ “	–	–	–	100	1.134	Stevens,
“ C_2H_3OH	101–223	0.4580	Regnault.	100	1.256	“
Ammonia	23–100	0.5202	Wiedemann.	0	1.3172	Wüllner.
“	27–200	0.5356	“	100	1.2770	“
“	24–216	0.5125	Regnault.			
Argon	20–90	0.1233	Dittenberger.	0	1.667	Niemeyer.
Benzole, C_6H_6	34–115	0.2990	Wiedemann.	20	1.403	Pagliani.
“ “	35–180	0.3325	“	60	1.403	“
“ “	116–218	0.3754	Regnault.	99.7	1.105	Stevens
Bromine	83–228	0.0555	“	20–388	1.293	Strecker.
“	19–388	0.0553	Strecker.			
Carbon dioxide, CO_2	—28–+7	0.1843	Regnault.	4–11	1.2995	Lummer and Pringsheim.
“ “ “	15–100	0.2025	“			
“ “ “	11–214	0.2169	“			
“ monoxide, CO	23–99	0.2425	Wiedemann.	0	1.403	Wüllner.
“ “ “	26–198	0.2426	“	100	1.395	“
“ disulphide, CS_2	86–190	0.1596	Regnault.	3–67	1.205	Beyme.
Chlorine	13–202	0.1241	“	20–340	1.323	Strecker.
“	16–343	0.1125	Strecker.	0	1.336	Martini.
Chloroform, $CHCl_3$	27–118	0.1441	Wiedemann.	22–78	1.102	Beyme.
“ “	28–189	0.1489	“	99.8	1.150	Stevens.
Ether, $C_4H_{10}O$	69–224	0.4797	Regnault.	3–46	1.025	Beyme.
“ “	27–189	0.4618	Wiedemann.	42–45	1.029	Müller.
“ “	25–111	0.4280	“	12–20	1.024	Low.
Hydrochloric acid, HCl	13–100	0.1940	Strecker.	20	1.389	Strecker.
“ “ “	22–214	0.1867	Regnault.	100	1.400	“
Hydrogen	—28–+9	3.3996	“	4–16	1.4080	Lummer and Pringsheim.
“	12–198	3.4090	“			
“	21–100	3.4100	Wiedemann.			
“ sulphide, H_2S	20–206	0.2451	Regnault.	10–40	1.276	Müller.
Methane, CH_4	18–208	0.5929	“	11–30	1.316	“
Nitrogen	0–200	0.2438	“	–	1.41	Cazin.
“	20–440	0.2419	Holborn and Austin.			
“	20–630	0.2464				
“	20–800	0.2497	“			
Nitric oxide, NO	13–172	0.2317	Regnault.			
Nitrogen tetroxide, NO_2	27–67	1.625	Berthelot and Olger.	–	1.31	Natanson.
“ “ “	27–150	1.115				
“ “ “	27–280	0.65	“			
Nitrous oxide, N_2O	16–207	0.2262	Regnault.	0	1.311	Wüllner.
“ “ “	26–103	0.2126	Wiedemann.	100	1.272	“
“ “ “	27–206	0.2241	“			
Oxygen	13–207	0.2175	Regnault.	5–14	1.3977	Lummer and Pringsheim.
“	20–440	0.2240	Holborn and Austin.			
“	20–630	0.2300				
Sulphur dioxide, SO_2	16–202	0.1544	Regnault.	16–34	1.256	Müller.
Water vapor, H_2O	0	0.4655	Thiesen.	78	1.274	Beyme.
“ “ “	100	0.421	“	94	1.33	Jaeger.
“ “ “	180	0.51	“			

THERMOMETERS.

TABLE 266. — Gas and Mercury Thermometers.

If t_H, t_N, t_{CO2}, t_{16}, t_{59}, t_T, are temperatures measured with the hydrogen, nitrogen, carbonic acid, 16^{III}, 59^{III}, and "verre dur" (Tonnelot), respectively, then

$$t_H - t_T = \frac{(100-t)t}{100^2}\,[-0.61859 + 0.0047351.t - 0.000011577.t^2]^*$$

$$t_N - t_T = \frac{(100-t)t}{100^2}\,[-0.55541 + 0.0048240.t - 0.0000024807.t^2]^*$$

$$t_{CO2} - t_T = \frac{(100-t)t}{100^2}\,[-0.33386 + 0.0039910.t - 0.000016678.t^2]^*$$

$$t_H - t_{16} = \frac{(100-t)t}{100^2}\,[-0.67039 + 0.0047351.t - 0.000011577.t^2]^\dagger$$

$$t_H - t_{59} = \frac{(100-t)t}{100^2}\,[-0.31089 + 0.0047351.t - 0.000011577.t^2]^\dagger$$

* Chappuis; Trav. et Mém. du Bur. internat. des Poids et Mes. 6, 1888.

† Thiesen, Scheel, Sell; Wiss. Abh. d. Phys. Techn. Reichanstalt, 2, 1895; Scheel; Wied. Ann. 58, 1896; D. Mech. Ztg. 1897.

TABLE 267. $t_H - t_{16}$ (Hydrogen — 16^{III}).

	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
0°	.000°	—.007°	—.013°	—.019°	—.025°	—.031°	—.036°	—.042°	—.047°	—.051°
10	—.056	—.061	—.065	—.069	—.073	—.077	—.080	—.084	—.087	—.090
20	—.093	—.096	—.098	—.101	—.103	—.105	—.107	—.109	—.110	—.112
30	—.113	—.114	—.115	—.116	—.117	—.118	—.119	—.119	—.119	—.120
40	—.120	—.120	—.120	—.120	—.119	—.119	—.118	—.118	—.117	—.116
50	—.116	—.115	—.114	—.113	—.111	—.110	—.109	—.107	—.106	—.104
60	—.103	—.101	—.099	—.097	—.096	—.094	—.092	—.090	—.087	—.085
70	—.083	—.081	—.078	—.076	—.074	—.071	—.069	—.066	—.064	—.061
80	—.058	—.056	—.053	—.050	—.048	—.045	—.042	—.039	—.036	—.033
90	—.030	—.027	—.024	—.021	—.018	—.015	—.012	—.009	—.006	—.003
100	.000									

TABLE 268. $t_H - t_{59}$ (Hydrogen — 59^{III}).

	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
0°	.000°	—.003°	—.006°	—.009°	—.011°	—.014°	—.016°	—.018°	—.020°	—.022°
10	—.024	—.025	—.027	—.028	—.030	—.031	—.032	—.033	—.034	—.035
20	—.035	—.036	—.036	—.037	—.037	—.037	—.038	—.038	—.038	—.038
30	—.038	—.037	—.037	—.037	—.037	—.036	—.036	—.035	—.035	—.034
40	—.034	—.033	—.032	—.032	—.031	—.030	—.029	—.028	—.028	—.027
50	—.026	—.025	—.024	—.023	—.022	—.021	—.020	—.019	—.018	—.017
60	—.016	—.015	—.015	—.014	—.013	—.012	—.011	—.010	—.009	—.008
70	—.008	—.007	—.006	—.005	—.005	—.004	—.003	—.003	—.002	—.001
80	—.001	—.001	.000	.000	+.001	+.001	+.001	+.002	+.002	+.002
90	+.002	+.002	+.002	+.002	+.002	+.002	+.001	+.001	+.001	.000
100	.000									

TABLE 269. (Hydrogen — 16^{III}), (Hydrogen — 59^{III}).

	—5°	—10°	—15°	—20°	—25°	—30°	—35°
$t_H - t_{16}$	+0.04°	+0.08°	+0.13°	+0.19°	+0.25°	+0.32°	+0.40°
$t_H - t_{59}$	+0.02°	+0.04°	+0.07°	+0.10°	+0.14°	+0.18°	+0.23°

All compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.

AIR AND MERCURY THERMOMETERS.

TABLE 270. $t_{AIR} - t_{16}$. (Air — 16^{III}.)

° C.	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
0	.000	—.006	—.012	—.017	—.022	—.027	—.032	—.037	—.041	—.045
10	—.049	—.053	—.057	—.061	—.065	—.068	—.071	—.074	—.077	—.080
20	—.083	—.086	—.089	—.091	—.093	—.095	—.097	—.099	—.101	—.102
30	—.103	—.104	—.105	—.106	—.107	—.108	—.109	—.110	—.110	—.110
40	—.110	—.110	—.111	—.111	—.110	—.110	—.110	—.109	—.109	—.108
50	—.107	—.107	—.106	—.105	—.104	—.103	—.102	—.101	—.100	—.098
60	—.096	—.095	—.093	—.092	—.090	—.088	—.086	—.084	—.082	—.080
70	—.078	—.076	—.074	—.072	—.070	—.067	—.065	—.062	—.060	—.057
80	—.054	—.052	—.049	—.047	—.044	—.041	—.039	—.036	—.034	—.031
90	—.028	—.025	—.023	—.020	—.017	—.014	—.011	—.009	—.006	—.003
100	.000	+.003	+.006	+.008	+.011	+.014	+.017	+.019	+.022	+.025
110	+.028	+.030	+.033	+.035	+.038	+.041	+.043	+.046	+.048	+.050
120	+·053	+.055	+.057	+.060	+.062	+.064	+.066	+.068	+.070	+.072
130	+.074	+.076	+.078	+.080	+.081	+.083	+.084	+.086	+.087	+.089
140	+.090	+.091	+.092	+.093	+.094	+.095	+.096	+.096	+.097	+.097
150	+.098	+.098	+.098	+.099	+.099	+.099	+.098	+.098	+.098	+.097
160	+.097	+.096	+.095	+.094	+.093	+.092	+.090	+.089	+.088	+.086
170	+.084	+.082	+.080	+.078	+.076	+.073	+.071	+.068	+.065	+.062
180	+.059	+.055	+.052	+.048	+.045	+.041	+.037	+.033	+.028	+.023
190	+.019	+.014	+.009	+.004	—.001	—.007	—.013	—.019	—.025	—.031
200	—.038	—.045	—.051	—.058	—.066	—.073	—.080	—.088	—.096	—.105
210	—.113	—.122	—.130	—.139	—.148	—.158	—.168	—.177	—.187	—.198
220	—.208	—.219	—.230	—.241	—.252	—.264	—.275	—.287	—.300	—.312
230	—.325	—.338	—.351	—.365	—.378	—.392	—.407	—.421	—.436	—.450
240	—.466	—.481	—.497	—.513	—.529	—.546	—.562	—.579	—.597	—.614
250	—.632	—.650	—.668	—.687	—.706	—.725	—.745	—.765	—.785	—.805
260	—.825	—.846	—.867	—.889	—.911	—.933	—.955	—.978	—1.001	—1.025
270	—1.048	—1.072	—1.096	—1.121	—1.146	—1.171	—1.196	—1.222	—1.248	—1.274
280	—1.301	—1.328	—1.356	—1.384	—1.412	—1.440	—1.469	—1.498	—1.528	—1.558
290	—1.588	—1.618	—1.649	—1.680	—1.711	—1.743	—1.776	—1.808	—1.841	—1.874
300	—1.908									

TABLE 271. $t_{AIR} - t_{59}$. (Air — 59^{III}.)

° C.	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
100	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
110	.000	.000	.000	—.001	—.001	—.001	—.001	—.001	—.002	—.002
120	—.002	—.002	—.002	—.002	—.002	—.003	—.003	—.003	—.004	—.004
130	—.004	—.004	—.005	—.005	—.006	—.006	—.006	—.007	—.007	—.008
140	—.008	—.008	—.009	—.009	—.010	—.010	—.011	—.011	—.012	—.012
150	—.013	—.013	—.014	—.015	—.016	—.016	—.016	—.017	—.018	—.019
160	—.019	—.020	—.021	—.021	—.022	—.023	—.024	—.025	—.026	—.027
170	—.028	—.029	—.030	—.031	—.032	—.033	—.034	—.035	—.037	—.038
180	—.039	—.040	—.041	—.043	—.044	—.045	—.046	—.048	—.049	—.051
190	—.052	—.053	—.055	—.056	—.057	—.059	—.060	—.062	—.064	—.066
200	—.067									

GAS, MERCURY, ALCOHOL, TOLUOL, PETROLETHER, PENTANE, THERMOMETERS.

TABLE 272. — $t^H—t_M$ (Hydrogen-Mercury).

Temperature, C.	Thuringer Glass.*	Verre dur. Tonnelot.†	Resistance Glass.*	English Crystal Glass.*	Choisy-le-Roi.*	122^{III}.*	Nitrogen Thermometer. $T_H—T_N$.†	CO_2 Thermometer. $T_H—T_{CO_2}$.†
°	°	°	°	°	°	°	°	°
0	.000	.000	.000	.000	.000	.000	.000	.000
10	—.075	—.052	—.066	—.008	—.007	—.005	—.006	—.025
20	—.125	—.085	—.108	—.001	—.004	—.006	—.010	—.043
30	—.156	—.102	—.131	+.017	+.004	—.002	—.011	—.054
40	—.168	—.107	—.140	+.037	+.014	+.001	—.011	—.059
50	—.166	—.103	—.135	+.057	+.025	+.004	—.009	—.059
60	—.150	—.090	—.119	+.073	+.033	+.008	—.005	—.053
70	—.124	—.072	—.095	+.079	+.037	+.009	—.001	—.044
80	—.088	—.050	—.068	+.070	+.032	+.007	+.002	—.031
90	—.047	—.026	—.034	+.046	+.022	+.006	+.003	—.016
100	.000	.000	.000	.000	.000	.000	.000	.000

* Schlösser, Zt. Instrkde. 21, 1901. † Chappuis, Trav. et mém. du Bur. Intern. des Poids et Mes. 6, 1888.

TABLE 273. — Comparison of Air and High Temperature Mercury Thermometers.

Comparison of the air thermometer with the high temperature mercury thermometer, filled under pressure and made of 59^{III} glass.

Air.	59^{III}.	Air.	59^{III}.
°	°	°	°
0	0.	375	385.4
100	100.	400	412.3
200	200.4	425	440.7
300	304.1	450	469.1
325	330.9	475	498.0
350	358.1	500	527.8

Mahlke, Wied. Ann. 1894.

TABLE 274. — Comparison of Hydrogen and Other Thermometers.

Comparison of the hydrogen thermometer with the toluol, alcohol, petrolether, and pentane thermometers (verre dur).

Hydrogen.	Toluol.*	Alcohol I.*	Alcohol II.*	Petrolether.†	Pentane.‡
°	°	°	°	°	°
0	0.00	0.00	0.00	-	0.00
—10	—8.54	—9.31	—9.44	-	—9.03
—20	—16.90	—18.45	—18.71	-	—17.87
—30	—25.10	—27.44	—27.84	-	—26.55
—40	—33.15	—36.30	—36.84	-	—35.04
—50	—41.08	—45.05	—45.74	—42.6	—43.36
—60	—48.90	—53.71	—54.55	-	—51.50
—70	—56.63	—62.31	—63.31	-	—59.46
—100	-	-	-	—80.2	—82.28
—150	-	-	-	—113.0	—116.87
—200	-	-	-	—140.7	—146.84

* Chappuis, Arch. sc. phys. (3) 18, 1892. † Holborn, Ann. d. Phys. (4) 6, 1901. ‡ Rothe, unpublished.

All compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.

TABLE 275. — Platinum Resistance Thermometers.

Callendar has shown that if we define the platinum temperature, pt, by $pt = 100\{(R - R_0)/(R_{100} - R_0)\}$, where R is the observed resistance at t° C., R_0 that at 0°, R_{100} at 100°, then the relation between the platinum temperature and the temperature t on the scale of the gas thermometer is represented by $t - pt = \delta\{t/100 - 1\}t/100$ where δ is a constant for any given sample of platinum and about 1.50 for pure platinum (impure platinum having higher values). This holds good between −23° and 450° when δ has been determined by the boiling point of sulphur (445°.)

See Waidner and Burgess, Bul. Bureau Standards, 6, p. 149, 1909.

TABLE 276. — Thermodynamic Temperature of the Ice Point, and Reduction to Thermodynamic Scale.

Mean = 273.10° C. (ice point)

For a discussion of the various values and for the corrections of the various gas thermometers to the thermodynamic scale see Buckingham, Bull. Bureau Standards, 3, p. 237, 1907.

Scale Corrections for Gas Thermometers.

Temp. C.	Constant pressure = 76 cm.			Constant volume $\Theta_0 = 273.10$ C.		
	He	H	N	He	H	N
−250°	—	—	—	+0.02	—	—
−200	+0.10	+0.26	—	+0.01	+0.06	—
−100	+ .03	+0.03	+0.33	.000	+ .014	+0.07
− 50	+ .009	+0.004	+ .09	.000	+ .004	+ .02
+ 25	− .002	− .002	− .013	.000	.000	− .006
+ 50	− .002	− .003	− .017	.000	.000	− .006
+ 75	− .002	− .002	− .012	.000	.000	− .004
+150	+ .005	+ .003	+ .04	.000	+ .001	+ .01
+200	+ .01	+ .01	+ .10	.000	+ .002	+ .04
+450	+ .07	+ .04	+ .50	0.00	+ .01	+ .15
+1000	+ .24	+ .01	+1.7	—	+0.04	+ .70
+1500	—	—	+3.0	—	—	+1.3

See Burgess, The Present Status of the Temperature Scale, Chemical News, 107, p. 169, 1913.

TABLE 277. — Standard Points for the Calibration of Thermometers.

Substance.	Point.	Atmosphere.	Crucible.	Temperatures.	
				°C.	Thermodynamic.
Water	boiling, 760 mm.	air	-	100.00	100.00
Napthalene	" " "	"	-	218.0	218.0
Benzophenone	" " "	-	-	305.85 ± 0.1	305.9
Cadmium	melting or solidify.	air	graphite	320.8 ± 0.2	320.9
Zinc	" " "	"	"	419.3 ± 0.3	419.4
Sulphur	boiling, 760 mm.	-	-	444.45 ± 0.1	444.55
Antimony	melting or solidify.	CO_2	graphite	629.8 ± 0.5	630.0
Aluminum	solidification	"	"	658.5 ± 0.6	658.7
Silver	melting or solidify.	"	"	960.0 ± 0.7	
Gold	" " "	"	"	1062.4 ± 0.8	
Copper	" " "	"	"	1082.6 ± 0.8	
Li_2SiO_3	melting	air	platinum	1201.0 ± 1.0	
Diopside, pure	"	"	"	1391.2 ± 1.5	
Nickel	melting or solidify.	H and N	magnesia and Mg. aluminate	1452.3 ± 2.0	
Cobalt	" " "	"	magnesia	1489.8 ± 2.0	
Palladium	" " "	air	"	1549.2 ± 2.0	
Anorthite, pure	melting	"	platinum	1549.5 ± 2.0	
Platinum	"	"		1752. ± 5.* 1755. ± 5.†	

* Thermoelectric extrapolation. † Optical extrapolation.

(Day and Sosman, Journal de Physique, 1912. Mesure des témperatures élevées.) A few additional points are: H, boils −252.7°; O, boils −182.9°; Hg. freezes −37.7°; Alumina melts 2000°; Tungsten melts 3000°.

CORRECTION FOR TEMPERATURE OF MERCURY IN THERMOMETER STEM.

The Stem Correction is proportional to $n\beta(T-t)$: where n is the number of degrees in the exposed stem; β is the apparent coefficient of expansion of mercury in the glass; T is the measured temperature; and t is the mean temperature of the exposed stem determined by another thermometer, exposed some 10 cm. from, and at about half the height of, the exposed stem of the first.

For temperatures up to 100°C, the value of β is for:

Jena glass XVI$^{\text{III}}$ or Greiner and Friedrich resistance glass, $\frac{1}{6300}$ or 0.000159;

Jena glass 59$^{\text{III}}$, $\frac{1}{6100}$ or 0.000164.

At 100° the correction is in round numbers 0.01° for each degree of the exposed stem; at 200° 0.02°; and for higher temperatures proportionately greater. At 500° it may amount to 0.07° for each exposed degree.

Tables 278–280 are taken from Rimbach, Zeitschrift für Instrumentenkunde, 10, 153, 1890, and apply to thermometers of Jena or of resistance glass.

TABLE 278. — Stem Correction for Thermometer of Jena Glass (0°–360° C.).

Degree length 0.9 to 1.1 mm; t = the observed temperature; t' = that of the surrounding air 1 dm. away; n = the length of the exposed thread.

Correction to be added to the Reading t.										
n	$t - t'$									
	70°	80°	90°	100°	120°	140°	160°	180°	200°	220°
10	0.01	0.01	0.03	0.04	0.07	0.10	0.13	0.17	0.19	0.21
20	0.08	0.12	0.14	0.19	0.25	0.28	0.32	0.40	0.49	0.54
30	0.25	0.28	0.32	0.36	0.42	0.48	0.54	0.66	0.78	0.87
40	0.30	0.35	0.41	0.48	0.60	0.67	0.77	0.92	1.08	1.20
50	0.41	0.46	0.52	0.59	0.79	0.89	0.98	1.16	1.38	1.53
60	0.52	0.60	0.68	0.79	0.99	1.11	1.23	1.46	1.70	1.87
70	0.63	0.74	0.85	0.98	1.20	1.32	1.45	1.70	1.99	2.21
80	0.75	0.87	1.01	1.15	1.38	1.53	1.70	1.98	2.29	2.54
90	0.87	0.99	1.13	1.28	1.62	1.82	1.94	1.25	2.60	2.89
100	0.98	1.12	1.29	1.47	1.82	2.03	2.20	2.55	2.92	3.24
120	–	–	–	1.88	2.28	2.49	2.68	3.13	3.59	3.96
140	–	–	–	–	2.75	2.97	3.22	3.75	4.24	4.69
160	–	–	–	–	–	3.35	3.80	4.35	4.92	5.45
180	–	–	–	–	–	–	4.37	4.99	5.63	6.22
200	–	–	–	–	–	–	–	5.68	6.34	6.98
220	–	–	–	–	–	–	–	–	7.05	7.82

See "The correction for Emergent Stem of Mercurial Thermometer." Buckingham, Bul. Bur. of Standards, 8, p. 239, 1912.

CORRECTION FOR TEMPERATURE OF MERCURY IN THERMOMETER STEM (*continued*).

TABLE 279.—Stem Correction for Thermometer of Jena Glass (0°–360° C).

Degree length 1 to 1.6 mm.; t = the observed temperature; t' = that of the surrounding air one dm. away; n = the length of the exposed thread.

CORRECTION TO BE ADDED TO THERMOMETER READING.*

n	$t-t'$										n
	70°	80°	90°	100°	120°	140°	160°	180°	200°	220°	
10°	0.02	0.03	0.05	0.07	0.11	0.17	0.21	0.27	0.33	0.38	**10°**
20	0.13	0.15	0.18	0.22	0.29	0.38	0.46	0.53	0.61	0.67	20
30	0.24	0.28	0.33	0.39	0.48	0.59	0.70	0.78	0.88	0.97	30
40	0.35	0.41	0.48	0.56	0.68	0.82	0.94	1.04	1.16	1.28	40
50	0.47	0.53	0.62	0.72	0.88	1.03	1.17	1.31	1.44	1.59	**50**
60	0.57	0.66	0.77	0.89	1.09	1.25	1.42	1.58	1.74	1.90	60
70	0.69	0.79	0.92	1.06	1.30	1.47	1.67	1.86	2.04	2.23	70
80	0.80	0.91	1.05	1.21	1.52	1.71	1.94	2.15	2.33	2.55	80
90	0.91	1.04	1.19	1.38	1.73	1.96	2.20	2.42	2.64	2.89	**90**
100	1.02	1.18	1.35	1.56	1.97	2.18	2.45	2.70	2.94	3.23	100
110	–	–	–	1.78	2.19	2.43	2.70	2.98	3.26	3.57	110
120	–	–	–	1.98	2.43	2.69	2.95	3.26	3.58	3.92	120
130	–	–	–	–	2.68	2.94	3.20	3.56	3.89	4.28	**130**
140	–	–	–	–	2.92	3.22	3.47	3.86	4.22	4.64	140
150	–	–	–	–	–	–	3.74	4.15	4.56	5.01	150
160	–	–	–	–	–	–	4.00	4.46	4.90	5.39	160
170	–	–	–	–	–	–	4.27	4.76	5.24	5.77	**170**
180	–	–	–	–	–	–	4.54	5.07	5.59	6.15	180
190	–	–	–	–	–	–	–	5.38	5.95	6.54	190
200	–	–	–	–	–	–	–	5.70	6.30	6.94	200
210	–	–	–	–	–	–	–	–	6.68	7.35	**210**
220	–	–	–	–	–	–	–	–	7.04	7.75	220

---

* See Hovestadt's "Jena Glass" (translated by J. D. and A. Everett) for data on changes of thermometer zeros.

TABLE 280.—Stem Correction for a so-called Normal Thermometer of Jena Glass (0°–100° C).

Divided into tenth degrees; degree length about 4 mm.

CORRECTION TO BE ADDED TO THE READING t.

n	$t-t'$											
	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°
10	0.04	0.04	0.05	0.05	0.05	0.06	0.06	0.07	0.08	0.09	0.10	0.10
20	0.12	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.22	0.23
30	0.21	0.22	0.23	0.24	0.25	0.25	0.27	0.29	0.31	0.33	0.35	0.37
40	0.28	0.29	0.31	0.33	0.35	0.37	0.39	0.41	0.43	0.45	0.48	0.51
50	0.36	0.38	0.40	0.42	0.44	0.46	0.48	0.50	0.53	0.57	0.61	0.65
60	0.45	0.48	0.51	0.53	0.55	0.57	0.60	0.63	0.66	0.69	0.73	0.78
70	–	–	–	–	–	0.66	0.69	0.71	0.75	0.81	0.87	0.92
80	–	–	–	–	–	–	0.76	0.81	0.87	0.93	1.00	1.06
90	–	–	–	–	–	–	–	0.92	0.99	1.06	1.13	1.20
100	–	–	–	–	–	–	–	–	1.10	1.18	1.26	1.34

TABLE 281.—Standard Calibration Curve for Pt.—Pt. Rh. (10% Rh.) Thermo-Element.

Giving the temperature for every 100 microvolts. For use in conjunction with a deviation curve determined by calibration of the particular element at some of the following fixed points:

Water	boiling-pt.	100.0	643mv.	Silver	melting-pt.	960.2	9111mv.
Napthalene	" "	217.95	1585	Gold	" "	1062.6	10296
Tin	melting-pt.	231.9	1706	Copper	" "	1082.8	10534
Benzophenone	boiling-pt.	305.9	2365	Li_2SiO_3	" "	1201.	11941
Cadmium	melting-pt.	320.9	2503	Diopside	" "	1391.5	14230
Zinc	" "	419.4	3430	Nickel	" "	1452.6	14973
Sulphur	boiling-pt.	444.55	3672				
Antimony	melting-pt.	630.0	5530	Palladium	" "	1549.5	16144
Aluminum	" "	658.7	5827	Platinum	" "	1755.	18608

E micro-volts.	0	1000.	2000.	3000.	4000.	5000.	6000.	7000.	8000.	9000.	E micro-volts.
	TEMPERATURES, °C.										
0.	0.0	147.1	265.4	374.3	478.1	578.3	675.3	769.5	861.1	950.4	0.
100.	17.8	159.7	276.6	384.9	488.3	588.1	684.8	778.8	870.1	959.2	100.
200.	34.5	172.1	287.7	395.4	498.4	597.9	694.3	788.0	879.1	968.0	200.
300.	50.3	184.3	298.7	405.9	508.5	607.7	703.8	797.2	888.1	976.7	300.
400.	65.4	196.3	309.7	416.3	518.6	617.4	713.3	806.4	897.1	985.4	400.
500.	80.0	208.1	320.6	426.7	528.6	627.1	722.7	815.6	906.1	994.1	500.
600.	94.1	219.7	331.5	437.1	538.6	636.8	732.1	824.7	915.0	1002.8	600.
700.	107.8	231.2	342.3	447.4	548.6	646.5	741.5	833.8	923.9	1011.5	700.
800.	121.2	242.7	353.0	457.7	558.5	656.1	750.9	842.9	932.8	1020.1	800.
900.	134.3	254.1	363.7	467.9	568.4	665.7	760.2	852.0	941.6	1028.7	900.
1000.	147.1	265.4	374.3	478.1	578.3	675.3	769.5	861.1	950.4	1037.3	1000.

E micro-volts.	10000.	11000.	12000.	13000.	14000.	15000.	16000.	17000.	18000.	E micro-volts.
	TEMPERATURES, °C.									
0.	1037.3	1122.2	1205.9	1289.3	1372.4	1454.8	1537.5	1620.9	1704.3	0.
100.	1045.9	1130.6	1214.2	1297.7	1380.7	1463.0	1545.8	1629.2	1712.6	100.
200.	1054.4	1139.0	1222.6	1306.0	1389.0	1471.2	1554.1	1637.6	1721.0	200.
300.	1062.9	1147.4	1230.9	1314.3	1397.3	1479.4	1562.4	1645.9	1729.3	300.
400.	1071.4	1155.8	1239.3	1322.6	1405.6	1487.7	1570.8	1654.3	1737.7	400.
500.	1079.9	1164.2	1247.6	1330.9	1413.8	1496.0	1579.1	1662.6	1746.0	500.
600.	1088.4	1172.5	1255.9	1339.2	1422,0	1504.3	1587.5	1670.9	1754.3	600.
700.	1096.9	1180.9	1264.3	1347.5	1430.2	1512.6	1595.8	1679.3		700.
800.	1105.4	1189.2	1272.6	1355.8	1438.4	1520.9	1604.2	1687.6		800.
900.	1113.8	1197.6	1281.0	1364.1	1446.6	1529.2	1612.5	1696.0		900.
1000.	1122.2	1205.9	1289.3	1372.4	1454.8	1537.5	1620.9	1704.3		1000.

TABLE 282.—Standard Calibration Curve for Copper—Constantan Thermo-Element.

For use in conjunction with a deviation curve determined by the calibration of the particular element at some of the following fixed points:

Water, boiling-point, 100°, 4276 microvolts; Napthalene, boiling-point, 217.95, 10248 mv.; Tin, melting-point, 231.9, 11009 mv.; Benzophenone, boiling-point, 305.9, 15203 mv.; Cadmium, melting-point, 320.9, 16083 mv.

E. micro-volts.	0	1000.	2000.	3000.	4000.	5000.	6000.	7000.	8000.	9000.	E micro-volts.
	TEMPERATURES, °C.										
0.	0.00	25.27	49.20	72.08	94.07	115.31	135.91	155.95	175.50	194.62	0.
100.	2.60	27.72	51.53	74.31	96.23	117.40	137.94	157.92	177.43	196.51	100.
200.	5.17	30.15	53.85	76.54	98.38	119.48	139.96	159.89	179.36	198.40	200.
300.	7.73	32.57	56.16	78.76	100.52	121.56	141.98	161.86	181.28	200.28	300.
400.	10.28	34.98	58.46	80.97	102.66	123.63	143.99	163.82	183.20	202.16	400.
500.	12.81	37.38	60.76	83.17	104.79	125.69	146.00	165.78	185.11	204.04	500.
600.	15.33	39.77	63.04	85.37	106.91	127.75	148.00	167.73	187.02	205.91	600.
700.	17.83	42.15	65.31	87.56	109.02	129.80	150.00	169.68	188.93	207.78	700.
800.	20.32	44.51	67.58	89.74	111.12	131.84	151.99	171.62	190.83	209.64	800.
900.	22.80	46.86	69.83	91.91	113.22	133.88	153.97	173.56	192.73	211.50	900.
1000.	25.27	49.20	72.08	94.07	115.31	135.91	155.95	175.50	194.62	213.36	1000.

E micro-volts.	10000.	11000.	12000.	13000.	14000.	15000.	16000.	17000.	18000.	E micro-volts.
	TEMPERATURES, °C.									
0.	213.36	231.74	249.82	267.60	285.13	302.42	319.49	336.36	353.09	0.
100.	215.21	233.56	251.61	269.36	286.87	304.14	321.19	338.04		100.
200.	217.06	235.38	253.40	271.12	288.61	305.85	322.88	339.72		200.
300.	218.91	237.20	255.18	272.88	290.35	307.56	324.57	341.40		300.
400.	220.75	239.01	256.96	274.64	292.08	309.27	326.26	343.07		400.
500.	222.59	240.82	258.74	276.40	293.81	310.98	327.95	344.74		500.
600.	224.43	242.63	260.52	278.15	295.54	312.69	329.64	346.41		600.
700.	226.26	244.43	262.29	279.90	297.26	314.39	331.32	348.08		700.
800.	228.09	246.23	264.06	281.65	298.98	316.09	333.00	349.75		800.
900.	229.92	248.03	265.83	283.39	300.70	317.79	334.68	351.42		900.
1000.	231.74	249.82	267.60	285.13	302.42	319.49	336.36	353.09		1000.

Cf. Day and Sosman, Am. Jour. Sci. 29, p. 93, 32, p. 51; ; *ibid.* R. B. Sosman, 30, p. 1.

RADIATION CONSTANTS.

TABLE 283.—Radiation Formulæ and Constants for Perfect Radiator.

The radiation per sq. cm. from a "black body" (exclusive of convection losses) at the temperature T° (absolute, C) to one at t° is equal to

$$J = \sigma\,(T^4 - t^4) \quad \text{(Stefan–Boltzmann)};$$

where $\sigma = 1.374 \times 10^{-12}$ gram-calories per second per sq. centimeter.
$= 8.26 \times 10^{-11}$ " " " minute " " "
$= 5.75 \times 10^{-12}$ watts per sq. centimeter.

The distribution of this energy in the spectrum is represented by Planck's formula:

$$J_\lambda = C_1 \lambda^{-5} \left[e^{\frac{C_2}{\lambda T}} - 1 \right]^{-1}$$

where J_λ is the intensity of the energy at the wave-length λ (λ expressed in microns, μ) and e is the base of the Napierian logarithms.

$C_1 = 9.226 \times 10^{-23}$ for J in $\frac{gram.\ cal.}{sec.\ cm.^2} = 3.86 \times 10^{-22}$ for J in $\frac{watts}{cm.^2}$
$C_2 = 1.4450$ for λ in *cm.*
$J_{max} = 3.11 \times 10^{+4}\ T^6$ for J in $\frac{gram.\ cal.}{sec.\ cm.^2} = 1.30 \times 10^{+5}\ T^5$ for J in $\frac{watts}{cm.^2}$
$\lambda_{max} T = 0.2910$ for λ in *cm.*
h = Planck's unit = elementary "Wirkungs quantum" $= 6.83 \times 10^{-27}$ ergs. sec.
k = constant of entropy equation $= 1.42 \times 10^{-16}$ ergs./degrees.

TABLE 284.—Radiation in Gram-Calories per 24 Hours per sq. cm. from a Perfect Radiator at t° C to an absolutely Cold Space (—273° C).

Computed from the Stefan-Boltzmann formula.

t° C	J	t° C	J	t° C	J	t° C	J	t° C	J	t° C	J
—273	0	—120	65	—10	571	+12	787	+34	1059	+56	1400
—220	1	—110	84	—8	588	+14	808	+36	1087	+58	1430
—210	2	—100	107	—6	606	+16	831	+38	1115	+60	1470
—200	3	—90	134	—4	625	+18	855	+40	1145	+70	1650
—190	5	—80	165	—2	643	+20	879	+42	1174	+80	1850
—180	9	—70	201	0	662	+22	903	+44	1204	+90	2070
—170	13	—60	245	+2	682	+24	928	+46	1234	+100	2310
—160	19	—50	294	+4	701	+26	953	+48	1265	+200	5960
—150	27	—40	350	+6	722	+28	979	+50	1298	+1000	313×10^3
—140	38	—30	416	+8	744	+30	1005	+52	1330	+2000	318×10^4
—130	50	—20	488	+10	765	+32	1032	+54	1363	+5000	921×10^5

TABLE 285.—Values of J_λ for Various Temperatures Centigrade.

Ekholm, Met. Z. 1902, used $C_1 = 8346$ and $C_2 = 14349$, and for the unit of time the day.
For 10°, the values for J_λ have been multiplied by 10, for the other temperatures by 100.

λ	$T =$ 100° C	30° C	15° C	0° C	—30° C	—80° C	λ	100° C	30° C	15° C	0° C	—30° C	—80° C
μ							μ						
2	1	0	0	0	0	0	18	511	2961	2557	2175	1491	623
3	80	41	18	7	1	0	19	443	2626	2281	1954	1363	594
4	469	508	272	138	27	1	20	386	2329	2034	1754	1242	561
5	1047	1777	1085	628	172	8	21	337	2068	1816	1574	1129	527
6	1526	3464	2296	1454	493	39	22	295	1840	1622	1413	1026	494
7	1768	4954	3481	2353	931	105	23	259	1639	1448	1270	931	460
8	1810	5928	4352	3088	1372	203	24	228	1462	1298	1141	846	428
9	1724	6382	4834	3646	1730	316	25	202	1307	1165	1028	768	398
10	1573	6386	4979	3781	1971	426	26	179	1170	1047	926	698	369
11	1398	6127	4833	3798	2098	520	28	142	947	850	757	579	317
12	1225	5712	4633	3676	2114	592	30	114	771	696	623	482	272
13	1063	5222	4300	3467	2090	640	40	44	311	285	259	209	130
14	918	4713	3930	3215	2004	666	50	20	146	135	124	102	67
15	792	4220	3556	2944	1889	673	60	10	77	72	66	55	38
16	683	3759	3198	2674	1760	663	80	4	27	25	24	20	14
17	590	3340	2862	2417	1626	649	100	2	12	11	10	9	7

COOLING BY RADIATION AND CONVECTION.

TABLE 286. — At Ordinary Pressures.

According to McFarlane* the rate of loss of heat by a sphere placed in the centre of a spherical enclosure which has a blackened surface, and is kept at a constant temperature of about 14° C, can be expressed by the equations

$$e = .000238 + 3.06 \times 10^{-6}t - 2.6 \times 10^{-8}t^2,$$

when the surface of the sphere is blackened, or

$$e = .000168 + 1.98 \times 10^{-6}t - 1.7 \times 10^{-8}t^2,$$

when the surface is that of polished copper. In these equations, e is the amount of heat lost in c. g. s. units, that is, the quantity of heat, small calories, radiated per second per square centimeter of surface of the sphere, per degree difference of temperature t, and t is the difference of temperature between the sphere and the enclosure. The medium through which the heat passed was moist air. The following table gives the results.

Difference of temperature t	Value of e.		Ratio.
	Polished surface.	Blackened surface.	
5	.000178	.000252	.707
10	.000186	.000266	.699
15	.000193	.000279	.692
20	.000201	.000289	.695
25	.000207	.000298	.694
30	.000212	.000306	.693
35	.000217	.000313	.693
40	.000220	.000319	.693
45	.000223	.000323	.690
50	.000225	.000326	.690
55	.000226	.000328	.690
60	.000226	.000328	.690

TABLE 287. — At Different Pressures.

Experiments made by J. P. Nicol in Tait's Laboratory show the effect of pressure of the enclosed air on the rate of loss of heat. In this case the air was dry and the enclosure kept at about 8° C.

Polished surface.		Blackened surface.	
t	et	t	et
PRESSURE 76 CMS. OF MERCURY.			
63.8	.00987	61.2	.01746
57.1	.00862	50.2	.01360
50.5	.00736	41.6	.01078
44.8	.00628	34.4	.00860
40.5	.00562	27.3	.00640
34.2	.00438	20.5	.00455
29.6	.00378	–	–
23.3	.00278	–	–
18.6	.00210	–	–
PRESSURE 10.2 CMS. OF MERCURY.			
67.8	.00492	62.5	.01298
61.1	.00433	57.5	.01158
55	.00383	53.2	.01048
49.7	.00340	47.5	.00898
44.9	.00302	43.0	.00791
40.8	.00268	28.5	.00490
PRESSURE 1 CM. OF MERCURY.			
65	.00388	62.5	.01182
60	.00355	57.5	.01074
50	.00286	54.2	.01003
40	.00219	41.7	.00726
30	.00157	37.5	.00639
23.5	.00124	34.0	.00569
–	–	27.5	.00446
–	–	24.2	.00391

---

* "Proc. Roy. Soc." 1872.
† "Proc. Roy. Soc." Edinb. 1869.
See also Compan, Annal. de chi. et phys. 26, p. 526.

COOLING BY RADIATION AND CONVECTION.

TABLE 288. — Cooling of Platinum Wire in Copper Envelope.

Bottomley gives for the radiation of a bright platinum wire to a copper envelope when the space between is at the highest vacuum attainable the following numbers: —

$t = 408°$ C., $et = 378.8 \times 10^{-4}$, temperature of enclosure 16° C.
$t = 505°$ C., $et = 726.1 \times 10^{-4}$, " " 17° C.

It was found at this degree of exhaustion that considerable relative change of the vacuum produced very small change of the radiating power. The curve of relation between degree of vacuum and radiation becomes asymptotic for high exhaustions. The following table illustrates the variation of radiation with pressure of air in enclosure.

Temp. of enclosure 16° C., $t = 408°$ C.		Temp. of enclosure 17° C., $t = 505°$ C.	
Pressure in mm.	et	Pressure in mm.	et
740.	8137.0×10^{-4}	0.094	1688.0×10^{-4}
440.	7971.0 "	.053	1255.0 "
140.	7875.0 "	.034	1126.0 "
42.	7591.0 "	.013	920.4 "
4.	6036.0 "	.0046	831.4 "
0.444	2683.0 "	.00052	767.4 "
.070	1045.0 "	.00019	746.4 "
.034	727.3 "	Lowest reached but not measured	726.1 "
.012	539.2 "		
.0051	436.4 "		
.00007	378.8 "		

TABLE 289. — Effect of Pressure on Loss of Heat at Different Temperatures.

The temperature of the enclosure was about 15° C. The numbers give the total radiation in therms per square centimeter per second.

Temp. of wire in C°.	Pressure in mm.				
	10.0	1.0	0.25	0.025	About 0.1 M.
100°	0.14	0.11	0.05	0.01	0.005
200	.31	.24	.11	.02	.0055
300	.50	.38	.18	.04	.0105
400	.75	.53	.25	.07	.025
500	–	.69	.33	.13	.055
600	–	.85	.45	.23	.13
700	–	–	–	.37	.24
800	–	–	–	.56	.40
900	–	–	–	–	.61

NOTE. — An interesting example (because of its practical importance in electric lighting) of the effect of difference of surface condition on the radiation of heat is given on the authority of Mr. Evans and himself in Bottomley's paper. The energy required to keep up a certain degree of incandescence in a lamp when the filament is dull black and when it is "flashed" with coating of hard bright carbon, was found to be as follows: —

Dull black filament, 57.9 watts.
Bright " " 39.8 watts.

TABLE 290.

PROPERTIES OF STEAM.

Metric Measure.

The temperature Centigrade and the absolute temperature in degrees Centigrade, together with other data for steam or water vapor stated in the headings of the columns, are here given. The quantities of heat are in therms or calories according as the gram or the kilogram is taken as the unit of mass.

Temp. C.	Absolute temp.	Pressure in mm. of mercury.	Pressure in grams per sq. centimeter $= p$.	Pressure in atmospheres.	Total heat of evaporation from 0° at $t^\circ = H$.	Heat of liquid $= h$.	Heat of evaporation $= H - h$.	Outer latent or external-work heat $= Apv$.*	Total heat of steam $= H - Apv$.	Inner latent or internal-work heat $= H - (h + Apv)$.	Liters per gram, or cubic meters per kilog. $= v$.	Ratio of inner latent heat to volume of steam.†
0°	273	4.60	6.25	0.006	606.5	0.00	606.5	31.07	575.4	575.4	210.66	2.732
5	278	6.53	8.88	.009	608.0	5.00	603.0	31.47	576.5	571.5	150.23	3.805
10	283	9.17	12.47	.012	609.5	10.00	599.5	31.89	577.7	567.7	108.51	5.231
15	288	12.70	17.27	.017	611.1	15.00	596.0	32.32	578.8	563.7	79.35	7.104
20	293	17.39	23.64	.023	612.6	20.01	592.6	32.75	579.8	559.8	58.72	9.532
25	298	23.55	32.02	0.031	614.1	25.02	589.1	33.20	580.9	555.9	43.96	12.64
30	303	31.55	42.89	.042	615.6	30.03	585.6	33.66	582.0	552.0	33.27	16.59
35	308	41.83	56.87	.055	617.2	35.04	582.1	34.12	583.1	548.2	25.44	21.54
40	313	54.91	74.65	.072	618.7	40.05	578.6	34.59	584.1	544.1	19.64	27.70
45	318	71.39	97.06	.094	620.2	45.07	575.1	35.06	585.2	540.1	15.31	35.26
50	323	91.98	125.0	0.121	621.7	50.09	571.7	35.54	586.2	536.1	12.049	44.49
55	328	117.47	159.7	.155	623.3	55.11	568.2	36.02	587.2	532.1	9.561	55.65
60	333	148.79	202.3	.196	624.8	60.13	564.7	36.51	588.3	528.1	7.653	69.02
65	338	186.94	254.2	.246	626.3	65.17	561.1	37.00	589.3	524.2	6.171	84.94
70	343	233.08	316.9	.306	627.8	70.20	557.6	37.48	590.4	520.2	5.014	103.75
75	348	288.50	392.3	0.380	629.4	75.24	554.1	37.96	591.4	516.2	4.102	125.8
80	353	354.62	482.1	.466	630.9	80.28	550.6	38.42	592.5	512.2	3.379	151.6
85	358	433.00	588.7	.570	632.4	85.33	547.1	38.88	593.5	508.2	2.800	181.5
90	363	525.39	714.4	.691	633.9	90.38	543.6	39.33	594.6	504.2	2.334	216.0
95	368	633.69	861.7	.834	635.5	95.44	540.0	39.76	595.7	500.3	1.957	255.7
100	373	760.00	1033.	1.000	637.0	100.5	536.5	40.20	596.8	496.3	1.6496	300.8
105	378	906.41	1232.	.193	638.5	105.6	533.0	40.63	597.9	492.3	1.3978	352.2
110	383	1075.4	1462.	.415	640.0	110.6	529.4	41.05	599.0	488.4	1.1903	410.3
115	388	1269.4	1726.	.670	641.6	115.7	525.8	41.46	600.1	484.4	1.0184	475.6
120	393	1491.3	2027.	.962	643.1	120.8	522.3	41.86	601.2	480.4	0.8752	549.0
125	398	1743.9	2371.	2.295	644.6	125.9	518.7	42.25	602.4	476.5	0.7555	630.7
130	403	2030.3	2760.	2.671	646.1	131.0	515.1	42.63	603.5	472.5	0.6548	721.6
135	408	2353.7	3200.	3.097	647.7	136.1	511.6	43.01	604.7	468.6	0.5698	822.3
140	413	2717.6	3695.	3.576	649.2	141.2	508.0	43.38	605.8	464.6	0.4977	933.5
145	418	3125.6	4249.	4.113	650.7	146.3	504.4	43.73	607.0	460.7	0.4363	1055.7
150	423	3581.2	4869.	4.712	652.2	151.5	500.8	44.09	608.2	456.7	0.3839	1190.
155	428	4088.6	5589.	5.380	653.8	156.5	497.2	44.43	609.3	452.8	0.3388	1336.
160	433	4651.6	6324.	6.120	655.3	161.7	493.5	44.76	610.5	448.8	0.3001	1496.
165	438	5274.5	7171.	6.940	656.8	166.9	489.9	45.09	611.7	444.8	0.2665	1669.
170	443	5961.7	8105.	7.844	658.3	172.0	486.3	45.40	612.9	440.9	0.2375	1856.
175	448	6717.4	9133.	8.839	659.9	177.2	482.7	45.71	614.2	436.9	0.2122	2059.
180	453	7546.4	10260.	9.929	661.4	182.4	479.0	46.01	615.4	433.0	0.1901	2277.
185	458	8453.2	11490.	11.123	662.9	187.6	475.3	46.30	616.6	429.0	0.1708	2512.
190	463	9442.7	12838.	12.425	664.4	192.8	471.7	46.59	617.9	425.0	0.1538	2763.
195	468	10520.	14303.	13.842	666.0	198.0	468.0	46.86	619.1	421.1	0.1389	3031.
200	473	11689.	15892.	15.380	667.5	203.2	464.3	47.13	620.4	417.1	0.1257	3318.

* Where A is the reciprocal of the mechanical equivalent of the thermal unit.

† $= \frac{H - (h + Apv)}{v} = \frac{\text{internal-work pressure}}{\text{mechanical equivalent of heat}}$. Where v is taken in litres the pressure is given per square decimetre, and where v is taken in cubic metres the pressure is given per square metre, — the mechanical equivalent being that of the therm and the kilogram-degree or calorie respectively.

Table 291.

PROPERTIES OF STEAM.

British Measure.

The quantities given in the different columns of this table are sufficiently explained by the headings. The abbreviation B. T. U. stands for British thermal units. With the exception of column 3, which was calculated for this table, the data are taken from a table given by Dwelshauvers-Dery (Trans. Am. Soc. Mech. Eng. vol. xi.).

Pressure in pounds per square inch.	Pressure in pounds per square foot.	Pressure in atmospheres.	Temp. in degrees Fahr.	Volume per pound in cubic feet.	Weight per cubic foot in pounds.	Heat of water per pound in B. T. U.	Internal latent heat per pound of steam in B. T. U.	External latent heat per pound of steam in B. T. U.	Total latent heat per pound of steam in B. T. U.	Total heat per pound of steam in B. T. U.
1	144	0.068	102.0	334.23	0.0030	70.1	980.6	62.34	1043.	1113.0
2	288	.136	126.3	173.23	.0058	94.4	961.4	64.62	1026.	1120.4
3	432	.204	141.6	117.98	.0085	109.9	949.2	66.58	1011.	1127.0
4	576	.272	153.1	89.80	.0111	121.4	940.2	67.06	1007.	1128.6
5	720	.340	162.3	72.50	.0137	130.7	932.8	67.89	1001.	1131.4
6	864	0.408	170.1	61.10	0.0163	138.6	926.7	68.58	995.2	1133.8
7	1008	.476	176.9	53.00	.0189	145.4	921.3	69.18	990.5	1135.9
8	1152	.544	182.9	46.60	.0214	151.5	916.5	69.71	986.2	1137.7
9	1296	.612	188.3	41.82	.0239	156.9	912.2	70.18	982.4	1139.4
10	1440	.680	193.2	37.80	.0264	161.9	908.3	70.61	979.0	1140.9
11	1584	0.748	197.8	34.61	0.0289	166.5	904.8	70.99	975.8	1142.3
12	1728	.816	202.0	31.90	.0314	170.7	901.5	71.34	972.8	1143.5
13	1872	.884	205.9	29.58	.0338	174.7	898.4	71.68	970.0	1144.7
14	2016	.952	209.5	27.59	.0362	178.4	895.4	72.00	967.4	1145.9
15	2160	1.020	213.0	25.87	.0387	181.9	892.7	72.29	965.0	1146.9
16	2304	1.088	216.3	24.33	0.0411	185.2	890.1	72.57	962.7	1147.9
17	2448	.156	219.4	22.98	.0435	188.4	887.6	72.82	960.4	1148.9
18	2592	.224	222.4	21.78	.0459	191.4	885.3	73.07	958.3	1149.8
19	2736	.292	225.2	20.70	.0483	194.3	883.1	73.30	956.3	1150.6
20	2880	.360	227.9	19.72	.0507	197.0	880.9	73.53	954.4	1151.4
21	3024	1.429	230.5	18.84	0.0531	199.7	878.8	73.74	952.6	1152.2
22	3168	.497	233.0	18.03	.0554	202.2	876.8	73.94	950.8	1153.0
23	3312	.565	235.4	17.30	.0578	204.7	874.9	74.13	949.1	1153.7
24	3456	.633	237.7	16.62	.0602	207.0	873.1	74.32	947.4	1154.4
25	3600	.701	240.0	15.99	.0625	209.3	871.3	74.51	945.8	1155.1
26	3744	1.769	242.2	15.42	0.0649	211.5	869.6	74.69	944.3	1155.8
27	3888	.837	244.3	14.88	.0672	213.7	867.9	74.85	942.8	1156.4
28	4032	.905	246.3	14.38	.0695	215.7	866.3	75.01	941.3	1157.1
29	4176	.973	248.3	13.91	.0619	217.8	864.7	75.17	939.9	1157.7
30	4320	2.041	250.2	13.48	.0742	219.7	863.2	75.33	938.5	1158.3
31	4464	2.109	252.1	13.07	0.0765	221.6	861.7	75.47	937.2	1158.8
32	4608	.177	253.9	12.68	.0788	223.5	860.3	75.61	935.9	1159.4
33	4752	.245	255.7	12.32	.0811	225.3	858.9	75.76	934.6	1159.9
34	4896	.313	257.5	11.98	.0835	227.1	857.5	75.89	933.4	1160.5
35	5040	.381	259.2	11.66	.0858	228.8	856.1	76.02	932.1	1161.0
36	5184	2.449	260.8	11.36	0.0881	230.5	854.8	76.16	931.0	1161.5
37	5328	.517	262.5	11.07	.0903	232.2	853.5	76.28	929.8	1162.0
38	5472	.585	264.0	10.79	.0926	233.8	852.3	76.40	928.7	1162.5
39	5616	.653	265.6	10.53	.0949	235.4	851.0	76.52	927.6	1162.9
40	5760	.722	267.1	10.29	.0972	236.9	849.8	76.63	926.5	1163.4
41	5904	2.789	268.6	10.05	0.0995	238.5	848.7	76.75	925.4	1163.9
42	6048	.857	270.1	9.83	.1018	239.9	847.5	76.86	924.4	1164.3
43	6192	.925	271.5	9.61	.1040	241.4	846.4	76.97	923.3	1164.7
44	6336	.993	272.9	9.41	.1063	242.9	845.2	77.07	922.3	1165.2
45	6480	3.061	274.3	9.21	.1086	244.3	844.1	77.18	921.3	1165.6
46	6624	3.129	275.6	9.02	0.1108	245.6	843.1	77.29	920.4	1166.0
47	6768	.197	277.0	8.84	.1131	247.0	842.0	77.39	919.4	1166.4
48	6912	.265	278.3	8.67	.1153	248.3	841.0	77.49	918.5	1166.8
49	7056	.333	279.6	8.50	.1176	249.7	840.0	77.58	917.5	1167.2

TABLE 291 (*continued*).

PROPERTIES OF STEAM.

British Measure.

Pressure in pounds per square inch.	Pressure in pounds per square foot.	Pressure in atmospheres.	Temp. in degrees Fahr.	Volume per pound in cubic feet.	Weight per cubic foot in pounds.	Heat of water per pound in B. T. U.	Internal latent heat per pound of steam in B. T. U.	External latent heat per pound of steam in B. T. U.	Total latent heat per pound of steam in B. T. U.	Total heat per pound of steam in B. T. U.
50	7200	3.401	280.8	8.34	0.1198	251.0	839.0	77.67	916.6	1167.6
51	7344	.469	282.1	8.19	.1221	252.2	838.0	77.76	915.7	1168.0
52	7488	.537	283.3	8.04	.1243	253.5	837.0	77.85	914.9	1168.3
53	7632	.605	284.5	7.90	.1266	254.7	836.0	77.94	914.0	1168.7
54	7776	.673	285.7	7.76	.1288	256.0	835.1	78.03	913.1	1169.1
55	7920	3.741	286.9	7.63	0.1310	257.1	834.2	78.12	912.3	1169.4
56	8064	.810	288.1	7.50	.1333	258.3	833.2	78.21	911.5	1169.8
57	8208	.878	289.2	7.38	.1355	259.5	832.3	78.29	910.6	1170.1
58	8352	.946	290.3	7.26	.1377	260.7	831.5	78.37	909.8	1170.5
59	8496	4.014	291.4	7.14	.1400	261.8	830.6	78.45	909.0	1170.8
60	8640	4.082	292.5	7.03	0.1422	262.9	829.7	78.53	908.2	1171.2
61	8784	.150	293.6	6.92	.1444	264.0	828.9	78.61	907.5	1171.5
62	8928	.218	294.7	6.82	.1466	265.1	828.0	78.68	906.7	1171.8
63	9072	.286	295.7	6.72	.1488	266.1	827.2	78.76	905.9	1172.1
64	9216	.354	296.7	6.62	.1511	267.2	826.4	78.83	905.2	1172.4
65	9360	4.422	297.8	6.52	0.1533	268.3	825.6	78.90	904.5	1172.8
66	9504	.490	298.8	6.43	.1555	269.3	824.8	78.97	903.7	1173.1
67	9648	.558	299.8	6.34	.1577	270.4	824.0	79.04	903.1	1173.4
68	9792	.626	300.8	6.25	.1599	271.4	823.2	79.11	902.3	1173.7
69	9936	.694	301.8	6.17	.1621	272.4	822.4	79.18	901.6	1174.0
70	10080	4.762	302.7	6.09	0.1643	273.4	821.6	79.25	900.9	1174.3
71	10224	.830	303.7	6.00	.1665	274.3	820.9	79.32	900.2	1174.6
72	10368	.898	304.6	5.93	.1687	275.3	820.1	79.39	899.5	1174.9
73	10512	.966	305.5	5.85	.1709	276.3	819.4	79.46	898.8	1175.1
74	10656	5.034	306.5	5.78	.1731	277.2	818.7	79.53	898.1	1175.4
75	10800	5.102	307.4	5.70	0.1753	278.2	817.9	79.59	897.5	1175.7
76	10944	.170	308.3	5.63	.1775	279.1	817.2	79.65	896.9	1176.0
77	11088	.238	309.2	5.57	.1797	280.0	816.5	79.71	896.2	1176.2
78	11232	.306	310.1	5.50	.1818	280.9	815.8	79.77	895.6	1176.5
79	11376	.374	310.9	5.43	.1840	281.8	815.1	79.83	895.0	1176.8
80	11520	5.442	311.8	5.37	0.1862	282.7	814.4	79.89	894.3	1177.0
81	11664	.510	312.7	5.31	.1884	283.6	813.8	79.95	893.7	1177.3
82	11808	.578	313.5	5.25	.1906	284.5	813.0	80.01	893.1	1177.6
83	11952	.646	314.4	5.19	.1928	285.3	812.4	80.07	892.5	1177.8
84	12096	.714	315.2	5.13	.1949	286.2	811.7	80.13	891.9	1178.0
85	12240	5.782	316.0	5.07	0.1971	287.0	811.1	80.19	891.3	1178.3
86	11384	.850	316.8	5.02	.1993	287.9	810.4	80.25	890.7	1178.6
87	12528	.918	317.6	4.96	.2015	288.7	809.8	80.30	890.1	1178.9
88	12672	.986	318.4	4.91	.2036	289.5	809.2	80.35	889.5	1179.0
89	12816	6.054	319.2	4.86	.2058	290.4	808.5	80.40	888.9	1179.3
90	12960	6.122	320.0	4.81	0.2080	291.2	807.9	80.45	888.4	1179.5
91	13104	.190	320.8	4.76	.2102	292.0	807.3	80.50	887.8	1179.8
92	13248	.258	321.6	4.71	.2123	292.8	806.7	80.56	887.2	1180.0
93	13392	.327	322.4	4.66	.2145	293.6	806.1	80.61	886.7	1180.3
94	13536	.396	323.1	4.62	.2166	294.3	805.5	80.66	886.1	1180.5
95	13680	6.463	323.9	4.57	0.2188	295.1	804.9	80.71	885.6	1180.7
96	13824	.531	324.6	4.53	.2209	295.9	804.3	80.76	885.0	1180.9
97	13968	.599	325.4	4.48	.2231	296.7	803.7	80.81	884.5	1181.2
98	14112	.667	326.1	4.44	.2252	297.4	803.1	80.86	884.0	1181.4
99	14256	.735	326.8	4.40	.2274	298.2	802.5	80.91	883.4	1181.6

TABLE 291 (*continued*).

PROPERTIES OF STEAM.

British Measure.

Pressure in pounds per square inch.	Pressure in pounds per square foot.	Pressure in atmospheres.	Temp. in degrees Fahr.	Volume per pound in cubic feet.	Weight per cubic foot in pounds.	Heat of water per pound in B. T. U.	Internal latent heat per pound of steam in B. T. U.	External latent heat per pound of steam in B. T. U.	Total latent heat per pound of steam in B. T. U.	Total heat per pound of steam in B. T. U.
100	14400	6.803	327.6	4.356	0.2295	298.9	802.0	80.95	882.9	1181.8
101	14544	.871	328.3	.316	.2317	299.7	801.4	81.00	882.4	1182.1
102	14688	.939	329.0	.276	.2338	300.4	800.8	81.05	881.9	1182.3
103	14832	7.007	329.7	.237	.2360	301.1	800.3	81.10	881.4	1182.5
104	14976	.075	330.4	.199	.2381	301.9	799.7	81.14	880.8	1182.7
105	15120	7.143	331.1	4.161	0.2403	302.6	799.2	81.18	880.3	1182.9
106	15264	.211	331.8	.125	.2424	303.3	798.6	81.23	879.8	1183.1
107	15408	.279	332.5	.088	.2446	304.0	798.1	81.27	879.3	1183.4
108	15552	.347	333.2	.053	.2467	304.7	797.5	81.31	878.8	1183.6
109	15696	.415	333.8	.018	.2489	305.4	797.0	81.36	878.3	1183.8
110	15840	7.483	334.5	3.984	0.2510	306.1	796.5	81.41	877.9	1184.0
111	15984	.551	335.2	.950	.2531	306.8	795.9	81.45	877.4	1184.2
112	16128	.619	335.8	.917	.2553	307.5	795.4	81.50	876.9	1184.4
113	16272	.687	336.5	.885	.2574	308.2	794.9	81.54	876.4	1184.6
114	16416	.755	337.2	.853	.2596	308.8	794.4	81 58	875.9	1184.8
115	16560	7.823	337.8	3.821	0.2617	309.5	793.8	81.62	875.5	1185.0
116	16704	.891	338.5	.790	.2638	310.2	793.3	81.66	875.0	1185.2
117	16848	.959	339.1	.760	.2660	310.8	792.8	81.70	874.5	1185.4
118	16992	8.027	339.7	.730	.2681	311.5	792.3	81.74	874.1	1185.6
119	17136	.095	340.4	.700	.2702	312.1	791.8	81.78	873.6	1185.7
120	17280	8.163	341.0	3.671	0.2724	312.8	791.3	81.82	873.2	1185.9
121	17424	.231	341.6	.643	.2745	313.4	790.8	81.86	872.7	1186.1
122	17568	.299	342.2	.615	.2766	314.1	790.3	81.90	872.2	1186.3
123	17712	.367	342.8	.587	.2787	314.7	789.9	81.94	871.8	1186.5
124	17856	.435	343.5	.560	.2809	315.3	789.4	81.98	871.4	1186.7
125	18000	8.503	344.1	3.534	0.2830	316.0	788.9	82.02	870.9	1186.9
126	18144	.571	344.7	.507	.2851	316.6	788.4	82.06	870.5	1187.1
127	18288	.639	345.3	.481	.2872	317.2	787.9	82.09	870.0	1187.2
128	18432	.708	345.9	.456	.2893	317.8	787.5	82.13	869.6	1187.4
129	18576	.776	346.5	.431	.2915	318.4	787.0	82.17	869.2	1187.6
130	18720	8.844	347.1	3.406	0.2936	319.0	786.5	82.21	868.7	1187.8
131	18864	.912	347.6	.382	.2957	319.7	786.1	82.25	868.3	1188.0
132	19008	.980	348.2	.358	.2978	320.3	785.6	82.28	867.9	1188.1
133	19152	9.048	348.8	.334	.2999	320.9	785.1	82.32	867.5	1188.3
134	19296	.116	349.4	.310	.3021	321.5	784.7	82.35	867.0	1188.5
135	19440	9.184	349.9	3.287	0.3042	322.1	784.2	82.38	866.6	1188.7
136	19584	.252	350.5	.265	.3063	322.6	783.8	82.42	866.2	1188.8
137	19728	.320	351.1	.442	.3084	323.2	783.3	82.45	865.8	1189.0
138	19872	.388	351.6	.220	.3105	323.8	782.9	82.49	865.4	1189.2
139	20016	.456	352.2	.199	.3126	324.4	782.4	82.52	865.0	1189.4
140	20160	9.524	352.8	3.177	0.3147	325.0	782.0	82.56	864.6	1189.5
141	20304	.592	353.3	.156	.3168	325.5	781.6	82.59	864.2	1189.7
142	20448	.660	353.9	.135	.3190	326.1	781.1	82.63	863.8	1189.9
143	20592	.728	354.4	.115	.3211	326.7	780.7	82.66	863.4	1190.0
144	20736	.796	355.0	.094	.3232	327.2	780.3	82.69	863.0	1190.2
145	20880	9.864	355.5	3.074	0.3253	327.8	779.8	82.72	862.6	1190.4
146	21024	.932	356.0	.054	.3274	328.4	779.4	82.75	862.2	1190.5
147	21168	10.000	356.6	.035	.3295	328.9	779.0	82.79	861.8	1190.7
148	21312	.068	357.1	.016	.3316	329.5	778.6	82.82	861.4	1190.9
149	21456	.136	357.6	.997	.3337	330.0	778.1	82.86	861.0	1191.0

TABLE 291 *(continued).*

PROPERTIES OF STEAM.

British Measure.

Pressure in pounds per square inch.	Pressure in pounds per square foot.	Pressure in atmospheres.	Temp. in degrees Fahr.	Volume per pound in cubic feet.	Weight per cubic foot in pounds.	Heat of water per pound in B. T. U.	Internal latent heat per pound of steam in B. T. U.	External latent heat per pound of steam in B. T. U.	Total latent heat per pound of steam in B. T. U.	Total heat per pound of steam in B. T. U.
150	21600	10.204	358.2	2.978	0.3358	330.6	777.7	82.89	860.6	1191.2
151	21744	.272	358.7	.960	.3379	331.1	777.3	82.92	860.2	1191.3
152	21888	.340	359.2	.941	.3400	331.6	776.9	82.95	859.9	1191.5
153	22032	.408	359.7	.923	.3421	332.2	776.5	82.98	859.5	1191.7
154	22176	.476	360.2	.906	.3442	332.7	776.1	83.01	859.1	1191.8
155	22320	10.544	360.7	2.888	0.3462	333.2	775.7	83.04	858.7	1192.0
156	22464	.612	361.3	.871	.3483	333.8	775.3	83.07	858.3	1192.1
157	22608	.680	361.8	.854	.3504	334.3	774.9	83.10	858.0	1192.3
158	22752	.748	362.3	.837	.3525	334.8	774.5	83.13	857.6	1192.4
159	22896	.816	362.8	.820	.3546	335.3	774.1	83.16	857.2	1192.6
160	23040	10.884	363.3	2.803	0.3567	335.9	773.7	83.19	856.9	1192.7
161	23184	.952	363.8	.787	.3588	336.4	773.3	83.22	856.5	1192.9
162	23328	11.020	364.3	.771	.3609	336.9	772.9	83.25	856.1	1193.0
163	23472	.088	364.8	.755	.3630	337.4	772.5	83.28	855.8	1193.2
164	23616	.157	365.3	.739	.3650	337.9	772.1	83.31	855.4	1193.3
165	23760	11.225	365.7	2.724	0.3671	338.4	771.7	83.34	855.1	1193.5
166	23904	.293	366.2	.708	.3692	338.9	771.3	83.37	854.7	1193.6
167	24048	.361	366.7	.693	.3713	339.4	771.0	83.39	854.3	1193.8
168	24192	.429	367.2	.678	.3734	339.9	770.6	83.42	854.0	1193.9
169	24336	.497	367.7	.663	.3754	340.4	770.2	83.45	853.6	1194.1
170	24480	11.565	368.2	2.649	0.3775	340.9	769.8	83.48	853.3	1194.2
171	24624	.633	368.6	.634	.3796	341.4	769.4	83.51	852.9	1194.4
172	24768	.701	369.1	.620	.3817	341.9	769.1	83.54	852.6	1194.5
173	24912	.769	369.6	.606	.3838	342.4	768.7	83.56	852.2	1194.7
174	25056	.837	370.0	.592	.3858	342.9	768.3	83.59	851.9	1194.8
175	25200	11.905	370.5	2.578	0.3879	343.4	767.9	83.62	851.6	1194.9
176	25344	.973	371.0	.564	.3900	343.9	767.6	83.64	851.2	1195.1
177	25488	12.041	371.4	.550	.3921	344.3	767.2	83.67	850.9	1195.2
178	25632	.109	371.9	.537	.3942	344.8	766.8	83.70	850.5	1195 4
179	25776	.177	372.4	524	.3962	345.3	766.5	83.73	850.2	1195.5
180	25920	12.245	372.8	2.510	0.3983	345.8	766.1	83.75	849.9	1195.6
181	26064	.313	373.3	.497	.4004	346.3	765.8	83.77	849.5	1195.8
182	26208	.381	373.7	.485	.4025	346.7	765.4	83.80	849.2	1195.9
183	26352	.449	374.2	.472	.4046	347.2	765.0	83.83	848.9	1196.1
184	26496	.517	374.6	.459	.4066	347.7	764.7	83.86	848.5	1196.2
185	26640	12.585	375.1	2.447	0.4087	348.1	764.3	83.88	848.2	1196.3
186	26784	.653	375.5	.434	.4108	348.6	764.0	83.90	847.9	1196.5
187	26928	.721	376.0	.422	.4129	349.1	763.6	83.92	847.5	1196.6
188	27072	.789	376.4	.410	.4150	349.5	763.3	83.95	847.2	1196.7
189	27216	.857	376.8	.398	.4170	350.0	762.9	83.97	846.9	1196.9
190	27360	12.925	377.3	2.386	0.4191	350.4	762.6	83.99	846.6	1197.0
191	27504	.993	377.7	.374	.4212	350.9	762.2	84.02	846.3	1197.1
192	27648	13.061	378.2	.362	.4233	351.3	761.9	84.04	845.9	1197.3
193	27792	.129	378.6	.351	.4254	351.8	761.6	84.06	845.6	1197.4
194	27936	.197	379.0	.339	.4275	352.2	761.2	84.08	845.3	1197.5
195	28080	13.265	379.4	2.328	0.4296	352.7	760.9	84.10	845.0	1197.7
196	28224	.333	379.9	.317	.4316	353.1	760.5	84.13	844.7	1197.8
197	28368	.401	380.3	.306	.4337	353.6	760.2	84.16	844.4	1197.9
198	28512	.469	380.7	.295	.4358	354.0	759.9	84.19	844.0	1198.1
199	28656	.537	381.1	.284	.4379	354.4	759.5	84.21	843.7	1198.2

TABLE 291 (*continued*).

PROPERTIES OF STEAM.

British Measure.

Pressure in pounds per square inch.	Pressure in pounds per square foot.	Pressure in atmospheres.	Temp. in degrees Fahr.	Volume per pound in cubic feet.	Weight per cubic foot in pounds.	Heat of water per pound in B. T. U.	Internal latent heat per pound of steam in B. T. U.	External latent heat per pound of steam in B. T. U.	Total latent heat per pound of steam in B. T. U.	Total heat per pound of steam in B. T. U.
200	28800	13 605	381.6	2.273	0.4399	354.9	759.2	84.23	843.4	1198.3
201	28944	13.673	382.0	.262	.4420	355.3	758.9	84.26	843.1	1198.4
202	29088	13.742	382.4	.252	.4441	355.8	758.5	84.28	842.8	1198.6
203	29232	13.810	382.8	.241	.4461	356.2	758.2	84.30	842.5	1198.7
204	29376	13.878	383.2	.231	.4482	356.6	757.9	84.33	842.2	1198.8
205	29520	13.946	383.7	2.221	0.4503	357.1	757.5	84.35	841.9	1199.0
206	29664	14.014	384.1	.211	.4523	357.5	757.2	84.37	841.6	1199.1
207	29808	14.082	384.5	.201	.4544	357.9	756.9	84.40	841.3	1199.2
208	29952	14.150	384.9	.191	.4564	358.3	756.6	84.42	841.0	1199.3
209	30096	14.218	385.3	.181	.4585	358.8	756.2	84.44	840.7	1199.4
210	30240	14.386	385.7	2.171	0.4605	359.2	755.9	84.46	840.4	1199.6
211	30384	14.454	386.1	.162	.4626	359.6	755.6	84.48	840.1	1199.7
212	30528	14.522	386.5	.152	.4646	360.0	755.3	84.51	839.8	1199.8
213	30672	14.590	386.9	.143	.4666	360.4	755.0	84.53	839.5	1199.9
214	30816	14.658	387.3	.134	.4687	360.9	754.7	84.55	839.2	1200.1
215	30960	14.726	387.7	2.124	0.4707	361.3	754.3	84.57	838.9	1200.2
216	31104	14.794	388.1	.115	.4727	361.7	754.0	84.60	838.6	1200.3
217	31248	14.862	388.5	.106	.4748	362.1	753.7	84.62	838.3	1200.4
218	31392	14.930	388.9	.097	.4768	362.5	753.4	84.64	838.0	1200.5
219	31536	14.998	389.3	.088	.4788	362.9	753.1	84.66	837.7	1200.7

TABLE 292.

RATIO OF THE ELECTROSTATIC TO THE ELECTROMAGNETIC UNIT OF ELECTRICITY = V.

Date.	V Cm. per sec.	Mean.	Determined by	Reference.
1856		3.11×10^{10}	R. Kohlrausch and W. Weber.	Pogg. Ann. 99; 1856.
1868	$2.75–2.92 \times 10^{10}$	2.84	Maxwell.	Phil. Trans.; 1868.
1869	2.71–2.88	2.81	Thomson and King.	B. A. Report; 1869.
1874	2.86–3.00	2.90	McKichan.	Phil. Mag. 47; 1874.
1879	2.950–3.018	2.981	Rowland.	Phil. Mag. 28; 1889.
1879	–	2.96	Ayrton and Perry.	Phil. Mag. 7; 1879.
1879	–	2.967	Hockin.	B. A. Report; 1879.
1880	–	2.955	Shida.	Phil. Mag. 10; 1880.
1881	2.98–3.00	2.99	Stoletow.	Jour. de Phys.; 1881.
1882	–	2.87	Exner.	Wien. Ber.; 1882.
1883	–	2.963	J. J. Thomson.	Phil. Trans.; 1883.
1884	3.001–3.029	3.019	Klemenčič.	Wien. Ber. 83, 89, 93; 1881–6.
"	3.016–3.031			
1886	–	3.015	Colley.	Wied. Ann. 28; 1886.
1886–8	2.999–3.009			
"	3.003–3.008	3.009	Himstedt.	Wied. Ann. 29, 33, 35; 1887–8.
"	3.005–3.015			
1888	–	2.92	Thomson, Ayrton and Perry.	Electr. Rev. 23; 1888–9.
1889	2.995–3.010	3.000	Rosa.	Phil. Mag. 28; 1889.
1890	–	2.996	J. J. Thomson and Searle.	Phil. Trans.; 1890.
1891	–	3.009	Pellat.	Jour. de Phys. 10; 1891.
1892	2.990–2.995	2.991	Abraham.	Ann. Chim. et Phys. 27; 1829.
1896	–	3.001	Hurmuzescu.	Ann. Chim. et Phys. 10; 1897.
1898	–	2.9973	Perot and Fabry.	Ann. Chim. et Phys. 13; 1898.
1898	–	3.026	Webster.	Phys. Rev. 6; 1898.
1899	–	3.009	Lodge and Glazebrook.	Cam. Phil. Soc. 18; 1899.
1904–7	2.99706–2.99741	2.9971	Rosa and Dorsey.	Bull. Bur. Standards 3; 1907.

The last of the above determinations is the result of an extended series of measurements upon various forms of condensers, and is believed to be correct within 1/100 per cent. This, however, assumes that the International Ohm is 10^9 c.g.s. units. The value of V is therefore subject to one-half the error of the International Ohm.

TABLE 293.

ABSOLUTE MEASUREMENTS OF CURRENTS AND OF THE ELECTROMOTIVE FORCE OF STANDARD CELLS.

Date.	Observer.	Method.	Electromotive Force* of		Electrochemical Equivalent of Silver.			References.
			Clark Cell at 15° C.	Weston Cell at 20° C.	Filter Paper Voltameter.	Porous Cup Voltameter.	No-Septum Voltameter.	
			Volts.	Volts.	Mg.	Mg.	Mg.	
1872	Clark	Electrodynamometer Sine Galvanometer	1.4573 1.4562	– –	– –	– –	– –	1
1873	F. Kohlrausch	Tangent Galvanometer	–	–	1.1363	–	–	2
1882	Mascart	Current Balance	–	–	–	–	1.1156	3
1884	F. and W. Kohlrausch	Tangent Galvanometer	–	–	–	–	1.1183	4
1884	Rayleigh and Sedgwick	Current Balance	1.435	–	1.11794	–	–	5
1886	Gray	Sine Galvanometer	–	–	–	–	1.1183	6
1887	Koepsel	Electromag. Balance	–	–	1.11740	–	–	7
1890	Potier and Pellat	Electrodynamometer	–	–	–	–	1.1192	8
1896	Kahle †	Electrodynamometer	1.4325	1.0183	–	–	1.1183	9
1898	Patterson and Guthe	Electrodynamometer	–	–	1.1192	–	–	10
1899	Carhart and Guthe	Electrodynamometer	1.4333	–	–	–	–	11
1902	Callendar and King	Electrodynamometer	1.4334	–	–	–	–	12
1903	Pellat and Leduc	Electrodynamometer	–	–	1.1195	–	–	13
1904	Van Dijk and Kunst	Tangent Galvanometer	–	–	1.11823	–	–	14
1905	Guthe	Electrodynamometer	1.43296	1.01853	–	1.11773	–	15
1906	Van Dijk	Revision of 1904 work	–	–	–	1.1180	–	16
1907	Ayrton, Mather and Smith	Current Balance	1.4323	1.01819	–	–	–	17
1907	Smith, Mather and Lowry	With the above	–	–	1.11827	–	–	18
1908	Janet, Laporte and Jouaust ‡	Current Balance	–	1.01836	–	–	–	19
1908	Janet, Laporte and de la Gorce	With the above	–	–	1.11821	–	–	20
1908	Guillet ‡	Current Balance	–	1.01812	–	–	–	21
1908	Pellat ‡	Electrodynamometer	–	1.01831	–	–	–	22
1910	Haga and Boerema	Tangent Galvanometer	–	1.01825	–	–	–	23
1911	Rosa, Dorsey and Miller	Current Balance	–	1.01822	–	–	–	24
1911	Rosa, Vinal and McDaniel	With the above	–	–	–	1.11804	1.11804	25
1913	Haga and Boerema	Tangent Galvanometer	–	–	–	–	1.11802	26

1 Proc. Roy. Soc. May 30th, 1872 (Values in B. A. volts at 15.5 C.).
2 Pogg. Ann. vol. 149, p. 170 (anode wrapped in cloth).
3 J. de Phys. vol. 1, p. 109, vol. 3, p. 283.
4 Wied. Ann. vol. 27, p. 1, 1886.
5 Phil. Trans. A, vol. 175, p. 411, 1884.
6 Phil. Mag. vol. 22, p. 389, 1886.
7 Ann. d. Phys. vol. 31, p. 250, 1887.
8 J. de Phys. vol. 9, p. 381, 1890.
9 Zs f Instr. vol. 17, p. 97, 143–4, vol. 18, p. 276.
10 Phys. Rev. vol. 7, p. 257. (Added Ag_{20}).
11 Phys. Rev. vol. 9, p. 288, 1899.
12 Phil. Trans. A, vol. 199, p. 81, 1902.
13 C. R. vol. 136, p. 1649. (Muslin and filter paper both used.)
14 Ann. d. Phys. vol. 14, p. 569, 1904.
15 Bull. B. S. vol. 2, p. 33, 1906.
16 Ann. d. Phys. vol. 19, p. 249, 1906.
17 Phil. Trans. A, vol, 207, p. 463, 1908.
18 Phil. Trans. A, vol. 207, p. 545, 1908.
19 Bull. Int. Soc. Electr. vol. 8, p. 459, 1908. C. R. vol. 153, p. 718, 1911.
20 Bull. Int. Soc. Electr. vol. 8, p. 523, 1908.
21 Bull. Int. Soc. Electr. vol. 8, p. 535, 1908.
22 Bull. Int. Soc. Electr. vol. 8, p. 573, 1908.
23 Proc. Ak. Wiss. Amster. vol. 13, p. 587.
24 Bull. Bureau Standards, vol. 8, p. 269, 1912.
25 Bull. Bulletin Standards, vol. 8, p. 367, 1912.
26 Arch. Neer. Sci. IIIA, vol. 3, p. 324, 1913.

* The values given in these columns are not strictly absolute volts since they were in most cases determined in terms of an absolute ampere and an international ohm. Hence they may be called "semi-absolute." No absolute determinations of the ohm have been made in recent times, but some are in progress.

† Other values usually given as Kahle's results and officially used by the Reichsanstalt are voltameter determinations. To include them here would necessitate including many others similarly made. The value 1.1183 includes 5 filter paper determinations out of 26 observations.

‡ These values have been corrected for the difference between the French ohm at this time and that in use elsewhere. (C. R. vol. 153, p. 718.)

Measurements prior to Van Dijk (1906) and the subsequent filter paper voltameter determinations are now only of historical interest, but the large amount of work done in recent years makes these early determinations of especial interest. The errors due to the use of filter paper and other impurities (acid, alkali, colloidal matter, etc.) in the voltameter electrolyte make it impossible to apply corrections. The values for the cell are not readily comparable owing to variations in the voltage of the cell itself and the unit of resistance. See Dorn, Wiss. Abhl. der Phys. Tech. Reich., vol. II, p. 257. Since 1911 the voltage adopted for the Weston Normal Cell at 20° C. is 1.0183 international volts in all the leading countries. The international volt is to be distinguished from the absolute volt since it is based on the definition of the mercury ohm and the silver voltameter, taking the electrochemical equivalent of silver to be 1.11800 mg per coulomb. The difference between the international volt and the absolute volt is negligible for practical purposes. The temperature coefficient of the Weston Normal Cell (saturated type) is given in Table 294. The new value of the Weston cell was adopted in the United States on January 1, 1911.

TABLE 294.

COMPOSITION AND ELECTROMOTIVE FORCE OF VOLTAIC CELLS.

The electromotive forces given in this table approximately represent what may be expected from a cell in good working order, but with the exception of the standard cells all of them are subject to considerable variation.

(a) Double Fluid Cells.

Name of cell.	Negative pole.	Solution.	Positive pole.	Solution.	E.M.F. in volts.
Bunsen . .	Amalgamated zinc	1 part H_2SO_4 to 12 parts H_2O .	Carbon	Fuming H_2NO_3 .	1.94
“ . .	“ “	“	“	HNO_3, density 1.38	1.86
Chromate .	“ “	12 parts $K_2Cr_2O_7$ to 25 parts of H_2SO_4 and 100 parts H_2O . .	“	1 part H_2SO_4 to 12 parts H_2O .	2.00
“ .	“ “	1 part H_2SO_4 to 12 parts H_2O .	“	12 parts $K_2Cr_2O_7$ to 100 parts H_2O	2.03
Daniell* .	“ “	1 part H_2SO_4 to 4 parts H_2O .	Copper	Saturated solution of $CuSO_4+5H_2O$	1.06
“ .	“ “	1 part H_2SO_4 to 12 parts H_2O .	“	“	1.09
“ .	“ “	5% solution of $ZnSO_4+6H_2O$	“	“	1.08
“ .	“ “	1 part NaCl to 4 parts H_2O .	“	“	1.05
Grove . .	“ “	1 part H_2SO_4 to 12 parts H_2O .	Platinum	Fuming HNO_3 . .	1.93
“ . .	“ “	Solution of $ZnSO_4$	“	HNO_3, density 1.33	1.66
“ . .	“ “	H_2SO_4 solution, density 1.136 .	“	Concentrated HNO_3	1.93
“ . .	“ “	H_2SO_4 solution, density 1.136 .	“	HNO_3, density 1.33	1.79
“ . .	“ “	H_2SO_4 solution, density 1.06 .	“	“	1.71
“ . .	“ “	H_2SO_4 solution, density 1.14 .	“	HNO_3, density 1.19	1.66
“ . .	“ “	H_2SO_4 solution, density 1.06 .	“	“ “ “	1.61
“ . .	“ “	NaCl solution . .	“	“ density 1.33	1.88
Marié Davy	“ “	1 part H_2SO_4 to 12 parts H_2O	Carbon	Paste of protosulphate of mercury and water . . .	1.50
Partz . .	“ “	Solution of $MgSO_4$	“	Solution of $K_2Cr_2O_7$	2.06

---

* The Minotto or Sawdust, the Meidinger, the Callaud, and the Lockwood cells are modifications of the Daniell, and hence have about the same electromotive force.

COMPOSITION AND ELECTROMOTIVE FORCE OF VOLTAIC CELLS.

Name of cell.	Negative pole.	Solution.	Positive pole.	E. M. F. in volts.
(b) Single Fluid Cells.				
Leclanche . . .	Amal. zinc	Solution of sal-ammoniac	Carbon. Depolarizer: manganese peroxide with powdered carbon	1.46
Chaperon . . .	" "	Solution of caustic potash	Copper. Depolarizer: CuO . . .	0.98
Edison-Lelande .	" "	"	"	0.70
Chloride of silver	Zinc . .	23 % solution of sal-ammoniac	Silver. Depolarizer: silver chl'ride	1.02
Law	" . .	15 % " "	Carbon	1.37
Dry cell (Gassner)	" . .	1 pt. ZnO, 1 pt. NH_4Cl, 3 pts. plaster of paris, 2 pts. $ZnCl_2$, and water to make a paste . .	"	1.3
Poggendorff . .	Amal. zinc	Solution of chromate of potash	"	1.08
" . . .	" "	12 parts $K_2Cr_2O_7$ + 25 parts H_2SO_4 + 100 parts H_2O . .	"	2.01
J. Regnault . . .	" "	1 part H_2SO_4 + 12 parts H_2O + 1 part $CaSO_4$ . .	Cadmium . . .	0.34
Volta couple . .	Zinc . .	H_2O	Copper	0.98
(c) Standard Cells.				
Weston normal .	Cadmi'm am'lgam	Saturated solution of $CdSO_4$	Mercury. Depolarizer: paste of Hg_2SO_4 and $CdSO_4$	1.0183* at 20° C
Clark standard .	Zinc am'lgam	Saturated solution of $ZnSO_4$	Mercury. Depolarizer: paste of Hg_2SO_4 and $ZnSO_4$	1.434‡ at 15° C
(d) Secondary Cells.				
Lead accumulator	Lead . .	H_2SO_4 solution of density 1.1 . . .	PbO_2	2.2†
Regnier (1) . . .	Copper .	$CuSO_4 + H_2SO_4$ . .	"	1.68 to 0.85, average 1.3.
" (2) . . .	Amal. zinc	$ZnSO_4$ solution . . .	" in H_2SO_4 .	2.36
Main	Amal. zinc	H_2SO_4 density ab't 1.1	"	2.50
Edison	Iron . .	KOH 20 % solution .	A nickel oxide .	1.1, mean of full discharge.

---

* E. M. F. hitherto used at Bureau of Standards. See p. 251. The temperature formula is $E_t = E_{20} - 0.0000406 (t-20) - 0.00000095 (t-20)^2 + 0.00000001 (t-20)^3$. ‡The value given is that adopted by the Chicago International Electrical Congress in 1893. The temperature formula is $E_t = E_{15} - 0.00119 (t-15) - 0.000007 (t-15)^2$.

† F. Streintz gives the following value of the temperature variation $\frac{dE}{dt}$ at different stages of charge:

E. M. F.	1.9223	1.9828	2.0031	2.0084	2.0105	2.0779	2.2070
$dE/dt \times 10^6$	140	228	335	285	255	130	73

Dolezalek gives the following relation between E. M. F and acid concentration:

Per cent H_2SO_4	64.5	52.2	35.3	21.4	5.2
E.M.F., 0° C	2.37	2.25	2.10	2.00	1.89

TABLE 295.

CONTACT DIFFERENCE OF

Solids with Liquids and

Temperature of substances

	Carbon.	Copper.	Iron.	Lead.	Platinum.	Tin.	Zinc.
Distilled water	.01 to .17	.269 to .100	.148	.171	.285 to .345	.177	—.105 to +.156
Alum solution: saturated at 16°.5 C.	-	—.127	—.653	—.139	.246	—.225	—.536
Copper sulphate solution: sp. gr. 1.087 at 16°.6 C.	-	.103	-	-	-	-	-
Copper sulphate solution: saturated at 15° C. . .	-	.070	-	-	-	-	-
Sea salt solution: sp. gr. 1.18 at 20°.5 C. . . .	-	—.475	—.605	-	—.856	—.334	—.565
Sal-ammoniac solution: saturated at 15°.5 C. .	-	—.396	—.652	—.189	.059	—.364	—.637
Zinc sulphate solution: sp. gr. 1.125 at 16°.9 C. . .	-	-	-	-	-	-	—.238
Zinc sulphate solution: saturated at 15°.3 C. .	-	-	-	-	-	-	—.430
One part distilled water + 3 parts saturated zinc sulphate solution . . .	-	-	-	-	-	-	—.444
Strong sulphuric acid in distilled water:							
1 to 20 by weight . . .	-	-	-	-	-	-	—.344
1 to 10 by volume . . .	about —.035	-	-	-	-	-	-
1 to 5 by weight	-	-	-	-	-	-	-
5 to 1 by weight	.01 to 3.0	-	-	—.120	-	—.25	-
Concentrated sulphuric acid	.55 to .85	1.113	-	.72 to 1.252	1.3 to 1.6	-	-
Concentrated nitric acid .	-	-	-	-	.672	-	-
Mercurous sulphate paste .	-	-	-	-	-	-	-
Distilled water containing trace of sulphuric acid	-	-	-	-	-	-	—.241

---

* Everett's "Units and Physical Constants:" Table of

POTENTIAL IN VOLTS.

Liquids with Liquids in Air.*

during experiment about 16° C.

	Amalgamated zinc.	Brass.	Mercury.	Distilled water.	Alum solution: saturated at 16°.5 C.	Copper sulphate solution: saturated at 15° C.	Zinc sulphate solution: sp. gr. 1.25 at 16°.9 C.	Zinc sulphate solution: saturated at 15°.3 C.	One part distilled water + 3 pts. zinc sulphate.	Strong nitric acid.
Distilled water	.100	.231	–	–	–	—.043	–	.164	–	–
Alum solution: saturated at 16°.5 C.	–	—.014	–	–	–	–	–	–	–	–
Copper sulphate solution: sp. gr. 1.087 at 16°.6 C.	–	–	–	–	–	–	.090	–	–	–
Copper sulphate solution: saturated at 15° C. . .	–	–	–	—.043	–	–	–	.095	.102	–
Sea salt solution: sp. gr. 1.18 at 20°.5 C. . . .	–	—.435	–	–	–	–	–	–	–	–
Sal-ammoniac solution: saturated at 15°.5 C. .	–	—.348	–	–	–	–	–	–	–	–
Zinc sulphate solution: sp. gr. 1.125 at 16°.9 C.	–	–	–	–	–	–	–	–	–	–
Zinc sulphate solution: saturated at 15°.3 C. .	—.284	–	–	—.200	–	—.095	–	–	–	–
One part distilled water + 3 parts saturated zinc sulphate solution . .	–	–	–	–	–	—.102	–	–	–	–
Strong sulphuric acid in distilled water:										
1 to 20 by weight . . .	–	–	–	–	–	–	–	–	–	–
1 to 10 by volume . . .	—.358	–	–	–	–	–	–	–	–	–
1 to 5 by weight	.429	–	–	–	–	–	–	–	–	–
5 to 1 by weight	–	—.016	–	–	–	–	–	–	–	–
Concentrated sulphuric acid	.848	–	–	1.298	1.456	1.269	–	1.699	–	–
Concentrated nitric acid .			–	–	–	–	–	–	–	–
Mercurous sulphate paste .	–	–	.475	–	–	–	–	–	–	–
Distilled water containing trace of sulphuric acid .	–	–	–	–	–	–	–	–	–	.078

Ayrton and Perry's results, prepared by Ayrton.

TABLE 296.

CONTACT DIFFERENCE OF POTENTIAL IN VOLTS.

Solids with Solids in Air.*

The following results are the " Volta differences of potential," as measured by an electrometer. They represent the difference of the potentials of the air near each of two metals placed in contact. This should not be confused with the junction electromotive force at the junction of two metals in metallic contact, which has a definite value, proportional to the coefficient of Peltier effect. The Volta difference of potential has been found to vary with the condition of the metallic surfaces and with the nature of the surrounding gas. No great reliance, therefore, can be placed on the tabulated values.

The temperature of the substances during the experiment was about 18° C.

	Carbon.	Copper.	Iron.	Lead.	Platinum.	Tin.	Zinc.	Zinc amalgam.	Brass.
Carbon . . .	0	.370	.485	.858	.113	.795	1.096†	1.208†	.414†
Copper . . .	—.370	0	.146	.542	—.238	.456	.750	.894	.087
Iron	—.485†	—.146	0	.401†	—.369	.313†	.600†	.744†	—.064
Lead . . .	—.858	—.542	—.401	0	—.771	—.099	.210	.357†	—.472
Platinum . .	—.113†	.238	.369	.771	0	.690	.981	1.125†	.287
Tin	—.795†	—.458	—.313	.099	—.690	0	.281	.463	—.372
Zinc	—1.096†	—.750	—.600	—.216	—.981	.281	0	.144	—.679
" amalgam	—1.208†	—.894	—.744	—.357†	—1.125†	—.463	—.144	0	—.822
Brass . . .	—.414	—.087	.064	.472	—.287	.372	.679	.822	0

The numbers not marked were obtained by direct experiment, those marked with a dagger by calculation, on the assumption that in a compound circuit of metals, all at the same temperature, there is no electromotive force.

The numbers in the same vertical column are the differences of potential in volts between the substance named at the top of the column and the substance named on the same line in the first column, when the two substances are in contact.

The metals used were those ordinarily obtained in commerce.

---

* Everett's " Units and Physical Constants." The table is from Ayrton and Perry's experiments, and was prepared by Ayrton.

TABLE 297.

DIFFERENCE OF POTENTIAL BETWEEN METALS IN SOLUTIONS OF SALTS.

The following numbers are given by G. Magnanini[*] for the difference of potential in hundredths of a volt between zinc in a normal solution of sulphuric acid and the metals named at the head of the different columns when placed in the solution named in the first column. The solutions were contained in a U-tube, and the sign of the difference of potential is such that the current will flow from the more positive to the less positive through the external circuit.

Strength of the solution in gram molecules per liter.		Zinc.†	Cadmium.†	Lead.	Tin.	Copper.	Silver.
No. of molecules.	Salt.	Difference of potential in centivolts.					
0.5	H_2SO_4	0.0	36.6	51.3	51.3	100.7	121.3
1.0	$NaOH$	—32.1	19.5	31.8	0.2	80.2	95.8
1.0	KOH	—42.5	15.5	32.0	—1.2	77.0	104.0
0.5	Na_2SO_4	1.4	35.6	50.8	51.4	101.3	120.9
1.0	$Na_2S_2O_3$	—5.9	24.1	45.3	45.7	38.8	64.8
1.0	KNO_3	11.8‡	31.9	42.6	31.1	81.2	105.7
1.0	$NaNO_3$	11.5	32.3	51.0	40.9	95.7	114.8
0.5	K_2CrO_4	23.9‡	42.8	41.2	40.9	94.6	121.0
0.5	$K_2Cr_2O_7$	72.8	61.1	78.4	68.1	123.6	132.4
0.5	K_2SO_4	1.8	34.7	51.0	40.9	95.7	114.8
0.5	$(NH_4)_2SO_4$	—0.5	37.1	53.2	57.6‡	101.5	125.7
0.25	$K_4FeC_6N_6$	—6.1	33.6	50.7	41.2	— ‡	87.8
0.167	$K_6Fe_2(CN)_2$	41.0§	80.8	81.2	130.9	110.7	124.9
1.0	$KCNS$	—1.2	32.5	52.8	52.7	52.5	72.5
1.0	$NaNO_3$	4.5	35.2	50.2	49.0	103.6	104.6?
0.5	$SrNO_3$	14.8	38.3	50.6	48.7	103.0	119.3
0.125	$Ba(NO_3)_2$	21.9	39.3	51.7	52.8	109.6	121.5
1.0	KNO_3	— ‡	35.6	47.5	49.9	104.8	115.0
0.2	$KClO_3$	15–10‡	39.9	53.8	57.7	105.3	120.9
0.167	$KBrO_3$	13–20‡	40.7	51.3	50.9	111.3	120.8
1.0	NH_4Cl	2.9	32.4	51.3	50.9	81.2	101.7
1.0	KF	2.8	22.5	41.1	50.8	61.3	61.5
1.0	$NaCl$	—	31.9	51.2	50.3	80.9	101.3
1.0	KBr	2.3	31.7	47.2	52.5	73.6	82.4
1.0	KCl	—	32.1	51.6	52.6	81.6	107.6
0.5	Na_2SO_3	—8.2	28.7	41.0	31.0	68.7	103.7
– ‖	$NaOBr$	18.4	41.6	73.1	70.6 ‡	89.9	99.7
1.0	$C_4H_6O_6$	5.5	39.7	61.3	54.4§	104.6	123.4
0.5	$C_4H_6O_6$	4.1	41.3	61.6	57.6	110.9	125.7
0.5	$C_4H_4KNaO_6$	—7.9	31.5	51.5	42–47	100.8	119.7

[*] "Rend. della R. Acc. di Roma," 1890.

† Amalgamated.

‡ Not constant.

§ After some time.

‖ A quantity of bromine was used corresponding to NaOH = 1.

TABLE 298.

THERMOELECTRIC POWER.

The thermoelectric power of a circuit of two metals is the electromotive force produced by one degree C. difference of temperature between the junctions. The thermoelectric power varies with the temperature, thus: thermoelectric power $= Q = dE/dt = A + Bt$, where A is the thermoelectric power at 0° $C.$, B is a constant, and t is the mean temperature of the junctions. The neutral point is the temperature at which $dE/dt = 0$, and its value is $-A/B$. When a current is caused to flow in a circuit of two metals originally at a uniform temperature, heat is liberated at one of the junctions and absorbed at the other. The rate of production or liberation of heat at each junction, or Peltier effect, is given in calories per second, by multiplying the current by the coefficient of the Peltier effect. This coefficient in calories per coulomb $= QT/J$, in which Q is in volts, T is the absolute temperature of the junction, and $J = 4.19$. Heat is also liberated or absorbed in each of the metals as the current flows through portions of varying temperature. The rate of production or liberation of heat in each metal, or the Thomson effect, is given in calories per second by multiplying the current by the coefficient of the Thomson effect. This coefficient, in calories per coulomb, $= BT\theta/J$, in which B is in volts per degree C., T is the mean absolute temperature of the junctions, and θ is the difference of temperature of the junctions. (BT) is Sir W. Thomson's "Specific Heat of electricity." The algebraic signs are so chosen in the following table that when A is positive, the current flows in the metal considered from the cold junction to the hot. When B is positive, Q increases (algebraically) with the temperature. The values of A, B, and thermoelectric power, in the following table are with respect to lead as the other metal of the thermoelectric circuit. The thermoelectric power of a couple composed of two metals, 1 and 2, is given by subtracting the value for 2 from that for 1; when this difference is positive, the current flows from the cold junction to the hot in 1. In the following table, A is given in microvolts, B in microvolts per degree C., and the neutral point in degrees C.

The table has been compiled from the results of Becquerel, Matthiessen and Tait; in reducing the results, the electromotive force of the Grove and Daniell cells has been taken as 1.95 and 1.07 volts. The value for constantin was reduced from results given in Landolt-Börnstein's tables. The thermoelectric powers of antimony and bismuth alloys are given by Becquerel in the reference given below.

Substance.	A Microvolts.	B Microvolts.	Thermoelectric power at mean temp. of junctions (microvolts).		Neutral point $-\frac{A}{B}$.	Authority.
			20° C.	50° C.		
Aluminum	0.76	—0.0039	0.68	0.56	195	T
Antimony, comm'l pressed wire	-	-	—6.0	-	-	M
" axial	-	-	—22.6	-	-	"
" equatorial	-	-	—26.4	-	-	"
" ordinary	-	-	—17.0	-	-	B
Argentan	11.94	0.0506	12.95	14.47	—236	T
"	-	-	-	12.7	-	B
Arsenic	-	-	13.56	-	-	M
Bismuth, comm'l pressed wire	-	-	97.0	-	-	"
" pure " "	-	-	89.0	-	-	"
" crystal, axial	-	-	65.0	-	-	"
" " equatorial	-	-	45.0	-	-	"
" commercial	-	-	-	39.9	-	B
Cadmium	—2.63	—0.0424	—3.48	—4.75	—62	T
" fused	-	-	-	—2.45	-	B
Cobalt	-	-	22.	-	-	M
Constantin	-	-	-	+19.3	-	-
Copper	—1.34	—0.0094	—1.52	—1.81	—143	T
" commercial	-	-	—0.10	-	-	M
" galvanoplastic	-	-	—3.8	-	-	"
Gold	-	-	—1.2	-	-	"
"	—2.80	—0.0101	—3.0	—3.30	[—277]	T
Iron	—17.15	0.0482	—16.2	—14.74	356	"
" pianoforte wire	-	-	—17.5	-	-	M
" commercial	-	-	-	—12.10	-	B
" "	-	-	-	—9.10	-	"
Lead	-	0.0000	0.00	0.00	-	-
Magnesium	—2.22	0.0094	—2.03	—1.75	236	T
Mercury	-	-	0.413	-	-	M
"	-	-	-	3.30	-	B
Nickel	-	-	-	15.50	-	"
" (—18° to 175°)	21.8	0.0506	22.8	24.33	[—431]	T
" (250°–300°)	83.57	—0.2384	-	-	-	"
" (above 340°)	3.04	0.0506	-	-	-	"

TABLE 298.—Thermoelectric Power (*continued*).

Substance.	A Microvolts.	B Microvolts.	Thermoelectric power at mean temp of junctions (microvolts).		Neutral point $-\frac{A}{B}$.	Authority.
			20° C.	50° C.		
Palladium	6.18	0.0355	6.9	7.96	—174	T
"	–	–	–	6.9	–	B
Phosphorus (red)	–	–	—29.9	–	–	M
Platinum	–	–	—0.9	–	–	"
" (hardened)	—2.57	0.0074	—2.42	—2.20	347	T
" (malleable)	0.60	0.0109	8.82	1.15	—55	"
" wire	–	–	–	—0.94	–	B
" another specimen	–	–	–	2.14	–	"
Platinum-iridium alloys:						
85 % Pt+15 % Ir	—7.90	—0.0062	—8.03	—8.21	[—1274]	T
90 % Pt+10 % Ir	—5.90	0.0133	—5.63	—5.23	444	"
95 % Pt + 5 % Ir	—6.15	—0.0055	—6.26	—6.42	[—1118]	"
Selenium	–	–	—807.	–	–	M
Silver	—2.12	—0.0147	—2.41	—2.86	—144	T
" (pure hard)	–	–	—3.00	–	–	M
" wire	–	–	–	—2.18	–	B
Steel	—11.27	0.0325	—10.62	—9.65	347	T
Tellurium	–	–	—502.	–	–	M
"	–	–	–	—429.3	–	B
Tellurium β	–	–	—500.	–	–	H
" α	–	–	—160.	–	–	H
Tin (commercial)	–	–	–	—0.33	–	"
"	–	–	—0.1	–	–	M
"	0.43	—0.0055	0.33	0.16	78	T
Zinc	—2.32	—0.0238	—2.79	—3.51	—98	"
" pure pressed	–	–	—3.7	–	–	M

B Ed. Becquerel, "Ann. de Chim. et de Phys." [4] vol. 8.
M Matthiesen, "Pogg. Ann." vol. 103, reduced by Fleming Jenkin.
T Tait, "Trans. R. S. E." vol. 27, reduced by Mascart.
B Haken, Ann. der Phys. 32, p. 291, 1910. (Electrical conductivity of Teβ=0.04, Teα 1.7 e. m. units.)

TABLE 299.—Thermoelectric Power of Alloys.

The thermoelectric powers of a number of alloys are given in this table, the authority being Ed. Becquerel. They are relative to lead, and for a mean temperature of 50° C. In reducing the results from copper as, a reference metal, the thermoelectric power of lead to copper was taken as —1.9.

Substance.	Relative quantity.	Thermoelectric power in microvolts.	Substance.	Relative quantity.	Thermoelectric power in microvolts.	Substance.	Relative quantity.	Thermoelectric power in microvolts.
Antimony Cadmium	806 696	227	Antimony Zinc Tin	2 1 1	43	Bismuth Antimony	4 1	—51.4
Antimony Cadmium Zinc	4 2 1	146	Antimony Cadmium Zinc	12 10 3	35	Bismuth Antimony	8 1	—63.2
Antimony Cadmium Bismuth	806 696 121	137	Antimony Tellurium	10 1	10.2	Bismuth Antimony	10 1	—68.2
Antimony Zinc	806 406	95	Antimony Bismuth	10 1	8.8	Bismuth Antimony	12 1	—66.9
Antimony Zinc Bismuth	806 406 121	8.1	Antimony Iron	4 1	2.5	Bismuth Tin	2 1	60
Antimony Cadmium Lead Zinc	4 2 1 1	76	Antimony Magnesium	8 1	1.4	Bismuth Selenium	10 1	—24.5
Antimony Cadmium Zinc Tin	4 2 1 1	46	Antimony Lead	8 1	—0.4	Bismuth Zinc	12 1	—31.1
			Bismuth	–	—43.8	Bismuth Arsenic	12 1	—46.0
			Bismuth Antimony	2 1	—33.4	Bismuth Bismuth sulphide	1 1	68.1

TABLE 300.—Thermoelectric Power against Platinum.

One junction is supposed to be at 0° C; + indicates that the current flows from the 0° junction into the platinum. The rhodium and iridium were rolled, the other metals drawn.*

Temperature, °C.	Au.	Ag.	90%Pt+ 10%Pd.	10%Pt+ 90%Pd.	Pd.	90%Pt+ 10%Rh.	90%Pt+ 10%Ru.	Ir.	Rh.
—185	—0.15	—0.16	—0.11	+0.24	+0.77	-	—0.53	—0.28	—0.24
—80	—0.31	—0.30	—0.09	+0.15	+0.39	-	—0.39	—0.32	—0.31
+100	+0.74	+0.72	+0.26	—0.19	—0.56	-	+0.73	+0.65	+0.65
+200	+1.8	+1.7	+0.62	—0.31	—1.20	-	+1.6	+1.5	+1.5
+300	+3.0	+3.0	+1.0	—0.37	—2.0	+2.3	+2.6	+2.5	+2.6
+400	+4.5	+4.5	+1.5	—0.35	—2.8	+3.2	+3.6	+3.6	+3.7
+500	+6.1	+6.2	+1.9	—0.18	—3.8	+4.1	+4.6	+4.8	+5.1
+600	+7.9	+8.2	+2.4	+0.12	—4.9	+5.1	+5.7	+6.1	+6.5
+700	+9.9	+10.6	+2.9	+0.61	—6.3	+6.2	+6.9	+7.6	+8.1
+800	+12.0	+13.2	+3.4	+1.2	—7.9	+7.2	+8.0	+9.1	+9.9
+900	+14.3	+16.0	+3.8	+2.1	—9.6	+8.3	+9.2	+10.8	+11.7
+1000	+16.8	-	+4.3	+3.1	—11.5	+9.5	+10.4	+12.6	+13.7
+1100	-	-	+4.8	+4.2	—13.5	+10.6	+11.6	+14.5	+15.8
+(1300)	-	-	-	-	-	+13.1	+14.2	+18.6	+20.4
+(1500)	-	-	-	-	-	+15.6	+16.9	+23.1	+25.6

* Holborn and Day.

TABLE 301.—Thermal E. M. F. of Pure Platinum Against Platinum-Rhodium Alloys, in Millivolts.*

t	1 p. ct.	5 p. ct.	10 p. ct.			15 p. ct.	20 p. ct.	30 p. ct.†	40 p. ct.†	100 p. ct.‡
			Low.	High.	Standard.					
100°	0.21	0.55	0.63	0.64	0.64	0.65	.....	....	....	0.65
200	0.42	1.18	1.41	1.43	1.43	1.50	....	....	....	1.51
300	0.63	1.85	2.28	2.32	2.32	2.41	....	2.34	2.45	2.57
400	0.84	2.53	3.21	3.26	3.25	3.45	3.50	3.50	3.64	3.76
500	1.05	3.22	4.17	4.23	4.23	4.55	4.60	4.74	4.93	5.08
600	1.25	3.92	5.16	5.24	5.23	5.71	5.83	6.06	6.31	6.55
700	1.45	4.62	6.19	6.28	6.27	6.94	7.18	7.49	7.80	8.14
800	1.65	5.33	7.25	7.35	7.33	8.23	8.60	9.01	9.37	9.87
900	1.85	6.05	8.35	8.46	8.43	9.57	10.09	10.67	11.09	11.74
1000	2.05	6.79	9.47	9.60	9.57	10.96	11.65	12.42	12.94	13.74
1100	2.25	7.53	10.64	10.77	10.74	12.40	13.29	14.33	14.99	15.87
1200	2.45	8.29	11.82	11.97	11.93	13.87	14.96	16.39	17.13	18.10
1300	2.65	9.06	13.02	13.18	13.13	15.38	16.65	18.51	19.51	20.46
1400	2.86	9.82	14.22	14.39	14.34	16.98	18.39	20.67	21.73	....
1500	3.06	10.56	15.43	15.61	15.55	18.41	20.15	....	....	....
1600	3.26	11.31	16.63	16.82	16.75	19.94	21.90	....	....	....
1700	3.46	12.05	17.83	18.03	17.95	21.47	23.65	....	....	....
1755	3.56	12.44	18.49	18.70	18.61	22.31	24.55	....	....	....

* Carnegie Institution, Pub. 157, 1911.

† Holborn and Wien, 1892.

‡ Holborn and Day, mean value, 1899.

TABLE 302. — Peltier Effect.

The coefficient of Peltier effect may be calculated from the constants *A* and *B* of Table 298, as there shown. Experimental results, expressed in slightly different units, are here given. The figures are for the heat production at a junction of copper and the metal named, in calories per ampere-hour. The current flowing from copper to the metal named, a positive sign indicates a warming of the junction. The temperature not being stated by either author, and Le Roux not giving the algebraic signs, these results are not of great value.

	Calories per ampere-hour.										
	Sb. ‡	Sb. commercial.	Bi. pure.	Bi. §	Cd.	German Silver.	Fe.	Ni.	Pt.	Ag.	Zn.
Jahn* . .	-	-	-	-	—.62	-	—3.61	4.36	0.32	—.41	—.58
Le Roux† .	13.02	4.8	19.1	25.8	0.46	2.47	2.5	-	-	-	.39

* "Wied. Ann." vol. 34, p. 767.
† "Ann. de Chim. et de Phys." (4) vol. 10, p. 201.
‡ Becquerel's antimony is 806 parts Sb + 406 parts Zn + 121 parts Bi.
§ Becquerel's bismuth is 10 parts Bi + 1 part Sb.

TABLE 303. — Peltier Effect, Fe-Constantan, Ni-Cu, 0 — 560° C.

Temperature.	0°	20°	130°	240°	320°	560°	
Fe-Constantan . . .	3.1	3.6	4.5	6.2	8.2	12.5	in Gram. Cal. $\times -10^{8}$
Ni-Cu	1.92	2.15	2.45	2.06	1.91	2.38	per coulomb.

TABLE 304. — Peltier Electromotive Force in Millivolts.

Metal against Copper.	Sb.	Fe.	Cd.	Zn.	Ag.	An.	Pb.	Sn.	Al.	Pt.	Pd.	Ni.	Bi.
Le Roux .	—5.64	—2.93	—.53	—.45	-	-	-	-	-	-	-	-	+22.3
Jahn . . .	-	—3.68	—.72	—.68	—.48	-	-	-	-	+.37	-	+5.07	-
Edlund . .	-	—2.96	—.16	—.01	+.03	+.33	+.50	+.56	+.70	+1.02	+2.17	-	+17.7
Caswell . .	-	-	-	-	+.03	-	-	-	+.70	+.85	-	+6.0	+16.1

Le Roux, 1867; Jahn, 1888; Edlund, 1870-71; Caswell, Phys. Rev. 33, p. 381, 1911.

TABLE 305.

VARIOUS DETERMINATIONS OF THE VALUE OF THE OHM.

Date.	Observer.	Method.	Value of B. A. unit in ohms.	Value of Siemens unit, B. A. unit.	Value of ohm in cms. of Hg.
1882	Lord Rayleigh .	Rotating coil . .	0.98651	0.95412	106.24
1883	Lord Rayleigh .	Lorenz method . .	.98677	.95412	106.21
1884	Mascart . . .	Induced current . .	.98611	.95374	106.33
1887	Rowland . . .	Mean of several methods	.98644	.95349	106.32
1887	Kohlrausch . .	Damping of magnets .	.98660	.95338	106.32
1882 } 1888 }	Glazebrook . .	Induced currents . .	.98665	.95352	106.29
1890	Wuilleumeier . .	Mean effect of induced currents . . .	.98686	.95355	106.31
1890	Duncan and Wilkes	Lorenz method . .	.98634	.95341	106.34
1891	Jones . . .	Lorenz method . .	-	-	106.31
1894	Jones . . .	Lorenz method . .	-	-	106.33
1895	Himstedt . .	Mean effect of induced current . . .	-	-	106.28
1897	Ayrton and Jones .	Lorenz method . .	(.98634)	-	106.27
1899	Guillet . . .	Mean effect of induced current, using a calibrated 1000-ohm coil . . .		-	106.20
		Means . . .	0.98651	0.95366	106.288
1883	Wild . . .	Damping of magnet .	-	-	106.03
1884	Wiedemann . .	Earth inductor . .	-	-	106.19
1884	H. F. Weber . .	Induced current . .	-	-	105.37
1884	H. F. Weber . .	Rotating coil . . .	-	-	106.16
1884	Roiti . . .	Mean effect of induced current, using German silver coils certified by makers		-	105.89
1885	Himstedt . .	Mean effect of induced current, using German silver coils certified by makers		-	105.98
1885	Lorenz . . .	Lorenz method . .	-	-	105.93
1889	Dorn . . .	Damping of magnet .	-	-	106.24
1911	Nat. Phys. Lab. .	2 phase	-	-	106.27

The legal value of the ohm is the resistance of a column of mercury of uniform cross-section, weighing 14.4521 gms., and having a length of 106.30 cms. This is known as the international ohm. Mercury ohms conforming to these specifications have been prepared in recent years at the Physikalisch-Technische Reichsanstalt, the National Physical Laboratory, and the Bureau of Standards. The wire standards of resistance at the above-named laboratories agree in value to within two parts in 100000. Hence there is a very close agreement in the values of precision resistances calibrated at these laboratories.

SPECIFIC RESISTANCE OF METALLIC WIRES.

This table is modified from the table compiled by Jenkin (1862) from Matthiessen's results by taking the resistance of silver, gold, and copper from the observed metre gramme value and assuming the densities found by Matthiessen, namely, 10.468, 19.265, and 8.95.

Substance.	Resistance at 0° C. of a wire one cm. long, one sq. cm. in section.	Resistance at 0° C. of a wire one metre long, one mm. in diam.	Resistance at 0° C. of a wire one metre long, weighing one gram.	Resistance at 0° C. of a wire one foot long, $\frac{1}{1000}$ in. in diam.	Resistance at 0° C. of a wire one foot long, weighing one grain.	Percentage increase of resistance for 1° C. increase of temp. at 20° C.
Silver annealed . . .	1.460×10^{-6}	0.01859	.1523	8.781	.2184	0.377
" hard drawn . .	1.585 "	0.02019	.1659	9.538	.2379	–
Copper annealed . .	1.584 "	0.02017	.1421	9.529	.2037	0.388
" hard drawn . .	1.619 "	0.02062	.1449	9.741	.2078	–
Gold annealed . . .	2.088 "	0.02659	.4025	12.56	.5771	0.365
" hard drawn . .	2.125 "	0.02706	.4094	12.78	.5870	–
Aluminium annealed . .	2.906 "	0.03699	.0747	17.48	.1071	–
Zinc pressed . . .	5.613 "	0.07146	.4012	33.76	.5753	0.365
Platinum annealed . .	9.035 "	0.1150	1.934	54.35	2.772	–
Iron " . .	9.693 "	0.1234	.7551	58.31	1.083	–
Nickel " . .	12.43 "	0.1583	1.057	74.78	1.515	–
Tin pressed . . .	13.18 "	0.1678	.9608	79.29	1.377	0.365
Lead "	19.14 "	0.2437	2.227	115.1	3.193	0.387
Antimony pressed . .	35.42 "	0.4510	2.379	213.1	3.410	0.389
Bismuth " . .	130.9 "	1.667	12.86	787.5	18.43	0.354
Mercury " . .	94.07 "	1.198	12.79	565.9	18.34	0.072
Platinum-silver, 2 parts Ag, 1 part Pt, by weight .	24.33 "	0.3098	2.919	146.4	4.186	0.031
German silver . . .	20.89 "	0.2660	1.825	125.7	2.617	0.044
Gold-silver, 2 parts Au, 1 part Ag, by weight .	10.84 "	0.1380	1.646	65.21	2.359	0.065

Table 307.

SPECIFIC RESISTANCE OF METALS.

The resistance is here given as the resistance in microhms per cm. cube when the specific resistance of mercury at 0° is taken as 94.1 microhms.

Substance.	State.	Temperature, °C.	Resistance.	Authority.
Aluminum . . .	c. p.	—189.	0.64	Niccolai, 1907.
“	“	—100.	1.53	“ “
“	“	0.	2.62	“ “
“	“	+100.	3.86	“ “
“	“	400.	8.0	“ “
“		20.	2.828	See p. 284.
Antimony . . .		—190.	10.5	Eucken, Gelhoff.
“		0.	38.6	Mean.
“	liquid	+860.	120.	de la Rive.
Arsenic		0.	35.	Matthiessen.
Bismuth . . .		18.	119.0	Jäger, Diesselhorst.
“		100.	160.2	“ “
Cadmium . . .	drawn	—160.	2.72	Lees, 1908.
“	“	18.	7.54	Jäger, Diesselhorst.
“	“	100.	9.82	“ “
“	liquid	318.	34.1	Mean.
Cæsium		—187.	5.25	Guntz, Broniewski.
“		0.	19.	Mean.
Calcium . . .	99.5 pure	20.	10.5	Moissan, Chavanne
Chromium . . .		0.	2.6	Shukow.
Cobalt	99.8 pure	20.	9.7	Reichardt, 1901.
Copper	annealed	20.	1.724	See p. 284.
“	hard-drawn	20.	1.77	“ “
“	electrolytic	—206.	.144	Dewar, Fleming, Dickson.
“	“	+205.	2.92	
“	pure	400.	4.10	Niccolai, 1907.
Gallium		0.	53.	Guntz, Broniewski.
Gold	99.9 pure	—183.	0.68	D, F, D, 1898.
“		0.	2.22	Mean.
“	pure, drawn	18.	2.42	J, D, 1900.
“	99.9 pure	194.5	3.77	D, F, D, 1898.
Indium		0.	8.37	Erhardt, 1881.
Iridium		—186.	1.92	Broniewski, Hackspill, 1911.
“		0.	6.10	
“		+100.	8.3	“ “
Iron	pure, soft	—205.3	.652	D, F, D, 1898.
“	“ “	—78.	5.32	“ “ “ “
“	“ “	0.	8.85	“ “ “ “
“	“ “	+98.5	17.8	“ “ “ “
“	“ “	196.1	21.5	“ “ “ “
“	“	400.	43.3	Niccolai, 1907.
—steel . . .	cast	ord.	19.1	Kohlrausch.
“	“	yel. ht.	104.	“
“	“	wh. ht.	114.	“
“	piano-wire	0.	11.8	Strouhal, Barus,’83.
“	temp. glass, hard	0.	45.7	“ “ “
“	“ “ yellow	0.	27.	“ “ “
“	“ “ blue	0.	20.5	“ “ “
“	“ “ soft	0.	15.9	“ “ “
Lead	cold-pressed	—183.	6.02	D, F, D, 1898.
“	“ “	— 78.	14.1	“ “ “ “
“	“ “	0.	20.4	“ “ “ “
“	“ “	90.4	28.0	“ “ “ “
“	“ “	196.1	36.9	“ “ “ “
“		318.	94.	Vincentini, Omodei.
Lithium	solid	—187.	1.34	Guntz, Broniewski.

TABLE 307 (*continued*).

SPECIFIC RESISTANCE OF METALS.

The resistance is here given as the resistance in microhms per cm. cube when the specific resistance of mercury at 0° C is taken as 94.1 microhms.

Substance.	State.	Temperature, °C.	Resistance.	Authority.
Lithium, continued		0.	8.55	Guntz, Broniewski.
" "		99.3	12.7	" "
" "	liquid	230.	45.2	Bernini, 1905.
Manganese . . .			5.0±	Shukow.
Magnesium . . .	free from zn.	−183.	1.00	Dewar, Fleming, Dickson, 1898.
"	" " "	−78.	2.97	
"	" " "	0.	4.35	D, F, D, 1898.
"	" " "	98.5	5.99	" " " "
"	pure	400.	11.9	Niccolai, 1907.
Mercury	solid	−183.5	6.97	D, F, D, 1898.
"	"	−147.5	10.57	" "
"	"	−102.9	15.04	" "
"	"	−50.3	21.3	" "
"	"	−39.2	25.5	" "
"	"	−36.1	80.6	" "
"	liquid	0.0	94.07	" "
"	"	10.	94.92	Strecker, 1885.
"	"	20.	95.74	" "
"	"	50.	98.50	Grimaldi, 1888.
"	"	100.	103.25	Vincentini, Omodei, 1890.
"	"	200.	114.27	
"	"	350.	135.5	"
Nickel	pure	−182.5	1.44	Fleming, 1900.
"	"	−78.2	4.31	" "
"	"	0.	6.93	" "
"	"	94.9	11.1	" "
"		400.	60.2	Niccolai, 1907.
Osmium		20.	9.5	Blau, 1905.
Palladium . . .	very pure	−183.	2.78	Dewar, Fleming, '96
"	" "	−78.	7.17	" " "
"	" "	0.	10.21	" " "
"	" "	98.5	13.79	" " "
Platinum	wire	−203.1	2.44	D, F, D.
"	"	−97.5	6.87	" " "
"	"	0.	10.96	" " "
"	"	100.	14.85	" " "
"		400.	26.0	Niccolai, 1907.
Rhodium . . .		−186.	0.70	Broniewski, Hackspill, 1911.
"		−78.3	3.09	
"		0.	4.69	" "
"		100.	6.60	" "
Rubidium . . .	solid	−190.	2.5	Hackspill, 1910.
"	"	0.	11.6	" "
"	liquid	40.	19.6	" "
Silver	electrolytic	−183.	0.390	D, F, D, 1898.
"	"	−78.	1.021	" " " "
"	"	0.	1.468	" " " "
"	"	98.15	2.062	" " " "
"	"	192.1	2.608	" " " "
"	"	400.	3.77	Niccolai, 1907.
"	999.8 pure	18.	1.629	Jäger, Diesselhorst
Silicium		—	58.±	—
Strontium . . .		20.	24.8	Matthiessen, 1857.
Sodium	solid	−178.	0.80	Guntz, Broniewski, 1909.
"	"	−78.3	2.86	
"	"	0.	4.48	"
"	"	50.	5.32	"

SPECIFIC RESISTANCE OF METALS.

TABLE 307 (*concluded*).

The resistance is here given as the resistance in microhms per cm. cube when the specific resistance of mercury at 0° C. is taken as 94.1 microhms.

Substance.	State.	Temperature, C.	Resistance.	Authority.
Tantalum	Pure	-	14.6	Pirani.
Tellurium	-	19.6°	21.5	Matthiessen, 1852.
Thallium	Pure	—183.	4.08	Dewar, Fleming, Dickson, 1898.
"	"	— 78.	11.8	" " " "
"	"	0.	17.60	" " " "
"	"	98.5	24.7	" " " "
Titanium	-	-	3.19	Shukow.
Tin	-	—183.	3.40	D, F, D, 1898.
"	-	— 78.	8.8	" " " "
"	-	0.	13.0	" " " "
"	-	91.45	18.2	" " " "
"	-	176.	23.6	" " " "
Zinc	Trace Fe	—183.	1.62	" " " "
"	" "	— 78.	3.34	" " " "
"	" "	0.	5.75	" " " "
"	" "	92.45	8.00	" " " "
"	" "	191.5	10.37	" " " "
"	Liquid	440.	37.2	De la Rive, 1863.

TABLE 308. — Temperature Resistance Coefficients.

If R_0 is the resistance at the temperature t_0, and R_t at the temperature t, then R_t may over small ranges of temperature be approximately represented by the formula $R_t = R_0 (1 + at)$.

Substance.	Temperature.	a.	See at foot.	Substance.	Temperature.	a.	See at foot.
Aluminum	18–100° C.	0.0039	1	Nickel	0–100° C.	0.0062	3
"	$t_0 = 25°$	.0034	2	"	$t_0 = 25°$	0.0043	2
"	100	.0040	"	"	100	.0043	"
"	500	.0050	"	"	500	.0030	"
Bismuth	0–100	.00458	–	"	1000	.0037	"
Cadmium	0–100	.0042	–	Palladium	0–100	.0035	3
Copper	see p. 284–85	.0040	–	Platinum	0–100	.0037	"
"	$t_0 = 100°$	.0038	2	Silver	0–100	.0040	"
"	400	.0042	"	"	$t_0 = 25°$	.0030	2
"	1000	.0062	"	"	100	.0036	"
Gold	18–100	.00368	1	"	500	.0044	"
" annealed	$t_0 = 100°$	.0025	2	Tantalum	0–100	.0033	6
" "	500	.0035	"	Tin	18–100	.0046	1
" "	1000	.0049	"	Tungsten	18–100	.0045	"
Iron, pure	0–100	.0062	3	"	$t_0 = 500°$	.0057	2
" "	$t_0 = 25°$	.0052	2	"	1000	.0089	"
" "	100	.0068	"	Zinc	0–100	.0040	3
" "	500	.0147	"				
" "	1000	.0050	"	Advance	$t_0 = 12°$	+.000020	2
— steel	glass, h'd	.0016	4	"	50	—.000008	"
"	blue	.0033	"	"	100	—.000007	"
"	piano wire	.0032	"	"	200	+.000007	"
Lead	18–100	.0043	1	Constantin	12	+.000008	"
Magnesium	0–100	.0038	3	"	25	+.000002	"
"	$t_0 = 25°$	.0050	2	"	100	—.000033	"
"	100	.0045	"	"	200	—.000020	"
"	500	.0036	"	"	500	+.000027	"
"	600	.0100	"	Manganin	12	+.000006	"
Mercury*	0–15	.00088	5	"	25	.000000	"
Molybdenum	$t_0 = 25°$	.0033	2	"	100	—.000042	"
"	100	.0034	"	"	250	—.000052	"
"	500	.0050	"	"	475	.000000	"
"	1000	.0048	"	"	500	—.000110	"

1, Jäger, Diesselhorst, Wiss. Abh. D., Phys. Tech. Reich. 3, p. 269, 1900; 2, Somerville, Phys. Rev. 31, p. 261, 1910, 33, p. 77, 1911; 3, Dewar, Fleming, 1893, 1896; Strouhal, Barus, 1883; 5, Glazebrook Phil. Mag. 20, p. 343, 1885; 6, Pirani.

* Mercury, $R = R_0 (1 + .00089t + 000001t^2)$.

TABLE 309.

CONDUCTIVITY OF THREE-METAL AND MISCELLANEOUS ALLOYS.

Conductivity in mhos or $\frac{1}{\text{ohms per cm. cube}} = C_t = C_0\,(1 - at + bt^2)$.

Metals and alloys.	Composition by weight.	$\frac{C_0}{10^4}$	$a \times 10^6$	$b \times 10^9$	Authority.
Gold-copper-silver . . .	58.3 Au + 26.5 Cu + 15.2 Ag	7.58	574	924	1
" " " . . .	66.5 Au + 15.4 Cu + 18.1 Ag	6.83	529	93	1
" " " . . .	7.4 Au + 78.3 Cu + 14.3 Ag	28.06	1830	7280	1
Nickel-copper-zinc . . .	12.84 Ni + 30.59 Cu + 6.57 Zn by volume . . .	4.92	444	51	1
Brass	Various	12.2–15.6	1–2 × 10³	–	2
" hard drawn . . .	70.2 Cu + 29.8 Zn	12.16	–	–	3
" annealed	" "	14.35	–	–	3
German silver	Various	3–5	–	–	2
" "	60.16 Cu + 25.37 Zn + 14.03 Ni + .30 Fe with trace of cobalt and manganese .	3.33	360	–	4
Aluminum bronze . . .	– – –	7.5–8.5	5–7 × 10²	–	2
Phosphor bronze . . .	– – –	10–20	–	–	2
Silicium bronze	– – –	41	–	–	5
Manganese-copper . . .	30 Mn + 70 Cu	1.00	40	–	4
Nickel-manganese-copper	3 Ni + 24 Mn + 73 Cu . .	2.10	—30	–	4
Nickelin	18.46 Ni + 61.63 Cu + 19.67 Zn + 0.24 Fe + 0.19 Co + 0.18 Mn . . .	3.01	300	–	4
Patent nickel	25.1 Ni + 74.41 Cu + 0.42 Fe + 0.23 Zn + 0.13 Mn + trace of cobalt	2.92	190	–	4
Rheotan	53.28 Cu + 25.31 Ni + 16.89 Zn + 4.46 Fe + 0.37 Mn	1.90	410	–	4
Copper-manganese-iron .	91 Cu + 7.1 Mn + 1.9 Fe .	4.98	120	–	6
" " " .	70.6 Cu + 23.2 Mn + 6.2 Fe	1.30	22	–	6
" " " .	69.7 Cu + 29.9 Ni + 0.3 Fe .	2.60	120	–	7
Manganin	84 Cu + 12 Mn + 4 Ni . . .	2.3	6	–	2
Constantan	60 Cu + 40 Ni	2.04	8	–	7

[1] Matthiessen.
[2] Various.
[3] W. Siemens.
[4] Feussner and Lindeck.
[5] Van der Ven.
[6] Blood.
[6] Feussner.
[7] Jaeger-Diesselhorst.

TABLE 310.

CONDUCTING POWER OF ALLOYS.

This table shows the conducting power of alloys and the variation of the conducting power with temperature.* The values of C_0 were obtained from the original results by assuming silver $= \frac{10^6}{1.585}$ mhos. The conductivity is taken as $C_t = C_0 (1 - at + bt^2)$, and the range of temperature was from 0° to 100° C.

The table is arranged in three groups to show (1) that certain metals when melted together produce a solution which has a conductivity equal to the mean of the conductivities of the components, (2) the behavior of those metals alloyed with others, and (3) the behavior of the other metals alloyed together.

It is pointed out that, with a few exceptions, the percentage variation between 0° and 100° can be calculated from the formula $P = P_c \frac{l}{l'}$, where l is the observed and l' the calculated conducting power of the mixture at 100° C., and P_c is the calculated mean variation of the metals mixed.

Alloys.	Weight %	Volume %	$\frac{C_0}{10^4}$	$a \times 10^6$	$b \times 10^9$	Variation per 100° C.	
	of first named.					Observed.	Calculated.
GROUP 1.							
Sn_6Pb	77.04	83.96	7.57	3890	8670	30.18	29.67
Sn_4Cd	82.41	83.10	9.18	4080	11870	28.89	30.03
$SnZn$	78.06	77.71	10.56	3880	8720	30.12	30.16
$PbSn$	64.13	53.41	6.40	3780	8420	29.41	29.10
$ZnCd_2$	24.76	26.06	16.16	3780	8000	29.86	29.67
$SnCd_4$	23.05	23.50	13.67	3850	9410	29.08	30.25
$CdPb_6$	7.37	10.57	5.78	3500	7270	27.74	27.60
GROUP 2.							
Lead-silver ($Pb_{20}Ag$)	95.05	94.64	5.60	3630	7960	28.24	19.96
Lead-silver ($PbAg$)	48.97	46.90	8.03	1960	3100	16.53	7.73
Lead-silver ($PbAg_2$)	32.44	30.64	13.80	1990	2600	17.36	10.42
Tin-gold ($Sn_{12}Au$)	77.94	90.32	5.20	3080	6640	24.20	14.83
“ “ (Sn_5Au)	59.54	79.54	3.03	2920	6300	22.90	5.95
Tin-copper	92.24	93.57	7.59	3680	8130	28.71	19.76
“ “ †	80.58	83.60	8.05	3330	6840	26.24	14.57
“ “ †	12.49	14.91	5.57	547	294	5.18	3.99
“ “ †	10.30	12.35	6.41	666	1185	5.48	4.46
“ “ †	9.67	11.61	7.64	691	304	6.60	5.22
“ “ †	4.96	6.02	12.44	995	705	9.25	7.83
“ “ †	1.15	1.41	39.41	2670	5070	21.74	20.53
Tin-silver	91.30	96.52	7.81	3820	8190	30.00	23.31
“ “	53.85	75.51	8.65	3770	8550	29.18	11.89
Zinc-copper †	36.70	42.06	13.75	1370	1340	12.40	11.29
“ “ †	25.00	29.45	13.70	1270	1240	11.49	10.08
“ “ †	16.53	23.61	13.44	1880	1800	12.80	12.30
“ “ †	8.89	10.88	29.61	2040	3030	17.41	17.42
“ “ †	4.06	5.03	38.09	2470	4100	20.61	20.62

NOTE. — Barus, in the “Am. Jour. of Sci.” vol. 36, has pointed out that the temperature variation of platinum alloys containing less than 10% of the other metal can be nearly expressed by an equation $y = \frac{n}{x} - m$, where y is the temperature coefficient and x the specific resistance, m and n being constants. If a be the temperature coefficient at 0° C. and s the corresponding specific resistance, $s(a + m) = n$.

For platinum alloys Barus's experiments gave $m = -.000194$ and $n = .0378$.
For steel $m = -.000303$ and $n = .0620$.

Matthiessen's experiments reduced by Barus gave for

Gold alloys $m = -.000045$, $n = .00721$.
Silver “ $m = -.000112$, $n = .00538$.
Copper “ $m = -.000386$, $n = .00055$.

---

* From the experiments of Matthiessen and Vogt, “Phil. Trans. R. S.” v. 154.
† Hard-drawn.

TABLE 310.—Conducting Power of Alloys.

GROUP 3.

Alloys.	Weight %	Volume %	$\frac{C_0}{10^4}$	$a \times 10^6$	$b \times 10^9$	Variation per 100° C.	
	of first named.					Observed.	Calculated.
Gold-copper † . . .	99.23	98.36	35.42	2650	4650	21.87	23.22
" " † . . .	90.55	81.66	10.16	749	81	7.41	7.53
Gold-silver †	87.95	79.86	13.46	1090	793	10.09	9.65
" " *	87.95	79.86	13.61	1140	1160	10.21	9.59
" " †	64.80	52.08	9.48	673	246	6.49	6.58
" " *	64.80	52.08	9.51	721	495	6.71	6.42
" " †	31.33	19.86	13.69	885	531	8.23	8.62
" " *	31.33	19.86	13.73	908	641	8.44	8.31
Gold-copper † . . .	34.83	19.17	12.94	864	570	8.07	8.18
" " † . . .	1.52	0.71	53.02	3320	7300	25.90	25.86
Platinum-silver † . .	33.33	19.65	4.22	330	208	3.10	3.21
" " † . .	9.81	5.05	11.38	774	656	7.08	7.25
" " † . .	5.00	2.51	19.96	1240	1150	11.29	11.88
Palladium-silver † . .	25.00	23.28	5.38	324	154	3.40	4.21
Copper-silver † . . .	98.08	98.35	56.49	3450	7990	26.50	27.30
" " † . . .	94.40	95.17	51.93	3250	6940	25.57	25.41
" " † . . .	76.74	77.64	44.06	3030	6070	24.29	21.92
" " † . . .	42.75	46.67	47.29	2870	5280	22.75	24.00
" " † . . .	7.14	8.25	50.65	2750	4360	23.17	25.57
" " † . . .	1.31	1.53	50.30	4120	8740	26.51	29.77
Iron-gold †	13.59	27.93	1.73	3490	7010	27.92	14.70
" " †	9.80	21.18	1.26	2970	1220	17.55	11.20
" " †	4.76	10.96	1.46	487	103	3.84	13.40
Iron-copper † . . .	0.40	0.46	24.51	1550	2090	13.44	14.03
Phosphorus-copper † .	2.50	–	4.62	476	145	–	–
" " † .	0.95	–	14.91	1320	1640	–	–
Arsenic-copper † . .	5.40	–	3.97	516	989	–	–
" " † . .	2.80	–	8.12	736	446	–	–
" " † . .	trace	–	38.52	2640	4830	–	–

* Annealed. † Hard-drawn.

TABLE 311.—Allowable Carrying Capacity of Rubber-covered Copper Wires.

(For inside wiring—Nat. Board Fire Underwriters' Rules.)

B + S Gage	18	16	14	12	10	8	6	5	4	3	2	1	0	00	0000
Amperes	3	6	12	17	24	33	46	54	65	76	90	107	127	150	210

500,000 circ. mills, 390 amp.; 1,000,000 c. m., 650 amp.; 2,000,000 c. m., 1,050 amp. For insulated al. wire, capacity = 84% of cu. Preece gives as formula for fusion of bare wires $I = ad^{\frac{3}{2}}$, where d = diam. in inches, a for cu. is 10,244; al., 7585; pt., 5172; German silver, 5230; platinoid, 4750; Fe, 3148; Pb., 1379; alloy 2 pts. Pb., 1 of Sn., 1318.

TABLE 312.

RESISTANCE OF METALS AND

The electrical resistance of some pure metals and of some alloys have been determined by Dewar and Fleming and increases as the temperature is lowered. The resistance seems to approach zero for the pure metals, but not for temperature tried. The following table gives the results of Dewar and Fleming.*

When the temperature is raised above 0° C. the coefficient decreases for the pure metals, as is shown by the experi- experiments to be approximately true, namely, that the resistance of any pure metal is proportional to its absolute is greater the lower the temperature, because the total resistance is smaller. This rule, however, does not even zero Centigrade, as is shown in the tables of resistance of alloys. (Cf. Table 262.)

Temperature =	100°	20°	0°	− 80°
Metal or alloy.	Specific resistance in c. g. s. units.			
Aluminium, pure hard-drawn wire	4745	3505	3161	-
Copper, pure electrolytic and annealed	1920	1457	1349	-
Gold, soft wire	2665	2081	1948	1400
Iron, pure soft wire	13970†	9521	8613	-
Nickel, pure (prepared by Mond's process from compound of nickel and carbon monoxide)	19300	13494	12266	7470
Platinum, annealed	10907	8752	8221	6133
Silver, pure wire	2139	1647	1559	1138
Tin, pure wire	13867	10473	9575	6681
German silver, commercial wire	35720	34707	34524	33664
Palladium-silver, 20 Pd + 80 Ag	15410	14984	14961	14482
Phosphor-bronze, commercial wire	9071	8588	8479	8054
Platinoid, Martino's platinoid with 1 to 2% tungsten	44590	43823	43601	43022
Platinum-iridium, 80 Pt + 20 Ir	31848	29902	29374	27504
Platinum-rhodium, 90 Pt + 10 Rh	18417	14586	13755	10778
Platinum-silver, 66.7 Ag + 33.3 Pt	27404	26915	26818	26311
Carbon, from Edison-Swan incandescent lamp	-	4046×10^3	4092×10^3	4189×10^3
Carbon, from Edison-Swan incandescent lamp	3834×10^3	3908×10^3	3955×10^3	4054×10^3
Carbon, adamantine, from Woodhouse and Rawson incandescent lamp	6168×10^3	6300×10^3	6363×10^3	6495×10^3

---

* "Phil. Mag." vol. 34, 1892.

† This is given by Dewar and Fleming as 13777 for 96°.4, which appears from the other measurements too high.

ALLOYS AT LOW TEMPERATURES.

by Cailletet and Bouty at very low temperatures. The results show that the coefficient of change with temperature the alloys. The resistance of carbon was found by Dewar and Fleming to increase continuously to the lowest

ments or Müller, Benoit, and others. Probably the simplest rule is that suggested by Clausius, and shown by these temperature. This gives the actual change of resistance per degree, a constant; and hence the percentage of change approximately hold for alloys, some of which have a negative temperature coefficient at temperatures not far from

Temperature =	− 100°	− 182°	− 197°	Mean value of temperature co-efficient between − 100° and + 100° C.*
Metal or alloy.	Specific resistance in c. g. s. units.			
Aluminum, pure hard-drawn wire	1928	894	-	.00446
Copper, pure electrolytic and annealed	757	272	178	431
Gold, soft wire	1207	604	-	375
Iron, pure soft wire	4010	1067	608	578
Nickel, pure (prepared by Mond's process from compound of nickel and carbon monoxide)	6110	1900	-	538
Platinum, annealed	5295	2821	2290	341
Silver, pure wire	962	472	-	377
Tin, pure wire	5671	2553	-	428
German silver, commercial wire	33280	32512	-	035
Palladium-silver, 20 Pd + 80 Ag	14256	13797	-	039
Phosphor-bronze, commercial wire	7883	7371	-	070
Platinoid, Martino's platinoid with 1 to 2% tungsten	42385	41454	-	025
Platinum-iridium, 80 Pt + 20 Ir	26712	24440	-	087
Platinum-rhodium, 90 Pt + 10 Rh	9834	7134	-	312
Platinum-silver, 66.7 Ag + 33.3 Pt	26108	25537	-	024
Carbon, from Edison-Swan incandescent lamp	4218×10^3	4321×10^3	-	-
Carbon, from Edison-Swan incandescent lamp	4079×10^3	4180×10^3	-	031
Carbon, adamantine, from Woodhouse and Rawson incandescent lamp	6533×10^3	-	-	029

---

* This is α in the equation $R = R_0 (1 + \alpha t)$, as calculated from the equation $\alpha = \frac{R_{100} - R_{-100}}{200 R_0}$.

TABLE 313. — Variation of Electrical Resistance of Glass and Porcelain with Temperature.

The following table gives the values of a, b, and c in the equation

$$\log R = a + bt + ct^2,$$

where R is the specific resistance expressed in ohms, that is, the resistance in ohms per centimeter of a rod one square centimeter in cross section.*

No.	Kind of glass.	Density.	a	b	c	Range of temp. Centigrade.
1	Test-tube glass	-	13.86	—.044	.000065	0°–250°
2	" " "	2.458	14.24	—.055	.0001	37–131
3	Bohemian glass	2.43	16.21	—.043	.0000394	60–174
4	Lime glass (Japanese manufacture) .	2.55	13.14	—.031	—.000021	10–85
5	" " " " .	2.499	14.002	—.025	—.00006	35–95
6	Soda-lime glass (French flask) .	2.533	14.58	—.049	.000075	45–120
7	Potash-soda lime glass . . .	2.58	16.34	—.0425	.0000364	66–193
8	Arsenic enamel flint glass . .	3.07	18.17	—.055	.000088	105–135
9	Flint glass (Thomson's electrometer jar)	3.172	18.021	—.036	—.0000091	100–200
10	Porcelain (white evaporating dish) .	-	15.65	—.042	.00005	68–290

COMPOSITION OF SOME OF THE ABOVE SPECIMENS OF GLASS.

Number of specimen =	3	4	5	7	8	9
Silica	61.3	57.2	70.05	75.65	54.2	55.18
Potash	22.9	21.1	1.44	7.92	10.5	13.28
Soda	Lime, etc.	Lime, etc.	14.32	6.92	7.0	-
Lead oxide	by diff.	by diff.	2.70	-	23.9	31.01
Lime	15.8	16.7	10.33	8.48	0.3	0.35
Magnesia	-	-	-	0.36	0.2	0.06
Arsenic oxide . . .	-	-	-	-	3.5	-
Alumina, iron oxide, etc. .	-	-	1.45	0.70	0.4	0.67

* T. Gray, "Phil. Mag." 1880, and "Proc. Roy. Soc." 1882.

TABLE 314. — Temperature Resistance Coefficients of Glass, Porcelain and Quartz dr/dt.

Temperature.	450°	500°	575°	600°	700°	750°	800°	900°	1000°
Glass . . .	—32.	—6.	—1.5	—.8	—0.17	—0.1	—0.06	-	-
Porcelain . .	-	-	—16.	—9.8	—2.8	—1.6	—.70	—0.30	—0.12
Quartz. . .	-	-	-	-	-	—10.	—6.40	—2.60	—1.00

Somerville, Physical Review, 31, p. 261, 1910.

TABLE 315.

TABULAR COMPARISON OF WIRE GAGES.

Gage No.	American Wire Gage (B. & S.) Mils.	American Wire Gage (B. & S.) mm.	Steel Wire Gage* Mils.	Steel Wire Gage* mm.	Stubs' Steel Wire Gage Mils.	(British) Standard Wire Gage Mils.	Birmingham Wire Gage (Stubs') Mils.	Gage No.
7–0			490.0	12.4		500.		7–0
6–0			461.5	11.7		464.		6–0
5–0			430.5	10.9		432.		5–0
4–0	460.	11.7	393.8	10.0		400.	454.	4–0
3–0	410.	10.4	362.5	9.2		372.	425.	3–0
2–0	365.	9.3	331.0	8.4		348.	380.	2–0
0	325.	8.3	306.5	7.8		324.	340.	0
1	289.	7.3	283.0	7.2	227.	300.	300.	1
2	258.	6.5	262.5	6.7	219.	276.	284.	2
3	229.	5.8	243.7	6.2	212.	252.	259.	3
4	204.	5.2	225.3	5.7	207.	232.	238.	4
5	182.	4.6	207.0	5.3	204.	212.	220.	5
6	162.	4.1	192.0	4.9	201.	192.	203.	6
7	144.	3.7	177.0	4.5	199.	176.	180.	7
8	128.	3.3	162.0	4.1	197.	160.	165.	8
9	114.	2.91	148.3	3.77	194.	144.	148.	9
10	102.	2.59	135.0	3.43	191.	128.	134.	10
11	91.	2.30	120.5	3.06	188.	116.	120.	11
12	81.	2.05	105.5	2.68	185.	104.	109.	12
13	72.	1.83	91.5	2.32	182.	92.	95.	13
14	64.	1.63	80.0	2.03	180.	80.	83.	14
15	57.	1.45	72.0	1.83	178.	72.	72.	15
16	51.	1.29	62.5	1.59	175.	64.	65.	16
17	45.	1.15	54.0	1.37	172.	56.	58.	17
18	40.	1.02	47.5	1.21	168.	48.	49.	18
19	36.	0.91	41.0	1.04	164.	40.	42.	19
20	32.	.81	34.8	0.88	161.	36.	35.	20
21	28.5	.72	31.7	.81	157.	32.	32.	21
22	25.3	.62	28.6	.73	155.	28.	28.	22
23	22.6	.57	25.8	.66	153.	24.	25.	23
24	20.1	.51	23.0	.58	151.	22.	22.	24
25	17.9	.45	20.4	.52	148.	20.	20.	25
26	15.9	.40	18.1	.46	146.	18.	18.	26
27	14.2	.36	17.3	.439	143.	16.4	16.	27
28	12.6	.32	16.2	.411	139.	14.8	14.	28
29	11.3	.29	15.0	.381	134.	13.6	13.	29
30	10.0	.25	14.0	.356	127.	12.4	12.	30
31	8.9	.227	13.2	.335	120.	11.6	10.	31
32	8.0	.202	12.8	.325	115.	10.8	9.	32
33	7.1	.180	11.8	.300	112.	10.0	8.	33
34	6.3	.160	10.4	.264	110.	9.2	7.	34
35	5.6	.143	9.5	.241	108.	8.4	5.	35
36	5.0	.127	9.0	.229	106.	7.6	4.	36
37	4.5	.113	8.5	.216	103.	6.8		37
38	4.0	.101	8.0	.203	101.	6.0		38
39	3.5	.090	7.5	.191	99.	5.2		39
40	3.1	.080	7.0	.178	97.	4.8		40
41			6.6	.168	95.	4.4		41
42			6.2	.157	92.	4.0		42
43			6.0	.152	88.	3.6		43
44			5.8	.147	85.	3.2		44
45			5.5	.140	81.	2.8		45
46			5.2	.132	79.	2.4		46
47			5.0	.127	77.	2.0		47
48			4.8	.122	75.	1.6		48
49			4.6	.117	72.	1.2		49
50			4.4	.112	69.	1.0		50

---

* The Steel Wire Gage is the same gage which has been known by the various names: "Washburn and Moen," "Roebling," "American Steel and Wire Co.'s." Its abbreviation should be written "Stl. W. G.," to distinguish it from "S. W. G.," the usual abbreviation for the (British) Standard Wire Gage.

Taken from Circular No. 31. Copper Wire Tables, U.S. Bureau of Standards which contains more complete tables.

WIRE TABLES.

TABLE 316. — Introduction. Mass and Volume Resistivity of Copper and Aluminum.

The following wire tables are abridged from those prepared by the Bureau of Standards at the request and with the coöperation of the Standards Committee of the American Institute of Electrical Engineers (Circular No. 31 of the Bureau of Standards). The standard of copper resistance used is "The International Annealed Copper Standard" as adopted Sept. 5, 1913, by the International Electrotechnical Commission and takes the Resistivity at 20° C. of an annealed copper wire one meter long weighing one gram as equal to 0.15328 ohm. This standard corresponds to a conductivity of $58. \times 10^{-5}$ cgs. units, and a density of 8.89, at 20° C.

In the various units of mass and volume resistivity this may be stated as

0.15328 ohm (meter, gram) at 20° C.
875.20 ohms (mile, pound) at 20° C.
1.7241 microhm-cm. at 20° C.
0.67879 microhm-inch at 20° C.
10.371 ohms (mil, foot) at 20° C.

The temperature coefficient for this particular resistivity is $a_{20} = 0.00393$ or $a_0 = 0.00427$. However, the temperature coefficient is proportional to the conductivity, and hence the change of resistivity per degree C. is a constant, 0.000597 ohm (meter, gram). The "constant mass" temperature coefficient of any sample is

$$a_t = \frac{0.000597 + 0.000005}{\text{resistivity in ohms (meter, gram) at } t^\circ\text{ C}}.$$

The density is 8.89 grams per cubic centimeter at 20° C., which is equivalent to 0.3212 pounds per cubic inch.

The values in the tables are for annealed copper of standard resistivity. The user of the tables must apply the proper correction for copper of other resistivity. Hard-drawn copper may be taken as about 2.7 per cent higher resistivity than annealed copper.

The aluminum tables are based on a figure for the conductivity published by the U. S. Bureau of Standards, which is the result of many thousands of determinations by the Aluminum Company of America. A volume resistivity of 2.828 michrom-cm., and a density of 2.70 may be considered to be good average values for commercial hard-drawn aluminum. These values give:

Mass resistivity, in ohms (meter, gram) at 20° C.	0.0764
" " " " (mile, pound) at 20° C.	436.
Mass per cent conductivity	200.7%
Volume resistivity, in michrom-cm. at 20° C.	2.828
" " in microhm-inch at 20° C.	1.113
Volume per cent conductivity	61.0%
Density, in grams per cubic centimeter	2.70
Density, in pounds per cubic inch	0.0975

WIRE TABLES.

TABLE 317.—Temperature Coefficients of Copper for Different Initial Temperatures (Centigrade) and Different Conductivities.

Ohms (meter, gram) at 20° C.	Per cent conductivity.	α_0	α_{15}	α_{20}	α_{25}	α_{30}	α_{50}
0.161 34	95%	0.004 03	0.003 80	0.003 73	0.003 67	0.003 60	0.003 36
.159 66	96%	.004 08	.003 85	.003 77	.003 70	.003 64	.003 39
.158 02	97%	.004 13	.003 89	.003 81	.003 74	.003 67	.003 42
.157 53	97.3%	.004 14	.003 90	.003 82	.003 75	.003 68	.003 43
.156 40	98%	.004 17	.003 93	.003 85	.003 78	.003 71	.003 45
.154 82	99%	.004 22	.003 97	.003 89	.003 82	.003 74	.003 48
.153 28	100%	.004 27	.004 01	**.003 93**	.003 85	.003 78	.003 52
.151 70	101%	.004 31	.004 05	.00 397	.003 89	.003 82	.003 55

NOTE. — The fundamental relation between resistance and temperature is the following:

$$R_t = R_{t_1}(1 + \alpha_{t_1}[t - t_1]),$$

where α_{t_1} is the "temperature coefficient," and t_1 is the "initial temperature" or "temperature of reference."

The values of α in the above table exhibit the fact that the temperature coefficient of copper is proportional to the conductivity. The table was calculated by means of the following formula, which holds for any per cent conductivity, n, within commercial ranges, and for centigrade temperatures. (n is considered to be expressed decimally: e.g., if per cent conductivity = 99 per cent, $n = 0.99$.)

$$\alpha_{t_1} = \frac{1}{\dfrac{1}{n(0.00393)} + (t_1 - 20)}.$$

TABLE 318.—Reduction of Observations to Standard Temperature. (Copper.)

Temperature C.	Corrections to reduce Resistivity to 20° C.				Factors to reduce Resistance to 20° C.			Temperature C.
	Ohm (meter, gram).	Microhm—cm.	Ohm (mile, pound).	Microhm—inch.	For 96 per cent conductivity.	For 98 per cent conductivity.	For 100 per cent conductivity.	
0	+0.011 94	+0.1361	+ 68.20	+0.053 58	1.0816	1.0834	1.0853	0
5	+ .008 96	+ .1021	+ 51.15	+ .040 18	1.0600	1.0613	1.0626	5
10	+ .005 97	+ .0681	+ 34.10	.026 79	1.0392	1.0401	1.0409	10
11	+ .005 37	+ .0612	+ 30.69	+ .024 11	1.0352	1.0359	1.0367	11
12	+ .004 78	+ .0544	+ 27.28	+ .021 43	1.0311	1.0318	1.0325	12
13	+ .004 18	+ .0476	+ 23.87	+ .018 75	1.0271	1.0277	1.0283	13
14	+ .003 58	+ .0408	+ 20.46	+ .016 07	1.0232	1.0237	1.0242	14
15	+ .002 99	+ .0340	+ 17.05	+ .013 40	1.0192	1.0196	1.0200	15
16	+ .002 39	+ .0272	+ 13.64	+ .010 72	1.0153	1.0156	1.0160	16
17	+ .001 79	+ .0204	+ 10.23	+ .008 04	1.0114	1.0117	1.0119	17
18	+ .001 19	+ .0136	+ 6.82	+ .005 36	1.0076	1.0078	1.0079	18
19	+ .000 60	+ .0068	+ 3.41	+ .002 68	1.0038	1.0039	1.0039	19
20	0	0	0	0	1.0000	1.0000	1.0000	20
21	− .000 60	− .0068	− 3.41	− .002 68	0.9962	0.9962	0.9961	21
22	− .001 19	− .0136	− 6.82	− .005 36	.9925	.9924	.9922	22
23	− .001 79	− .0204	− 10.23	− .008 04	.9888	.9886	.9883	23
24	− .002 39	− .0272	− 13.64	− .010 72	.9851	.9848	.9845	24
25	− .002 99	− .0340	− 17.05	− .013 40	.9815	.9811	.9807	25
26	− .003 58	− .0408	− 20.46	− .016 07	.9779	.9774	.9770	26
27	− .004 18	− .0476	− 23.87	− .018 75	.9743	.9737	.9732	27
28	− .004 78	− .0544	− 27.28	− .021 43	.9707	.9701	.9695	28
29	− .005 37	− .0612	− 30.69	− .024 11	.9672	.9665	.9658	29
30	− .005 97	− .0681	− 34.10	− .026 79	.9636	.9629	.9622	30
35	− .008 96	− .1021	− 51.15	− .040 18	.9464	.9454	.9443	35
40	− .011 94	− .1361	− 68.20	− .053 58	.9298	.9285	.9271	40
45	− .014 93	− .1701	− 85.25	− .066 98	.9138	.9122	.9105	45
50	− .017 92	− .2042	−102.30	− .080 37	.8983	.8964	.8945	50
55	− .020 90	− .2382	−119.35	− .093 76	.8833	.8812	.8791	55
60	− .023 89	− .2722	−136.40	− .107 16	.8689	.8665	.8642	60
65	− .026 87	− .3062	−153.45	− .120 56	.8549	.8523	.8497	65
70	− .029 86	− .3403	−170.50	− .133 95	.8413	.8385	.8358	70
75	− .032 85	− .3743	−187.55	− .147 34	.8281	.8252	.8223	75

WIRE TABLE, STANDARD ANNEALED COPPER.

American Wire Gage (B. & S.). English Units.

Gage No.	Diameter in Mils. at 20° C.	Cross-Section at 20° C.		Ohms per 1000 Feet.*			
		Circular Mils.	Square Inches.	0° C (= 32° F)	20° C (= 68° F)	50° C (= 122° F)	75° C (= 167° F)
0000	460.0	211 600.	0.1662	0.045 16	0.049 01	0.054 79	0.059 61
000	409.6	167 800.	.1318	.056 95	.061 80	.069 09	.075 16
00	364.8	133 100.	.1045	.071 81	.077 93	.087 12	.094 78
0	324.9	105 500.	.082 89	.090 55	.098 27	.1099	.1195
1	289.3	83 690.	.065 73	.1142	.1239	.1385	.1507
2	257.6	66 370.	.052 13	.1440	.1563	.1747	.1900
3	229.4	52 640.	.041 34	.1816	.1970	.2203	.2396
4	204.3	41 740.	.032 78	.2289	.2485	.2778	.3022
5	181.9	33 100.	.026 00	.2887	.3133	.3502	.3810
6	162.0	26 250.	.020 62	.3640	.3951	.4416	.4805
7	144.3	20 820.	.016 35	.4590	.4982	.5569	.6059
8	128.5	16 510.	.012 97	.5788	.6282	.7023	.7640
9	114.4	13 090.	.010 28	.7299	.7921	.8855	.9633
10	101.9	10 380.	.008 155	.9203	.9989	1.117	1.215
11	90.74	8234.	.006 467	1.161	1.260	1.408	1.532
12	80.81	6530.	.005 129	1.463	1.588	1.775	1.931
13	71.96	5178.	.004 067	1.845	2.003	2.239	2.436
14	64.08	4107.	.003 225	2.327	2.525	2.823	3.071
15	57.07	3257.	.002 558	2.934	3.184	3.560	3.873
16	50.82	2583.	.002 028	3.700	4.016	4.489	4.884
17	45.26	2048.	.001 609	4.666	5.064	5.660	6.158
18	40.30	1624.	.001 276	5.883	6.385	7.138	7.765
19	35.89	1288.	.001 012	7.418	8.051	9.001	9.792
20	31.96	1022.	.000 802 3	9.355	10.15	11.35	12.35
21	28.45	810.1	.000 636 3	11.80	12.80	14.31	15.57
22	25.35	642.4	.000 504 6	14.87	16.14	18.05	19.63
23	22.57	509.5	.000 400 2	18.76	20.36	22.76	24.76
24	20.10	404.0	.000 317 3	23.65	25.67	28.70	31.22
25	17.90	320.4	.000 251 7	29.82	32.37	36.18	39.36
26	15.94	254.1	.000 199 6	37.61	40.81	45.63	49.64
27	14.20	201.5	.000 158 3	47.42	51.47	57.53	62.59
28	12.64	159.8	.000 125 5	59.80	64.90	72.55	78.93
29	11.26	126.7	.000 099 53	75.40	81.83	91.48	99.52
30	10.03	100.5	.000 078 94	95.08	103.2	115.4	125.5
31	8.928	79.70	.000 062 60	119.9	130.1	145.5	158.2
32	7.950	63.21	.000 049 64	151.2	164.1	183.4	199.5
33	7.080	50.13	.000 039 37	190.6	206.9	231.3	251.6
34	6.305	39.75	.000 031 22	240.4	260.9	291.7	317.3
35	5.615	31.52	.000 024 76	303.1	329.0	367.8	400.1
36	5.000	25.00	.000 019 64	382.2	414.8	463.7	504.5
37	4.453	19.83	.000 015 57	482.0	523.1	584.8	636.2
38	3.965	15.72	.000 012 35	607.8	659.6	737.4	802.2
39	3.531	12.47	.000 009 793	766.4	831.8	929.8	1012.
40	3.145	9.888	.000 007 766	966.5	1049.	1173.	1276.

---

* Resistance at the stated temperatures of a wire whose length is 1000 feet at 20° C.

WIRE TABLE, STANDARD ANNEALED COPPER (*continued*).

American Wire Gage (B. & S.). English Units (*continued*).

Gage No.	Diameter in Mils. at 20° C.	Pounds per 1000 Feet.	Feet per Pound.	Feet per Ohm.*			
				0° C (=32° F)	20° C (=68° F)	50° C (=122° F)	75° C (=167° F)
0000	460.0	640.5	1.561	22 140.	20 400.	18 250.	16 780.
000	409.6	507.9	1.968	17 560.	16 180.	14 470.	13 300.
00	364.8	402.8	2.482	13 930.	12 830.	11 480.	10 550.
0	324.9	319.5	3.130	11 040.	10 180.	9103.	8367.
1	289.3	253.3	3.947	8758.	8070.	7219.	6636.
2	257.6	200.9	4.977	6946.	6400.	5725.	5262.
3	229.4	159.3	6.276	5508.	5075.	4540.	4173.
4	204.3	126.4	7.914	4368.	4025.	3600.	3309.
5	181.9	100.2	9.980	3464.	3192.	2855.	2625.
6	162.0	79.46	12.58	2747.	2531.	2264.	2081.
7	144.3	63.02	15.87	2179.	2007.	1796.	1651.
8	128.5	49.98	20.01	1728.	1592.	1424.	1309.
9	114.4	39.63	25.23	1370.	1262.	1129.	1038.
10	101.9	31.43	31.82	1087.	1001.	895.6	823.2
11	90.74	24.92	40.12	861.7	794.0	710.2	652.8
12	80.81	19.77	50.59	683.3	629.6	563.2	517.7
13	71.96	15.68	63.80	541.9	499.3	446.7	410.6
14	64.08	12.43	80.44	429.8	396.0	354.2	325.6
15	57.07	9.858	101.4	340.8	314.0	280.9	258.2
16	50.82	7.818	127.9	270.3	249.0	222.8	204.8
17	45.26	6.200	161.3	214.3	197.5	176.7	162.4
18	40.30	4.917	203.4	170.0	156.6	140.1	128.8
19	35.89	3.899	256.5	134.8	124.2	111.1	102.1
20	31.96	3.092	323.4	106.9	98.50	88.11	80.99
21	28.46	2.452	407.8	84.78	78.11	69.87	64.23
22	25.35	1.945	514.2	67.23	61.95	55.41	50.94
23	22.57	1.542	648.4	53.32	49.13	43.94	40.39
24	20.10	1.223	817.7	42.28	38.96	34.85	32.03
25	17.90	0.9699	1031.	33.53	30.90	27.64	25.40
26	15.94	.7692	1300.	26.59	24.50	21.92	20.15
27	14.20	.6100	1639.	21.09	19.43	17.38	15.98
28	12.64	.4837	2067.	16.72	15.41	13.78	12.67
29	11.26	.3836	2607.	13.26	12.22	10.93	10.05
30	10.03	.3042	3287.	10.52	9.691	8.669	7.968
31	8.928	.2413	4145.	8.341	7.685	6.875	6.319
32	7.950	.1913	5227.	6.614	6.095	5.452	5.011
33	7.080	.1517	6591.	5.245	4.833	4.323	3.974
34	6.305	.1203	8310.	4.160	3.833	3.429	3.152
35	5.615	.095 42	10 480.	3.299	3.040	2.719	2.499
36	5.000	.075 68	13 210.	2.616	2.411	2.156	1.982
37	4.453	.060 01	16 660.	2.075	1.912	1.710	1.572
38	3.965	.047 59	21 010.	1.645	1.516	1.356	1.247
39	3.531	.037 74	26 500.	1.305	1.202	1.075	0.9886
40	3.145	.029 93	33 410.	1.035	0.9534	0.8529	.7840

* Length at 20° C. of a wire whose resistance is 1 ohm at the stated temperatures.

Table 319 *(continued)*.

WIRE TABLE, STANDARD ANNEALED COPPER *(continued)*.

American Wire Gage (B. & S.). English Units *(continued)*.

Gage No.	Diameter in Mils at 20° C.	Ohms per Pound.			Pounds per Ohm.
		0° C. (=32° F.)	20° C. (=68° F.)	50° C. (=122° F.)	20° C. (=68° F.)
0000	460.0	0.000 070 51	0.000 076 52	0.000 085 54	13 070.
000	409.6	.000 1121	.000 1217	.000 1360	8219.
00	364.8	.000 1783	.000 1935	.000 2163	5169.
0	324.9	.000 2835	.000 3076	.000 3439	3251.
1	289.3	.000 4507	.000 4891	.000 5468	2044.
2	257.6	.000 7166	.000 7778	.000 8695	1286.
3	229.4	.001 140	.001 237	.001 383	808.6
4	204.3	.001 812	.001 966	.002 198	508.5
5	181.9	.002 881	.003 127	.003 495	319.8
6	162.0	.004 581	.004 972	.005 558	201.1
7	144.3	.007 284	.007 905	.008 838	126.5
8	128.5	.011 58	.012 57	.014 05	79.55
9	114.4	.018 42	.019 99	.022 34	50.03
10	101.9	.029 28	.031 78	.035 53	31.47
11	90.74	.046 56	.050 53	.056 49	19.79
12	80.81	.074 04	.080 35	.089 83	12.45
13	71.96	.1177	.1278	.1428	7.827
14	64.08	.1872	.2032	.2271	4.922
15	57.07	.2976	.3230	.3611	3.096
16	50.82	.4733	.5136	.5742	1.947
17	45.26	.7525	.8167	.9130	1.224
18	40.30	1.197	1.299	1.452	0.7700
19	35.89	1.903	2.065	2.308	.4843
20	31.96	3.025	3.283	3.670	.3046
21	28.46	4.810	5.221	5.836	.1915
22	25.35	7.649	8.301	9.280	.1205
23	22.57	12.16	13.20	14.76	.075 76
24	20.10	19.34	20.99	23.46	.047 65
25	17.90	30.75	33.37	37.31	.029 97
26	15.94	48.89	53.06	59.32	.018 85
27	14.20	77.74	84.37	94.32	.011 85
28	12.64	123.6	134.2	150.0	.007 454
29	11.26	196.6	213.3	238.5	.004 688
30	10.03	312.5	339.2	379.2	.002 948
31	8.928	497.0	539.3	602.9	.001 854
32	7.950	790.2	857.6	958.7	.001 166
33	7.080	1256.	1364.	1524.	.000 7333
34	6.305	1998.	2168.	2424.	.000 4612
35	5.615	3177.	3448.	3854.	.000 2901
36	5.000	5051.	5482.	6128.	.000 1824
37	4.453	8032.	8717.	9744.	.000 1147
38	3.965	12 770.	13 860.	15 490.	.000 072 15
39	3.531	20 310.	22 040.	24 640.	.000 045 38
40	3.145	32 290.	35 040.	39 170.	.000 028 54

WIRE TABLE, STANDARD ANNEALED COPPER.

American Wire Gage (B. & S.) Metric Units.

Gage No.	Diameter in mm. at 20° C.	Cross Section in mm.^{2} at 20° C.	Ohms per Kilometer.*			
			0° C.	20° C.	50° C.	75° C.
0000	11.68	107.2	0.1482	0.1608	0.1798	0.1956
000	10.40	85.03	.1868	.2028	.2267	.2466
00	9.266	67.43	.2356	.2557	.2858	.3110
0	8.252	53.48	.2971	.3224	.3604	.3921
1	7.348	42.41	.3746	.4066	.4545	.4944
2	6.544	33.63	.4724	.5127	.5731	.6235
3	5.827	26.67	.5956	.6465	.7227	.7862
4	5.189	21.15	.7511	.8152	.9113	.9914
5	4.621	16.77	.9471	1.028	1.149	1.250
6	4.115	13.30	1.194	1.296	1.449	1.576
7	3.665	10.55	1.506	1.634	1.827	1.988
8	3.264	8.366	1.899	2.061	2.304	2.506
9	2.906	6.634	2.395	2.599	2.905	3.161
10	2.588	5.261	3.020	3.277	3.663	3.985
11	2.305	4.172	3.807	4.132	4.619	5.025
12	2.053	3.309	4.801	5.211	5.825	6.337
13	1.828	2.624	6.054	6.571	7.345	7.991
14	1.628	2.081	7.634	8.285	9.262	10.08
15	1.450	1.650	9.627	10.45	11.68	12.71
16	1.291	1.309	12.14	13.17	14.73	16.02
17	1.150	1.038	15.31	16.61	18.57	20.20
18	1.024	0.8231	19.30	20.95	23.42	25.48
19	0.9116	.6527	24.34	26.42	29.53	32.12
20	.8118	.5176	30.69	33.31	37.24	40.51
21	.7230	.4105	38.70	42.00	46.95	51.08
22	.6438	.3255	48.80	52.96	59.21	64.41
23	.5733	.2582	61.54	66.79	74.66	81.22
24	.5106	.2047	77.60	84.21	94.14	102.4
25	.4547	.1624	97.85	106.2	118.7	129.1
26	.4049	.1288	123.4	133.9	149.7	162.9
27	.3606	.1021	155.6	168.9	188.8	205.4
28	.3211	.080 98	196.2	212.9	238.0	258.9
29	.2859	.064 22	247.4	268.5	300.1	326.5
30	.2546	.050 93	311.9	338.6	378.5	411.7
31	.2268	.040 39	393.4	426.9	477.2	519.2
32	.2019	.032 03	496.0	538.3	601.8	654.7
33	.1798	.025 40	625.5	678.8	758.8	825.5
34	.1601	.020 14	788.7	856.0	956.9	1041.
35	.1426	.015 97	994.5	1079.	1207.	1313.
36	.1270	.012 67	1254.	1361.	1522.	1655.
37	.1131	.010 05	1581.	1716.	1919.	2087.
38	.1007	.007 967	1994.	2164.	2419.	2632.
39	.089 69	.006 318	2514.	2729.	3051.	3319.
40	.079 87	.005 010	3171.	3441.	3847.	4185.

*Resistance at the stated temperatures of a wire whose length is 1 kilometer at 20° C.

WIRE TABLE, STANDARD ANNEALED COPPER (*continued*).

American Wire Gage (B. & S.) Metric Units (*continued*).

Gage No.	Diameter in mm. at 20° C.	Kilograms per Kilometer.	Meters per Gram.	Meters per Ohm.*			
				0° C.	20° C.	50° C.	75° C.
0000	11.68	953.2	0.001 049	6749.	6219.	5563.	5113.
000	10.40	755.9	.001 323	5352.	4932.	4412.	4055.
00	9.266	599.5	.001 668	4245.	3911.	3499.	3216.
0	8.252	475.4	.002 103	3366.	3102.	2774.	2550.
1	7.348	377.0	.002 652	2669.	2460.	2200.	2022.
2	6.544	299.0	.003 345	2117.	1951.	1745.	1604.
3	5.827	237.1	.004 217	1679.	1547.	1384.	1272.
4	5.189	188.0	.005 318	1331.	1227.	1097.	1009.
5	4.621	149.1	.006 706	1056.	972.9	870.2	799.9
6	4.115	118.2	.008 457	837.3	771.5	690.1	634.4
7	3.665	93.78	.010 66	664.0	611.8	547.3	503.1
8	3.264	74.37	.013 45	526.6	485.2	434.0	399.0
9	2.906	58.98	.016 96	417.6	384.8	344.2	316.4
10	2.588	46.77	.021 38	331.2	305.1	273.0	250.9
11	2.305	37.09	.026 96	262.6	242.0	216.5	199.0
12	2.053	29.42	.034 00	208.3	191.9	171.7	157.8
13	1.828	23.33	.042 87	165.2	152.2	136.1	125.1
14	1.628	18.50	.054 06	131.0	120.7	108.0	99.24
15	1.450	14.67	.068 16	103.9	95.71	85.62	78.70
16	1.291	11.63	.085 95	82.38	75.90	67.90	62.41
17	1.150	9.226	.1084	65.33	60.20	53.85	49.50
18	1.024	7.317	.1367	51.81	47.74	42.70	39.25
19	0.9116	5.803	.1723	41.09	37.86	33.86	31.13
20	.8118	4.602	.2173	32.58	30.02	26.86	24.69
21	.7230	3.649	.2740	25.84	23.81	21.30	19.58
22	.6438	2.894	.3455	20.49	18.88	16.89	15.53
23	.5733	2.295	.4357	16.25	14.97	13.39	12.31
24	.5106	1.820	.5494	12.89	11.87	10.62	9.764
25	.4547	1.443	.6928	10.22	9.417	8.424	7.743
26	.4049	1.145	.8736	8.105	7.468	6.680	6.141
27	.3606	0.9078	1.102	6.428	5.922	5.298	4.870
28	.3211	.7199	1.389	5.097	4.697	4.201	3.862
29	.2859	.5709	1.752	4.042	3.725	3.332	3.063
30	.2546	.4527	2.209	3.206	2.954	2.642	2.429
31	.2268	.3590	2.785	2.542	2.342	2.095	1.926
32	.2019	.2847	3.512	2.016	1.858	1.662	1.527
33	.1798	.2258	4.429	1.599	1.473	1.318	1.211
34	.1601	.1791	5.584	1.268	1.168	1.045	0.9606
35	.1426	.1420	7.042	1.006	0.9265	0.8288	.7618
36	.1270	.1126	8.879	0.7974	.7347	.6572	.6041
37	.1131	.089 31	11.20	.6324	.5827	.5212	.4791
38	.1007	.070 83	14.12	.5015	.4621	.4133	.3799
39	.089 69	.056 17	17.80	.3977	.3664	.3278	.3013
40	.079 87	.044 54	22.45	.3154	.2906	.2600	.2390

---

* Length at 20° C. of a wire whose resistance is 1 ohm at the stated temperatures.

WIRE TABLE, STANDARD ANNEALED COPPER (*continued*).

American Wire Gage (B. & S.). Metric Units (*continued*).

Gage No.	Diameter in mm. at 20° C.	Ohms per Kilogram.			Grams per Ohm.
		0° C.	20° C.	50° C.	20° C.
0000	11.68	0.000 155 4	0.000 168 7	0.000 188 6	5 928 000.
000	10.40	.000 247 2	.000 268 2	.000 299 9	3 728 000.
00	9.266	.000 393 0	.000 426 5	.000 476 8	2 344 000.
0	8.252	.000 624 9	.000 678 2	.000 758 2	1 474 000.
1	7.348	.000 993 6	.001 078	.001 206	927 300.
2	6.544	.001 580	.001 715	.001 917	583 200.
3	5.827	.002 512	.002 726	.003 048	366 800.
4	5.189	.003 995	.004 335	.004 846	230 700.
5	4.621	.006 352	.006 893	.007 706	145 100.
6	4.115	.010 10	.010 96	.012 25	91 230.
7	3.665	.016 06	.017 43	.019 48	57 380.
8	3.264	.025 53	.027 71	.030 98	36 080.
9	2.906	.040 60	.044 06	.049 26	22 690.
10	2.588	.064 56	.070 07	.078 33	14 270.
11	2.305	.1026	.1114	.1245	8976.
12	2.053	.1632	.1771	.1980	56.45
13	1.828	.2595	.2817	.3149	3550.
14	1.628	.4127	.4479	.5007	2233.
15	1.450	.6562	.7122	.7961	1404.
16	1.291	1.043	1.132	1.266	883.1
17	1.150	1.659	1.801	2.013	555.4
18	1.024	2.638	2.863	3.201	349.3
19	0.9116	4.194	4.552	5.089	219.7
20	.8118	6.670	7.238	8.092	138.2
21	.7230	10.60	11.51	12.87	86.88
22	.6438	16.86	18.30	20.46	54.64
23	.5733	26.81	29.10	32.53	34.36
24	.5106	42.63	46.27	51.73	21.61
25	.4547	67.79	73.57	82.25	13.59
26	.4049	107.8	117.0	130.8	8.548
27	.3606	171.4	186.0	207.9	5.376
28	.3211	272.5	295.8	330.6	3.381
29	.2859	433.3	470.3	525.7	2.126
30	.2546	689.0	747.8	836.0	1.337
31	.2268	1096.	1189.	1329.	0.8410
32	.2019	1742.	1891.	2114.	.5289
33	.1798	2770.	3006.	3361.	.3326
34	.1601	4404.	4780.	5344.	.2092
35	.1426	7003.	7601.	8497.	.1316
36	.1270	11140.	12090.	13510.	.082 74
37	.1131	17710.	19220.	21480.	.052 04
38	.1007	28150.	30560.	34160.	.032 73
39	.089 69	44770.	48590.	54310.	.020 58
40	.079 87	71180.	77260.	86360.	.012 94

TABLE 321.—ALUMINUM WIRE TABLE.

Hard-Drawn Aluminum Wire at 20° C. (or, 68° F.).

American Wire Gage (B. & S.). English Units.

Gage No.	Diameter in Mils.	Cross Section.		Ohms per 1000 Feet.	Pounds per 1000 Feet.	Pounds per Ohm.	Feet per Ohm.
		Circular Mils.	Square Inches.				
0000	460.	212 000.	0.166	0.0804	195.	2420.	12 400.
000	410.	168 000.	.132	.101	154.	1520.	9860.
00	365.	133 000.	.105	.128	122.	957.	7820.
0	325.	106 000.	.0829	.161	97.0	602.	6200.
1	289.	83 700.	.0657	.203	76.9	379.	4920.
2	258.	66 400.	.0521	.256	61.0	238.	3900.
3	229.	52 600.	.0413	.323	48.4	150.	3090.
4	204.	41 700.	.0328	.408	38.4	94.2	2450.
5	182.	33 100.	.0260	.514	30.4	59.2	1950.
6	162.	26 300.	.0206	.648	24.1	37.2	1540.
7	144.	20 800.	.0164	.817	19.1	23.4	1220.
8	128.	16 500.	.0130	1.03	15.2	14.7	970.
9	114.	13 100.	.0103	1.30	12.0	9.26	770.
10	102.	10 400.	.008 15	1.64	9.55	5.83	610.
11	91.	8230.	.006 47	2.07	7.57	3.66	484.
12	81.	6530.	.005 13	2.61	6.00	2.30	384.
13	72.	5180.	.004 07	3.29	4.76	1.45	304.
14	64.	4110.	.003 23	4.14	3.78	0.911	241.
15	57.	3260.	.002 56	5.22	2.99	.573	191.
16	51.	2580.	.002 03	6.59	2.37	.360	152.
17	45.	2050.	.001 61	8.31	1.88	.227	120.
18	40.	1620.	.001 28	10.5	1.49	.143	95.5
19	36.	1290.	.001 01	13.2	1.18	.0897	75.7
20	32.	1020.	.000 802	16.7	0.939	.0564	60.0
21	28.5	810.	.000 636	21.0	.745	.0355	47.6
22	25.3	642.	.000 505	26.5	.591	.0223	37.8
23	22.6	509.	.000 400	33.4	.468	.0140	29.9
24	20.1	404.	.000 317	42.1	.371	.008 82	23.7
25	17.9	320.	.000 252	53.1	.295	.005 55	18.8
26	15.9	254.	.000 200	67.0	.234	.003 49	14.9
27	14.2	202.	.000 158	84.4	.185	.002 19	11.8
28	12.6	160.	.000 126	106.	.147	.001 38	9.39
29	11.3	127.	.000 099 5	134.	.117	.000 868	7.45
30	10.0	101.	.000 078 9	169.	.0924	.000 546	5.91
31	8.9	79.7	.000 062 6	213.	.0733	.000 343	4.68
32	8.0	63.2	.000 049 6	269.	.0581	.000 216	3.72
33	7.1	50.1	.000 039 4	339.	.0461	.000 136	2.95
34	6.3	39.8	.000 031 2	428.	.0365	.000 085 4	2.34
35	5.6	31.5	.000 024 8	540.	.0290	.000 053 7	1.85
36	5.0	25.0	.000 019 6	681.	.0230	.000 033 8	1.47
37	4.5	19.8	.000 015 6	858.	.0182	.000 021 2	1.17
38	4.0	15.7	.000 012 3	1080.	.0145	.000 013 4	0.924
39	3.5	12.5	.000 009 79	1360.	.0115	.000 008 40	.733
40	3.1	9.9	.000 007 77	1720.	.0091	.000 005 28	.581

TABLE 322.—ALUMINUM WIRE TABLE.

Hard-Drawn Aluminum Wire at 20° C.

American Wire Gage (B. & S.) Metric Units.

Gage No.	Diameter in mm.	Cross Section in mm.^{2}	Ohms per Kilometer.	Kilograms per Kilometer.	Grams per Ohm.	Ohms per Meter.
0000	11.7	107.	0.264	289.	1 100 000.	3790.
000	10.4	85.0	.333	230.	690 000.	3010.
00	9.3	67.4	.419	182.	434 000.	2380.
0	8.3	53.5	.529	144.	273 000.	1890.
1	7.3	42.4	.667	114.	172 000.	1500.
2	6.5	33.6	.841	90.8	108 000.	1190.
3	5.8	26.7	1.06	72.0	67 900.	943.
4	5.2	21.2	1.34	57.1	42 700.	748.
5	4.6	16.8	1.69	45.3	26 900.	593.
6	4.1	13.3	2.13	35.9	16 900.	470.
7	3.7	10.5	2.68	28.5	10 600.	373.
8	3.3	8.37	3.38	22.6	6680.	296.
9	2.91	6.63	4.26	17.9	4200.	235.
10	2.59	5.26	5.38	14.2	2640.	186.
11	2.30	4.17	6.78	11.3	1660.	148.
12	2.05	3.31	8.55	8.93	1050.	117.
13	1.83	2.62	10.8	7.08	657.	92.8
14	1.63	2.08	13.6	5.62	413.	73.6
15	1.45	1.65	17.1	4.46	260.	58.4
16	1.29	1.31	21.6	3.53	164.	46.3
17	1.15	1.04	27.3	2.80	103.	36.7
18	1.02	0.823	34.4	2.22	64.7	29.1
19	0.91	.653	43.3	1.76	40.7	23.1
20	.81	.518	54.6	1.40	25.6	18.3
21	.72	.411	68.9	1.11	16.1	14.5
22	.64	.326	86.9	0.879	10.1	11.5
23	.57	.258	110.	.697	6.36	9.13
24	.51	.205	138.	.553	4.00	7.24
25	.45	.162	174.	.438	2.52	5.74
26	.40	.129	220.	.348	1.58	4.55
27	.36	.102	277.	.276	0.995	3.61
28	.32	.0810	349.	.219	.626	2.86
29	.29	.0642	440.	.173	.394	2.27
30	.25	.0509	555.	.138	.248	1.80
31	.227	.0404	700.	.109	.156	1.43
32	.202	.0320	883.	.0865	.0979	1.13
33	.180	.0254	1110.	.0686	.0616	0.899
34	.160	.0201	1400.	.0544	.0387	.712
35	.143	.0160	1770.	.0431	.0244	.565
36	.127	.0127	2230.	.0342	.0153	.448
37	.113	.0100	2820.	.0271	.009 63	.355
38	.101	.0080	3550.	.0215	.006 06	.282
39	.090	.0063	4480.	.0171	.003 81	.223
40	.080	.0050	5640.	.0135	.002 40	.177

DIELECTRIC STRENGTH.

TABLE 323. — Steady Potential Difference in Volts required to produce a Spark in Air with Ball Electrodes.

Spark length. cm.	$R = 0$. Points.	$R = 0.25$ cm.	$R = 0.5$ cm.	$R = 1$ cm.	$R = 2$ cm.	$R = 3$ cm.	$R = \infty$. Plates.
0.02	–	–	1560	1530			
0.04	–	–	2460	2430	2340		
0.06	–	–	3300	3240	3060		
0.08	–	–	4050	3990	3810		
0.1	3720	5010	4740	4560	4560	4500	4350
0.2	4680	8610	8490	8490	8370	7770	7590
0.3	5310	11140	11460	11340	11190	10560	10650
0.4	5970	14040	14310	14340	14250	13140	13560
0.5	6300	15990	16950	17220	16650	16470	16320
0.6	6840	17130	19740	20070	20070	19380	19110
0.8	8070	18960	23790	24780	25830	26220	24960
1.0	8670	20670	26190	27810	29850	32760	30840
1.5	9960	22770	29970	37260			
2.0	10140	24570	33060	45480			
3.0	11250	28380					
4.0	12210	29580					
5.0	13050						

Based on the results of Baille, Bichat-Blondot, Freyburg, Liebig, Macfarlane, Orgler, Paschen, Quincke, de la Rue, Wolff. For spark lengths from 1 to 200 wave-lengths of sodium light, see Earhart, Phys. Rev. 15, p. 163; Hobbs, Phil. Mag. 10, p. 607, 1905.

TABLE 324. — Alternating Current Potentials required to produce a Spark in Air with various Ball Electrodes.

The potentials given are the maxima of the alternating waves used. Frequency, 33 cycles per second.

Spark length. cm.	$R = 1$ cm.	$R = 1.92$	$R = 5$	$R = 7.5$	$R = 10$	$R = 15$
0.08	3770					
.10	4400	4380	4330	4290	4245	4230
.15	5990	5940	5830	5790	5800	5780
.20	7510	7440	7340	7250	7320	7330
.25	9045	8970	8850	8710	8760	8760
0.30	10480	10400	10270	10130	10180	10150
.35	11980	11890	11670	11570	11610	11590
.40	13360	13300	13100	12930	12980	12970
.45	14770	14700	14400	14290	14330	14320
.50	16140	16070	15890	15640	15690	15690
0.6	18700	18730	18550	18300	18350	18400
.7	21350	21380	21140	20980	20990	21000
.8	23820	24070	23740	23490	23540	23550
0.9	26190	26640	26400	26130	26110	26090
1.0	28380	29170	28950	28770	28680	28610
1.2	32400	34100	33790	33660	33640	33620
1.4	35850	38850	38850	38580	38620	38580
1.6	38750	43400	43570	43250	43520	
1.8	40900	–	48300	47900		
2.0	42950	–	–	52400		

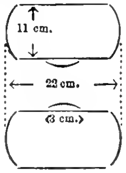
Based upon the results of Kawalski, Phil. Mag. 18, p. 699, 1909.

DIELECTRIC STRENGTH.

TABLE 325. — Potential Necessary to produce a Spark in Air between more widely Separated Electrodes.

Spark length, cm.	Dull points. Alternating current.	Steady potentials.				Spark length, cm.	Dull points. Alternating current.	Steady potentials.	
		Ball electrodes.		Cup electrodes.				Ball electrodes.	
		R=1 cm.	R=2.5 cm.	Projection.				R=1 cm.	R=2.5 cm.
				4.5 mm.	1.5 mm.				
0.3	–	–	–	–	11280	6.0	61000	–	86830
0.5	–	17610	17620	–	17420	7.0	–	52000	–
0.7	–	–	23050	–	22950	8.0	67000	52400	90200
1.0	12000	30240	31390	31400	31260	10.0	73000	74300	91930
1.2	–	33800	36810	–	36700	12.0	82600	–	93300
1.5	–	37930	44310	–	44510	14.0	92000	–	94400
2.0	29200	42320	56000	56500	56530	15.0	–	–	94700
2.5	–	45000	65180	–	68720	16.0	101000	–	101000
3.0	40000	46710	71200	80400	81140	20.0	119000		
3.5	–	–	75300	–	92400	25.0	140600		
4.0	48500	49100	78600	101700	103800	30.0	165700		
4.5	–	–	81540	–	114600	35.0	190900		
5.0	56500	50310	83800	–	126500				
5.5	–	–	–	–	135700				

This table for longer spark lengths contains the results of Voege, Ann. der Phys. 14, 1904, using alternating current and "dull point" electrodes, and the results with steady potential found in the recent very careful work of C. Müller, Ann. d. Phys. 28, p. 585, 1909.



The specially constructed electrodes for the columns headed "cup electrodes" had the form of a projecting knob 3 cm. in diameter and having a height of 4.5 mm. and 1.5 mm. respectively, attached to the plane face of the electrodes. These electrodes give a very satisfactory linear relation between the spark lengths and the voltage throughout the range studied.

TABLE 326. — Effect of the Pressure of the Gas on the Dielectric Strength.

Voltages are given for different spark lengths l.

Pressure. cm. Hg.	l=0.04	l=0.06	l=0.08	l=0.10	l=0.20	l=0 30	l=0.40	l=0.50
2	–	–	–	–	744	939	1110	1266
4	–	483	567	648	1015	1350	1645	1915
6	–	582	690	795	1290	1740	2140	2505
10	–	771	933	1090	1840	2450	3015	3580
15	–	1060	1280	1490	2460	3300	4080	4850
25	1110	1420	1725	2040	3500	4800	6000	7120
35	1375	1820	2220	2615	4505	6270	7870	9340
45	1640	2150	2660	3120	5475	7650	9620	11420
55	1820	2420	3025	3610	6375	8950	11290	13455
65	2040	2720	3400	4060	7245	10210	12950	15470
75	2255	3035	3805	4565	8200	11570	14650	17450

This table is based upon the results of Orgler, 1899. See this paper for work on other gases (or Landolt-Börnstein-Meyerhoffer).

For long spark lengths in various gases see Voege, Electrotechn. Z. 28, 1907. For dielectric strength of air and CO_2 in cylindrical air condensers, see Wien, Ann. d. Phys. 29, p. 679, 1909.

DIELECTRIC STRENGTH.

TABLE 327.—Dielectric Strength of Materials.

Potential necessary for puncture expressed in kilovolts per centimeter thickness of the dielectric.

Substance.	Kilovolts per cm	Substance.	Kilovolts per cm.	Substance.	Kilovolts per cm.
Ebonite	300–1100	Oils: Thickness		Papers:	
Empire cloth	80–300	Castor 0.2 mm.	190	Beeswaxed	770
" paper	450	" 1.0 "	130	Blotting	150
Fibre	20	Cottonseed	70	Manilla	25
Fuller board	200–300	Lard 0.2 "	140	Paraffined	500
Glass	300–1500	" 1.0 "	40	Varnished	100–250
Granite (fused)	90	Linseed, raw 0.2 "	185	Paraffine:	
Guttapercha	80–200	" " 1.0 "	90	Melted	75
Impregnated jute	20	" boiled 0.2 "	190	Melt point.	
Leatheroid	30–60	" " 1.0 "	80	Solid 43°	350
Linen, varnished	100–200	Lubricating	50	" 47°	400
Liquid air	40–90	Neatsfoot 0.2 "	200	" 52°	230
Mica: Thickness.		" 1.0 "	90	" 70°	450
Madras 0.1 mm.	1600	Olive 0.2 "	170	Presspaper	45–75
" 1.0 "	300	" 1.0 "	75	Rubber	160–500
Bengal 0.1 "	2200	Paraffin 0.2 "	215	Vaseline	90–130
" 1.0 "	700	" 1.0 "	160	Thickness.	
Canada 0.1 "	1500	Sperm, mineral 0.2 "	180	Xylol 0.2 mm.	140
" 1.0 "	500	" " 1.0 "	85	" 1.0 "	80
South America	1500	" natural 0.2 "	195		
Micanite	400	" " 1.0 "	90		
		Turpentine 0.2 "	160		
		" 1.0 "	110		

TABLE 328.—Potentials in Volts to Produce a Spark in Kerosene.

Spark length. mm.	Electrodes Balls of Diam. *d*.			
	0.5 cm.	1 cm.	2 cm.	3 cm.
0.1	3800	3400	2750	2200
.2	7500	6450	4800	3500
.3	10250	9450	7450	4600
.4	11750	10750	9100	5600
.5	13050	12400	11000	6900
.6	14000	13550	12250	8250
.8	15500	15100	13850	10450
1.0	16750	16400	15250	12350

Determinations of the dielectric strength of the same substance by different observers do not agree well. For a discussion of the sources of error see Mościcki, Electrotechn. Z. 25, 1904.

For more detailed information on the dependence of the sparking distance in oils as a function of the nature of the electrodes, see Edmondson, Phys. Review 6, p. 65, 1898.

TABLE 329. — Electrical Resistance of Straight Wires with Alternating Currents of Different Frequencies.

This table gives the ratio of the resistance of straight copper wires with alternating currents of different frequencies to the value of the resistance with direct currents.

Diameter of wire in millimeters.	Frequency n =					
	60	100	1000	10000	100000	1000000
0.05	-	-	-	-	-	*1.001
0.1	-	-	-	-	*1.001	1.008
0.25	-	-	-	-	1.003	1.247
0.5	-	-	-	*1.001	1.047	2.240
1.0	-	-	-	1.008	1.503	4.19
2	-	-	1.001	1.120	2.756	
3	-	-	1.006	1.437	4.00	
4	-	-	1.021	1.842		
5	-	*1.001	1.047	2.240		
7.5	1.001	1.002	1.210	3.22		
10	1.003	1.008	1.503	4.19		
15	1.016	1.038	2.136			
20	1.044	1.120	2.756			
25	1.105	1.247	3.38			
40	1.474	1.842				
100	3.31	4.19				

Values between 1.000 and 1.001 are indicated by *1.001.

The change of resistance of wires other than copper (iron wires excepted) may be calculated from the above table, making use of the fact that the change of resistance is a function of the argument $p = 2\pi r\sqrt{2n\lambda}$ where r = radius of cross-section, n = frequency, λ = conductivity.

If a given wire be wound into a solenoid, its resistance, at a given frequency, will be greater than the values in the table, which apply to straight wires only. The resistance in this case is a complicated function of the pitch and radius of the winding, the frequency, and the diameter of the wire, and is found by experiment to be sometimes as much as twice the value for a straight wire.

TABLE 330. — Electrical Resistance for High Frequencies.

For which the high frequency resistance will be less than 1 per cent greater than direct current resistance.

Wave-length.	Constantan or Advance Wire.		Manganin Diameter.	Platinum Diameter.	Copper Diameter.
	Diameter.	Maximum Current.			
m.	*mm.*	*amp.*	*mm.*	*mm.*	*mm.*
100	0.30	3.5	0.29	0.13	0.006
200	0.46	4.5	0.40	0.29	0.045
300	0.57	5.5	0.50	0.27	0.09
400	0.66	7.0	0.60	0.30	0.10
600	0.83	8.0	0.75	0.37	0.15
800	0.98	10.0	0.88	0.42	0.20
1000	1.10	11.5	0.99	0.50	0.21
1200	1.20	12.5	1.10	0.57	0.22
1500	1.30	14.0	1.21	0.63	0.26
2000	1.52	17.0	1.38	0.73	0.30
3000	1.80	24.0	1.62	0.80	0.33

Advance wire is practically identical electrically with constantan, while for high resistance German silver the values are nearly the same as for manganin. The column of the table under maximum current gives the approximate current which may be carried by the various sizes without undue heating. The current capacity of the manganin is very nearly the same.

From Austin, Jour. Wash. Acad. of Sci. 2, p. 190, 1911.

TABLE 331.

WIRELESS TELEGRAPHY.

Wave-Length in Meters, Frequency in periods per second, and Oscillation Constant LC in Microhenries and Microfarads.

Meters.	n	L C	Meters.	n	L C	Meters.	n	L C
100	3,000,000	0.00282	600	500,000	0.101	1100	272,700	0.341
110	2,727,000	0.00341	610	491,800	0.105	1110	270,300	0.347
120	2,500,000	0.00405	620	485,500	0.108	1120	267,900	0.353
130	2,308,000	0.00476	630	476,200	0.111	1130	265,500	0.359
140	2,143,000	0.00552	640	468,700	0.115	1140	263,100	0.366
150	2,000,000	0.00633	650	461,500	0.119	1150	260,900	0.372
160	1,875,000	0.00721	660	454,500	0.123	1160	258,600	0.379
170	1,765,000	0.00813	670	447,800	0.126	1170	256,400	0.385
180	1,667,000	0.00912	680	441,200	0.130	1180	254,200	0.392
190	1,579,000	0.01016	690	434,800	0.134	1190	252,100	0.399
200	1,500,000	0.0113	700	428,600	0.138	1200	250,000	0.405
210	1,429,000	0.0124	710	422,500	0.142	1210	247,900	0.412
220	1,364,000	0.0136	720	416,700	0.146	1220	245,900	0.419
230	1,304,000	0.0149	730	411,000	0.150	1230	243,900	0.426
240	1,250,000	0.0162	740	405,400	0.154	1240	241,900	0.433
250	1,200,000	0.0176	750	400,000	0.158	1250	240,000	0.440
260	1,154,000	0.0190	760	394,700	0.163	1260	238,100	0.447
270	1,111,000	0.0205	770	389,600	0.167	1270	236,200	0.454
280	1,071,000	0.0221	780	384,600	0.171	1280	234,400	0.461
290	1,034,000	0.0237	790	379,800	0.176	1290	232,600	0.468
300	1,000,000	0.0253	800	375,000	0.180	1300	230,800	0.476
310	967,700	0.0270	810	370,400	0.185	1310	229,000	0.483
320	937,500	0.0288	820	365,900	0.189	1320	227,300	0.490
330	909,100	0.0307	830	361,400	0.194	1330	225,600	0.498
340	882,400	0.0326	840	357,100	0.199	1340	223,900	0.505
350	859,100	0.0345	850	352,900	0.203	1350	222,200	0.513
360	833,300	0.0365	860	348,800	0.208	1360	220,600	0.521
370	810,800	0.0385	870	344,800	0.213	1370	218,900	0.529
380	789,500	0.0406	880	340,900	0.218	1380	217,400	0.536
390	769,200	0.0428	890	337,100	0.223	1390	215,800	0.544
400	750,000	0.0450	900	333,300	0.228	1400	214,300	0.552
410	731,700	0.0473	910	329,700	0.233	1410	212,800	0.559
420	714,300	0.0496	920	326,100	0.238	1420	211,300	0.567
430	697,700	0.0520	930	322,600	0.243	1430	209,800	0.576
440	681,800	0.0545	940	319,100	0.249	1440	208,300	0.584
450	666,700	0.0570	950	315,900	0.254	1450	206,900	0.592
460	652,200	0.0596	960	312,500	0.259	1460	205,500	0.600
470	638,300	0.0622	970	309,300	0.265	1470	204,100	0.608
480	625,000	0.0649	980	306,100	0.270	1480	202,700	0.617
490	612,200	0.0676	990	303,000	0.276	1490	201,300	0.625
500	600,000	0.0704	1000	300,000	0.281	1500	200,000	0.633
510	588,200	0.0732	1010	297,000	0.287	1510	198,700	0.642
520	576,900	0.0761	1020	294,100	0.293	1520	197,400	0.650
530	566,000	0.0791	1030	291,300	0.299	1530	196,100	0.659
540	555,600	0.0821	1040	288,400	0.305	1540	194,800	0.668
550	545,500	0.0851	1050	285,700	0.310	1550	193,600	0.676
560	535,700	0.0883	1060	283,600	0.316	1560	192,300	0.685
570	526,300	0.0915	1070	280,400	0.322	1570	191,100	0.694
580	517,200	0.0947	1080	277,800	0.328	1580	189,900	0.703
590	508,500	0.0981	1090	275,200	0.335	1590	188,700	0.712

Prepared by Greenleaf W. Picard; copyright by Wireless Specialty Apparatus Company, New York. Computed on basis of 300,000 kilometers per second for the velocity of propagation of electromagnetic waves.

TABLE 331 (*concluded*).

WIRELESS TELEGRAPHY.

Wave-Length, Frequency and Oscillation Constant.

Meters.	n	L C	Meters.	n	L C	Meters.	n	L C
1600	187,500	0.721	2000	150,000	1.13	6000	50,000	10.1
1610	186,300	0.730	2100	142,900	1.24	6100	49,180	10.5
1620	185,200	0.739	2200	136,400	1.36	6200	48,550	10.8
1630	184,100	0.748	2300	130,400	1.49	6300	47,620	11.1
1640	182,900	0.757	2400	125,000	1.62	6400	46,870	11.5
1650	181,800	0.766	2500	120,000	1.76	6500	46,150	11.9
1660	180,700	0.776	2600	115,400	1.90	6600	45,450	12.3
1670	179,600	0.785	2700	111,100	2.05	6700	44,780	12.6
1680	178,600	0.794	2800	107,100	2.21	6800	44,120	13.0
1690	177,500	0.804	2900	103,400	2.37	6900	43.480	13.4
1700	176,500	0.813	3000	100,000	2.53	7000	42,860	13.8
1710	175,400	0.823	3100	96,770	2.70	7100	42,250	14.2
1720	174,400	0.833	3200	93,750	2.88	7200	41,670	14.6
1730	173,400	0.842	3300	90,910	3.07	7300	41,100	15.0
1740	172,400	0.852	3400	88,240	3.26	7400	40,540	15.4
1750	171,400	0.862	3500	85,910	3.45	7500	40,000	15.8
1760	170,500	0.872	3600	83,330	3.65	7600	39,470	16.3
1770	169,400	0.882	3700	81,080	3.85	7700	38,960	16.7
1780	168,500	0.892	3800	78,950	4.06	7800	38,460	17.1
1790	167,600	0.902	3900	76,920	4.28	7900	37,980	17.6
1800	166,700	0.912	4000	75,000	4.50	8000	37,500	18.0
1810	165,700	0.923	4100	73,170	4.73	8100	37,040	18.5
1820	164,800	0.933	4200	71,430	4.96	8200	36,590	18.9
1830	163,900	0.943	4300	69,770	5.20	8300	36,140	19.4
1840	163,000	0.953	4400	68,180	5.45	8400	35,710	19.9
1850	162,200	0.963	4500	66,670	5.70	8500	35,290	20.3
1860	161,300	0.974	4600	65,220	5.96	8600	34,880	20.8
1870	160.400	0.985	4700	63,830	6.22	8700	34,480	21.3
1880	159,600	0.995	4800	62,500	6.49	8800	34,090	21.8
1890	158,700	1.006	4900	61,220	6.76	8900	33,710	22.3
1900	157,900	1.016	5000	60,000	7.04	9000	33,330	22.8
1910	157,100	1.026	5100	58,820	7.32	9100	32,970	23.3
1920	156,300	1.037	5200	57,690	7.61	9200	32,610	23.8
1930	155,400	1.048	5300	56,600	7.91	9300	32,260	24.3
1940	154,600	1.059	5400	55,560	8.21	9400	31,910	24.9
1950	153,800	1.070	5500	54,550	8.51	9500	31,590	25.4
1960	153,100	1.081	5600	53,570	8.83	9600	31,250	25.9
1970	152,300	1.092	5700	52,630	9.15	9700	30,930	26.5
1980	151,500	1.103	5800	51,720	9.47	9800	30,610	27.0
1990	150,800	1.114	5900	50,850	9.81	9900	30,310	27.6
						10000	30,000	28.1

TABLE 332.

WIRELESS TELEGRAPHY.

Radiation Resistances for Various Wave-Lengths and Antenna Heights.

The radiation theory of Hertz shows that the radiated energy of an oscillator may be represented by E = constant $(h^2/\lambda^2)\ I^2$, where h is the length of the oscillator, λ, the wave-length and I the current at its center. For a flat-top antenna $E = 1600\ (h^2/\lambda^2)\ I^2$ watts; $1600\ h^2/\lambda^2$ is called the radiation resistance.

(h = height to center of capacity of conducting system.)

h = Wave-Length λ	40 Ft.	60 Ft.	80 Ft.	100 Ft.	120 Ft.	160 Ft.	200 Ft.	300 Ft.	450 Ft.	600 Ft.	1200 Ft.
m	*ohm*	*ohm*	*ohm*	*ohm*	*ohm*	*ohm*	*ohm*	*ohm*	*ohm*	*ohm*	*ohm*
200	6.0	13.4	24.0	37.0	54.0	95.0					
300	2.7	6.0	10.6	16.5	23.8	42.4					
400	1.5	3.4	6.0	9.3	13.4	23.8					
600	0.66	1.5	2.7	4.1	6.0	10.6	16.4	37.4	84.0	149.0	
800	0.37	0.84	1.5	2.3	3.4	6.0	9.2	21.0	47.0	84.0	
1000	0.24	0.54	0.95	1.5	2.1	3.8	6.0	13.5	30.0	54.0	215.0
1200	0.17	0.37	0.66	1.03	1.5	2.6	4.1	9.3	21.0	37.0	149.0
1500	0.11	0.24	0.42	0.66	0.95	1.7	2.6	6.0	13.4	24.0	95.0
2000		0.13	0.24	0.37	0.54	0.95	1.5	3.4	7.5	13.4	54.0
2500			0.15	0.24	0.34	0.61	0.95	2.2	4.8	8.6	34.0
3000			0.11	0.17	0.24	0.42	0.66	1.5	3.4	6.0	24.0
4000			0.06	0.09	0.13	0.24	0.37	0.84	1.9	3.4	13.4
5000							0.24	0.53	1.20	2.2	8.6
6000							0.16	0.37	0.84	1.5	6.0
7000							0.12	0.27	0.61	1.1	4.4

Austin, Jour. Wash. Acad. of Sci. 1, p. 190, 1911.

TABLE 333.

INTERNATIONAL ATOMIC WEIGHTS. ELECTROCHEMICAL EQUIVALENTS.

The International Atomic Weights are quoted from the report of the International Committee on Atomic Weights (Journal American Chemical Society, 35, p. 1807, 1913).

The Electrochemical equivalent of Silver is 0.0011180 gram. sec.$^{-1}$ amp.$^{-1}$. (See definition of International Ampere, p. xxxiii.) The electrochemical equivalent for any other element is

$$\frac{\text{atomic weight element}}{\text{atomic weight silver}} \times \frac{.0011180}{\text{valency}} \text{ gm. sec.}^{-1} \text{ amp.}^{-1}.$$

The equivalent for iodine has been recently (1913) determined at the Bureau of Standards as 1.3150. The valencies given are only those commonly shown by the elements.

Substance.	Symbol.	Relative atomic wt. Oxygen = 16.	Valency.	Substance.	Symbol.	Relative atomic wt. Oxygen = 16.	Valency.
Aluminum	Al	27.1	3.	Mercury	Hg	200.6	1, 2.
Antimony	Sb	120.2	3, 5.	Molybdenum	Mo	96.0	4, 6.
Argon	A	39.88	0.	Neodymium	Nd	144.3	3.
Arsenic	As	74.96	3, 5.	Neon	Ne	20.2	0.
Barium	Ba	137.37	2.	Nickel	Ni	58.68	2, 3.
Bismuth	Bi	208.0	3, 5.	Niton (Ra emanation)	Nt.	222.4	—
Boron	B	11.0	3.	Nitrogen	N	14.01	3, 5.
Bromine	Br	79.92	1.	Osmium	Os	190.9	6, 8.
Cadmium	Cd	112.40	2.	Oxygen	O	16.00	2.
Cæsium	Cs	132.81	1.	Palladium	Pd	106.7	2, 4.
Calcium	Ca	40.07	2.	Phosphorus	P	31.04	3, 5.
Carbon	C	12.00	4.	Platinum	Pt	195.2	2, 4.
Cerium	Ce	140.25	3, 4.	Potassium	K	39.10	1.
Chlorine	Cl	35.46	1.	Praseodymium	Pr	140.6	3.
Chromium	Cr	52.0	2, 3, 6.	Radium	Ra	226.4	2.
Cobalt	Co	58.97	2, 3.	Rhodium	Rh	102.9	3.
Columbium	Cb	93.5	5.	Rubidium	Rb	85.45	1.
Copper	Cu	63.57	1, 2.	Ruthenium	Ru	101.7	6, 8.
Dysprosium	Dy	162.5	3.	Samarium	Sa	150.4	3.
Erbium	Er	167.7	3.	Scandium	Sc	44.1	3.
Europium	Eu	152.0	3.	Selenium	Se	79.2	2, 4, 6.
Fluorine	F	19.0	1.	Silicon	Si	28.3	4.
Gadolinium	Gd	157.3	3.	Silver	Ag	107.88	1.
Gallium	Ga	69.9	3.	Sodium	Na	23.00	1.
Germanium	Ge	72.5	4.	Strontium	Sr	87.63	2.
Glucinum	Gl	9.1	2.	Sulphur	S	32.07	2, 4, 6.
Gold	Au	197.2	1, 3.	Tantalum	Ta	181.5	5.
Helium	He	3.99	0.	Tellurium	Te	127.5	2, 4, 6.
Holmium	Ho	163.5	3.	Terbium	Tb	159.2	3.
Hydrogen	H	1.008	1.	Thallium	Tl	204.0	1, 3.
				Thorium	Th	232.4	4.
Indium	In	114.8	3.	Thulium	Tm	168.5	3.
Iodine	I	126.92	1.	Tin	Sn	119.0	2, 4.
Iridium	Ir	193.1	4.	Titanium	Ti	48.1	4.
Iron	Fe	55.84	2, 3.	Tungsten	W	184.0	6.
Krypton	Kr	82.92	0.	Uranium	U	238.5	4, 6.
Lanthanum	La	139.0	3.	Vanadium	V	51.0	3, 5.
Lead	Pb	207.10	2, 4.	Xenon	Xe	130.2	0.
Lithium	Li	6.94	1.	Ytterbium	Yb	173.0	3.
Lutecium	Lu	174.0	3.	Yttrium	Yt	89.0	3.
Magnesium	Mg	24.32	2.	Zinc	Zn	65.37	2.
Manganese	Mn	54.93	2, 3, 7.	Zirconium	Zr	90.6	4.

CONDUCTIVITY OF ELECTROLYTIC SOLUTIONS.

This subject has occupied the attention of a considerable number of eminent workers in molecular physics, and a few results are here tabulated. It has seemed better to confine the examples to the work of one experimenter, and the tables are quoted from a paper by F. Kohlrausch,* who has been one of the most reliable and successful workers in this field.

The study of electrolytic conductivity, especially in the case of very dilute solutions, has furnished material for generalizations, which may to some extent help in the formation of a sound theory of the mechanism of such conduction. If the solutions are made such that per unit volume of the solvent medium there are contained amounts of the salt proportional to its electrochemical equivalent, some simple relations become apparent. The solutions used by Kohlrausch were therefore made by taking numbers of grams of the pure salts proportional to their electrochemical equivalent, and using a liter of water as the standard of quantity of the solvent. Taking the electrochemical equivalent number as the chemical equivalent or atomic weight divided by the valence, and using this number of grams to the liter of water, we get what is called the normal or gram molecule per liter solution. In the table, m is used to represent the number of gram molecules to the liter of water in the solution for which the conductivities are tabulated. The conductivities were obtained by measuring the resistance of a cell filled with the solution by means of a Wheatstone bridge alternating current and telephone arrangement. The results are for 18° C., and relative to mercury at 0° C., the cell having been standardized by filling with mercury and measuring the resistance. They are supposed to be accurate to within one per cent of the true value.

The tabular numbers were obtained from the measurements in the following manner: —

Let K_{18} = conductivity of the solution at 18° C. relative to mercury at 0° C.

K^{w}_{18} = conductivity of the solvent water at 18° C. relative to mercury at 0° C.

Then $K_{18} - K^{w}_{18} = k_{18}$ = conductivity of the electrolyte in the solution measured.

$\frac{k_{18}}{m} = \mu$ = conductivity of the electrolyte in the solution per molecule, or the "specific molecular conductivity."

TABLE 334. — Value of k_{18} for a few Electrolytes.

This short table illustrates the apparent law that the conductivity in very dilute solutions is proportional to the amount of salt dissolved.

m	KCl	NaCl	$AgNO_3$	$KC_2H_3O_2$	K_2SO_4	$MgSO_4$
0.000001	1.216	1.024	1.080	0.939	1.275	1.056
0.00002	2.434	2.056	2.146	1.886	2.532	2.104
0.00006	7.272	6.162	6.462	5.610	7.524	6.216
0.0001	12.09	10.29	10.78	9.34	12.49	10.34

TABLE 335. — Electro-Chemical Equivalents and Normal Solutions.

The following table of the electro-chemical equivalent numbers and the densities of approximately normal solutions of the salts quoted in Table 271 may be convenient. They represent grams per cubic centimeter of the solution at the temperature given.

Salt dissolved.	Grams per liter.	m	Temp. C.	Density.	Salt dissolved.	Grams per liter.	m	Temp. C.	Density.
KCl . . .	74.59	1.0	15.2	1.0457	$\frac{1}{2}K_2SO_4$.	87.16	1.0	18.9	1.0658
NH_4Cl . .	53.55	1.0009	18.6	1.0152	$\frac{1}{2}Na_2SO_4$.	71.09	1.0003	18.6	1.0602
NaCl . . .	58.50	1.0	18.4	1.0391	$\frac{1}{2}Li_2SO_4$.	55.09	1.0007	18.6	1.0445
LiCl . . .	42.48	1.0	18.4	1.0227	$\frac{1}{2}MgSO_4$.	60.17	1.0023	18.6	1.0573
$\frac{1}{2}BaCl_2$ . .	104.0	1.0	18.6	1.0888	$\frac{1}{2}ZnSO_4$.	80.58	1.0	5.3	1.0794
$\frac{1}{2}ZnCl_2$ . .	68.0	1.012	15.0	1.0592	$\frac{1}{2}CuSO_4$.	79.9	1.001	18.2	1.0776
KI	165.9	1.0	18.6	1.1183	$\frac{1}{2}K_2CO_3$.	69.17	1.0006	18.3	1.0576
KNO_3 . .	101.17	1.0	18.6	1.0601	$\frac{1}{2}Na_2CO_3$.	53.04	1.0	17.9	1.0517
$NaNO_3$ . .	85.08	1.0	18.7	1.0542	KOH . .	56.27	1.0025	18.8	1.0477
$AgNO_3$ . .	169.9	1.0	–	–	HCl . .	36.51	1.0041	18.6	1.0161
$\frac{1}{2}Ba(NO_3)_2$.	65.28	0.5	–	–	HNO_3 . .	63.13	1.0014	18.6	1.0318
$KClO_3$ . .	61.29	0.5	18.3	1.0367	$\frac{1}{2}H_2SO_4$.	49.06	1.0006	18.9	1.0300
$KC_2H_3O_2$.	98.18	1.0005	18.6	1.0467					

---

* "Wied. Ann." vol. 26, pp. 161–226, 1885.

TABLE 336.

SPECIFIC MOLECULAR CONDUCTIVITY μ : MERCURY $= 10^8$.

Salt dissolved.	$m = 10$	5	3	1	0.5	0.1	.05	.03	.01
$\frac{1}{2}K_2SO_4$	–	–	–	–	672	736	897	959	1098
KCl	–	–	827	919	958	1047	1083	1107	1147
KI	–	770	900	968	997	1069	1102	1123	1161
NH_4Cl	–	752	825	907	948	1035	1078	1101	1142
KNO_3	–	–	572	752	839	983	1037	1067	1122
$\frac{1}{2}BaCl_2$	–	–	487	658	725	861	904	939	1006
$KClO_3$	–	–	–	–	799	927	(976)	1006	1053
$\frac{1}{2}Ba_2N_2O_6$	–	–	–	–	531	755	828	(870)	951
$\frac{1}{2}CuSO_4$	–	–	150	241	288	424	479	537	675
$AgNO_3$	–	351	448	635	728	886	936	(966)	1017
$\frac{1}{2}ZnSO_4$	–	82	146	249	302	431	500	556	685
$\frac{1}{2}MgSO_4$	–	82	151	270	330	474	532	587	715
$\frac{1}{2}Na_2SO_4$	–	–	–	475	559	734	784	828	906
$\frac{1}{2}ZnCl_2$	60	180	280	514	601	768	817	851	915
$NaCl$	–	398	528	695	757	865	897	(920)	962
$NaNO_3$	–	–	430	617	694	817	855	877	907
$KC_2H_3O_2$	30	240	381	594	671	784	820	841	879
$\frac{1}{2}Na_2CO_3$	–	–	254	427	510	682	751	799	899
$\frac{1}{2}H_2SO_4$	660	1270	1560	1820	1899	2084	2343	2515	2855
C_2H_4O	0.5	2.6	5.2	12	19	43	62	79	132
HCl	600	1420	2010	2780	3017	3244	3330	3369	3416
HNO_3	610	1470	2070	2770	2991	3225	3289	3328	3395
$\frac{1}{3}H_3PO_4$	148	160	170	200	250	430	540	620	790
KOH	423	990	1314	1718	1841	1986	2045	2078	2124
NH_3	0.5	2.4	3.3	8.4	12	31	43	50	92

Salt dissolved.	.006	.002	.001	.0006	.0002	.0001	.00006	.00002	.00001
$\frac{1}{2}K_2SO_4$	1130	1181	1207	1220	1241	1249	1254	1266	1275
KCl	1162	1185	1193	1199	1209	1209	1212	1217	1216
KI	1176	1197	1203	1209	1214	1216	1216	1216	1207
NH_4Cl	1157	1180	1190	1197	1204	1209	1215	1209	1205
KNO_3	1140	1173	1180	1190	1199	1207	1220	1198	1215
$\frac{1}{2}BaCl_2$	1031	1074	1092	1102	1118	1126	1133	1144	1142
$KClO_3$	1068	1091	1101	1109	1119	1122	1126	1135	1141
$\frac{1}{2}Ba_2N_2O_6$	982	1033	1054	1066	1084	1096	1100	1114	1114
$\frac{1}{2}CuSO_4$	740	873	950	987	1039	1062	1074	1084	1086
$AgNO_3$	1033	1057	1068	1069	1077	1078	1077	1073	1080
$\frac{1}{2}ZnSO_4$	744	861	919	953	1001	1023	1032	1047	1060
$\frac{1}{2}MgSO_4$	773	881	935	967	1015	1034	1036	1052	1056
$\frac{1}{2}Na_2SO_4$	933	980	998	1009	1026	1034	1038	1056	1054
$\frac{1}{2}ZnCl_2$	939	979	994	1004	1020	1029	1031	1035	1036
$NaCl$	976	998	1008	1014	1018	1029	1027	1028	1024
$NaNO_3$	921	942	952	956	966	975	970	972	975
$KC_2H_3O_2$	891	913	919	923	933	934	935	943	939
$\frac{1}{2}Na_2CO_3$	956	1010	1037	1046	988	874	790	715	697*
$\frac{1}{2}H_2SO_4$	3001	3240	3316	3342	3280	3118	2927	2077	1413*
C_2H_4O	170	283	380	470	796	995	1133	1328	1304*
HCl	3438	3455	3455	3440	3340	3170	2968	2057	1254*
HNO_3	3421	3448	3427	3408	3285	3088	2863	1904	1144*
$\frac{1}{3}H_3PO_4$	858	945	968	977	920	837	746	497	402*
KOH	2141	2140	2110	2074	1892	1689	1474	845	747*
NH_3	116	190	260	330	500	610	690	700	560*

* Acids and alkaline salts show peculiar irregularities.

LIMITING VALUES OF μ. TEMPERATURE COEFFICIENTS.

TABLE 337. — Limiting Values of μ.

This table shows limiting values of $\mu = \frac{k}{m} .10^8$ for infinite dilution for neutral salts, calculated from Table **271**.

Salt.	μ	Salt.	μ	Salt.	μ	Salt.	μ
$\frac{1}{2}K_2SO_4$	1280	$\frac{1}{2}BaCl_2$	1150	$\frac{1}{2}MgSO_4$	1080	$\frac{1}{2}H_2SO_4$	3700
KCl	1220	$\frac{1}{2}KClO_3$	1150	$\frac{1}{2}Na_2SO_4$	1060	HCl	3500
KI	1220	$\frac{1}{2}BaN_2O_6$	1120	$\frac{1}{2}ZnCl$	1040	HNO_3	3500
NH_4Cl	1210	$\frac{1}{2}CuSO_4$	1100	$NaCl$	1030	$\frac{1}{3}H_3PO_4$	1100
KNO_3	1210	$AgNO_3$	1090	$NaNO_3$	980	KOH	2200
–	–	$\frac{1}{2}ZnSO_4$	1080	$K_2C_2H_3O_2$	940	$\frac{1}{2}Na_2CO_3$	1400

If the quantities in Table 336 be represented by curves, it appears that the values of the specific molecular conductivities tend toward a limiting value as the solution is made more and more dilute. Although these values are of the same order of magnitude, they are not equal, but depend on the nature of both the ions forming the electrolyte.

When the numbers in Table 337 are multiplied by Hittorf's constant, or 0.00011, quantities ranging between 0.14 and 0.10 are obtained which represent the velocities in millimetres per second of the ions when the electromotive force gradient is one volt per millimetre.

Specific molecular conductivities in general become less as the concentration is increased, which may be due to mutual interference. The decrease is not the same for different salts, but becomes much more rapid in salts of high valence.

Salts having acid or alkaline reactions show marked differences. They have small specific molecular conductivity in very dilute solutions, but as the concentration is increased the conductivity rises, reaches a maximum and again falls off. Kohlrausch does not believe that this can be explained by impurities. H_3PO_4 in dilute solution seems to approach a monobasic acid, while H_2SO_4 shows two maxima, and like H_3PO_4 approaches in very weak solution to a monobasic acid.

Kohlrausch concludes that the law of independent migration of the ions in media like water is sustained.

TABLE 338. — Temperature Coefficients.

The temperature coefficient in general diminishes with dilution, and for very dilute solutions appears to approach a common value. The following table gives the temperature coefficient for solutions containing 0.01 gram molecule of the salt.

Salt.	Temp. Coeff.	Salt.	Temp. Coeff.	Salt.	Temp. Coeff.	Salt.	Temp. Coeff.
KCl	0.0221	KI	0.0219	$\frac{1}{2}K_2SO_4$	0.0223	$\frac{1}{2}K_2CO_3$	0.0249
NH_4Cl	0.0226	KNO_3	0.0216	$\frac{1}{2}Na_2SO_4$	0.0240	$\frac{1}{2}Na_2CO_3$	0.0265
$NaCl$	0.0238	$NaNO_3$	0.0226	$\frac{1}{2}Li_2SO_4$	0.0242	KOH	0.0194
$LiCl$	0.0232	$AgNO_3$	0.0221	$\frac{1}{2}MgSO_4$	0.0236	HCl	0.0159
$\frac{1}{2}BaCl_2$	0.0234	$\frac{1}{2}Ba(NO_3)_2$	0.0224	$\frac{1}{2}ZnSO_3$	0.0234	HNO_3	0.0162
$\frac{1}{2}ZnCl_2$	0.0239	$KClO_3$	0.0219	$\frac{1}{2}CuSO_4$	0.0229	$\frac{1}{2}H_2SO_4$	0.0125
$\frac{1}{2}MgCl_2$	0.0241	$KC_2H_3O_2$	0.0229	–	–	$\frac{1}{2}H_2SO_4$ for $m = .001$	0.0159

TABLE 339.

THE EQUIVALENT CONDUCTIVITY OF SALTS, ACIDS AND BASES IN AQUEOUS SOLUTIONS.

In the following table the equivalent conductance is expressed in reciprocal ohms. The concentration is expressed in milli-equivalents of solute per litre of solution at the temperature to which the conductance refers. (In the cases of potassium hydrogen sulphate and phosphoric acid the concentration is expressed in milli-formula-weights of solute, $KHSO_4$ or H_3PO_4, per liter of solution, and the values are correspondingly the modal, or "formal," conductances.) Except in the cases of the strong acids the conductance of the water was subtracted, and for sodium acetate, ammonium acetate and ammonium chloride the values have been corrected for the hydrolysis of the salts. The atomic weights used were those of the International Commission for 1905, referred to oxygen as 16.00. Temperatures are on the hydrogen gas scale.

$$\text{Concentration in } \frac{\text{gram equivalents}}{\text{1000 liter}}.$$

$$\text{Equivalent conductance in } \frac{\text{reciprocal ohms per centimeter cube}}{\text{gram equivalents per cubic centimeter}}.$$

Substance.	Concentration.	Equivalent conductance at the following °C temperatures.									
		18°	25°	50°	75°	100°	128°	156°	218°	281°	306°
Potassium chloride .	0	130.1	(152.1)	(232.5)	(321.5)	414	(519)	625	825	1005	1120
" " .	2	126.3	146.4	–	–	393	–	588	779	930	1008
" " .	10	122.4	141.5	215.2	295.2	377	470	560	741	874	910
" " .	80	113.5	–	–	–	342	–	498	638	723	720
" " .	100	112.0	129.0	194.5	264.6	336	415	490			
Sodium chloride . .	0	109.0	–	–	–	362	–	555	760	970	1080
" " . .	2	105.6	–	–	–	349	–	534	722	895	955
" " . .	10	102.0	–	–	–	336	–	511	685	820	860
" " . .	80	93.5	–	–	–	301	–	450	500	674	680
" " . .	100	92.0	–	–	–	296	–	442			
Silver nitrate . . .	0	115.8	–	–	–	367	–	570	780	965	1065
" " . . .	2	112.2	–	–	–	353	–	539	727	877	935
" " . . .	10	108.0	–	–	–	337	–	507	673	790	818
" " . . .	20	105.1	–	–	–	326	–	488	639		
" " . . .	40	101.3	–	–	–	312	–	462	599	680	680
" " . . .	80	96.5	–	–	–	294	–	432	552	614	604
" " . . .	100	94.6	–	–	–	289					
Sodium acetate . .	0	78.1	–	–	–	285	–	450	660	–	924
" " . .	2	74.5	–	–	–	268	–	421	578	–	801
" " . .	10	71.2	–	–	–	253	–	396	542	–	702
" " . .	80	63.4	–	–	–	221	–	340	452		
Magnesium sulphate	0	114.1	–	–	–	426	–	690	1080		
" " .	2	94.3	–	–	–	302	–	377	260		
" " .	10	76.1	–	–	–	234	–	241	143		
" " .	20	67.5	–	–	–	190	–	195	110		
" " .	40	59.3	–	–	–	160	–	158	88		
" " .	80	52.0	–	–	–	136	–	133	75		
" " .	100	49.8	–	–	–	130	–	126			
" " .	200	43.1	–	–	–	110	–	109			
Ammonium chloride	0	131.1	152.0	–	–	(415)	–	(628)	(841)	–	(1176)
" " .	2	126.5	146.5	–	–	399	–	601	801	–	1031
" " .	10	122.5	141.7	–	–	382	–	573	758	–	925
" " .	30	118.1	–	–	–	–	–	–	–	–	828
Ammonium acetate .	0	(99.8)	–	–	–	(338)	–	(523)			
" " .	10	91.7	–	–	–	300	–	456			
" " .	25	88.2	–	–	–	286	–	426			

From the investigations of Noyes, Melcher, Cooper, Eastman and Kato; Journal of the American Chemical Society, 30, p. 335, 1908.

THE EQUIVALENT CONDUCTIVITY OF SALTS, ACIDS AND BASES IN AQUEOUS SOLUTIONS.

Substance.	Concentration.	Equivalent conductance at the following ° C temperatures.									
		18°	25°	50°	75°	100°	128°	156°	218°	281°	306°
Barium nitrate . . .	0	116.9	–	–	–	385	–	600	840	1120	1300
“ “ . . .	2	109.7	–	–	–	352	–	536	715	828	824
“ “ . . .	10	101.0	–	–	–	322	–	481	618	658	615
“ “ . . .	40	88.7	–	–	–	280	–	412	507	503	448
“ “ . . .	80	81.6	–	–	–	258	–	372	449	430	
“ “ . . .	100	79.1	–	–	–	249					
Potassium sulphate .	0	132.8	–	–	–	455	–	715	1065	1460	1725
“ “ . .	2	124.8	–	–	–	402	–	605	806	893	867
“ “ . .	10	115.7	–	–	–	365	–	537	672	687	637
“ “ . .	40	104.2	–	–	–	320	–	455	545	519	466
“ “ . .	80	97.2	–	–	–	294	–	415	482	448	396
“ “ . .	100	95.0	–	–	–	286					
Hydrochloric acid .	0	379.0	–	–	–	850	–	1085	1265	1380	1424
“ “ . .	2	373.6	–	–	–	826	–	1048	1217	1332	1337
“ “ . .	10	368.1	–	–	–	807	–	1016	1168	1226	1162
“ “ . .	80	353.0	–	–	–	762	–	946	1044	1046	862
“ “ . .	100	350.6	–	–	–	754	–	929	1006		
Nitric acid	0	377.0	421.0	570	706	826	945	1047	(1230)	–	(1380)
“ “	2	371.2	413.7	559	690	806	919	1012	1166	–	1156
“ “	10	365.0	406.0	548	676	786	893	978			
“ “	50	353.7	393.3	528	649	750	845	917			
“ “	100	346.4	385.0	516	632	728	817	880	–	–	454*
Sulphuric acid . . .	0	383.0	(429)	(591)	(746)	891	(1041)	1176	1505	–	(2030)
“ “ . . .	2	353.9	390.8	501	561	571	551	536	563	–	637
“ “ . . .	10	309.0	337.0	406	435	446	460	481	533		
“ “ . . .	50	253.5	273.0	323	356	384	417	448	502		
“ “ . . .	100	233.3	251.2	300	336	369	404	435	483	–	474*
Potassium hydrogen sulphate . . .	2	455.3	506.0	661.0	754	784	773	754			
	50	295.5	318.3	374.4	403	422	446	477			
	100	263.7	283.1	329.1	354	375	402	435			
Phosphoric acid . .	0	338.3	376	510	631	730	839	930			
“ “ . .	2	283.1	311.9	401	464	498	508	489			
“ “ . .	10	203.0	222.0	273	300	308	298	274			
“ “ . .	50	122.7	132.6	157.8	168.6	168	158	142			
“ “ . .	100	96.5	104.0	122.7	129.9	128	120	108			
Acetic acid	0	(347.0)	–	–	–	(773)	–	(980)	(1165)	–	(1268)
“ “	10	14.50	–	–	–	25.1	–	22.2	14.7		
“ “	30	8.50	–	–	–	14.7	–	13.0	8.65		
“ “	80	5.22	–	–	–	9.05	–	8.00	5.34		
“ “	100	4.67	–	–	–	8.10	–	–	4.82	–	1.57
Sodium hydroxide .	0	216.5	–	–	–	594	–	835	1060		
“ “ . .	2	212.1	–	–	–	582	–	814			
“ “ . .	20	205.8	–	–	–	559	–	771	930		
“ “ . .	50	200.6	–	–	–	540	–	738	873		
Barium hydroxide .	0	222	256	389	(520)	645	(760)	847			
“ “ . . .	2	215	–	359	4	591					
“ “ . . .	10	207	235	342	449	548	664	722			
“ “ . . .	50	191.1	215.1	308	399	478	549	593			
“ “ . . .	100	180.1	204.2	291	373	443	503	531			
Ammonium hydroxide	0	(238)	(271)	(404)	(526)	(647)	(764)	(908)	(1141)	–	(1406)
	10	9.66	–	–	–	23.2	–	22.3	15.6		
	30	5.66	–	–	–	13.6	–	13.0			
	100	3.10	3.62	5.35	6.70	7.47	–	7.17	4.82	–	1.33

* These values are at the concentration 80.0.

TABLE 340.

THE EQUIVALENT CONDUCTIVITY OF SOME ADDITIONAL SALTS IN AQUEOUS SOLUTION.

Conditions similar to those of the preceding table except that the atomic weights for 1908 were used.

Substance.	Concentration.	Equivalent conductance at the following ° C temperature.							
		0°	18°	25°	50°	75°	100°	128°	156°
Potassium nitrate	0	80.8	126.3	145.1	219	299	384	485	580
" "	2	78.6	122.5	140.7	212.7	289.9	370.3	460.7	551
" "	12.5	75.3	117.2	134.9	202.9	276.4	351.5	435.4	520.4
" "	50	70.7	109.7	126.3	189.5	257.4	326.1	402.9	476.1
" "	100	67.2	104.5	120.3	180.2	244.1	308.5	379.5	447.3
Potassium oxalate	0	79.4	127.6	147.5	230	322	419	538	653
" "	2	74.9	119.9	139.2	215.9	300.2	389.3	489.1	587
" "	12.5	69.3	111.1	129.2	199.1	275.1	354.1	438.8	524.3
" "	50	63	101	116.5	178.6	244.9	312.2	383.8	449.5
" "	100	59.3	94.6	109.5	167	227.5	288.9	353.2	409.7
" "	200	55.8	88.4	102.3	155	210.9	265.1	321.9	372.1
Calcium nitrate	0	70.4	112.7	130.6	202	282	369	474	575
" "	2	66.5	107.1	123.7	191.9	266.7	346.5	438.4	529.8
" "	12.5	61.6	98.6	114.5	176.2	244	314.6	394.5	473.7
" "	50	55.6	88.6	102.6	157.2	216.2	276.8	343	405.1
" "	100	51.9	82.6	95.8	146.1	199.9	255.5	315.1	369.1
" "	200	48.3	76.7	88.8	135.4	184.7	234.4	288	334.7
Potassium ferrocyanide	0	98.4	159.6	185.5	288	403	527		
" "	0.5	91.6	–	171.1					
" "	2.	84.8	137	158.9	243.8	335.2	427.6		
" "	12.5	71	113.4	131.6	200.3	271	340		
" "	50	58.2	93.7	108.6	163.3	219.5	272.4		
" "	100	53	84.9	98.4	148.1	198.1	245		
" "	200	48.8	77.8	90.1	135.7	180.6	222.3		
" "	400	45.4	72.1	83.3	124.8	165.7	203.1		
Barium ferrocyanide	0	91	150	176	277	393	521		
" "	2	46.9	75	86.2	127.5	166.2	202.3		
" "	12.5	30.4	48.8	56.5	83.1	107	129.8		
Calcium ferrocyanide	0	88	146	171	271	386	512		
" "	2	47.1	75.5	86.2	130				
" "	12.5	31.2	49.9	57.4					
" "	50	24.1	38.5	44.4	64.6	81.9			
" "	100	21.9	35.1	40.2	58.4	73.7	84.3		
" "	200	20.6	32.9	37.8	55	68.7	77.5		
" "	400	20.2	32.2	37.1	54	67.5	76.2		
Potassium citrate	0	76.4	124.6	144.5	228	320	420		
" "	0.5	–	120.1	139.4					
" "	2	71	115.4	134.5	210.1	293.8	381.2		
" "	5	67.6	109.9	128.2	198.7	276.5	357.2		
" "	12.5	62.9	101.8	118.7	183.6	254.2	326		
" "	50	54.4	87.8	102.1	157.5	215.5	273		
" "	100	50.2	80.8	93.9	143.7	196.5	247.5		
" "	300	43.5	69.8	81	123.5	167	209.5		
Lanthanum nitrate	0	75.4	122.7	142.6	223	313	413	534	651
" "	2	68.9	110.8	128.9	200.5	279.8	363.5	457.5	549
" "	12.5	61.4	98.5	114.4	176.7	243.4	311.2	383.4	447.8
" "	50	54	86.1	99.7	152.5	207.6	261.4	315.8	357.7
" "	100	49.9	79.4	91.8	139.5	189.1	236.7	282.5	316.3
" "	200	46	72.1	83.5	126.4	170.2	210.8	249.6	276.2

From the investigations of Noyes and Johnston, Journal of the American Chemical Society, 31, p. 287, 1909.

CONDUCTANCE OF IONS. — HYDROLYSIS OF AMMONIUM ACETATE.

TABLE 341. — The Equivalent Conductance of the Separate Ions.

Ion.	0°	18°	25°	50°	75°	100°	128°	156°
K	40.4	64.6	74.5	115	159	206	263	317
Na	26	43.5	50.9	82	116	155	203	249
NH_4	40.2	64.5	74.5	115	159	207	264	319
Ag	32.9	54.3	63.5	101	143	188	245	299
$\frac{1}{2}Ba$	33	55^2	65	104	149	200	262	322
$\frac{1}{2}Ca$	30	51^2	60	98	142	191	252	312
$\frac{1}{3}La$	35	61	72	119	173	235	312	388
Cl	41.1	65.5	75.5	116	160	207	264	318
NO_3	40.4	61.7	70.6	104	140	178	222	263
$C_2H_8O_2$	20.3	34.6	40.8	67	96	130	171	211
$\frac{1}{2}SO_4$	41	68^2	79	125	177	234	303	370
$\frac{1}{2}C_2O_4$	39	63^2	73	115	163	213	275	336
$\frac{1}{3}C_6H_5O_7$	36	60	70	113	161	214		
$\frac{1}{4}Fe(CN)_6$	58	95	111	173	244	321		
H	240	314	350	465	565	644	722	777
OH	105	172	192	284	360	439	525	592

From Johnson, Journ. Amer. Chem. Soc., 31, p. 1010, 1909.

TABLE 342. — Hydrolysis of Ammonium Acetate and Ionization of Water.

Temperature.	Percentage hydrolysis.	Ionization constant of water.	Hydrogen-ion concentration in pure water. Equivalents per liter.
t	100_h	$K_W \times 10^{14}$	$C_H \times 10^7$
0	–	0.089	0.30
18	(0.35)	0.46	0.68
25	–	0.82	0.91
100	4.8	48.	6.9
156	18.6	223.	14.9
218	52.7	461.	21.5
306	91.5	168.	13.0

Noyes, Kato, Kanolt, Sosman, No. 63 Publ. Carnegie Inst., Washington.

DIELECTRIC CONSTANTS.

TABLE 343. — Dielectric Constant (Specific Inductive Capacity) of Gases. Atmospheric Pressure.

Wave-lengths of the measuring current greater than 10000 cm.

Gas.	Temp. ° C.	Dielectric constant referred to		Authority.
		Vacuum = 1	Air = 1	
Air	0	1.000590	1.000000	Boltzmann, 1875.
"	–	1.000586	1.000000	Klemenčič, 1885.
Ammonia	20	1.00718	1.00659	Bädeker, 1901.
Carbon bisulphide . . .	0	1.00290	1.00231	Klemenčič.
" "	100	1.00239	1.00180	Bädeker.
Carbon dioxide	0	1.000946	1.000356	Boltzmann.
" "	0	1.000985	1.000399	Klemenčič.
Carbon monoxide	0	1.000690	1.000100	Boltzmann.
" "	0	1.000695	1.000109	Klemenčič.
Ethylene	0	1.00131	1.00072	Boltzmann.
"	0	1.00146	1.00087	Klemenčič.
Hydrochloric acid . . .	100	1.00258	1.00199	Bädeker.
Hydrogen	0	1.000264	0.999674	Boltzmann.
"	0	1.000264	0.999678	Klemenčič.
Methane	0	1.000944	1.000354	Boltzmann.
"	0	1.000953	1.000367	Klemenčič.
Nitrous oxide (N_2O) . .	0	1.00116	1.00057	Boltzmann.
" " " . . .	0	1.00099	1.00041	Klemenčič.
Sulphur dioxide	0	1.00993	1.00934	Bädeker.
" "	0	1.00905	1.00846	Klemenčič.
Water vapor, 4 atmospheres	145	1.00705	1.00646	Bädeker.

TABLE 344. — Variation of the Dielectric Constant with the Temperature.

For variation with the pressure see next table.

If D_θ = the dielectric constant at the temperature θ° C., D_t at the temperature t° C., and α and β are quantities given in the following table, then

$$D_\theta = D_t[1 - \alpha(t - \theta) + \beta(t - \theta)^2].$$

The temperature coefficients are due to Bädeker.

Gas.	α	β	Range of temp. ° C.
Ammonia . .	5.45×10^{-6}	2.59×10^{-7}	10 — 110
Sulphur dioxide	6.19×10^{-6}	1.86×10^{-7}	0 — 110
Water vapor .	1.4×10^{-4}	–	145

The dielectric constant of air at atmospheric pressure but with varying temperature may also be calculated from the fact that $D - 1$ is approximately proportional to the density.

DIELECTRIC CONSTANTS (*continued*).

TABLE 345.—Change of the Dielectric Constant of Gases with the Pressure.

Gas.	Temperature, ° C.	Pressure atmos.	Dielectric constant.	Authority.
Air	19	20	1.0108	Tangl, 1907.
"	–	40	1.0218	" "
"	–	60	1.0330	" "
"	–	80	1.0439	" "
"	–	100	1.0548	" "
"	11	20	1.0101	Occhialini, 1905.
"	–	40	1.0196	" "
"	–	60	1.0294	" "
"	–	80	1.0387	" "
"	–	100	1.0482	" "
"	–	120	1.0579	" "
"	–	140	1.0674	" "
"	–	160	1.0760	" "
"	–	180	1.0845	" "
Carbon dioxide . .	15	10	1.008	Linde, 1895.
" " . .	–	20	1.020	" "
" " . .	–	40	1.060	" "
Nitrous oxide, N_2O	15	10	1.010	"
" " "	–	20	1.025	"
" " "	–	40	1.070	"

TABLE 346.—Dielectric Constants of Liquids.

A wave-length greater than 10000 centimeters is denoted by ∞.

Substance.	Temp. ° C.	Wave-length, cm.	Dielectric constant.	Authority.	Substance.	Temp. ° C.	Wave-length, cm.	Dielectric constant.	Authority.
Alcohol:					Alcohol:				
Amyl . . .	frozen	∞	2.4	1	Methyl . .	−50	∞	45.3	1
" . . .	−100	"	30.1	1	" . . .	0	"	35.0	1
" . . .	−50	"	23.0	1	" . . .	+20	"	31.2	1
" . . .	0	"	17.4	1	" . . .	17	75	33.2	2
" . . .	+20	"	16.0	1	Propyl . .	−120	∞	46.2	1
" . . .	18	200	10.8	2	" . . .	−60	"	33.7	1
" . . .	18	73	4.7	2	" . . .	0	"	24.8	1
Ethyl . . .	frozen	∞	2.7	1	" . . .	+20	"	22.2	1
" . . .	−120	"	54.6	1	" . . .	15	75	12.3	2
" . . .	−80	"	44.3	1	Acetone . . .	−80	∞	33.8	5
" . . .	−40	"	35.3	1	" . . .	0	"	26.6	5
" . . .	0	"	28.4	1	" . . .	15	1200	21.85	6
" . . .	+20	"	25.8	1	" . . .	17	73	20.7	7
" . . .	17	200	24.4	2	Acetic acid .	18	∞	9.7	8
" . . .	"	75	23.0	2	" " . .	15	1200	10.3	6
" . . .	"	53	20.6	3	" " . .	17	200	7.07	2
" . . .	"	4	8.8	3	" " . .	19	75	6.29	2
" . . .	"	0.4	5.0	4	Amyl acetate .	19	∞	4.81	9
Methyl . .	frozen	∞	3.07	1	Amylene . .	16	"	2.20	10
" . . .	−100	"	58.0	1					

References on page 311.

TABLE 346 (*continued*).

DIELECTRIC CONSTANTS OF LIQUIDS.

A wave-length greater than 10000 centimeters is desiguated by ∞.

Substance.	Temp. °C.	Wave-length cm.	Diel. const.	Author-ity.
Anilin	18	∞	7.316	11
Benzol (benzene)	18	"	2.288	"
" "	19	73	2.26	2
Bromine	23	84	3.18	12
Carbon bisulphide	20	∞	2.626	13
" "	17	73	2.64	2
Chloroform	18	∞	5.2	11
"	17	73	4.95	2
Decane	14	∞	1.97	10
Decylene	17	"	2.24	"
Ethyl ether	—80	∞	7.05	5
" "	—40	"	5.67	"
" "	0	"	4.68	"
" "	18	"	4.368	11
" "	20	"	4.30	13
" "	60	"	3.65	"
" "	100	"	3.12	"
" "	140	"	2.66	"
" "	180	"	2.12	"
" "	Crit. temp. 192	"	1.53	"
" "	18	83	4.35	14
Formic acid	+2 (frozen)	73	19.0	2
" "	15	1200	62.0	6
" "	16	73	58.5	2
Glycerine	15	1200	56.2	6
"	15	200	39.1	2
"	15	75	25.4	"
"	–	8.5	4.4	15
"	–	0.4	2.6	4
Hexane	17	∞	1.880	16
Hydrogen peroxide 46 % in H_2O	18	75	84.7	17
Nitrobenzol	(frozen) —10	∞	9.9	1
"	—5	"	42.0	"
"	0	"	41.0	"
"	+15	"	37.8	"
"	30	"	35.1	"
"	18	"	36.45	11
"	17	73	34.0	2
Octane	17	∞	1.949	16
Oils:				
Almond	20	∞	2.83	18
Castor	11	"	4.67	19
Colza	20	"	3.11	20
Cottonseed	14	"	3.10	21
Lemon	21	"	2.25	22
Linseed	13	"	3.35	21
Neatsfoot	–	"	3.02	20
Olive	20	"	3.11	23
Peanut	11.4	"	3.03	21
Petroleum	–	2000	2.13	24
Petroleum ether	20	∞	1.92	20
Rape seed	16	"	2.85	21
Sesame	13.4	"	3.02	"
Sperm	20	"	3.17	20
Turpentine	20	"	2.23	"
Vaseline	–	"	2.17	25
Phenol	48	73	9.68	2
Toluol	—83	∞	2.51	5
"	+16	"	2.33	"
"	19	73	2.31	2
Meta-xylol	18	∞	2.37^6	11
" "	17	73	2.37	2
Water	18	∞	81.07	11
for temp. coeff.	17	200	80.6	2
see Table 344.	17	74	81.7	"
	17	38	83.6	"

1 Abegg-Seitz, 1899.
2 Drude, 1896.
3 Marx, 1898.
4 Lampa, 1896.
5 Abegg, 1897.
6 Thwing, 1894.
7 Drude, 1898.
8 Francke, 1893.
9 Löwe, 1898.
10 Landolt-Jahn, 1892.
11 Turner, 1900.
12 Schlundt.
13 Tangl, 1903.
14 Coolidge, 1899.
15 v. Lang, 1896.
16 Nernst, 1894.
17 Calvert, 1900.
18 Hasenöhrl, 1896.
19 Arons-Rubens, 1892.
20 Hopkinson, 1881.
21 Salvioni, 1888.
22 Tomaszewski, 1888.
23 Heinke, 1896.
24 Marx.
25 Fuchs.

DIELECTRIC CONSTANTS OF LIQUIDS (*continued*).

TABLE 347. — Temperature Coefficients of the Formula:

$$D_\theta = D_t[1 - \alpha(t-\theta) + \beta(t-\theta)^2].$$

Substance.	α	β	Temp. range, °C.	Authority.
Amyl acetate	0.0024	–	–	Löwe.
Aniline	0.00351	–	–	Ratz.
Benzol	0.00106	0.0000087	10–40	Hasenöhrl.
Carbon bisulphide	0.000966	–	–	Ratz.
" "	0.000922	0.00000060	20–181	Tangl.
Chloroform	0.00410	0.0000015	22–181	"
Ethyl ether	0.00459	–	–	Ratz.
Methyl alcohol	0.0057	–	–	Drude.
Oils: Almond	0.00163	0.000026	–	Hasenöhrl.
Castor	0.01067	–	–	Heinke, 1896.
Olive	0.00364	–	–	" "
Paraffine	0.000738	0.0000072	–	Hasenöhrl.
Toluol	0.000921	–	0–13	Ratz.
"	0.000977	0.00000046	20–181	Tangl.
Water	0.004474	–	5–20	Heerwagen.
"	0.004583	0.0000117	0–76	Drude.
"	0.00436	–	4–25	Coolidge.
Meta-xylol	0.000817	–	20–181	Tangl.

(See Table 344 for the signification of the letters.)

TABLE 348. — Dielectric Constants of Liquified Gases.

A wave-length greater than 10000 centimeters is designated by ∞.

Substance.	Temp. °C.	Wave-length cm.	Dial. constant.	Authority.
Air	—191	∞	1.432	1
"	"	75	1.47–1.50	2
Ammonia	—34	75	21–23	3
"	14	130	16.2	4
Carbon dioxide	—5	∞	1.608	5
" "	0	"	1.583	"
" "	+10	"	1.540	"
" "	+15	"	1.526	"
Chlorine	—60	"	2.150	"
"	—20	"	2.030	"
"	0	"	1.970	"
"	+10	"	1.940	"
"	0	"	2.08	6
"	+14	100	1.88	4
Cyanogen	23	84	2.52	7
Hydrocyanic acid	21	"	about 95	"
Hydrogen sulph.	10	∞	5.93	6
" "	50	"	4.92	"
" "	90	"	3.76	"
Nitrous oxide N_2O	—88	∞	1.933	8
" "	—5	"	1.630	5
" "	+5	"	1.578	"
" "	+15	"	1.520	"
Oxygen	—182	"	1.491	9
"	"	"	1.465	8
Sulphur dioxide	14.5	120	13.75	4
" "	20	∞	14.0	6
" "	40	"	12.5	"
" "	60	"	10.8	"
" "	80	"	9.2	"
" "	100	"	7.8	"
" "	120	"	6.4	"
" "	140	"	4.8	"
Critical	154.2	"	2.1	"

1 v. Pirani, 1903.
2 Bahn-Kiebitz, 1904.
3 Goodwin-Thompson, 1899.
4 Coolidge, 1899.
5 Linde, 1895.
6 Eversheim, 1904.
7 Schlundt, 1901.
8 Hasenöhrl, 1900.
9 Fleming-Dewar, 1896.

TABLE 349.—Standard Solutions for the Calibration of Apparatus for the Measuring of Dielectric Constants.

Turner.

Substance.	Diel. const. at 18°. λ = ∞.
Benzol	2.288
Meta-xylol	2.376
Ethyl ether	4.367
Aniline	7.298
Ethyl chloride	10.90
O-nitro toluol	27.71
Nitrobenzol	36.45
Water (conduct. 10^{-6})	81.07

Drude.

Per cent by weight.	Density 16°.	Dielectric constant.	Temp. coefficient.
Acetone in benzol at 19°. λ = 75 cm.			
0	0.885	2.26	0.1%
20	0.866	5.10	0.3
40	0.847	8.43	0.4
60	0.830	12.1	0.5
80	0.813	16.2	0.5
100	0.797	20.5	0.6
Water in acetone at 19°. λ = 75 cm.			
0	0.797	20.5	0.6%
20	0.856	31.5	0.5
40	0.903	43.5	0.5
60	0.940	57.0	0.5
80	0.973	70.6	0.5
100	0.999	80.9	0.4

Nernst.

Ethyl alcohol in water at 19.5°. λ = ∞.

Per cent by weight.	Dielectric constant.
100	26.0
90	29.3
80	33.5
70	38.0
60	43.1

TABLE 350.—Dielectric Constants of Solids.

Substance.	Condition.	Wave-length, cm.	Dielectric constant.	Authority.
Asphalt	–	∞	2.68	1
Barium sulphate	–	75	10.2	2
Caoutchouc	–	∞	2.22	3
Diamond	–	"	16.5	1
"	–	75	5.50	2
Ebonite	–	∞	2.72	4
"	–	"	2.86	5
"	–	1000	2.55	6
Glass *	Density.			
Flint (extra heavy)	4.5	∞	9.90	7
Flint (very light)	2.87	"	6.61	7
Hard crown	2.48	"	6.96	7
Mirror	–	"	6.44–7.46	5
"	–	"	5.37–5.90	8
"	–	600	5.42–6.20	8
Lead (Powell)	3.0–3.5	∞	5.4–8.0	9
Jena				
Boron	–	"	5.5–8.1	10
Barium	–	"	7.8–8.5	10
Borosilicate	–	"	6.4–7.7	1
Gutta percha	–	–	3.3–4.9	11
	Temp.			
Ice	−5	1200	2.85	12
"	−18	5000	3.16	13
"	−190	75	1.76–1.88	14

Substance.	Condition.	Wave-length, cm.	Dielectric constant.	Authority.
	Temp.			
Iodine (cryst.)	23	75	4.00	2
Lead chloride (powder)	–	"	42	2
" nitrate	–	"	16	2
" sulphate	–	"	28	2
" molybdenate	–	"	24	2
Marble (Carrara)	–	"	8.3	2
Mica	–	∞	5.66–5.97	5
"	–	"	5.80–6.62	15
Madras, brown	–	"	2.5–3.4	16
" green	–	"	3.9–5.5	16
" ruby	–	"	4.4	16
Bengal, yellow	–	"	2.8	16
" white	–	"	4.2	16
" ruby	–	"	4.2–4.7	16
Canadian amber	–	"	3.0	16
South America	–	"	5.9	16
Ozokerite (raw)	–	"	2.21	1
Paper (telephone)	–	"	2.0	17
" (cable)	–	"	2.0–2.5	1
Paraffine		"	2.46	18
"	Melting point.	"	2.32	19
"	44–46	"	2.10	20
"	54–56	"	2.14	20
"	74–76	"	2.16	20

References on p. 314.

* For the effect of temperature, see Gray-Dobbie, Pr. Roy. Soc. 63, 1898; 67, 1900.
" " " " wave-length, see K. F. Löwe, Wied. Ann. 66, 1898.

DIELECTRIC CONSTANTS (*continued*).

TABLE 350. — Dielectric Constants of Solids (*continued*).

Substance.	Condition.	Wave-length, cm.	Diel. constant.	Authority.
Paraffine . .	47.°06	61	2.16	21
" . .	56.°2	61	2.25	21
Phosphorus:				
Yellow . .	-	75	3.60	2
Solid . . .	-	80	4.1	22
Liquid . .	-	80	3.85	22
Porcelain:				
Hard (Royal B'l'n)	-	∞	5.73	15
Seger " " .	-	"	6.61	15
Figure " " .	-	"	6.84	15
Selenium . .	-	"	7.44	1
" . .	-	75	6.60	2
" . .	-	∞	6.13	23
" . .	-	1000	6.14	23
Shellac . . .	-	∞	3.10	4
" . . .	-	"	2.95–3.73	24
" . . .	-	"	3.67	25
Sulphur				
Amorphous	-	∞	3.98	1
"	-	75	3.80	2
Cast, fresh	-	∞	4.22	1
" "	-	"	4.05	18
" "	-	75	3.95	2
Cast, old .	-	∞	3.60	18
" "	-	75	3.90	2
Liquid .	near melting-point	∞	3.42	1
Strontium sulphate	-	75	11.3	2
Thallium carbonate	-	75	17	2
" nitrate .	-	75	16.5	2
Wood			dried	
Red beech .	‖ fibres	∞	4.83–2.51	-
" " .	⊥ "	"	7.73–3.63	-
Oak . . .	‖ "	"	4.22–2.46	-
" . . .	⊥ "	"	6.84–3.64	-

1 v. Pirani, 1903.
2 Schmidt, 1903.
3 Gordon, 1879.
4 Winklemann, 1889.
5 Elsas, 1891.
6 Ferry, 1897.
7 Hopkinson, 1891.
8 Arons-Rubens, 1891.
9 Gray-Dobbie, 1898.
10 Löwe, 1898.
11 (submarine-data).
12 Thwing, 1894.
13 Abegg, 1897.
14 Behn-Kiebitz, 1904.
15 Starke, 1897.
16 E. Wilson.
17 Campbell, 1906.
18 Fallinger, 1902.
19 Boltzmann, 1875.
20 Zietkowski, 1900.
21 Hormell, 1902.
22 Schlundt, 1904.
23 Vonwiller-Mason, 1907.
24 Wüllner, 1887.
25 Donle.

TABLE 351. — Dielectric Constants of Crystals.

D*α*, D*β*, D*γ* are the dielectric constants along the brachy, macro and vertical axes respectively.

Substance.	Wave-length, cm.	Diel. const.		Authority.
		⊥ Axis.	‖ Axis.	
UNIAXIAL:				
Apatite	75	9.50	7.40	1
Beryl	∞	7.85	7.44	2
"	"	7.10	6.05	3
"	75	6.05	5.52	1
Calcspar	∞	8.49	7.56	4
"	"	8.78	8.29	5
Dolomite	75	7.80	6.80	1
Iceland spar . .	75	8.50	8.00	1
Quartz	∞	4.69	5.06	4
"	"	4.38	4.46	6
"	1000	4.27	4.34	6
"	75	4.32	4.60	1
Rutil (TiO_2). . .	75	89	173	1
Tourmaline . . .	∞	7.13	6.54	4
" . . .	75	6.75	5.65	1
Zircon	75	12.8	12.6	1

Substance.	Wave-length, cm.	Diel. const.			Authority.
		D*α*	D*β*	D*γ*	
RHOMBIC:					
Arragonite . . .	∞	9.14	-	7.13	4
"	75	9.80	7.68	6.55	1
Barite	∞	6.97	10.09	7.00	4
"	75	7.65	12.20	7.70	1
Cœlestin	75	7.70	18.5	8.30	1
Cerussite . . .	75	25.4	23.2	19.2	1
$MgSO_4 + 7H_2O$.	∞	5.26	6.05	8.28	7
K_2SO_4	"	6.09	5.08	4.48	7
Rochelle salt . .	"	6.70	6.92	8.89	7
Sulphur	"	3.81	3.97	4.77	8
"	"	3.65	3.85	4.66	7
"	75	3.62	3.85	4.66	1
Topaz	75	6.65	6.70	6.30	1

1 Schmidt, 1903.
2 Starke, 1897.
3 Curie, 1889.
4 Fallinger, 1902.
5 v. Pirani, 1903.
6 Ferry, 1897.
7 Borel, 1893.
8 Boltzmann, 1875.

PERMEABILITY OF IRON.

TABLE 352.—Permeability of Iron Rings and Wire.

This table gives, for a few specimens of iron, the magnetic induction B, and permeability μ, corresponding to the magneto-motive forces H recorded in the first column. The first specimen is taken from a paper by Rowland,[*] and refers to a welded and annealed ring of "Burden's Best" wrought iron. The ring was 6.77 cms. in mean diameter, and the bar had a cross sectional area of 0.916 sq. cms. Specimens 2–4 are taken from a paper by Bosanquet,[†] and also refers to soft iron rings. The mean diameters were 21.5, 22.1, and 22.725 cms., and the thickness of the bars 2.535, 1.295, and .7544 cms. respectively. These experiments were intended to illustrate the effect of thickness of bar on the induction. Specimen 5 is from Ewing's book,[‡] and refers to one of his own experiments on a soft iron wire .077 cms. diameter and 30.5 cms. long.

H	Specimen **1**		**2**		**3**		**4**		**5**		
	B	μ	B	μ	B	μ	B	μ	B	μ	
0.2	80	400	126	630	65	325	85	425	22	110	NOTE.—The comparatively high value of the magnetizing force required for maximum permeability when the specimen is a thin drawn wire is noticeable in specimen 5.
0.5	330	660	377	754	224	448	214	428	74	148	
1.0	1450	1450	1449	1449	840	840	885	885	246	246	
2.0	4840	2420	4564	2282	3533	1766	2417	1208	950	475	
5.0	9880	1976	9900	1980	8293	1659	8884	1777	12430	2486	
10.0	12970	1297	13023	1302	12540	1254	11388	1139	15020	1502	
20.0	14740	737	14911	746	14710	735	13273	664	15790	789	
50.0	16390	328	16217	324	16062	321	13890	278	–	–	
100.0	–	–	17148	171	17900	179	14837	148	–	–	

TABLE 353.—Permeability of Transformer Iron.[§]

This table contains the results of some experiments on transformers of the Westinghouse and Thomson-Houston types. Referring to the headings of the different columns, M is the total magneto-motive force applied to the iron; M/l the magneto-motive force per centimetre length of the iron circuit; B the total induction through the magnetizing coil; B/a the induction per square centimetre of the mean section of the iron core; M/B the magnetic reluctance of the iron circuit; Bl/Ma the permeability of the iron, a being taken as the mean cross section of the iron circuit as it exists in the transformer, which is thus slightly greater than the actual cross section of the iron.

(a) WESTINGHOUSE NO. 8 TRANSFORMERS (ABOUT 2500 WATTS CAPACITY).

M	$\frac{M}{l}$	First specimen.				Second specimen.			
		B	$\frac{B}{a}$	$\frac{M}{B}$	$\frac{Bl}{Ma}$	B	$\frac{B}{a}$	$\frac{M}{B}$	$\frac{Bl}{Ma}$
20	0.597	218×10^3	1406	0.917×10^{-4}	2360	16×10^4	1032	1.25×10^{-4}	1730
40	1.194	587 "	3790	0.681 "	3120	49 "	3140	0.82 "	2640
60	1.791	878 "	5660	0.683 "	3180	82 "	5290	0.73 "	2970
80	2.338	1091 "	7040	0.734 "	2960	104 "	6710	0.77 "	2820
100	2.985	1219 "	7860	0.819 "	2640	118 "	7610	0.85 "	2560
120	3.582	1330 "	8580	0.903 "	2410	124 "	8000	0.97 "	2250
140	4.179	1405 "	9060	0.994 "	2186	131 "	8450	1.07 "	2036
160	4.776	1475 "	9510	1.090 "	2000	135 "	8710	1.18 "	1830
180	5.373	1532 "	9880	1.180 "	1850	140 "	9030	1.29 "	1690
200	5.970	1581 "	10200	1.270 "	1720	142 "	9160	1.41 "	1540
220	6.567	1618 "	10430	1.360 "	1590	144 "	9290	1.53 "	1410
260	7.761	1692 "	10910	1.540 "	1410	–	–	–	–

---

[*] "Phil. Mag." 4th series, vol. xlv. p. 151.
[†] Ibid. 5th series, vol. xix. p. 73.
[‡] "Magnetic Induction in Iron and Other Metals."
[§] T. Gray, from special experiments.

PERMEABILITY OF TRANSFORMER IRON.

(b) Westinghouse No. 6 Transformers (about 1800 Watts Capacity).

M	$\frac{M}{l}$	First specimen.				Second specimen.			
		B	$\frac{B}{a}$	$\frac{M}{B}$	$\frac{Bl}{Ma}$	B	$\frac{B}{a}$	$\frac{M}{B}$	$\frac{Bl}{Ma}$
20	0.62	147×10^3	1320	1.36×10^{-4}	2140	215×10^3	1940	0.93×10^{-4}	3140
40	1.23	442 "	3980	0.91 "	3260	615 "	5540	0.64 "	4490
60	1.85	697 "	6280	0.86 "	3390	826 "	7440	0.72 "	4030
80	2.46	862 "	7770	0.93 "	3140	986 "	8880	0.81 "	3590
100	3.08	949 "	8550	1.05 "	2770	1050 "	9460	0.95 "	3060
120	3.70	1010 "	9106	1.19 "	2450	1100 "	9910	1.09 "	2670
140	4.31	1060 "	9550	1.33 "	2210	1140 "	10300	1.23 "	2430
160	4.93	1090 "	9820	1.47 "	1990	1170 "	10500	1.37 "	2180
180	5.55	1120 "	10100	1.61 "	1830	1190 "	10700	1.51 "	1970
200	6.16	1150 "	10400	1.74 "	1680	–	–	–	–

(c) Westinghouse No. 4 Transformer (about 1200 Watts Capacity).

M	$\frac{M}{l}$	B	$\frac{B}{a}$	$\frac{M}{B}$	$\frac{Bl}{Ma}$
20	0.69	147×10^3	1470	1.36×10^{-4}	2140
40	1.38	406 "	4066	0.98 "	2940
60	2.07	573 "	5730	1.05 "	2770
80	2.76	659 "	6590	1.21 "	2390
100	3.45	714 "	7140	1.40 "	2070
120	4.14	748 "	7490	1.60 "	1810
140	4.83	777 "	7770	1.80 "	1610

(d) Thomson-Houston 1500 Watts Transformer.

M	$\frac{M}{l}$	B	$\frac{B}{a}$	$\frac{M}{B}$	$\frac{Bl}{Ma}$
20	0.42	70×10^3	1560	2.86×10^{-4}	3730
40	0.84	142 "	3160	2.81 "	3780
60	1.26	214 "	4770	2.81 "	3790
80	1.68	265 "	5910	3.02 "	3520
100	2.10	309 "	6890	3.24 "	3280
120	2.52	348 "	7760	3.45 "	3080
160	3.36	408 "	9100	3.92 "	2710
200	4.20	456 "	10200	4.39 "	2430
240	5.04	495 "	11000	4.87 "	2190
280	5.88	524 "	11690	5.35 "	1990
320	6.72	550 "	12270	5.82 "	1820
360	7.56	573 "	12780	6.29 "	1690
400	8.40	591 "	13180	6.78 "	1570
440	9.24	504 "	13470	7.28 "	1460

TABLE 354. — Magnetic Properties of Iron and Steel.

		Electrolytic Iron.	Good Cast Steel.	Poor Cast Steel.	Steel.	Cast Iron.	Electrical Sheets.	
							Ordinary.	Silicon Steel.
Chemical composition in per cent	C	0.024	0.044	0.56	0.99	3.11	0.036	0.036
	Si	0.004	0.004	0.18	0.10	3.27	0.330	3.90
	Mn	0.008	0.40	0.29	0.40	0.56	0.260	0.090
	P	0.008	0.044	0.076	0.04	1.05	0.040	0.009
	S	0.001	0.027	0.035	0.07	0.06	0.068	0.006
Coercive force . . .		2.83 [0.36]	1.51 [0.37]	7.1 (44.3)	16.7 (52.4)	11.4 [4.6]	[1.30]	[0.77]
Residual B		11400 [10800]	10600 [11000]	10500 (10500)	13000 (7500)	5100 [5350]	[9400]	[9850]
Maximum permeability		1850 [14400]	3550 [14800]	700 (170)	375 (110)	240 [600]	[3270]	[6130]
B for H=150 . . .		19200 [18900]	18800 [19100]	17400 (15400)	16700 (11700)	10400 [11000]	[18200]	[17550]
4πI for saturation .		21620 [21630]	21420 [21420]	20600 (20200)	19800 (18000)	16400 [16800]	[20500]	[19260]

E. Gumlich, Zs. für Electrochemie, 15, p. 599; 1909.

Brackets indicate annealing at 800° C in vacuum. *Parentheses* indicate hardening by quenching from cherry-red.

TABLE 355. — Cast Iron in Intense Fields.

Soft Cast Iron.				Hard Cast Iron.			
H	B	I	μ	H	B	I	μ
114	9950	782	87.3	142	7860	614	55.4
172	10800	846	62.8	254	9700	752	38.2
433	13900	1070	32.1	339	10850	836	30.6
744	15750	1200	21.2	684	13050	983	19.1
1234	17300	1280	14.0	915	14050	1044	15.4
1820	18170	1300	10.0	1570	15900	1138	10.1
12700	31100	1465	2.5	2020	16800	1176	8.3
13550	32100	1475	2.4	10900	26540	1245	2.4
13800	32500	1488	2.4	13200	28600	1226	2.2
15100	33650	1472	2.2	14800	30200	1226	2.0

B. O. Peirce, Proc. Am. Acad. 44, 1909.

TABLE 356. — Corrections for Ring Specimens.

In the case of ring specimens, the average magnetizing force is not the value at the mean radius, the ratio of the two being given in the table. The flux density consequently is not uniform, and the measured hysteresis is less than it would be for a uniform distribution. This ratio is also given for the case of constant permeability, the values being applicable for magnetizations in the neighborhood of the maximum permeability. For higher magnetizations the flux density is more uniform, for lower it is less, and the correction greater.

Ratio of Radial Width to Diameter of Ring.	Ratio of Average H to H at Mean Radius.		Ratio of Hysteresis for Uniform Distribution to Actual Hysteresis.	
	Rectangular Cross-section.	Circular Cross-section.	Rectangular Cross-section.	Circular Cross-section.
1/2	1.0986	1.0718	1.112	1.084
1/3	1.0397	1.0294	1.045	1.033
1/4	1.0216	1.0162	1.024	1.018
1/5	1.0137	1.0102	1.015	1.011
1/6	1.0094	1.0070	1.010	1.008
1/7	1.0069	1.0052	1.008	1.006
1/8	1.0052	1.0040	1.006	1.004
1/10	1.0033	1.0025	1.003	1.002
1/19	1.0009	1.0007	1.001	1.001

M. G. Lloyd, Bull. Bur. Standards, 5, p. 435; 1908.

TABLE 357.

COMPOSITION AND MAGNETIC

This table and Table 358 below are taken from a paper by Dr. Hopkinson * on the magnetic properties of iron and steel.
which is stated in the paper to have been 240. The maximum magnetization is not tabulated; but as stated in the
by 4π. "Coercive force" is the magnetizing force required to reduce the magnetization to zero. The "demag-
previous magnetization in the opposite direction to the "maximum induction" stated in the table. The "energy
which, however, was only found to agree roughly with the results of experiment.

No. of Test.	Description of specimen.	Temper.	Chemical analysis.					
			Total Carbon.	Manganese.	Sulphur.	Silicon.	Phosphorus.	Other substances.
1	Wrought iron	Annealed	–	–	–	–	–	–
2	Malleable cast iron	"	–	–	–	–	–	–
3	Gray cast iron	–	–	–	–	–	–	–
4	Bessemer steel	–	0.045	0.200	0.030	None.	0.040	–
5	Whitworth mild steel	Annealed	0.090	0.153	0.016	"	0.042	–
6	" "	"	0.320	0.438	0.017	0.042	0.035	–
7	" "	Oil-hardened	"	"	"	"	"	–
8	" "	Annealed	0.890	0.165	0.005	0.081	0.019	–
9	" "	Oil-hardened	"	"	"	"	"	–
10	Hadfield's manganese steel	–	1.005	12.360	0.038	0.204	0.070	–
11	Manganese steel	As forged	0.674	4.730	0.023	0.608	0.078	–
12	" "	Annealed	"	"	"	"	"	–
13	" "	Oil-hardened	"	"	"	"	"	–
14	" "	As forged	1.298	8.740	0.024	0.094	0.072	–
15	" "	Annealed	"	"	"	"	"	–
16	" "	Oil-hardened	"	"	"	"	"	–
17	Silicon steel	As forged	0.685	0.694	"	3.438	0.123	–
18	" "	Annealed	"	"	"	"	"	–
19	" "	Oil-hardened	"	"	"	"	"	–
20	Chrome steel	As forged	0.532	0.393	0.020	0.220	0.041	0.621 Cr.
21	" "	Annealed	"	"	"	"	"	"
22	" "	Oil-hardened	"	"	"	"	"	"
23	" "	As forged	0.687	0.028	"	0.134	0.043	1.195 Cr.
24	" "	Annealed	"	"	"	"	"	"
25	" "	Oil-hardened	"	"	"	"	"	"
26	Tungsten steel	As forged	1.357	0.036	None.	0.043	0.047	4.649 W.
27	" "	Annealed	"	"	"	"	"	"
28	" "	Hardened in cold water	"	"	"	"	"	"
29	" "	Hardened in tepid water	"	"	"	"	"	"
30	" " (French)	Oil-hardened	0.511	0.625	None.	0.021	0.028	3.444 W.
31	" "	Very hard	0.855	0.312	–	0.151	0.089	2.353 W.
32	Gray cast iron	–	3.455	0.173	0.042	2.044	0.151	2.064 C.†
33	Mottled cast iron	–	2.581	0.610	0.105	1.476	0.435	1.477 C.†
34	White " "	–	2.036	0.386	0.467	0.764	0.458	–
35	Spiegeleisen	–	4.510	7.970	Trace.	0.502	0.128	–

---

* Phil. Trans. Roy. Soc. vol. 176.

† Graphitic carbon.

PROPERTIES OF IRON AND STEEL.

The numbers in the columns headed "magnetic properties" give the results for the highest magnetizing force used,
paper, it may be obtained by subtracting the magnetizing force (240) from the maximum induction and then dividing
netizing force " is the magnetizing force which had to be applied in order to leave no residual magnetization after
dissipated " was calculated from the formula:— Energy dissipated = coercive force × maximum induction ÷ π

No. of Test.	Description of specimen.	Temper.	Specific electrical resistance.	Magnetic properties.				Energy dissipated per cycle.
				Maximum induction.	Residual induction.	Coercive force.	Demagnetizive force.	
1	Wrought iron . . .	Annealed	.01378	18251	7248	2.30	–	13356
2	Malleable cast iron . .	"	.03254	12408	7479	8.80	–	34742
3	Gray cast iron . . .	–	.10560	10783	3928	3.80	–	13037
4	Bessemer steel . . .	–	.01050	18196	7860	2.96	–	17137
5	Whitworth mild steel .	Annealed	.01080	19840	7080	1.63	–	10289
6	" " .	"	.01446	18736	9840	6.73	–	40120
7	" " .	Oil-hardened	.01390	18796	11040	11.00	–	65786
8	" " .	Annealed	.01559	16120	10740	8.26	–	42366
9	" " .	Oil-hardened	.01695	16120	8736	19.38	–	99401
10	Hadfield's manganese steel .	–	.06554	310	–	–		–
11	Manganese steel . .	As forged	.05368	4623	2202	23.50	37.13	34567
12	" " . .	Annealed	.03928	10578	5848	33.86	46.10	113963
13	" " . .	Oil-hardened	.05556	4769	2158	27.64	40.29	41941
14	" " . .	As forged	.06993	747	–	–	–	–
15	" " . .	Annealed	.06316	1985	540	24.50	50.39	15474
16	" " . .	Oil-hardened	.07066	733	–	–	–	–
17	Silicon steel . . .	As forged	.06163	15148	11073	9.49	12.60	45740
18	" " . . .	Annealed	.06185	14701	8149	7.80	10.74	36485
19	" " . . .	Oil-hardened	.06195	14696	8084	12.75	17.14	59619
20	Chrome steel . . .	As forged	.02016	15778	9318	12.24	13.87	61439
21	" " . . .	Annealed	.01942	14848	7570	8.98	12.24	42425
22	" " . . .	Oil-hardened	.02708	13960	8595	38.15	48.45	169455
23	" " . . .	As forged	.01791	14680	7568	18.40	22.03	85944
24	" " . . .	Annealed	.01849	13233	6489	15.40	19.79	64842
25	" " . . .	Oil-hardened	.03035	12868	7891	40.80	56.70	167050
26	Tungsten steel . . .	As forged	.02249	15718	10144	15.71	17.75	78568
27	" " . . .	Annealed	.02250	16498	11008	15.30	16.93	80315
28	" " . . .	Hardened in cold water	.02274	–	–	–	–	–
29	" " . . .	Hardened in tepid water	.02249	15610	9482	30.10	34.70	149500
30	" " (French) .	Oil hardened	.03604	14480	8643	47.07	64.46	216864
31	" " . . .	Very hard	.04427	12133	6818	51.20	70.69	197660
32	Gray cast iron . .	–	.11400	9148	3161	13.67	17.03	39789
33	Mottled cast iron . .	–	.06286	10546	5108	12.24	–	41072
34	White " " . .	–	.05661	9342	5554	12.24	20.40	36383
35	Spiegeleisen . . .	–	.10520	385	77	–	–	–

PERMEABILITY OF SOME OF THE SPECIMENS IN TABLE 357.

TABLE 358.

This table gives the induction and the permeability for different values of the magnetizing force of some of the specimens in Table 357. The specimen numbers refer to the same table. The numbers in this table have been taken from the curves given by Dr. Hopkinson, and may therefore be slightly in error; they are the mean values for rising and falling magnetizations.

Magnetizing force. *H*	Specimen 1 (iron).		Specimen 8 (annealed steel).		Specimen 9 (same as 8 tempered).		Specimen 3 (cast iron).	
	B	μ	*B*	μ	*B*	μ	*B*	μ
1	–	–	–	–	–	–	265	265
2	200	100	–	–	–	–	700	350
3	–	–	–	–	–	–	1625	542
5	10050	2010	1525	300	750	150	3000	600
10	12550	1255	9000	900	1650	165	5000	500
20	14550	727	11500	575	5875	294	6000	300
30	15200	507	12650	422	9875	329	6500	217
40	15800	395	13300	332	11600	290	7100	177
50	16000	320	13800	276	12000	240	7350	149
70	16360	234	14350	205	13400	191	7900	113
100	16800	168	14900	149	14500	145	8500	85
150	17400	116	15700	105	15800	105	9500	63
200	17950	90	16100	80	16100	80	10190	51

Tables 359–363 give the results of some experiments by Du Bois,* on the magnetic properties of iron, nickel, and cobalt under strong magnetizing forces. The experiments were made on ovoids of the metals 18 centimeters long and 0.6 centimeters diameter. The specimens were as follows: (1) Soft Swedish iron carefully annealed and having a density 7.82. (2) Hard English cast steel yellow tempered at 230° C.; density 7.78. (3) Hard drawn best nickel containing 99 % Ni with some SiO_2 and traces of Fe and Cu; density 8.82. (4) Cast cobalt giving the following composition on analysis: Co = 93.1, Ni = 5.8, Fe = 0.8, Cu = 0.2, Si = 0.1, and C = 0.3. The specimen was very brittle and broke in the lathe, and hence contained a surfaced joint held together by clamps during the experiment. Referring to the columns, *H*, *B*, and μ have the same meaning as in the other tables, *S* is the magnetic moment per gram, and *I* the magnetic moment per cubic centimeter. *H* and *S* are taken from the curves published by Du Bois; the others have been calculated using the densities given.

MAGNETIC PROPERTIES OF SOFT IRON AT 0° AND 100° C.

TABLE 359.

Soft iron at 0° C.					Soft iron at 100° C.				
H	*S*	*I*	*B*	μ	*H*	*S*	*I*	*B*	μ
100	180.0	1408	17790	177.9	100	180.0	1402	17720	177.2
200	194.5	1521	19310	96.5	200	194.0	1511	19190	96.0
400	208.0	1627	20830	52.1	400	207.0	1613	20660	51.6
700	215.5	1685	21870	31.2	700	213.4	1663	21590	29.8
1000	218.0	1705	22420	22.4	1000	215.0	1674	22040	21.0
1200	218.5	1709	22670	18.9	1200	215.5	1679	22300	18.6

MAGNETIC PROPERTIES OF STEEL AT 0° AND 100° C.

TABLE 360.

Steel at 0° C.					Steel at 100° C.				
H	*S*	*I*	*B*	μ	*H*	*S*	*I*	*B*	μ
100	165.0	1283	16240	162.4	100	165.0	1278	16170	161.7
200	181.0	1408	17900	89.5	200	180.0	1395	17730	88.6
400	193.0	1500	19250	48.1	400	191.0	1480	19000	47.5
700	199.5	1552	20210	28.9	700	197.0	1527	19890	28.4
1000	203.5	1583	20900	20.9	1000	199.0	1543	20380	20.4
1200	205.0	1595	21240	17.7	1500	203.0	1573	21270	14.2
3750†	212.0	1650	24470	6.5	3000	205.5	1593	23020	7.7
					5000	208.0	1612	25260	5.1

---

* "Phil. Mag." 5 series, vol. xxix.

† The results in this and the other tables for forces above 1200 were not obtained from the ovoids above referred to, but from a small piece of the metal provided with a polished mirror surface and placed, with its polished face normal to the lines of force, between the poles of a powerful electromagnet. The induction was then inferred from the rotation of the plane of a polarized ray of red light reflected normally from the surface. (See Kerr's "Constants," p. 331.)

MAGNETIC PROPERTIES OF METALS.

TABLE 361. — Cobalt at 100° C.

H	*S*	*I*	*B*	*μ*
200	106	848	10850	54.2
300	116	928	11960	39.9
500	127	1016	13260	26.5
700	131	1048	13870	19.8
1000	134	1076	14520	14.5
1500	138	1104	15380	10.3
2500	143	1144	16870	6.7
4000	145	1164	18630	4.7
6000	147	1176	20780	3.5
9000	149	1192	23980	2.6
At 0° C. this specimen gave the following results :				
7900	154	1232	23380	3.0

TABLE 362. — Nickel at 100° C.

H	*S*	*I*	*B*	*μ*
100	35.0	309	3980	39.8
200	43.0	380	4966	24.8
300	46.0	406	5399	18.0
500	50.0	441	6043	12.1
700	51.5	454	6409	9.1
1000	53.0	468	6875	6.9
1500	56.0	494	7707	5.1
2500	58.4	515	8973	3.6
4000	59.0	520	10540	2.6
6000	59.2	522	12561	2.1
9000	59.4	524	15585	1.7
12000	59.6	526	18606	1.5
At 0° C. this specimen gave the following results :				
12300	67.5	595	19782	1.6

TABLE 363. — Magnetite.

The following results are given by Du Bois * for a specimen of magnetite.

H	*I*	*B*	*μ*
500	325	8361	16.7
1000	345	9041	9.0
2000	350	10084	5.0
12000	350	20084	1.7

Professor Ewing has investigated the effects of very intense fields on the induction in iron and other metals.† The results show that the intensity of magnetization does not increase much in iron after the field has reached an intensity of 1000 c. g. s. units, the increase of induction above this being almost the same as if the iron were not there, that is to say, dB/dH is practically unity. For hard steels, and particularly manganese steels, much higher forces are required to produce saturation. Hadfield's manganese steel seems to have nearly constant susceptibility up to a magnetizing force of 10,000. The following tables, taken from Ewing's papers, illustrate the effects of strong fields on iron and steel. The results for nickel and cobalt do not differ greatly from those given above.

TABLE 364. — Lowmoor Wrought Iron.

H	*I*	*B*	*μ*
3080	1680	24130	7.83
6450	1740	28300	4.39
10450	1730	32250	3.09
13600	1720	35200	2.59
16390	1630	36810	2.25
18760	1680	39900	2.13
18980	1730	40730	2.15

TABLE 365. — Vicker's Tool Steel.

H	*I*	*B*	*μ*
6210	1530	25480	4.10
9970	1570	29650	2.97
12120	1550	31620	2.60
14660	1580	34550	2.36
15530	1610	35820	2.31

TABLE 366. — Hadfield's Manganese Steel.

H	*I*	*B*	*μ*
1930	55	2620	1.36
2380	84	3430	1.44
3350	84	4400	1.31
5920	111	7310	1.24
6620	187	8970	1.35
7890	191	10290	1.30
8390	263	11690	1.39
9810	396	14790	1.51

TABLE 367. — Saturation Values for Steels of Different Kinds.

		H	*I*	*B*	*μ*
1	Bessemer steel containing about 0.4 per cent carbon . . .	17600	1770	39880	2.27
2	Siemens-Marten steel containing about 0.5 per cent carbon	18000	1660	38860	2.16
3	Crucible steel for making chisels, containing about 0.6 per cent carbon	19470	1480	38010	1.95
4	Finer quality of 3 containing about 0.8 per cent carbon . .	18330	1580	38190	2.08
5	Crucible steel containing 1 per cent carbon	19620	1440	37690	1.92
6	Whitworth's fluid-compressed steel	18700	1590	38710	2.07

---

* "Phil. Mag." 5 series, vol. xxix, 1890.

† "Phil. Trans. Roy. Soc." 1885 and 1889.

TABLE 368.—MAGNETIC PROPERTIES OF IRON IN VERY WEAK FIELDS.

The effect of very small magnetizing forces has been studied by C. Baur * and by Lord Rayleigh.† The following short table is taken from Baur's paper, and is taken by him to indicate that the susceptibility is finite for zero values of H and for a finite range increases in simple proportion to H. He gives the formula $k = 15 + 100\,H$, or $I = 15\,H + 100\,H^2$. The experiments were made on an annealed ring of round bar 1.013 cms. radius, the ring having a radius of 9.432 cms. Lord Rayleigh's results for an iron wire not annealed give $k = 6.4 + 5.1\,H$, or $I = 6.4\,H + 5.1\,H^2$. The forces were reduced as low as 0.00004 c. g. s., the relation of k to H remaining constant.

First experiment.			Second experiment.	
H	k	I	H	k
.01580	16.46	2.63	.0130	15.50
.03081	17.65	5.47	.0847	18.38
.07083	23.00	16.33	.0946	20.49
.13188	28.90	38.15	.1864	25.07
.23011	39.81	91.56	.2903	32.40
.38422	58.56	224.87	.3397	35.20

TABLES 369, 370.—DISSIPATION OF ENERGY IN CYCLIC MAGNETIZATION OF MAGNETIC SUBSTANCES.

When a piece of iron or other magnetic metal is made to pass through a closed cycle of magnetization dissipation of energy results. Let us suppose the iron to pass from zero magnetization to strong magnetization in one direction and then gradually back through zero to strong magnetization in the other direction and thence back to zero, and this operation to be repeated several times. The iron will be found to assume the same magnetization when the same magnetizing force is reached from the same direction of change, but not when it is reached from the other direction. This has been long known, and is particularly well illustrated in the permanency of hard steel magnets. That this fact involves a dissipation of energy which can be calculated from the open loop formed by the curves giving the relation of magnetization to magnetizing force was pointed out by Warburg ‡ in 1881, reference being made to experiments of Thomson, § where such curves are illustrated for magnetism, and to E. Cohn, ‖ where similar curves are given for thermo-electricity. The results of a number of experiments and calculations of the energy dissipated are given by Warburg. The subject was investigated about the same time by Ewing, who published results somewhat later. ¶ Extensive investigations have since been made by a number of investigators.

TABLE 369.—Soft Iron Wire.

(From Ewing's 1885 paper.)

Total induction per sq. cm. B	Dissipation of energy in ergs per cu. cm.	Horse-power wasted per ton at 100 cycles per sec.
2000	420	0.74
3000	800	1.41
4000	1230	2.18
5000	1700	3.01
6000	2200	3.89
7000	2760	4.88
8000	3450	6.10
9000	4200	7.43
10000	5000	8.84
11000	5820	10.30
12000	6720	11.89
13000	7650	13.53
14000	8650	15.30
15000	9670	17.10

TABLE 370.—Cable Transformers.

This table gives the results obtained by Alexander Siemens with one of Siemens' cable transformers. The transformer core consisted of 900 soft iron wires 1 mm. diameter and 6 meters long.** The dissipation of energy in watts is for 100 complete cycles per second.

Mean maximum induction density in core. B	Total observed dissipation of energy in the core in watts per 112 lbs.	Calculated eddy current loss in watts per 112 lbs.	Hysteresis loss of energy in watts per 112 lbs.	Hysteresis loss of energy in ergs per cu. cm. per cycle.
1000	43.2	4	39.2	602
2000	96.2	16	80.2	1231
3000	158.0	36	122.0	1874
4000	231.2	64	167.2	2566
5000	309.5	100	209.5	3217
6000	390.1	144	246.1	3779

---

* "Wied. Ann." vol. xi.

† "Phil. Mag." vol. xxiii.

‡ "Wied. Ann." vol. xiii. p. 141.

§ "Phil. Trans. Roy. Soc." vol. 175.

‖ "Wied. Ann." vol. 6.

¶ "Proc. Roy. Soc." 1882, and "Trans. Roy. Soc." 1885.

** "Proc. Inst. of Elect. Eng." Lond., 1892.

DEMAGNETIZING FACTORS FOR RODS.

TABLE 371.

H = true intensity of magnetizing field, H' = intensity of applied field, I = intensity of magnetization, $H = H' - NI$.

Shuddemagen says: The demagnetizing factor is not a constant, falling for highest values of I to about 1/7 the value when unsaturated; for values of B $(= H + 4\pi I)$ less than 10000, N is approximately constant; using a solenoid wound on an insulating tube, or a tube of split brass, the reversal method gives values for N which are considerably lower than those given by the step-by-step method; if the solenoid is wound on a thick brass tube, the two methods practically agree.

Ratio of Length to Diameter.	Values of $N \times 10^4$.						
		Cylinder.					
	Ellipsoid.	Uniform Magnetization.	Magnetometric Method (Mann).	Ballistic Step Method.			
				Dubois.	Shuddemagen for Range of Practical Constancy.		
				Diameter.			
				0.158 cm.	0.3175 cm.	1.111 cm.	1.905 cm.
5	7015	-	6800				
10	2549	630	2550	2160	-	-	1960
15	1350	280	1400	1206	-	-	1075
20	848	160	898	775	-	-	671
30	432	70	460	393	388	350	343
40	266	39	274	238	234	212	209
50	181	25	182	162	160	145	149
60	132	18	131	118	116	106	106
70	101	13	99	89	88		
80	80	9.8	78	69	69	66	63
90	65	7.8	63	55	56		
100	54	6.3	51.8	45	46	41	41
150	26	2.8	25.1	20	23	21	21
200	16	1.57	15.2	11	12.5	11	11
300	7.5	0.70	7.5	5.0			
400	4.5	0.39	-	2.8			

C. R. Mann, Physical Review, 3, p. 359; 1896.
H. DuBois, Wied. Ann. 7, p. 942; 1902.
C. L. B. Shuddemagen, Proc. Am. Acad. Arts and Sci. 43, p. 185, 1907 (Bibliography).

TABLE 372.

Shuddemagen also gives the following, where B is determined by the step method and $H = H' - KB$.

Ratio of Length to Diameter.	Values of $K \times 10^4$.	
	Diameter 0.3175 cm.	Diameter 1.1 to 2.0 cm.
15	-	85.2
20	-	53.3
25	-	36.6
30	30.9	27.3
40	18.6	16.6
50	12.7	11.6
60	9.25	8.45
80	5.5	5.05
100	3.66	3.26
150	1.83	1.67

DISSIPATION OF ENERGY IN THE CYCLIC MAGNETIZATION OF VARIOUS SUBSTANCES.

C. P. Steinmetz concludes from his experiments * that the dissipation of energy due to hysteresis in magnetic metals can be expressed by the formula $e = aB^{1.6}$, where e is the energy dissipated and a a constant. He also concludes that the dissipation is the same for the same range of induction, no matter what the absolute value of the terminal inductions may be. His experiments show this to be nearly true when the induction does not exceed ± 15000 c. g. s. units per sq. cm. It is possible that, if metallic induction only be taken, this may be true up to saturation; but it is not likely to be found to hold for total inductions much above the saturation value of the metal. The law of variation of dissipation with induction range in the cycle, stated in the above formula, is also subject to verification.†

Values of Constant a.

The following table gives the values of the constant a as found by Steinmetz for a number of different specimens. The data are taken from his second paper.

Number of specimen.	Kind of material.	Description of specimen.	Value of a.
1	Iron	Norway iron	.00227
2	"	Wrought bar	.00326
3	"	Commercial ferrotype plate	.00548
4	"	Annealed " "	.00458
5	"	Thin tin plate	.00286
6	"	Medium thickness tin plate	.00425
7	Steel	Soft galvanized wire	.00349
8	"	Annealed cast steel	.00848
9	"	Soft annealed cast steel	.00457
10	"	Very soft annealed cast steel	.00318
11	"	Same as 8 tempered in cold water	.02792
12	"	Tool steel glass hard tempered in water	.07476
13	"	" " tempered in oil	.02670
14	"	" " annealed	.01899
15	"	Same as 12, 13, and 14, after having been subjected to an alternating m. m. f. of from 4000 to 6000 ampere turns for demagnetization	.06130
16	"		.02700
17	"		.01445
18	Cast iron	Gray cast iron	.01300
19	" "	" " " containing $\frac{1}{8}$ % aluminium	.01365
20	" "	" " " " $\frac{1}{2}$ % "	.01459
21	Magnetite	A square rod 6 sq. cms. section and 6.5 cms. long, from the Tilly Foster mines, Brewsters, Putnam County, New York, stated to be a very pure sample	.02348
22	Nickel	Soft wire	.0122
23	"	Annealed wire, calculated by Steinmetz from Ewing's experiments	.0156
24	"	Hardened, also from Ewing's experiments	.0385
25	Cobalt	Rod containing about 2 % of iron, also calculated from Ewing's experiments by Steinmetz	.0120
26	Iron filings	Consisted of thin needle-like chips obtained by milling grooves about 8 mm. wide across a pile of thin sheets clamped together. About 30 % by volume of the specimen was iron.	
		1st experiment, continuous cyclic variation of m. m. f. 180 cycles per second	.0457
		2d experiment, 114 cycles per second	.0396
		3d " 79–91 cycles per second	.0373

---

* "Trans. Am. Inst. Elect. Eng." January and September, 1892.
† See T. Gray, "Proc. Roy. Soc." vol. lvi.

TABLE 374.

ENERGY LOSSES IN TRANSFORMER STEELS.

Determined by the wattmeter method.

Loss per cycle per $cc = AB^x + bnB^y$, where B = flux density in gausses and n = frequency in cycles per second. x shows the variation of hysteresis with B between 5000 and 10000 gausses, and y the same for eddy currents.

Designation.	Thickness. cm.	Ergs per Gramme per Cycle.				x	y	a	Watts per Pound at 60 Cycles and 10000 Gausses.		
		10000 Gausses.		5000 Gausses.							
		Hysteresis.	Eddy Currents at 60~	Hysteresis.	Eddy Currents at 60~				Eddy Current Loss for Gage No. 29.‡	Hysteresis.	Total.
Unannealed											
A	0.0399	1599	186	562	46	1.51	2.02	0.00490	0.41	4.35	4.76
B	.0326	1156	134	384	36	1.59	1.89	.00358	0.44	3.14	3.58
C	.0422	1032	242	356	70	1.51	1.79	.00319	0.47	2.81	3.28
D	.0381	1009	184	353	48	1.52	1.94	.00312	0.44	2.74	3.18
Annealed											
E	.0476	735	236	246	58	1.58	2.02	.00227	0.36	2.00	2.36
F	.0280	666	100	220	27	1.60	1.88	.00206	0.44	1.81	2.25
G	.0394	563	210	193	54	1.54	1.96	.00174	0.47	1.53	2.00
H*	.0307	412	146	138.5	39	1.58	1.90	.00127	0.54	1.12	1.66
J	.0318	341	202	111.5	55	1.62	1.88	.00105	0.70	0.93	1.63
K*	.0282	394	124	130	32	1.61	1.90	.00122	0.54	1.07	1.61
L	.0346	381	184	125	50	1.61	1.88	.00118	0.535	1.035	1.57
B	.0338	354	200	116	57	1.61	1.81	.00110	0.61	0.96	1.57
M	.0335	372	178	127	46	1.55	1.95	.00115	0.55	1.01	1.56
N	.0340	321	210	105	56	1.62	1.90	.00099	0.63	0.87	1.50
P	.0437	334	184	107	50	1.64	1.88	.00103	0.34	0.91	1.25
Silicon steels											
Q†	.0361	303	54	98	15	1.63	–	.00094	0.14	0.825	0.965
R	.0315	288	42	93	11	1.64	–	.00089	0.15	0.78	0.93
S	.0452	278	72	90	18	1.63	–	.00086	0.12	0.755	0.875
T	.0338	250	60	78	18	1.68	–	.00077	0.18	0.68	0.86
U	.0346	270	42	86	12	1.66	–	.00084	0.12	0.735	0.855
V*	.0310	251.5	47	79	13	1.68	–	.00078	0.17	0.685	0.855
W*	.0305	197	43	62.3	12.4	1.67	–	.00061	0.16	0.535	0.695
X	.0430	200	65	64.2	16.6	1.65	–	.00062	0.12	0.545	0.665

---

* German. † English.

‡ In order to make a fair comparison, the eddy current loss has been computed for a thickness of 0.0357 cm. (Gage No. 29), assuming the loss proportional to the thickness.

Lloyd and Fisher, Bull. Bur. Standards, 5, p. 453; 1909.

Note. — For formulæ and tables for the calculation of mutual and self inductance see Bulletin Bureau of Standards, vol. 8, p. 1-237, 1912.

TABLE 375.

MAGNETO-OPTIC ROTATION.

Faraday discovered that, when a piece of heavy glass is placed in magnetic field and a beam of plane polarized light passed through it in a direction parallel to the lines of magnetic force, the plane of polarization of the beam is rotated. This was subsequently found to be the case with a large number of substances, but the amount of the rotation was found to depend on the kind of matter and its physical condition, and on the strength of the magnetic field and the wave-length of the polarized light. Verdet's experiments agree fairly well with the formula —

$$\theta = clH\left(r - \lambda\frac{dr}{d\lambda}\right)\frac{r^2}{\lambda^2},$$

where c is a constant depending on the substance used, l the length of the path through the substance, H the intensity of the component of the magnetic field in the direction of the path of the beam, r the index of refraction, and λ the wave-length of the light in air. If H be different at different parts of the path, lH is to be taken as the integral of the variation of magnetic potential between the two ends of the medium. Calling this difference of potential v, we may write $\theta = Av$, where A is constant for the same substance, kept under the same physical conditions, when the one kind of light is used. The constant A has been called "Verdet's constant,"[*] and a number of values of it are given in Tables 376–380. For variation with temperature the following formula is given by Bichat: —

$$R = R_0\,(1 - 0.00104\,t - 0.000014\,t^2),$$

which has been used to reduce some of the results given in the table to the temperature corresponding to a given measured density. For change of wave-length the following approximate formula, given by Verdet and Becquerel, may be used: —

$$\frac{\theta_1}{\theta_2} = \frac{\mu_1^2(\mu_1^2 - 1)\lambda_2^2}{\mu_2^2(\mu_2^2 - 1)\lambda_1^2},$$

where μ is index of refraction and λ wave-length of light.

A large number of measurements of what has been called molecular rotation have been made, particularly for organic substances. These numbers are not given in the table, but numbers proportional to molecular rotation may be derived from Verdet's constant by multiplying in the ratio of the molecular weight to the density. The densities and chemical formulæ are given in the table. In the case of solutions, it has been usual to assume that the total rotation is simply the algebraic sum of the rotations which would be given by the solvent and dissolved substance, or substances, separately; and hence that determinations of the rotary power of the solvent medium and of the solution enable the rotary power of the dissolved substance to be calculated. Experiments by Quincke and others do not support this view, as very different results are obtained from different degrees of saturation and from different solvent media. No results thus calculated have been given in the table, but the qualitative result, as to the sign of the rotation produced by a salt, may be inferred from the table. For example, if a solution of a salt in water gives Verdet's constant less than 0.0130 at 20° C., Verdet's constant for the salt is negative.

The table has been for the most part compiled from the experiments of Verdet,[†] H. Becquerel,[‡] Quincke,[§] Koepsel,[||] Arons,[¶] Kundt,[**] Jahn,[††] Schönrock,[‡‡] Gordon,[§§] Rayleigh and Sidgewick,[||||] Perkin,[¶¶] Bichat.[***]

As a basis for calculation, Verdet's constant for carbon disulphide and the sodium line D has been taken as 0.0420 and for water as 0.0130 at 20° C.

[*] The constancy of this quantity has been verified through a wide range of variation of magnetic field by H. E. J. G. Du Bois (Wied. Ann. vol. 35), p. 137, 1888.

[†] "Ann. de Chim. et de Phys." [3] vol. 52, p. 129, 1858.

[‡] "Ann. de Chim. et de Phys." [5] vol. 12; "C. R." vols. 90, p. 1407, 1880, and 100, p. 1374, 1885.

[§] "Wied. Ann." vol. 24, p. 606, 1885.

[||] "Wied. Ann." vol. 26, p. 456, 1885.

[¶] "Wied. Ann." vol. 24, p. 161, 1885.

[**] "Wied. Ann." vols. 23, p. 228, 1884, and 27, p. 191, 1886.

[††] "Wied. Ann." vol. 43, p. 280, 1891.

[‡‡] "Zeits. für Phys. Chem." vol. 11, p. 753, 1893.

[§§] "Proc. Roy. Soc." 36, p. 4, 1883.

[||||] "Phil. Trans. R. S." 176, p. 343, 1885.

[¶¶] "Jour. Chem. Soc."

[***] "Jour. de Phys." vols. 8, p. 204, 1879, and 9, p. 204 and p. 275, 1880.

TABLE 376.

MAGNETO-OPTIC ROTATION.

Solids.

Substance.	Formula.	Wave-length.	Verdet's Constant. Minutes.	Temp. C.	Authority.
		μ			
Amber		0.589	0.0095	18–20°	Quincke.
Blende	ZnS	"	0.2234	15	Becquerel.
Diamond	C	"	0.0127	15	"
Lead borate	PbB_2O_4	"	0.0600	15	"
Selenium	Se	0.687	0.4625	15	"
Sodium borate . . .	$Na_2B_4O_7$	0.589	0.0170	15	"
Ziqueline	Cu_2O	0.687	0.5908	15	"
Fluorite	$CaFl_2$	0.2534	0.05989	20	Meyer, Ann. der Physik, 30, 1909.
		.3655	.02526	"	
		.4358	.01717	"	
		.4916	.01329	"	
		.589	.00897	"	
		1.00	.00300	"	
		2.50	.00049	"	
		3.00	.00030	"	
Glass, Jena: Medium phosphate crn.		0.589	0.0161	18	DuBois, Wied. Ann. 51, 1894.
Heavy crown, O1143 .		"	0.0220	"	
Light flint, O451 .		"	0.0317	"	
Heavy flint O500 .		"	0.0608	"	
" " S163 . .		"	0.0888	"	
Zeiss, Ultraviolet		0.313	0.0674	16	Landau, Phys. ZS. 9, 1908.
"		0.405	.0369	"	
"		0.436	.0311	"	
Quartz, along axis, i.e., plate cut ⊥ to axis	SiO_2	0.2194	0.1587	20	Borel, Arch. sc. phys. 16, 1903.
		.2573	.1079	"	
		.3609	.04617	"	
		.4800	.02574	"	
		.5892	.01664	"	
		.6439	.01368	"	
Rock salt	$NaCl$	0.2599	0.2708	20	Meyer, as above.
		.3100	.1561	"	
		.4046	.0775	"	
		.4916	.0483	"	
		.6708	.0245	"	
		1.00	.01050	"	
		2.00	.00262	"	
		4.00	.00069	"	
Sugar, cane: along axis IIA	$C_{12}H_{22}O_{11}$	0.451	.0122	20	Voigt, Phys. ZS. 9, 1908.
		.540	.0076	"	
		.626	.0066	"	
axis IIA^1 . .	–	0.451	0.0129	"	
		.540	.0084	"	
		.626	.0075	"	
Sylvine	KCl	0.4358	0.0534	20	Meyer, as above.
		.5461	.0316	"	
		.6708	.02012	"	
		.90	.01051	"	
		1.20	.00608	"	
		2.00	.00207	"	
		4.00	.00054	"	

Table 377.

MAGNETO-OPTIC ROTATION.

Liquids: Verdet's Constant for λ = 0.589μ.

Substance.	Chemical formula.	Density in grams per c. c.	Verdet's constant in minutes.	Temp. C.	Authority.
Acetone	C_3H_6O	0.7947	0.0113	20°	Jahn.
Acids: Acetic	$C_2H_4O_2$	1.0561	.0105	21	Perkin.
" Butyric	$C_4H_8O_2$	0.9663	.0116	15	"
" Formic	CH_2O_2	1.2273	.0105	"	"
" Hydrochloric	HCl	1.2072	.0224	"	"
" Hydrobromic	HBr	1.7859	.0343	"	"
" Hydroiodic	HI	1.9473	.0515	"	"
" Nitric	HNO_3	1.5190	.0070	13	"
" Sulphuric	H_2SO_4	—	.0121	15	Becquerel.
Alcohols: Amyl	$C_5H_{11}OH$	0.8107	.0128	20	Jahn.
" Butyl	C_4H_9OH	0.8021	.0124	"	"
" Ethyl	C_2H_5OH	0.7900	.0112	"	"
" Methyl	CH_3OH	0.7920	.0093	"	"
" Propyl	C_3H_7OH	0.8042	.0120	"	"
Benzol	C_6H_6	0.8786	.0297	"	"
Bromides: Bromoform	$CHBr_3$	2.9021	.0317	15	Perkin.
" Ethyl	C_2H_5Br	1.4486	.0183	"	"
" Ethylene	$C_2H_4Br_2$	2.1871	.0268	"	"
" Methyl	CH_3Br	1.7331	.0205	0	"
" Methylene	CH_2Br_2	2.4971	.0276	15	"
Carbon bisulphide	CS_2	—	.0433	0	Gordon.
" "	"	—	.0420	18	Rayleigh.
Chlorides: Amyl	$CHCl$	0.8740	.0140	20	Jahn.
" Arsenic	$AsCl_3$	—	.0422	15	Becquerel.
" Carbon	CCl_4	—	.0321	"	"
" Chloroform	$CHCl_3$	1.4823	.0164	20	Jahn.
" Ethyl	C_2H_5Cl	0.9169	0.0138	6	Perkin.
" Ethylene	$C_2H_4Cl_2$	1.2589	.0166	15	"
" Methyl	CH_3Cl	—	.0170	"	Becquerel.
" Methylene	CH_2Cl_2	1.3361	.0162	"	Perkin.
" Sulphur bi-	S_2Cl_2	—	.0393	"	Becquerel.
" Tin tetra	$SnCl_4$	—	.0151	"	"
" Zinc bi-	$ZnCl_2$	—	.0437	"	"
Iodides: Ethyl	C_2H_5I	1.9417	.0296	"	Perkin.
" Methyl	CH_3I	2.2832	.0336	"	"
" Propyl	C_3H_7I	1.7658	.0271	"	"
Nitrates: Ethyl	$C_2H_5O.NO_2$	1.1149	.0091	"	"
" Methyl	$CH_3O.NO_2$	1.2157	.0078	"	"
" Propyl	$C_3H_7O.NO_2$	1.0622	.0100	"	"
Paraffins: Heptane	C_7H_{16}	0.6880	.0125	"	"
" Hexane	C_6H_{14}	0.6743	.0125	"	"
" Pentane	C_5H_{12}	0.6332	.0118	"	"
Phosphorus, melted	P	—	.1316	33	Becquerel.
Sulphur, melted	S	—	.0803	114	"
Toluene	C_7H_8	0.8581	.0269	28	Schönrock.
Water, λ = 0.2496 μ	H_2O		.1042		See Meyer, Ann. der Physik, 30, 1909. Measures by Landau, Siertsema, Ingersoll.
0.275			.0776		
0.3609			.0384		
0.4046			.0293		
0.500			.0184		
0.589			.0131		
0.700			.0091		
1.000			.00410		
1.300			.00264		
Xylene	C_8H_{10}	0.8746	.0263	27	Schönrock.

TABLE 378.

MAGNETO-OPTIC ROTATION.

Solutions of acids and salts in water. Verdet's constant for $\lambda = 0.589\mu$.

Chemical formula.	Density, grams per c. c.	Verdet's constant in minutes.	Temp. C.	*	Chemical formula.	Density, grams per c. c.	Verdet's constant in minutes.	Temp. C.	*
C_3H_6O	0.9715	0.0129	20°	J	LiCl	1.0619	0.0145	20°	J
HBr	1.3775	0.0244	"	P	"	1.0316	0.0143	"	"
"	1.1163	0.0168	"	"	$MnCl_2$	1.1966	0.0167	15	B
HCl	1.1573	0.0204	"	"	"	1.0876	0.0150	"	"
"	1.0762	0.0168	"	"	$HgCl_2$	1.0381	0.0137	16	S
"	1.0158	0.0140	"	J	"	1.0349	0.0137	"	"
HI	1.9057	0.0499	"	P	$NiCl_2$	1.4685	0.0270	15	B
"	1.4495	0.0323	"	"	"	1.2432	0.0196	"	"
"	1.1760	0.0205	"	"	"	1.1233	0.0162	"	"
HNO_3	1.3560	0.0105	"	"	KCl	1.6000	0.0163	"	"
NH_3	0.8918	0.0153	15	"	"	1.0732	0.0148	20	J
NH_4Br	1.2805	0.0226	"	"	NaCl	1.2051	0.0180	15	B
"	1.1576	0.0186	"	"	"	1.0546	0.0144	"	"
$BaBr_2$	1.5399	0.0215	20	J	"	1.0418	0.0144	"	J
"	1.2855	0.0176	"	"	$SrCl_2$	1.1921	0.0162	"	"
$CdBr_2$	1.3291	0.0192	"	"	"	1.0877	0.0146	"	"
"	1.1608	0.0162	"	"	$SnCl_2$	1.3280	0.0266	15	V
$CaBr_2$	1.2491	0.0189	"	"	"	1.1112	0.0175	"	"
"	1.1337	0.0164	"	"	$ZnCl_2$	1.2851	0.0196	"	"
KBr	1.1424	0.0163	"	"	"	1.1595	0.0161	"	"
"	1.0876	0.0151	"	"	K_2CrO_4	1.3598	0.0098	"	"
NaBr	1.1351	0.0165	"	"	$K_2Cr_2O_7$	1.0786	0.0126	"	"
"	1.0824	0.0152	"	"	$Hg(CN)_2$	1.0638	0.0136	16	S
$SrBr_2$	1.2901	0.0186	"	"	"	1.0605	0.0135	"	"
"	1.1416	0.0159	"	"	NH_4I	1.5948	0.0396	15	P
K_2CO_3	1.1906	0.0140	20	"	"	1.5109	0.0358	"	"
Na_2CO_3	1.1006	0.0140	"	"	"	1.2341	0.0235	"	"
"	1.0564	0.0137	"	"	CdI	1.5156	0.0291	20	J
NH_4Cl	1.0718	0.0178	15	V	"	1.1521	0.0177	"	"
$BaCl_2$	1.2897	0.0168	20	J	KI	1.6743	0.0338	15	B
"	1.1338	0.0149	"	"	"	1.3398	0.0237	"	"
$CdCl_2$	1.3179	0.0185	"	"	"	1.1705	0.0182	"	"
"	1.2755	0.0179	"	"	NaI	1.1939	0.0200	"	J
"	1.1732	0.0160	"	"	"	1.1191	0.0175	"	"
"	1.1531	0.0157	"	"	NH_4NO_3	1.2803	0.0121	15	P
$CaCl_2$	1.1504	0.0165	"	"	KNO_3	1.0634	0.0130	20	J
"	1.0832	0.0152	"	"	$NaNO_3$	1.1112	0.0131	"	"
$CuCl_2$	1.5158	0.0221	15	B	$U_2O_3N_2O_5$	2.0267	0.0053	"	B
"	1.1330	0.0156	"	"	,,	1.1963	0.0115	"	"
$FeCl_2$	1.4331	0.0025	15	"	$(NH_4)_2SO_4$	1.2286	0.0140	15	P
"	1.2141	0.0099	"	"	$NH_4.HSO_4$	1.4417	0.0085	"	"
"	1.1093	0.0118	"	"	$BaSO_4$	1.1788	0.0134	20	J
Fe_2Cl_6	1.6933	—0.2026	"	"	"	1.0938	0.0133	"	"
"	1.5315	—0.1140	"	"	$CdSO_4$	1.1762	0.0139	"	"
"	1.3230	—0.0348	"	"	"	1.0890	0.0136	"	"
"	1.1681	—0.0015	"	"	Li_2SO_4	1.1762	0.0137	"	"
"	1.0864	0.0081	"	"	$MnSO_4$	1.2441	0.0138	"	"
"	1.0445	0.0113	"	"	K_2SO_4	1.0475	0.0133	"	"
"	1.0232	0.0122	"	"	$NaSO_4$	1.0661	0.0135	"	"

* J, Jahn, P, Perkin, V, Verdet, B, Becquerel, S, Schönrock; see p. 326 for references.

TABLE 379.—Magneto-Optic Rotation.

Gases.

Substance.	Pressure.	Temp.	Verdet's constant in minutes.	Authority.
Atmospheric air	Atmospheric	Ordinary	6.83×10^{-6}	Becquerel.
Carbon dioxide	"	"	13.00 "	"
Carbon disulphide	74 cms.	70° C.	23.49 "	Bichat.
Ethylene	Atmospheric	Ordinary	34.48 "	Becquerel.
Nitrogen	"	"	6.92 "	"
Nitrous oxide	"	"	16.90 "	"
Oxygen	"	"	6.28 "	"
Sulphur dioxide	"	"	31.39 "	"
" "	246 cms.	20° C.	38.40 "	Bichat.

See also Siertsema, Ziting. Kon. Akad. Watt., Amsterdam, 7, 1899; 8, 1900.

Du Bois shows that in the case of substances like iron, nickel, and cobalt which have a variable magnetic susceptibility the expression in Verdet's equation, which is constant for substances of constant susceptibility, requires to be divided by the susceptibility to obtain a constant. For this expression he proposes the name "Kundt's constant." These experiments of Kundt and Du Bois show that it is not the difference of magnetic potential between the two ends of the medium, but the product of the length of the medium and the induction per unit area, which controls the amount of rotation of the beam.

TABLE 380.—Verdet's and Kundt's Constants.

The following short table is quoted from Du Bois' paper. The quantities are stated in c. g. s. measure, circular measure (radians) being used in the expression of "Verdet's constant" and "Kundt's constant."

Name of substance.	Magnetic susceptibility.	Verdet's constant.		Wave-length of light in cms.	Kundt's constant.
		Number.	Authority.		
Cobalt . . .	–	–	–	6.44×10^{-5}	3.99
Nickel . . .	–	–	–	"	3.15
Iron . . .	–	–	–	6.56 "	2.63
Oxygen: 1 atmo. .	$+0.0126 \times 10^{-5}$	0.000179×10^{-6}	Becquerel.	5.89 "	0.014
Sulphur dioxide .	-0.0751 "	0.302 "	"	"	-4.00
Water . . .	-0.0694 "	0.377 "	Arons	"	-5.4
Nitric acid . .	-0.0633 "	0.356 "	Becquerel.	"	-5.6
Alcohol . . .	-0.0566 "	0.330 "	De la Rive.	"	-5.8
Ether	-0.0541 "	0.315 "	"	"	-5.8
Arsenic chloride .	-0.0876 "	1.222 "	Becquerel.	"	-14.9
Carbon disulphide .	-0.0716 "	1.222 "	Rayleigh.	"	-17.1
Faraday's glass .	-0.0982 "	1.738 "	Becquerel.	"	-17.7

TABLE 381. — Values of Kerr's Constant.*

Du Bois has shown that the rotation of the major axis of vibration of radiations normally reflected from a magnet is algebraically equal to the normal component of magnetization multiplied into a constant K. He calls this constant K, Kerr's constant for the magnetized substance forming the magnet.

Color of light.	Spectrum line.	Wave-length in cms. $\times 10^6$	Kerr's constant in minutes per c. g. s. unit of magnetization.			
			Cobalt.	Nickel.	Iron.	Magnetite.
Red	Li α	67.7	—0.0208	—0.0173	—0.0154	+0.0096
Red	—	62.0	—0.0198	—0.0160	—0.0138	+0.0120
Yellow	D	58.9	—0.0193	—0.0154	—0.0130	+0.0133
Green	b	51.7	—0.0179	—0.0159	—0.0111	+0.0072
Blue	F	48.6	—0.0180	—0.0163	—0.0101	+0.0026
Violet	G	43.1	—0.0182	—0.0175	—0.0089	-

* H. E. J. G. Du Bois, "Phil. Mag." vol. 29.

TABLE 382. — Dispersion of Kerr Effect.

Wave-length.	0.5μ	1.0μ	1.5μ	2.0μ	2.5μ
Steel . . .	—11′.	—16′.	—14′.	—11′.	—9′.0
Cobalt . . .	— 9.5	—11.5	— 9.5	—11.	—6.5
Nickel . . .	— 5.5	— 4.0	0	+1.75	+3.0

Field Intensity = 10,000 C. G. S. units. (Intensity of Magnetization = about 800 in steel, 700 to 800 in cobalt, about 400 in nickel). Ingersoll, Phil. Mag. 11, p. 41, 1906.

TABLE 383. — Dispersion of Kerr Effect.

Mirror.	Field (C. G. S.)	.41μ	.44μ	.48μ	.52μ	.56μ	.60μ	.64μ	.66μ
Iron . .	21,500	—.25	—.26	—.28	—.31	—.36	—.42	—.44	—.45
Cobalt . .	20,000	—.36	—.35	—.34	—.35	—.35	—.35	—.35	—.36
Nickel . .	19,000	—.16	—.15	—.13	—.13	—.14	—.14	—.14	—.14
Steel . .	19,200	—.27	—.28	—.31	—.35	—.38	—.40	—.44	—.45
Invar . .	19,800	—.22	—.23	—.24	—.23	—.23	—.22	—.23	—.23
Magnetite	16,400	—.07	—.02	+.04	+.06	+.08	+.06	+.04	+.03

Foote, Phys. Rev. 34, p. 96, 1912.

See also Ingersoll, Phys. Rev. 35, p. 312, 1912, for "The Kerr Rotation for Transverse Magnetic Fields," and Snow, l. c. 2, p. 29, 1913, "Magneto-optical Parameters of Iron and Nickel."

TABLE 384.

MAGNETIC SUSCEPTIBILITY.

If $\mathfrak{I}$ is the intensity of magnetization produced in a substance by a field strength $\mathfrak{H}$, then the magnetic susceptibility $H = \mathfrak{I}/\mathfrak{H}$. This is generally referred to the unit mass; italicized figures refer to the unit volume. The susceptibility depends greatly upon the purity of the substance, especially its freedom from iron. The mass susceptibility of a solution containing p per cent by weight of a water-free substance is, if H_0 is the susceptibility of water, $(p/100)\,H + (1 - p/100)\,H_0$.

Substance.	Susceptibility.	Temp. C.	Remarks	Substance.	Susceptibility.	Temp. C.	Remarks
Ag	—0.19	18°		K_2CO_3	—0.50	20°	Sol'n
AgCl	—0.28			Li	+0.38		
Air, 1 Atm.	+*0.024*	15		Mb	+0.04	18	
Al	+0.65	18		Mg	+0.55	18	
$Al_2K_2(SO_4)_4 24H_2O$	—*1.0*		Crys.	$MgSO_4$	—0.40		
A, 1 Atm	—*0.10*	0		Mn	+11.	18	
As	—0.3	18		$MnCl_2$	+122.	18	Sol'n
Au	—0.15	18		$MnSO_4$	+100.	18	“
B	—0.71	18		N_2, 1 Atm.	*0.001*	16	
$BaCl_2$	—0.36	20		NH_3	—1.1		
Be	+0.79	15	Powd.	Na	+0.51	18	
Bi	—1.4	18		NaCl	—0.50	20	
Br	—0.38	18		$NaCO_3$	—0.19	17	Powd.
C, arc-carbon	—*2.0*	18		$NaCO_3 . 10\,H_2O$	—0.46	17	“
C, diamond	—0.49	18		Nb	+1.3	18	
CH_4, 1 Atm.	+*0.001*	16		$NiCl_2$	+40.	18	Sol'n
CO_2, 1 Atm.	+*0.002*	16		$NiSO_4$	+30.	20	“
CS_2	—*0.77*	18		O_2, 1 Atm.	+0.120	20	
CaO	—0.27	16	Powd.	Os	+0.04	20	
$CaCl_2$	—0.40	19	“	P, white	—0.90	20	
$CaCO_3$, marble	—*0.7*			P, red	—0.50	20	
Cd	—0.17	18		Pb	—0.12	20	
$CeBr_3$	+6.3	18		$PbCl_3$	—0.25	15	Powd.
Cl_2, 1 Atm.	—0.59	16		Pd	+5.8	18	
$CoCl_2$	+90.	18	Sol'n	$PrCl_3$	+13.	18	Sol'n
$CoBr_2$	+47.	18	“	Pt.	+1.1	18	
CoI_2	+33.	18	“	$PtCl_4$	0.0	22	Sol'n
$CoSO_4$	+57.	19	“	Rh	+1.1	18	
$Co(NO_3)_2$	+57.	18	“	S	—0.48	18	
Cr	+3.7	18		SO_2, 1 Atm.	—0.30	16	
CsCl	—0.28	17	Powd.	Sb	—0.94	18	
Cu	—0.09	18		Se	—0.32	18	
$CuCl_2$	+12.	20	Sol'n	Si	—0.12	18	Crys.
$CuSO_4$	+10.	20	Sol'n	SiO_2, Quartz	—0.44	20	
CuS	+0.16	17	Powd.	—Glass	—0.5±		
$FeCl_3$	+90.	18	Sol'n	Sn	+0.03	20	
$FeCl_2$	+90.	18	“	$SrCl_2$	—0.42	20	Sol'n
$FeSO_4$	+82.	20	“	Ta	+0.93	18	
$Fe_2(NO_3)_6$	+50.	18	“	Te	—0.32	20	
$FeCn_6K_4$	—0.44		Powd.	Th	+0.18	18	
$FeCn_6K_3$	+9.1		“	Ti	+3.1	18	
He, 1 Atm.	—*0.002*	0		Va	+1.5	18	
H_2, 1 Atm.	*0.000*	16		Wo	+0.33	20	
H_2, 40 Atm.	*0.000*	16		Zn	—0.15	18	
H_2O	—0.79	20		$ZnSO_4$	—0.40		
HCl	—*0.80*	20		Zr	—0.45	18	
H_2SO_4	+*0.78*	20		CH_3OH	—0.73		
HNO_3	—*0.70*	20		C_2H_5OH	—0.80		
Hg	—0.19	20		C_3H_7OH	—0.80		
I	—0.4	20		$C_2H_5OC_2H_5$	—*0.60*	20	
In	0.1±	18		$CHCl_3$	—0.58		
Ir	+0.15	18		C_6H_6	—0.78		
K	+0.40	20		Ebonite	+*1.1*		
KCl	—0.50	20		Glycerine	—0.64	22	
KBr	—0.40	20		Sugar	—0.57		
KI	—0.38	20		Paraffin	—*0.58*		
KOH	—0.35	22	Sol'n	Petroleum	—0.91		
K_2SO_4	—0.42	20		Toluene	—0.77		
$KMnO_4$	+2.0			Wood	—0.2–5		
KNO_3	—0.33	20		Xylene	—0.81		

Values are mostly means taken of values given in Landolt-Börnstein's Physikalisch-chemische Tabellen. See especially Honda, Annalen der Physik (4), 32, 1910.

TABLE 385. — Variation of Resistance of Bismuth, with Temperature, in a Transverse Magnetic Field.

H	Proportional Values of Resistance.								
	−192°	−135°	−100°	−37°	0°	+18°	+60°	+100°	+183°
0	0.40	0.60	0.70	0.88	1.00	1.08	1.25	1.42	1.79
2000	1.16	0.87	0.86	0.96	1.08	1.11	1.26	1.43	1.80
4000	2.32	1.35	1.20	1.10	1.18	1.21	1.31	1.46	1.82
6000	4.00	2.06	1.60	1.29	1.30	1.32	1.39	1.51	1.85
8000	5.90	2.88	2.00	1.50	1.43	1.42	1.46	1.57	1.87
10000	8.60	3.80	2.43	1.72	1.57	1.54	1.54	1.62	1.89
12000	10.8	4.76	2.93	1.94	1.71	1.67	1.62	1.67	1.92
14000	12.9	5.82	3.50	2.16	1.87	1.80	1.70	1.73	1.94
16000	15.2	6.95	4.11	2.38	2.02	1.93	1.79	1.80	1.96
18000	17.5	8.15	4.76	2.60	2.18	2.06	1.88	1.87	1.99
20000	19.8	9.50	5.40	2.81	2.33	2.20	1.97	1.95	2.03
25000	25.5	13.3	7.30	3.50	2.73	2.52	2.22	2.10	2.09
30000	30.7	18.2	9.8	4.20	3.17	2.86	2.46	2.28	2.17
35000	35.5	20.35	12.2	4.95	3.62	3.25	2.69	2.45	2.25

TABLE 386. — Increase of Resistance of Nickel due to a Transverse Magnetic Field, expressed as % of Resistance at 0° and H = 0.

H	−190°	−75°	0°	+18°	+100°	+182°
0	+0	0	0	0	0	0
1000	+0.20	+0.23	+0.07	+0.07	+0.96	+0.04
2000	+0.17	+0.16	+0.03	+0.03	+0.72	−0.07
3000	0.00	−0.05	−0.34	−0.36	−0.14	−0.60
4000	−0.17	−0.15	−0.60	−0.72	−0.70	−1.15
6000	−0.19	−0.20	−0.70	−0.83	−1.02	−1.53
8000	−0.19	−0.23	−0.76	−0.90	−1.15	−1.66
10000	−0.18	−0.27	−0.82	−0.95	−1.23	−1.76
12000	−0.18	−0.30	−0.87	−1.00	−1.30	−1.85
14000	−0.18	−0.32	−0.91	−1.04	−1.37	−1.95
16000	−0.17	−0.35	−0.94	−1.09	−1.44	−2.05
18000	−0.17	−0.38	−0.98	−1.13	−1.51	−2.15
20000	−0.16	−0.41	−1.03	−1.17	−1.59	−2.25
25000	−0.14	−0.49	−1.12	−1.29	−1.76	−2.50
30000	−0.12	−0.56	−1.22	−1.40	−1.95	−2.73
35000	−0.10	−0.63	−1.32	−1.50	−2.13	−2.98

F. C. Blake, Ann. der Physik, 28, p. 449; 1909.

TABLE 387. — Change of Resistance of Various Metals in a Transverse Magnetic Field. Room Temperature.

Metal.	Field Strength in Gausses.	Per cent Increase.	Authority.
Nickel	10000	−1.2	Williams, Phil. Mag. 9, 1905.
"	"	−1.4	Barlow, Pr. Roy. Soc. 71, 1903.
"	6000	−1.0	Dagostino, Atti Ac. Linc. 17, 1908.
"	10000	−1.4	Grummach, Ann. der Phys. 22, 1906.
Cobalt	"	−0.53	"
Cadmium	"	+0.03	"
Zinc	"	+0.01	"
Copper	"	+0.004	"
Silver	"	+0.004	"
Gold	"	+0.003	"
Tin	"	+0.002	"
Palladium	"	+0.001	"
Platinum	"	+0.0005	"
Lead	"	+0.0004	"
Tantalum	"	+0.0003	"
Magnesium	6000	+0.01	Dagostino, *l. c.*
Manganin	"	+0.01	"
Tellurium	?	+0.02 to 0.34	Goldhammer, Wied Ann. 31, 1887.
Antimony	?	+0.02 to 0.16	"
Iron	Different specimens show very diverse results, usually an increase in weak fields, a decrease in strong.		Grummach, *l. c.* Barlow, *l. c.* Williams, *l. c.*
Nickel steel	Alloys behave similarly to iron.		Williams, *l. c.*

TABLE 388. — Transverse Galvanomagnetic and Thermomagnetic Effects.

Effects are considered positive when, the magnetic field being directed away from the observer, and the primary current of heat or electricity directed from left to right, the upper edge of the specimen has the higher potential or higher temperature.

E = difference of potential produced; T = difference of temperature produced; I = primary current; $\frac{dt}{dx}$ = primary temperature gradient; B = breadth, and D = thickness, of specimen; H = intensity of field. C. G. S. units.

Hall effect (Galvanomagnetic difference of Potential), $E = R\frac{HI}{D}$

Ettingshausen effect (" " " Temperature), $T = P\frac{HI}{D}$

Nernst effect (Thermomagnetic " " Potential), $E = QHB\frac{dt}{dx}$

Leduc effect (" " " Temperature), $T = SHB\frac{dt}{dx}$

Substance.	Values of R.	$P \times 10^6$.	$Q \times 10^6$.	$S \times 10^8$.
Tellurium	+400 to 800	+200	+360000	+400
Antimony	+ 0.9 " 0.22	+2	+9000 to 18000	+200
Steel	+.012 " 0.033	−0.07	−700 " 1700	+69
Heusler alloy	+.010 " 0.026	-	+1600 " 7000	
Iron	+.007 " 0.011	−0.06	−1000 " 1500	+39
Cobalt	+.0016 " 0.0046	+0.01	+1800 " 2240	+13
Zinc	-	-	−54 " 240	+13
Cadmium	+.00055			
Iridium	+.00040	-	up to −5.0	+5
Lead	+.00009	-	−5.0 (?)	
Tin	−.00003	-	−4.0 (?)	
Platinum	−.0002	-	-	−2
Copper	−.00052	-	−90 to 270	−18
German silver	−.00054			
Gold	−.00057 to .00071			
Constantine	−.0009			
Manganese	−.00093			
Palladium	−.0007 to .0012	-	+50 to 130	−3
Silver	−.0008 " .0015	-	−46 " 430	−41
Sodium	−.0023			
Magnesium	−.00094 to .0035			
Aluminum	−.00036 " .0037			
Nickel	−.0045 " .024	+0.04 to 0.19	+2000 " 9000	−45
Carbon	−.017	+5.	+100	
Bismuth	− up to 16.	+3 to 40	+ up to 132000	−200

TABLE 389. — Variation of Hall Constant with the Temperature.

Bismuth.[1]						Antimony.[2]				
H	−182°	−90°	−23°	+11.5°	+100°	H	−186°	−79°	+21.5°	+58°
1000	62.2	28.0	17.0	13.3	7.28	1750	0.263	0.249	0.217	
2000	55.0	25.0	16.0	12.7	7.17	3960	0.252	0.243	0.211	
3000	49.7	22.9	15.1	12.1	7.06	6160	0.245	02.35	0.209	0.203
4000	45.8	21.5	14.3	11.5	6.95					
5000	42.6	20.2	13.6	11.0	6.84					
6000	40.1	18.9	12.9	10.6	6.72					

Bismuth.[3]									
H	+14.5°	+104°	125°	189°	212°	239°	259°	269°	270°
890	5.28	2.57	2.12	1.42	1.24	1.11	0.97	0.83	0.77*

[1] Barlow, Ann. der Phys. 12, 1903.

[2] Everdingen, Comm. Phys. Lab. Leiden, 58.

[3] Traubenberg, Ann. der Phys. 17, 1905.

* Melting-point.

Both tables taken from Jahn, Jahrbuch der Radioactivität und Electronik, 5, p. 166; 1908, who has collected data of all observers and gives extensive bibliography.

RÖNTGEN (X-RAYS) RAYS.

Röntgen rays are produced whenever an electric discharge passes through a highly exhausted tube. The disturbance is propagated in straight lines probably with the velocity of light, affects photographic plates, excites phosphorescence, ionizes gases and suffers neither deviation by magnetic forces nor measurable refraction in passing through media of different densities. With extreme exhaustion in the tube they have an appreciable effect after passing through several millimeters of brass or iron. The quality by which it is best to classify the rays is their hardness which is the greater the greater the exhaustion. It is conveniently measured by the amount of absorption which they suffer in passing through a layer of aluminum or tin foil of standard thickness. The number of ions which the rays produce in 1 sec. in passing through 1 cu. cm. of a gas depends upon its nature and pressure. The absorption of any substance is equal to the sum of the absorption of the individual molecules and the absorption due to any molecule is independent of the nature of the chemical compound of which it forms a part, of its physical state, and probably of its temperature.

TABLE 390. — Ionization due to Röntgen Rays in Various Gases.

Gas.	Relative ionization.		Density.
	Soft rays, Strutt.	Hard rays, Eve.	
Hydrogen	.11	.42	0.069
Air	1.00	1.00	1.00
Oxygen	1.39	—	1.11
Carbon dioxide	1.60	—	1.53
Cyanogen	1.05	—	1.86
Sulphur dioxide	7.97	2.3	2.19
Chloroform	31.9	4.6	4.32
Methyl iodide	72.0	13.5	5.05
Carbon tetrachloride	45.3	4.9	5.31
Hydrogen sulphide	—	.9	1.18

Strutt, Proc. Roy. Soc. 72, p. 209, 1903; Eve, Phil. Mag. 8, p. 610, 1904.

When Röntgen rays pass through matter they produce secondary Röntgen rays as well as cathodic rays. The former are of two types: the first is like the original rays and may be regarded as scattered primary rays; the second type varies with the nature of the material struck and is independent of the primary rays. If the atomic weight of the material struck is less than that of Calcium then the first type alone is present. The higher the atomic weight of the material struck the more penetrating is the secondary radiation given out. This is shown in the following table where λ is the reciprocal of the distance (cm.) in Al. through which the rays must pass in order that their intensity is reduced to 1/2.7 of its original intensity.

TABLE 391. — Röntgen Secondary Rays.

Element.	Cr.	Fe.	Co.	Ni.	Cu.	Zn.	As.	Se.	Sr.	Ag.	Sn.
Atomic weight	52.	55.8	59.0	58.7	63.6	65.4	75.0	79.2	87.6	108.	119.
λ	367.	239.	193.	160.	129.	106.	61.	51.	35.2	6.75	4.33

The secondary cathodic rays seem to be independent of the material struck and of the intensity of the original rays. The velocity of these secondary rays depends upon the hardness of the original rays. The following table gives the thickness in cm. of the gas at 760 mm., 0° C. necessary to reduce the energy of the cathodic rays to one half (t) as well as λ as above defined.

TABLE 392. — Röntgen Secondary Cathodic Rays.

Element.	t		λ	
	Air.	Hydrogen.	Air.	Hydrogen
Fe	.0080	.041	87.2	17.0
Cu	.0135	.073	51.9	9.5
Zn	.0164	.091	42.7	7.7
As	.0255		27.4	
Sn	.176	1.37	3.97	.51

Beatty, Phil. Mag. 20, p. 320, 1910.

RÖNTGEN (X-RAYS) RAYS.

TABLE 393. — Mean Absorption Coefficients, $\frac{\lambda}{d}$.

If I_0 be the intensity of a parallel beam of homogeneous radiation incident normally on a plate of absorbing material of thickness t, then $I = I_0 e^{-\lambda x}$ gives the intensity I at the depth x. Because of the greater homogeneity of the secondary X-rays they were used in the determination of the following coefficients. The coefficients λ have been divided by the density d.

Radiator.	Absorber.										
	C.	Mg.	Al.	Fe.	Ni.	Cu.	Zn.	Ag.	Sn.	Pt.	Au.
Cr.	15.3	126.	136.	104.	129.	143.	170.	580.	714.	(517.)	(507.)
Fe.	10.1	80.	88.	66.	84.	95.	112.	381.	472.	340.	367.
Co.	8.0	64.	72.	67.	67.	75.	92.	314.	392.	281.	306.
Ni.	6.6	52.	59.	314.	56.	62.	74.	262.	328.	236.	253.
Cu.	5.2	41.	48.	268.	63.	53.	61.	214.	272.	194.	210.
Zn.	4.3	35.	39.	221.	265.	56.	50.	175.	225.	162.	178.
As.	2.5	19.	22.	134.	166.	176.	204.	105.	132.	106.	106.
Se.	2.0	16.	19.	116.	141.	150.	175.	88.	112.	93.	100.
Ag.	.4	2.2	2.5	17.	23.	24.	27.	13.	16.	56.	61.

Barkla, Sadla, Phil. Mag. 17, p. 739, 1909.

TABLE 394. — X-Ray Spectra and Atomic Numbers.

Kaye has shown that an element excited by sufficiently rapid cathode rays emits characteristic Röntgen radiations. These have been analyzed and the wave-lengths obtained by Moseley (Phil. Mag. 27, p. 703, 1914) using a crystal of potassium ferrocyanide as a grating. The "K" series of elements shows 2 lines, α and β, the "L" series several. The wave-lengths of the α and β lines of each series are given in the following table. $Q_K = (v/\frac{3}{4}\,v_0)^{\frac{1}{2}}$; $Q_L = (v/\frac{5}{36}\,v_0)^{\frac{1}{2}}$ where v is the frequency of the α line and v_0 the fundamental Rydberg frequency. The atomic number for the K series $= Q_K + 1$; for the L series $= Q_L + 7.4$ approximately. $v_0 = 3.29 \times 10^{15}$.

Element.	α line $\lambda \times 10^8$cm.	Q_K	Atomic Number N	β line $\lambda \times 10^8$cm.	Element.	α line $\lambda \times 10^8$cm.	Q_L	Atomic Number N	β line $\lambda \times 10^8$cm.
Al	8.364	12.0	13	7.912	Zr	6.091	32.8	40	
Si	7.142	13.0	14	6.729	Cb	5.749	33.8	41	5.507
Cl	4.750	16.0	17		Mo	5.423	34.8	42	5.187
K	3.759	18.0	19	3.463	Ru	4.861	36.7	44	4.660
Ca	3.368	19.0	20	3.094	Rh	4.622	37.7	45	
Ti	2.758	21.0	22	2.524	Pd	4.385	38.7	46	4.168
V	2.519	22.0	23	2.297	Ag	4.170	39.6	47	
Cr	2.301	23.0	24	2.093	Sn	3.619	42.6	50	
Mn	2.111	24.0	25	1.818	Sb	3.458	43.6	51	3.245
Fe	1.946	25.0	26	1.765	La	2.676	49.5	57	2.471
Co	1.798	26.0	27	1.629	Ce	2.567	50.6	58	2.360
Ni	1.662	27.0	28	1.506	Pr	(2.471)	51.5	59	2.265
Cu	1.549	28.0	29	1.402	Nd	2.382	52.5	60	2.175
Zn	1.445	29.0	30	1.306	Sa	2.208	54.5	62	2.008
Yt	0.838	38.1	39		Eu	2.130	55.5	63	1.925
Zr	0.794	39.1	40		Gd	2.057	56.5	64	1.853
Cb	0.750	40.2	41		Ho	1.914	58.6	66	1.711
Mo	0.721	41.2	42		Er	1.790	60.6	68	1.591
Ru	0.638	43.6	44		Ta	1.525	65.6	73	1.330
Pd	0.584	45.6	46		W	1.486	66.5	74	
Ag	0.560	46.6	47		Os	1.397	68.5	76	1.201
					Ir	1.354	69.6	77	1.155
					Pt	1.316	70.6	78	1.121
					Au	1.287	71.4	79	1.092

Moseley's summary condensed is as follows: Every element from Al to Au is characterized by an integer N which determines its X-ray spectrum; N is identified with the number of positive units of electricity in its atomic nucleus. The order of these atomic numbers (N) is that of the atomic weights except where the latter disagrees with the order of the chemical properties. Known elements correspond with all the numbers between 13 and 79 except 3. There are here 3 possible elements still undiscovered. The frequency of any line in the X-ray spectrum is approximately proportional to $A\,(N-b)^2$, where A and b are constants. All X-ray spectra of each series are similar in structure differing only in wave-lengths.

Radioactivity is a property of certain elements of high atomic weight. It is an additive property of the atom, dependent only on it and not on the chemical compound formed nor affected by physical conditions controlling ordinary reactions, viz: temperature, whether solid or liquid or gaseous, etc.

With the exception of actinium, radioactive bodies emit α, β, or γ rays. α rays are easily absorbed by thin metal foil or a few cms. of air and are positively charged atoms of helium emitted with about 1/15 the velocity of light. They are deflected but very slightly by intense electric or magnetic fields. The β rays are on the average more penetrating, are negatively charged particles projected with nearly the velocity of light, easily deflected by electric or magnetic fields and identical in type with the cathode rays of a vacuum tube. The γ rays are extremely penetrating and non-deviable, analogous in many respects to the very penetrating Röntgen rays. These rays produce ionization of gases, act on the photographic plate, excite phosphorescence, produce certain chemical reactions such as the formation of ozone or the decomposition of water. All radioactive compounds are luminous even at the temperature of liquid air.

Table 398 is based very greatly on Rutherford's Radioactive Substances and their radiations (Oct. 1912). To this and to Landolt-Börnstein Physikalisch-chemische Tabellen the reader is referred for references. In the three radioactive series each successive product (except Ur. Y, and Ra. C_2) results from the transformation of the preceding product and in turn produces the following. When the change is accompanied by the ejection of an α particle (helium, atomic weight = 4.0) the atomic weight decreases by 4. The italicized atomic weights are thus computed. Each product with its radiation decays by an exponential law; the product and its radiation consequently depend on the same law. $I = I_0 e^{-\lambda t}$ where I_0 = radioactivity when t = 0, I that at the time t, and λ the transformation constant. Radioactive equilibrium of a body with its products exists when that body is of such long period that its radiation may be considered constant and the decay and growth of its products are balanced.

International radium standard: As many radioactivity measures depend upon the purity of the radium used, in 1912 a committee appointed by the Congress of Radioactivity and Electricity, Brussels, 1910, compared a standard of 21.99 mg. of pure Ra. chloride sealed in a thin glass tube and prepared by Mme. Curie with similar standards by Hönigschmid and belonging to The Academy of Sciences of Vienna. The comparison showed an agreement of 1 in 300. Mme. Curie's standard was accepted and is preserved in the Bureau international des poids et mesures at Sèvres, near Paris. Arrangements have been made for the preparation of duplicate standards for governments requiring them.

TABLE 395.—Relative Phosphorescence Excited by Radium.

(Becquerel, C. R. 129, p. 912, 1899.)

Without screen,	Hexagonal zinc blende	13.36	With screen	.04
" "	Pt. cyanide of barium	1.99	" "	.05
" "	Diamond	1.14	" "	.01
" "	Double sulphate Ur and K	1.00	" "	.31
" "	Calcium fluoride	.30	" "	.02

The screen of black paper absorbed most of the α rays to which the phosphorescence was greatly due. For the last column the intensity without screen was taken as unity. The γ rays have very little effect.

TABLE 396.—The Production of α Particles (Helium).

(Geiger and Rutherford, Philosophical Magazine, 20, p. 691, 1910.)

Radioactive substance (1 gram.)	α particles per sec.	Helium per year.
Uranium	2.37×10^4	2.75×10^{-5} cu. mm.
Uranium in equilibrium with products	9.7×10^4	11.0×10^{-5} " "
Thorium " " " "	2.7×10^4	3.1×10^{-5} " "
Radium	3.4×10^{10}	39 " "
Radium in equilibrium with products	13.6×10^{10}	158 " "

TABLE 397.—Heating Effect of Radium and its Emanation.

(Rutherford and Robinson, Philosophical Magazine, 25, p. 312, 1913.)

	Heating effect in gram-calories per hour per gram radium.			
	α rays.	β rays.	γ rays.	Total.
Radium	25.1	-	-	25.1
Emanation	28.6	-	-	28.6
Radium A	30.5	-	-	30.5
Radium B + C	39.4	4.7	6.4	50.5
Totals	123.6	4.7	6.4	134.7

Other determinations: Hess, Wien. Ber. 121, p. 1, 1912, Radium (alone) 25.2 cal. per hour per gram. Meyer and Hess, Wien. Ber. 121, p. 603, 1912, Radium in equilibrium, 132.3 gram. cal. per hour per gram. See also, Callendar, Phys. Soc. Proceed. 23, p. 1, 1910; Schweidler and Hess, Ion. 1, p. 161, 1909; Ångström, Phys. ZS. 6, 685, 1905, etc.

TABLE 398.

RADIOACTIVITY.

P = 1/2 period = time when body is one-half transformed. λ = transformation constant (see previous page). The initial velocity of the α particle is deduced from the formula of Geiger $V^3 = aR$ where R = range and assuming the velocity for RaC of range 7.06 cm. at 20° is 2.06×10^9 cm. per sec., i.e. $v = 1.077 r^{1/3}$.

	Atomic Weights.	½ Period P	Transformation Constants. $\lambda = \frac{.6931}{P}$	Rays.	α rays.			
					Range. 760^{mm}, 15° C.	Initial Velocity.	Kinetic Energy	Whole no. of ions produced.
					c.m.	c.m. per s.	Ergs.	By an α particle.
URANIUM-RADIUM GROUP.								
Uranium 1	238.5	5×10^9 y	1.4×10^{-10} y	α	2.50	1.45×10^9	$.65 \times 10^{-5}$	1.26×10^5
Uranium 2	*234.5*	10^6 yrs	7×10^{-7} y	α	2.90	1.53 “	.72 “	1.37 “
Uranium X	*230.5*	24.6 d	.0282 d	$\beta+\gamma$				
Ur. Y	*230.5 ?*	1.5 d	.46 d	β				
Ionium	*230.5*	2×10^5 yr ?	3.5×10^{-6} y	α	3.00	1.56 “	.75 “	1.40 “
Radium	226.4	2000 y	.000346 y	$\alpha+\beta$	3.30	1.61 “	.79 “	1.50 “
Ra Emanation	*222*	3.85 d	.180 d	α	4.16	1.73 “	.92 “	1.74 “
Radium A	*218*	3.0 m	.231 m	α	4.75	1.82 “	1.01 “	1.88 “
Radium B	*214*	26.8 m	.0258 m	$\beta+\gamma$				
Radium C	*214*	19.5 m	.0355 m	$\alpha+\beta+\gamma$	6.94	2.06 “	1.31 “	2.37 “
Ra C_2	*210?*	1.4 m	.495 m	β				
Ra O, radio-lead	*210*	16.5 y	.042 y	slow β				
Ra E.	*210*	5.0 d	.139 d	$\beta+\gamma$				
Ra F. Polonium	*210*	136 d	.00510 d	α	3.77	1.68 “	.87 “	1.63 “
ACTINIUM GROUP.								
Actinium	*A*	?	-	none				
Radio-Act.	*A*	19.5 d	.0355 d	$\alpha+\beta$	4.80	1.83×10^9	1.02×10^{-5}	1.89×10^5
Actinium X	*A—4*	10.2 d	.068 d	α	4.40	1.76 “	.94 “	1.79 “
Act. Emanation	*A—8*	3.9 s	.178 s	α	5.70	1.94 “	1.15 “	2.10 “
Actinium A	*A—12*	.002 s	350 s	α	6.50	2.02 “	1.25 “	2.27 “
Actinium B	*A—16*	36 m	.0193 m	slow β				
Actinium C	*A—16*	2.1 m	.33 m	α	5.40	1.89 “	1.10 “	2.02 “
Actinium D	*A—20*	4.7 m	.147 m	$\beta+\gamma$				
THORIUM GROUP.								
Thorium	232	1.3×10^{10} y	5.3×10^{-11}	α	2.72	1.50×10^9	$.69 \times 10^{-5}$	1.32×10^5
Mesothorium 1	*228*	5.5 y	.126 yr	none				
Mesothorium 2	*228*	6.2 hr	.112 h	$\beta+\gamma$				
Radiothorium	*228*	2 yrs	.347 y	α	3.87	1.70 “	.89 “	1.66 “
Thorium X	*224*	3.65 d	.190 d	$\alpha+\beta$	5.7	1.94 “	1.15 “	2.1 “
Th. Emanation	*220*	54 sec	.0128 s	α	5.5	1.90 “	1.10 “	2.0 “
Thorium A	*216*	0.14 sec	4.95 s	α	5.9	1.97 “	1.19 “	2.2
Thorium B	*212*	10.6 h	.0654 h	$\beta+\gamma$				
Thorium C_1	*212*	60 m	.0118 m	$\alpha+\beta$	5.0	1.85 “	1.05 “	1.9 “
Thorium C_2	*212*	very short	-	α	8.6	2.22 “	1.53 “	2.9 “
Th. D	*208*	3.1 m	.224 m	$\beta+\gamma$				
Potassium	39.1	?	?	β				
Rubidium	85.5	?	?	β				

μ = coefficient of absorption for β rays in terms of cms. of aluminum, μ_1, of the γ rays in cms. of lead so that if J_0 is the incident intensity, J that after passage through d cms., $J = J_0 e^{-d\mu}$.

	β rays.		γ rays.	Remarks.
	Absorption Coefficient $= \mu$	Velocity Light = 1	Absorption Co-ef. $= \mu_1$	
	c.m.$^{-1}$		c.m.$^{-1}$	
URANIUM-RADIUM GROUP.				
Ur 1	—	—	—	1 gram U emits 2.37×10^4 α particles per sec.
Ur 2	—	—	—	Not separable from Ur 1.
Ur X	15, 510	Wide range	.72	β rays show no groups of definite velocities. Chemically allied to Th.
Ur Y	—	—	—	Probably branch product. Exists in small quantity.
Io	—	—	—	Chemically properties of and non-separable from Thorium.
Ra	312	.52, .65	—	Chemically properties of Ba. 1 gr. emits per sec. in equilib. 13.6×10^{10} α particles.
Ra Em	—	—	—	Inert gas, density 111 H, boils —65° C, density solid 5–6, condenses low pressure —150° C.
Ra A	—	—	—	Like solid, has + charge, volatile in H, 400°, in O about 550°.
Ra B	13, 80, 890	.36 to .74	4 to 6	Volatile about 400° C. in H. Separated pure by recoil from Ra A.
Ra C	13, 53	.80 to .98	.50	Volatile in H about 430°, in O about 1000°.
Ra C_2	13	—	—	Probably branch product. Separated by recoil from Ra C.
Ra D	.33, .39	.33, .39	—	Separated with Pb. not yet separable from it. Volatile below 1000°.
Ra E	43	Wide range	Easy abs.	
Ra F	—	—	—	Separated with Bi. Probably changes to Pb. Volatile about 1000°.
ACTINIUM GROUP.				
Act	—	—	—	Probably branch product Ur. series. Chemically allied to Lanthanum.
Rad. Act	140	—	—	
Act X	—	—	—	Chemical properties analogous to Ra.
Ac. Em.	—	—	—	Inert gas, condenses between —120° and —150°.
Act A	—	—	—	Analogous to Ra A. Volatile above 400°.
Act B	Very soft	—	—	" " Ra B. " " 700°.
Act C	—	—	—	" " Ra C.
Act D	28.5	—	.217 (Al)	(Obtained by recoil).
THORIUM GROUP.				
Th.	—	—	—	Volatile in electric arc. Colorless salts not spontaneously phosphorescent.
Mes. Th. 1	—	.37 to .66	—	Chemical property analogous to Ra from which non-separable.
Mes. Th. 2	20 to 38.5	—	.53	
Rad. Th.	—	—	—	Chemically allied to Th., non-separable from it.
Th. X	About 330	.47 .51	—	Chemically analogous to Ra.
Th. Em.	—	—	—	Inert gas, condenses at low pressure between —120° and —150°.
Th. A	—	—	—	+charged, collected on — electrode.
Th. B	110.	.63 .72	—	Chemically analogous to Ra B. Volatile above 630° C.
Th. C_1	15.6	—	Weak	Chemically analogous to Ra C. Volatile above 730°.
Th. C_2	—	—	—	Th.C_2 and Th.D are probably respectively β and α ray products from Th.C_1.
Th. D	24.8	.3, .4, .93–5	.46	Got by recoil from Th.C. Probably transforms to Bi.
K	38, 102	—	—	Activity = 1/1000 of Ur.
Rb.	380, 1020	—	—	„ = 1/500 of Ur.

RADIOACTIVITY.

TABLE 399.—Stopping Powers of Various Substances for α Rays.

s, the stopping power of a substance for the α rays is approximately proportional to the square root of the atomic weight, w.

Substance	H_2	Air	O_2	C_2H_2	C_2H_4	Al	N_2O	CO_2	CH_3Br	CS_2	Fe
s	.24	1.0	1.05	1.11	1.35	1.45	1.46	1.47	2.09	2.18	2.26
$\sqrt{w}$ . . .	.26	1.0	1.05	1.17	1.44	1.37	1.52	1.51	2.03	1.95	1.97
Substance	**Cu**	**Ni**	**Ag**	**Sn**	**C_6H_6**	**C_5H_{12}**	**C_2H_5I**	**CCl_4**	**Pt**	**Au**	**Pb**
s	2.43	2.46	3.17	3.37	3.37	3.59	3.13	4.02	4.16	4.45	4.27
$\sqrt{w}$ . . .	2.10	2.20	2.74	2.88	3.53	3.86	3.06	3.59	3.68	3.70	3.78

Bragg, Philosophical Magazine, 11, p. 617, 1906.

TABLE 400.—Absorption of β Rays by Various Substances.

μ, the coefficient of absorption for β rays is approximately proportional to the density, D. See Table 398 for μ for Al.

Substance . .	B	C	Na	Mg	Al	Si	P	S	K	Ca
μ/D	4.65	4.4	4.95	5.1	5.26	5.5	6.1	6.6	6.53	6.47
Atomic Wt. .	11	12	23	24.4	27	28	31	32	39	40
Substance . .	**Ti**	**Cr**	**Fe**	**Co**	**Cu**	**Zn**	**Ar**	**Se**	**Sr**	**Zr**
μ/D	6.2	6.25	6.4	6.48	6.8	6.95	8.2	8.65	8.5	8.3
Atomic Wt. .	48	52	56	59	63.3	65.5	75	79	87.5	90.7
Substance . .	**Pd**	**Ag**	**Sn**	**Sb**	**I**	**Ba**	**Pt**	**Au**	**Pb**	**U**
μ/D	8.0	8.3	9.46	9.8	10.8	8.8	9.4	9.5	10.8	10.1
Atomic Wt. .	106	108	118	120	126	137	195	197	207	240

For the above data the β rays from Uranium were used.

Crowther, Philosophical Magazine, 12, p. 379, 1906.

TABLE 401.—Absorption of γ Rays by Various Substances.

Substance.	Density.	Radium rays.		Uranium rays.		Th. D. $\mu(cm)^{-1}$	Meso. Th2 $\mu(cm)^{-1}$	Range of thickness cm.
		$\mu\ (cm)^{-1}$	100μ/D	$\mu(cm)^{-1}$	100μ/D			
Hg . .	13.59	.642	4.72	.832	6.12			.3 to 3.5
Pb . .	11.40	.495	4.34	.725	6.36	.462	.620	.0 " 7.9
Cu . .	8.81	.351	3.98	.416	4.72	.294	.373	.0 " 7.6
Brass .	8.35	.325	3.89	.392	4.70	.271	.355	.0 " 5.86
Fe . .	7.62	.304	3.99	.360	4.72	.250	.316	.0 " 7.6
Sn . .	7.24	.281	3.88	.341	4.70	.236	.305	.0 " 5.5
Zn . .	7.07	.228	3.93	.329	4.65	.233	.300	.0 " 6.0
Slate. .	2.85	.118	4.14	.134	4.69	.096	–	.0 " 9.4
Al . .	2.77	.111	4.06	.130	4.69	.092	.119	.0 " 11.2
Glass .	2.52	.105	4.16	.122	4.84	.089	.113	.0 " 11.3
S . . .	1.79	.078	4.38	.092	5.16	.066	.083	.0 " 11.6
Paraffin .	.86	.042	4.64	.043	5.02	.031	.050	.0 " 11.4

In determining the above values the rays were first passed through one cm. of lead.

Russell and Soddy, Philosophical Magazine, 21, p. 130, 1911.

RADIOACTIVITY.

TABLE 402. — Total Number of Ions produced by the α, β, and γ Rays.

The total number of ions per second due to the complete absorption in air of the β rays due to 1 gram of radium is 9×10^{14}, to the γ rays, 13×10^{14}.

The total number of ions due to the α rays from 1 gram of radium in equilibrium is 2.56×10^{16}. If it be assumed that the ionization is proportional to the energy of the radiation, then the total energy emitted by radium in equilibrium is divided as follows: 92.1 parts to the α, 3.2 to the β, 47 to the γ rays. (Rutherford, Moseley, Robinson.)

TABLE 403. — Amount of Radium Emanation. Curie.

At the Radiology Congress in Brussels in 1910. it was decided to call the amount of emanation in equilibrium with 1 gram of pure radium one Curie. [More convenient units are the millicurie (10^{-3}Curie) and the microcurie (10^{-6}Curie)]. The rate of production of this emanation is 1.24×10^{-9} cu. cm. per second. The volume in equilibrium is 0.59 cu. mm. (760 cm., 0°C.) assuming the emanation mon-atomic.

The Mache unit is the quantity of Radium emanation without disintegration products which produces a saturation current of 10^{-3} unit in a chamber of large dimensions. 1 curie $= 2.5 \times 10^{9}$ Mache units.

The amount of the radium emanation in the air varies from place to place; the amount per cubic centimeter of air expressed in terms of the number of grams of radium with which it would be in equilibrium varies from 24×10^{-12} to 350×10^{-12}.

TABLE 404. — Vapor Pressure of the Radium Emanation in cms. of Mercury.

(Rutherford and Ramsay, Phil. Mag. 17, p. 723, 1909, Gray and Ramsay, Trans. Chem. Soc. 95, p. 1073, 1909.)

Temperature C°.	−127°	−101°	−65°	−56°	−10°	+17°	+49°	+73°	+100°	+104° (crit)
Vapor Pressure.	0.9	5	76	100	500	1000	2000	3000	4500	4745

TABLE 405. — References to Spectra of Radioactive Substances.

Radium spectrum:	Demarçay, C. R. 131, p. 258, 1900.
Radium emanation spectrum:	Rutherford and Royds, Phil. Mag. 16, p. 313, 1908; Watson, Proc. Roy. Soc. A 83, p. 50, 1909.
Polonium spectrum:	Curie and Debierne, Rad. 7, p. 38, 1910, C. R. 150, p. 386, 1910.

TABLE 406.

MISCELLANEOUS CONSTANTS (ATOMIC, MOLECULAR, ETC.).

Elementary electrical charge, charge on electron, 1/2 charge on α particle,	$e = 4.774 \times 10^{-10}$ e. s. u. (M) $= 1.519 \times 10^{-20}$ e. m. u. $= 1.591 \times 10^{-19}$ coulombs	
Mass of an electron,	$m =$ about 6×10^{-28} grams.	
Radius of an electron,	$l =$ about 1×10^{-13} cm.	
Number of molecules per gram molecule,	$N = 6.06 \times 10^{23}$ gr^{-1} (M)	
Number of gas molecules per cc., 760^{mm}, 0°C,	$n = 2.70 \times 10^{19}$ (M)	
Kinetic energy of a molecule at 0°C,	$E_0 = 5.62 \times 10^{-14}$ ergs. (M)	
Constant of molecular energy, E_0/T,	$\epsilon = 2.06 \times 10^{-16}$ ergs/degrees	(M)
Constant of entropy equation (Boltzmann), $= R/N = p_0V_0/TN = (2/3)\,\epsilon$,	$k = 1.37 \times 10^{-16}$ " "	(M)
Elementary "Wirkungsquantum,"	$h = 6.62 \times 10^{-27}$ erg. sec.	(M)
Mass of hydrogen atom,	$= 1.64 \times 10^{-24}$ gram.	
Radius of an atom,	$=$ about 10^{-8} cm.	
Gas constant, $R = 22.412/273.1$ for 1 gram molecule of an ideal gas. Pressure in atmospheres, $g = 980.6$, vol. in liters,	$R = .08207$ liter. Atm/grm.	

	H_2	He	N_2	O_2	Xe	CO_2	H_2O
Sq. rt. of mean sq. molec. veloc., cm./sec. at 0°C. $\times 10^{-4}$	18.4	13.1	4.93	4.61	2.28	3.92	7.08
Mean free path cm. $\times 10^6$	18.	28.	9.4	9.9	5.6	6.4	7.2
Molecular diameter cm. $\times 10^8$	2.2	2.2	3.3	3.0	3.4	4.2	3.8

(M) Millikan, Phys. Rev. 2, p. 109, 1913. The other values are mostly means.

TABLE 407.

PERIODIC SYSTEM OF THE ELEMENTS.

O	I	II	III	IV	V	VI	VII	
-	R_2O	RO	R_2O_3	RO_2	R_2O_5	RO_3	R_2O_7	RO_4 ☞ Oxides
-	-	-	-	RH_4	RH_3	RH_2	RH	- ☞ Hydrides
He 4	Li 7	Gl 9	B 11	C 12	N 14	O 16	F 19	- -
Ne 20	Na 23	Mg 24	Al 27	Si 28	P 31	S 32	Cl 35	- -
A 40	K 39	Ca 40	Sc 44	Ti 48	V 51	Cr 52	Mn 55	Fe Ni Co 56 59 59
- -	Cu 64	Zn 65	Ga 70	Ge 72	As 75	Se 79	Br 80	- -
Kr 82	Rb 85	Sr 88	Yt 89	Zr 91	Cb 94	Mo 96	- -	Ru Rh Pd 102 103 107
- -	Ag 108	Cd 112	In 115	Sn 119	Sb 120	Te 128	I 127	- -
X 128	Cs 133	Ba 137	La 139	Ce 140	- -	- -	- -	- -
- -	- -	- -	- -	- -	- -	- -	- -	- -
- -	- -	- -	Yb 173	- -	Ta 181	W 184	- -	Os Ir Pt 191 193 195
- -	Au 197	Hg 201	Tl 204	Pb 207	Bi 208	- -	- -	- -
- -	- -	Ra 226	- -	Th 232	- -	U 238	- -	- -

APPENDIX.

DEFINITIONS OF UNITS.

ACTIVITY. Power or rate of doing work; unit, the watt.

AMPERE. Unit of electrical current. The international ampere, "which is one tenth of the unit of current of the C. G. S. system of electro-magnetic units, and which is represented sufficiently well for practical use by the unvarying current which, when passed through a solution of nitrate of silver in water, and in accordance with accompanying specifications" (*see* pages xxxvi, 261), "deposits silver at the rate of 0.001118 of a gram per second."

The ampere = 1 coulomb per second = 1 volt through 1 ohm = 10^{-1} E. M. U. = 3×10^{9} E. S. U.*

Amperes = volts/ohms = watts/volts = $(\text{watts}/\text{ohms})^{\frac{1}{2}}$.

Amperes × volts = amperes^{2} × ohms = watts.

ANGSTROM. Unit of wave-length = 10^{-10} meter.

ATMOSPHERE. Unit of pressure.

English normal = 14.7 pounds per sq. in = 29.929 in. = 760.18 mm. Hg. 32° F.

French " = 760 mm. of Hg. 0° C. = 29.922 in. = 14.70 lbs. per sq. in.

BOUGIE DECIMALE. Photometric standard; *see* page 178.

BRITISH THERMAL UNIT. Heat required to raise one pound of water at its temperature of maximum density, 1° F. = 252 gram-calories.

CALORY. Small calory = gram-calory = therm = quantity of heat required to raise one gram of water at its maximum density, one degree Centigrade.

Large calory = kilogram-calory = 1000 small calories = one kilogram of water raised one degree Centigrade at the temperature of maximum density.

For conversion factors *see* page 237.

CANDLE. Photometric standard, *see* page 178.

CARAT. The diamond carat standard in U. S. = 200 milligrams. Old standard = 205.3 milligrams = 3.168 grains.

The gold carat: pure gold is 24 carats; a carat is 1/24 part.

CARCEL. Photometric standard; *see* page 178.

CIRCULAR AREA. The square of the diameter = 1.2733 × true area.

True area = 0.785398 × circular area.

COULOMB. Unit of quantity. The international coulomb is the quantity of electricity transferred by a current of one international ampere in one second. = 10^{-1} E. M. U. = 3×10^{9} E. S. U.

Coulombs = (volts-seconds)/ohms = amperes × seconds.

CUBIT = 18 inches.

DAY. Mean solar day. = 1440 minutes = 86400 seconds = 1.0027379 sidereal day.

Sidereal day = 86164.10 mean solar seconds.

DIGIT. 3/4 inch; 1/12 the apparent diameter of the sun or moon.

DIOPTER. Unit of "power" of a lens. The number of diopters = the reciprocal of the focal length in meters.

DYNE. C. G. S. unit of force = that force which acting for one second on one gram produces a velocity of one centimeter per second.

= weight in grams divided by the acceleration of gravity in cm. per sec.

ELECTROCHEMICAL EQUIVALENT is the ratio of the mass in grams deposited in an electrolytic cell by an electrical current to the quantity of electricity.

ENERGY. *See* Erg.

ERG. C. G. S. unit of work and energy = one dyne acting through one centimeter.

For conversion factors *see* page 237.

FARAD. Unit of electrical capacity. The international farad is the capacity of a condenser charged to a potential of one international volt by one international coulomb of electricity. = 10^{-9} E. M. U. = 9×10^{11} E. S. U.

The one-millionth part of a farad (microfarad) is more commonly used.

Farads = coulombs/volts.

---

* E. M. U. = C. G. S. electromagnetic units. E. S. U. = C. G. S. electrostatic units.

FOOT-POUND. The work which will raise one pound one foot high.

For conversion factors *see* page 237.

FOOT-POUNDALS. The English unit of work = foot-pounds/g.

For conversion factors *see* page 237.

g. The acceleration produced by gravity.

GAUSS. A unit of intensity of magnetic field = 1 E. M. U. = $\frac{1}{3} \times 10^{-10}$ E. S. U.

GRAM. *See* page 6.

GRAM-CENTIMETER. The gravitation unit of work = g. ergs.

GRAM-MOLECULE, $= x$ grams where x = molecular weight of substance.

GRAVITATION CONSTANT = G in formula $G \frac{m_1 m_2}{r_2} = 666.07 \times 10^{-10}$ cm.^{3}/gr. sec.^{2}

For further conversion factors *see* page 237.

HEAT OF THE ELECTRIC CURRENT generated in a metallic circuit without self-induction is proportional to the quantity of electricity which has passed in coulombs multiplied by the fall of potential in volts, or is equal to (coulombs × volts)/4.181 in small calories.

The heat in small or gram-calories per second = (amperes^2 × ohms)/4.181 = volts^2/(ohms × 4.181) = (volts × amperes)/4.181 = watts/4.181.

HEAT. Absolute zero of heat = −273.13° C, −459.6° Fahrenheit, −218.5° Reaumur.

HEFNER UNIT. Photometric standard; *see* page 178.

HENRY. Unit of induction. It is "the induction in a circuit when the electromotive force induced in this circuit is one international volt, while the inducing current varies at the rate of one ampere per second." = 10^9 E. M. U. = $\frac{1}{9} \times 10^{-11}$ E. S. U.

HORSE-POWER. The practical unit of power = 33,000 pounds raised one foot per minute. = 550ft. pds. per sec. = 0. 746 kilowatt = 746 watts.

JOULE. Unit of work = 10^7 ergs.

Joules = (volts^2 × seconds)/ohms = watts × seconds = amperes^2 × ohms × sec.

For conversion factors *see* page 237.

JOULE'S EQUIVALENT. The mechanical equivalent of heat = 4.185×10^7 ergs. *See* page 227.

KILODYNE. 1000 dynes. About 1 gram.

LITER. *See* page 6.

LUMEN. Unit of flux of light-candles divided by solid angles.

MEGABAR. Unit of pressure = 0.987 atmospheres.

MEGADYNE. One million dynes. About one kilogram.

METER. *See* page 6.

METER CANDLE. The intensity lumination due to standard candle distant one meter.

MHO. The unit of electrical conductivity. It is the reciprocal of the ohm.

MICRO. A prefix indicating the millionth part.

MICROFARAD. One millionth of a farad, the ordinary measure of electrostatic capacity.

MICRON. (μ) = one millionth of a meter.

MIL. One thousandth of an inch.

MILE. *See* pages 5, 6.

MILE, NAUTICAL or GEOGRAPHICAL = 6080.204 feet.

MILLI-. A prefix denoting the thousandth part.

MONTH. The anomalistic month = time of revolution of the moon from one perigee to another = 27.55460 days.

The nodical month = draconitic month = time of revolution from a node to the same node again = 27.21222 days.

The sidereal month = the time of revolution referred to the stars = 27.32166 days (mean value), but varies by about three hours on account of the eccentricity of the orbit and "perturbations."

The synodic month = the revolution from one new moon to another = 29.5306 days (mean value) = the ordinary month. It varies by about 13 hours.

OHM. Unit of electrical resistance. The international ohm is based upon the ohm equal to 10^9 units of resistance of the C. G. S. system of electromagnetic units, and "is represented by the resistance offered to an unvarying electric current by a column of mercury, at the temperature of melting ice, 14.4521 grams in mass, of a constant cross section and of the length of 106.3 centimeters." = 10^3 E. M. U. = $\frac{1}{9} \times 10^{-11}$ E. S. U.

International ohm = 1.01367 B. A. ohms = 1.06292 Siemens' ohms.

B. A. ohm = 0.98651 international ohms.

Siemens' ohm = 0.94080 international ohms. *See* page 272.

PENTANE CANDLE. Photometric standard. *See* page 178.

PI = π = ratio of the circumference of a circle to the diameter = 3.14159265359.

POUNDAL. The British unit of force. The force which will in one second impart a velocity of one foot per second to a mass of one pound.

RADIAN = $180°/\pi = 57.29578° = 57° 17' 45'' = 206625''$.

SECOHM. A unit of self-induction = 1 second × 1 ohm.

THERM = small calory = quantity of heat required to warm one gram of water at its temperature of maximum density one degree Centigrade.

THERMAL UNIT, BRITISH = the quantity of heat required to warm one pound of water at its temperature of maximum density one degree Fahrenheit = 252 gram-calories.

VOLT. The unit of electromotive force (E. M. F.). The international volt is "the electromotive force that, steadily applied to a conductor whose resistance is one international ohm, will produce a current of one international ampere, and which is represented sufficiently well for practical use by 1000/1434 of the electromotive force between the poles or electrodes of the voltaic cell known as Clark's cell, at a temperature of 15° C and prepared in the manner described in the accompanying specification." $= 10^8$ E. M. U. = 1/300 E. S. U. *See* pages xxxiv and 261.

VOLT-AMPERE. Equivalent to Watt/Power factor.

WATT. The unit of electrical power = 10^7 units of power in the C. G. S. system. It is represented sufficiently well for practical use by the work done at the rate of one Joule per second.

Watts = volts × amperes = $\text{amperes}^2 \times \text{ohms} = \text{volts}^2/\text{ohms}$ (direct current or alternating current with no phase difference).

For conversion factors *see* page 237.

Watts × seconds = Joules.

WEBER. A name formerly given to the coulomb.

YEAR. *See* page 109.

Anomalistic year = 365 days, 6 hours, 13 minutes, 48 seconds.
Sidereal " = 365 " 6 " 9 " 9.314 seconds.
Ordinary " = 365 " 5 " 48 " 46 + "
Tropical " same as the ordinary year.

INDEX.

For the definition of units, see Appendix.

The Riverside Press
CAMBRIDGE · MASSACHUSETTS
U · S · A

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 63, NUMBER 7

NEW SUBSPECIES OF MAMMALS FROM EQUATORIAL AFRICA

BY

EDMUND HELLER
Naturalist, Smithsonian African Expedition

(Publication 2272)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
JUNE 24, 1914

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

NEW SUBSPECIES OF MAMMALS FROM EQUATORIAL AFRICA

By EDMUND HELLER

NATURALIST, SMITHSONIAN AFRICAN EXPEDITION

Further study of the collection of mammals from British East Africa and Uganda now in the United States National Museum, secured by the Smithsonian African Expedition under the direction of Colonel Roosevelt and the Paul J. Rainey African Expedition, has brought to light the several new forms of carnivores and rodents described in the present paper.

THOS

Jackals and Coyotes

The jackals and their American representatives the coyotes are separable from the true wolves, which are typical of the genus *Canis*, by several constant dental characters which seem to justify the recognition of the group under the generic name *Thos* first proposed by Oken in 1816 for the Indian jackal, *Canis aureus*. Oken placed four specific names under his group name *Thos*, the last of which, *Canis vulgaris*, he particularly mentions as being the *Thos* of the ancients and on this account it should stand as the type of the genus. *Canis vulgaris* is a synonym of *C. aureus*. *Thos* may be defined as a group of *Canidae* having long slender *Vulpes*-like canines, small outer incisors, small carnassials, upper molar teeth with well marked cingulums and the fourth lower premolar with a minute extra cusp on its hinder border. The genus *Canis* or the wolves are distinguishable by their much thicker and shorter canines; their greatly enlarged outer incisors which are more than twice the size of the inner ones, being somewhat hyena-like in this respect; large carnassial teeth; upper molars without a definite cingulum; and the fourth lower pre-molar without a third cusp on its posterior border.

East equatorial Africa or rather Northeast Africa generally is supplied with more species of jackals than any other region. Three distinct species are found living together on the same plains over most of the territory of British East Africa. The most distinct of the three species in coloration is the black-backed or *T. mesomelas* which has the black of the back sharply marked off from the bright rufous of the sides. The Indian species, *T. aureus*, which here reaches its southern limit in Africa, approaches *mesomelas* closely in shape of skull and the large size of its reddish ears but differs by the broken character of its black dorsal area which merges indefinitely into the color of the sides. The best marked species of the three in skull characters is the side-striped jackal or *T. adustus* which has a long slender snout and very long *Vulpes*-like canine teeth. In body coloration, however, it is not always easily distinguishable from the Indian but it may be recognized with certainty by its small dark colored ears and the presence of a more or less well marked white tail tip. An excellent series consisting of 68 specimens of skins with their skulls are in the National Museum from British East Africa representing the three species referred to above. A comparison of this material shows several well marked forms occupying definite geographical or faunal areas. The races of African jackals thus far described have come from South Africa or from Abyssinia and the Sudan and none of the names thus far proposed seem to be applicable in a restricted sense to the East African races which are described in the following pages.

KEY TO THE RACES AND SPECIES OF JACKALS OCCURRING IN BRITISH EAST AFRICA

A¹ Black of back not sharply defined against light color of sides; foreleg marked by a black stripe in front; chin dark brown or blackish in marked contrast to the light color of the throat.

  B¹ Sides marked by a more or less definite black stripe owing to the middle area of the back being vermiculated by whitish; back of ears dark brown; tip of tail usually showing some white hairs; snout long, the nasals bones extending as far posteriorly as the maxillaries or beyond; bony palate extending as far posteriorly as the posterior edge of the last molar.......................*Thos adustus*

    C¹ Underparts ochraceous-rufous, the hair basally dark gray; tail with a few white hairs at tip or none..........*T. adustus bweha*

    C² Underparts white or pale buff, the hair uniform to the roots; tail broadly tipped by white ....*T. adustus notatus*

  B² Sides merging gradually into the dark color of the back; backs of the ears ochraceous; tail black tipped; snout short, the nasal bones not extending as far posteriorly as the maxillaries; bony palate not reaching as far posteriorly as last molar......*T. aureus*

    C¹ Coloration lighter and body size less than in the northern races ....*T. aureus bea*

A² Black of back sharply defined against light color of sides and uniform throughout; foreleg not marked by a black stripe; chin whitish and uniform with the throat in color; tail tip black; snout short, the nasal bones not extending posteriorly to the maxillaries; palate not reaching to end of tooth row ....*T. mesomelas*

B¹ Size larger; underparts ochraceous with dark hair bases *T. mesomelas elgonae*
B² Size smaller; underparts white or light buff; the hair uniform to the roots .... *T. mesomelas mcmillani*

THOS ADUSTUS BWEHA, new subspecies

Elgon Side-striped Jackal

Type from Kisumu, British East Africa; adult male, number 182342, U. S. Nat. Mus.; collected by Edmund Heller, January 20, 1912; original number 2663.

Characters.—The Elgon side-striped jackal, *Thos adustus bweha*, resembles most closely the Abyssinian race *kaffensis* described by Neumann from the headwaters of the Sobat River in southwestern Abyssinia. It may be distinguished from that race by the much darker color of the legs and the reddish character of the dorsal hair basally. From *notatus* it differs by the darker underparts which are washed with ochraceous-rufous, and are dark haired basally throughout. The legs are a deep russet heavily black lined on their upper parts, the hind quarters being especially deep and rich in coloring. The back is heavily black-lined and merges into the black of the sides so that the side-striped effect is quite obscured or absent entirely. The tail is not conspicuously white-tipped as in *notatus*, this feature being reduced to a few scattered white hairs hidden among the black hairs of the tip. The tail is shorter and the foot averages smaller than that of *notatus*. The flesh measurements of the type were: head and body, 720 mm.; tail, 310; hindfoot, 148; ear from notch, 90. Skull: condylo-incisive length, 152; greatest length, 160; zygomatic width, 82; interorbital width, 27; postorbital width, 30; nasals 13.4 × 58; length of upper cheek to front of canine, 68; width of mesopterygoid fossa, 14.5; length of palate, 80; length of incisive foramina, 10. The skull shows considerable age, the sagittal crest being a high knife-like ridge and the basisphenoidal sutures obliterated. This specimen is unfortunately somewhat abnormal having two pairs of upper carnassial teeth, the smaller pair being inside the larger.

The collection contains three additional adult males from the type locality and two from the Uasin Gishu Plateau. The latter are more heavily lined with black than those from the Kavirondo country, but otherwise are quite indistinguishable from them. Two skins and four skulls are in the National Museum from Mashonaland, which represent the Zambesi race *holubi*. These are distinguishable from *bwcha* by their rufous-backed ears and their larger skulls and body size generally.

The Swahili name for the jackal and the one commonly adopted by the interior tribes now in touch with European civilization is *bwcha.* Distinctive names for the three species occurring together throughout the country do not appear to be in use among any of the tribes.

THOS ADUSTUS NOTATUS, new subspecies

Loita Side-striped Jackal

Type from the Loita Plains, British East Africa; young adult male, number 181486, U. S. Nat. Mus.; collected by Edmund Heller, April 16, 1911; original number 2033.

Characters.—*Thos adustus notatus* may be distinguished from all other races by its white underparts, the whole throat, chest and belly being white, the hair of the throat and chest being white to the roots but dark gray basally on the belly. From typical *adustus* of South Africa it may be further distinguished by its smaller size, the skull being decidedly smaller, by its drab instead of russet ears and the brighter rufous of the dorsal hair basally. It resembles *adustus* in the light color of its legs which are ochraceous-buff, the foreleg having a black stripe from the shoulder to the knee. The tail is conspicuously tipped by pure white as in *adustus.* It differs from *bwcha* of the Kavirondo and Uasin Gishu region by its light underparts, light colored legs, white tipped tail and distinctiveness of the black side stripe. The tail is considerably longer than in *bwcha* but the general body size is the same.

The flesh measurements of the type were: head and body, 715 mm.; tail, 390; hindfoot, 165; ear from notch, 80. Skull: condylo-incisive length, 152; greatest length, 157; zygomatic breadth, 80; interorbital width, 26.5; postorbital width, 30.5; nasals, 14 × 58; length of upper cheek teeth to outer edge of canine, 70; length of upper carnasial, 13.9; width of mesopterygoid fossa, 14.8; length of palate, 79. Skull somewhat immature with distinct sutures and lacking a sagittal crest.

Besides the type there is in the National Museum another adult male from the Loita Plains which resembles the type closely in color and an immature female from the same locality which shows a fulvous wash on the underparts, which may be a sexual color difference rather than individual in character. The type has been compared with two adult male specimens from south of the Zambesi River representing typical *adustus.*

THOS AUREUS BEA, new subspecies

Southern Golden Jackal

Type from the Loita Plains, British East Africa; adult female, number 162904, U. S. Nat. Mus.; collected by Edmund Heller, July 4, 1909; original number, 200.

Characters.—Thos aureus bea may be distinguished from the more northern African races by its much smaller body size and lighter coloration generally, the ears and legs being of a decidedly lighter fulvous shade. Compared to *variegatus,* the Abyssinia race, the size is much less, the difference in skull length being 25 millimeters less. Typical *aureus* of India differs only racially from these North Africa jackals which have usually been treated as a race of *anthus* originally described from Senegal. In skull characters and coloration the African resembles the Indian and Asiatic races of *aureus* so closely that their relationship is better shown by placing them under the Indian jackal as subspecific forms. The present form is the most southern race and the only one to extend south of the equator. It doubtless reaches its extreme southern limit in central German East Africa but no specimens have yet been reported from that region. In a general way this jackal coincides, in its geographical range, with the striped hyena throughout Africa and Asia.

The type is an adult female in fresh pelage, the back being heavily lined or overlaid by black from the nape to the tip of the tail which is wholly black and has the hair everywhere basally vinaceous.. The underparts are whitish or pale buff, the hair being uniform to the roots. The backs of the ears and the legs are bright ochraceous, the forelegs having a black stripe in front over the knee similar to the black stripe on *adustus.* Worn specimens often have the median area of the back lacking the black hair tips but the sides still retaining them, which produces a side-striped effect quite similar to the side-striped effect of *adustus.* Young and immature specimens lack the black lining of the back and are consequently much lighter colored than the adults.

The flesh measurements of the type were: head and body, 640 mm.; tail, 275; hindfoot, 140; ear from notch, 99. Skull: condylo-incisive length, 140; greatest length, 150; zygomatic breadth, 77; interorbital breadth, 23.5; postorbital constriction, 26; nasals, 13.2 × 53; length of upper cheek teeth including canine, 65; length of upper carnassial, 15.5; length of palate, 71; width of mesopterygoid fossa, 14; length of incisive foramina, 11.

Five specimens are in the National Museum from the plains north of Mount Kenia which mark the eastern limits of the Laikipia Plateau. Two additional specimens from the Loita Plains, one from the Rift Valley near Mount Suswa and another from Lake Naivasha complete the series.

THOS MESOMELAS ELGONAE, new subspecies

Highland Black-backed Jackal

Type from the Uasin Gishu Plateau, British East Africa, altitude 8,000 feet; adult male, number 164699, U. S. Nat. Mus.; collected by Edmund Heller, November 13, 1909; original number, 466.

Characters.—Thos mesomelas elgonae resembles most closely the Athi or coast race *mcmillani* but may be distinguished from it by its darker coloration, larger size and heavier coat. The underparts are darker than those of the desert race, being ochraceous-buff, the hair basally being quite grayish and the sides are duller ochraceous-rufous. The tail is tipped with black and the backs of the ears are tawny. From *mesomelas* of South Africa this race differs by its less rufous underparts and absence of rufous on the head.

The type measured in the flesh: head and body, 600 mm.; tail, 325; hindfoot, 150; ear from notch, 100. Skull: condylo-incisive length, 141; greatest length, 145; zygomatic breadth, 84; interorbital width, 28.5; postorbital constriction, 30; nasals, 13×48; length of upper cheek teeth including canine, 62.5; length of palate, 70; width of mesopterygoid fossa, 14.3; length of upper carnassial, 16.5.

A series of 10 specimens are in the collection from the type locality, which agree with the type in the character of their ventral coloration and long heavy coat. This is a highland race confined apparently to the upper elevations of the Nile watershed.

THOS MESOMELAS MCMILLANI, new subspecies

Athi Black-backed Jackal

Type from Mtoto Andei station, British East Africa, altitude 2,500 feet; adult female, number 181483, U. S. Nat. Mus.; collected by Edmund Heller, April 5, 1911; original number 2003.

Characters.—Thos mesomelas mcmillani differs from typical *mesomelas* of South Africa by its smaller body size and less rufous coloration. The underparts are especially light, the throat and belly being white or pale buff instead of rufous as in *mesomelas* and the hair of these parts is light to the roots rather than grayish basally.

This race approaches in its light coloration closely *schmidti* of Somaliland but it differs from this form by the absence of rufous on the head and the white tipped tail. The tip of the tail is marked by a tuft of white hair, a feature not found in the series of 35 skins from the Loita Plains and the northern Guaso Nyiro districts, all of which have black tips. The type is in fresh pelage and has the black back well marked and sharply contrasted from the bright ochraceous-rufous sides and legs. The hair of the back basally is hair-brown of Ridgway. The backs of the large ears are ochraceous and the chin is white like the throat in color.

The flesh measurements were: head and body, 690 mm.; tail, 350; hindfoot, 140; ear from notch, 95. The skull shows considerable age and has a high, well developed sagittal crest. Condylo-incisive length, 137; greatest length, 146; zygomatic breadth, 82; interorbital width, 29.5; postorbital constriction, 31.5; nasals, 13.2×53; length of upper cheek teeth including canine, 62.5; length of palate, 67; width of mesopterygoid fossa, 15.5; length of upper carnassial, 15.

The type is unique in the possession of the distinct white tail tip but a large series (35) of specimens from the Loita Plains, the northern Guaso Nyiro district, Athi Plains and Taveta, Kilimanjaro district, which are closely similar to the type in their white underparts, have the tail black tipped. This race is confined to the coast drainage and the lower parts of the Rift Valley and is the only jackal which is found in the low desert nyika country.

Named for William N. McMillan to whom the Smithsonian African Expedition is indebted for his generous hospitality at Juja Farm and in Nairobi.

HELIOSCIURUS RUFOBRACHIATUS SHINDI, new subspecies

Taiti Red-legged Squirrel

Type from the summit of Mount Umengo, Taita Hills, British East Africa, altitude, 6,000 feet; adult male, number 182768, U. S. Nat. Mus.; collected by Edmund Heller, November 11, 1911; original number 4731.

Characters.—Most closely related to *Heliosciurus rufobrachiatus undulatus* of Kilimanjaro but differing by having paler underparts, buffy-ochraceous in tone without the rufous cast of that form. The dorsal surface is lighter with less black lining than in *undulatus*. The feet differ by being ochraceous and never as dark as the rufous of *undulatus*. There are no apparent differences in size or proportion of parts.

The flesh measurements were: head and body, 225 mm.; tail, 283; hindfoot, 55; ear, 18. Skull; condylo-incisive length, 50; zygomatic breadth, 32; nasals, 18×8.2; interorbital width, 17; postorbital width, 16.5; length of upper tooth row, 11; diastema, 11.5.

This squirrel is confined to the remnant of forest covering the extreme summit of the Taita Hills, where it is very rare. The type was the only individual seen during a fortnight's stay on the summit of Umengo Mountain. It has been compared with the type of *undulatus* which was collected by Dr. L. W. Abbott on Mount Kilimanjaro and is now in the National Museum. Among the Wataita tribe this squirrel is known as "shindi."

TATERA NIGRACAUDA PERCIVALI, new subspecies

Lorian Black-tailed Gerbille

Type from the Lorian Swamp, British East Africa, altitude 700 feet; adult female, number 183945, U. S. Nat. Mus.; collected by A. Blayney Percival; original number 792.

Characters.—Tatera nigricauda percivali differs from the race *iconica* from the middle course of the Guaso Nyiro drainage by its duller or paler dorsal coloration, the reduction of black lining on the back and the smaller body size. The pelage throughout is much shorter and thinner, a condition brought about by the extremely arid and hot conditions of the Lorian desert which lies at an altitude of only 700 feet.

Flesh measurements: head and body, 133 mm.; tail, 170; hindfoot, 35; ear, 21. Skull: condylo-incisive length, 35.5; zygomatic breadth, 20; interorbital breadth, 8; nasals, 4×16.5; length of upper tooth row, 6.5; diastema, 10.8; length of incisive foramina, 7.8; mastoid breadth of skull, 18.2.

The type is the only specimen in the National Museum.

EPIMYS KAISERI TURNERI, new subspecies

Kavirondo Bush Rat

Type from Kisumu, British East Africa; adult female, number 183395, U. S. Nat. Mus.; collected by H. J. Allen Turner; original number 5121.

Characters.—Nearest in coloration to *Epimys kaiseri hindei* of the Athi River drainage but decidedly darker, the dorsal surface russet rather than ochraceous, the underparts gray instead of buff, and the feet drab, not white as in the other East African races. From *medicatus* of Mumias it differs decidedly by its shorter tail, the tail being considerably less than the head and body while in the former it is much greater. The skull differs from that of *medicatus* by its more arched dorsal profile, longer snout, smaller size and greater concavity to the antorbital plate on its outer margin.

Flesh measurements of the type: head and body, 155 mm.; tail, 135; hindfoot, 27; ear, 22. Skull: condylo-incisive length, 35; zygomatic breadth, 19; interorbital breadth, 5.5; nasals, 4.8×16; length of upper tooth row, 6.5; diastema, 10; length of incisive foramina, 8.5.

Ten specimens besides the type are in the collection from Kisumu where they were secured in the papyrus beds on the margin of Kavirondo Bay. This race appears to be confined to the papyrus beds of the Victoria Nyanza, the rising country immediately back of the lake being occupied by the long-tailed, light-colored *medicatus*.

Named for H. J. Allen Turner of Nairobi to whom the writer is indebted for much assistance in collecting mammal specimens throughout the Kavirondo country.

EPIMYS CONCHA ISMAILIAE, new subspecies

Gondokoro Multimammate Mouse

Type from Gondokoro, Uganda; adult male, number 165108, U. S. Nat. Mus.; collected by J. Alden Loring, February 23, 1910; original number 9056.

Characters.—This race is allied most closely to *Epimys concha blainei* of Chak-Chak, Bahr-el-Ghazal River, but may be distinguished by its larger feet and longer tail. The coloration is quite as in *blainei,* the dorsal surface being wood-brown slightly darker on the midline and the underparts are white, the hair basally dark gray.

The flesh measurements of the type were: head and body, 108 mm.; tail, 115; hindfoot, 24. Skull: Condylo-incisive length, 26.5; zygomatic breadth, 13.5; interorbital width, 4.1; nasals, 3.4×12; length of upper tooth row, 4.7; diastema, 7.4; length of incisive foramina, 6.8.

A series of 20 specimens are in the National Museum. Ten of these are from the type locality and the others are from Nimule and the stations just north of it on the Gondokoro Road which follows the east bank of the Nile.

EPIMYS KAISERI CENTRALIS, new subspecies

Nile Bush Rat

Type from Rhino Camp, Lado Enclave, British East Africa; adult male, number 165035, U. S. Nat. Mus.; collected by J. Alden Loring, January 11, 1910; original number 8633.

Characters.—The coloration of this race resembles closely that of *Epimys kaiseri norae* of the northern Guaso Nyiro drainage of British East Africa but differs by its less buffy tone to the dorsal surface and by the much shorter tail and wider skull.

Flesh measurements of the type were: head and body, 148 mm.; tail, 162; hindfoot, 30. Skull: condylo-incisive length, 35; zygomatic breadth, 19; interorbital width, 5.8; nasals, 4.5×15; length of upper tooth row, 5.8; diastema, 10; length of incisive foramina, 9.

A series of 38 specimens are in the National Museum from Rhino Camp, Lado Enclave. Others somewhat less typical in character are from Unyoro, Uganda, and from Nimule and Gondokoro in northern Uganda.

MUS GRATUS SORICOIDES, new subspecies

Taita Pygmy Mouse

Type from Mount Mbololo, Taita Hills, British East Africa; adult male, number 183544, U. S. Nat. Mus.; collected by Edmund Heller, November 8, 1911; original number 4675.

Characters.—Like *Mus gratus* of Ruwenzori but underparts much more buffy or rather ochraceous in tone. Body size somewhat less, both the feet and skull being smaller but the tail is longer. The dorsal color is bister-brown lined by black medially and bordered on the lower sides by an indefinite band of bright fulvous. The underparts are ochraceous, the hair basally gray. Feet buffy. This race is confined to the remnants of forest still left on the extreme summits of the Taita Hills at elevations of 5,000 or 6,000 feet. Two additional specimens are in the collection from Mbolobo Mountain and one other from Umengo Mountain.

Flesh measurements of the type: head and body, 60 mm.; tail, 59; hindfoot, 13; ear, 11. Skull: condylo-incisive length, 17.3; zygomatic breadth, 9.3; interorbital breadth, 3.5; nasals, 2.3×8.2; length of upper tooth row, 3.3; diastema, 4.5; length of incisive foramina, 4.2.

OENOMYS HYPOXANTHUS VALLICOLA, new subspecies

Naivasha Rusty-nosed Rat

Type from Lake Naivasha, British East Africa; adult female, number 162614, U. S. Nat. Mus.; collected by J. Alden Loring, July 15, 1909; original number 6640.

Characters.—This is a much lighter and smaller race than *bacchante* of the Mau and Kikuyu escarpments bounding the Rift Valley to the west and the east of Naivasha. In coloration it approaches nearer *editus* of Ruwenzori but is less rufous or rusty and is somewhat smaller in body size. The skull is shorter decidedly than that of *editus* but equals it in zygomatic width.

Flesh measurements of the type: head and body, 160 mm.; tail, 184; hindfoot, 31. Skull: condylo-incisive length, 34; zygomatic breadth, 17; interorbital width, 5.5; nasals, 4.6 × 15; length of upper tooth row, 7; diastema, 10; length of incisive foramina, 7.8.

Three other specimens from Naivasha are in the collection and they agree in coloration with the type.

ARVICANTHIS ABYSSINICUS VIRESCENS, new subspecies

Olivaceous Grass Rat

Type from Voi, British East Africa; adult male, number 183922, U. S. Nat. Mus.; collected by Edmund Heller, November 15, 1911; original number 4775.

Characters.—*Arvicanthis abyssinicus virescens* resembles *nairobae* most closely from which it may be readily distinguished by its darker dorsal coloration, which is heavily lined by blackish hairs having a distinct greenish iridescence. The body size is considerably smaller and the skull shows relatively smaller bullæ, and teeth, and narrower and more slender nasal bones. In the tone of its dark dorsal coloration it resembles *nubilans* of the Kavirondo region but it differs from this race by its white underparts and its much smaller body size.

The flesh measurements were: head and body, 125 mm.; tail, 103; hindfoot, 26; ear, 16.5. Skull: condylo-incisive length, 30; zygomatic breadth, 16.8; interorbital breadth, 4.8; nasals, 4.8 × 12; length of upper tooth row, 6.2; width of first upper molar, 2; diastema, 8.8; length of incisive foramina, 6.2.

The type is unique. It has been compared with a large series of topotypes of both *nairobae* and *nubilans* in the National Museum and is readily distinguishable from both of these races.

LEMNISCOMYS DORSALIS MEARNSI, new subspecies

Kikuyu Single-striped Grass Rat

Type from Fort Hall, British East Africa, altitude 6,200 feet; adult female, number 163616, U. S. Nat. Mus.; collected by J. Alden Loring, September 11, 1909; original number 7152.

Characters.—Lemniscomys dorsalis mearnsi is an intensely ferruginous form of *dorsalis* differing from the Taita race *maculosus* by richer coloring and larger size. The rump and hindlegs are bright ferruginous which, farther forward on the shoulders, becomes less intense and quite ochraceous in tone. The underparts are uniform white in sharp contrast to the bright ochraceous-rufous sides.

The flesh measurements of the type are: head and body, 131 mm.; tail, 140; hindfoot, 31; ear, 12. Skull: condylo-incisive length, 33; zygomatic breadth, 17; interorbital breadth, 5; nasals, 4.4×13; length of upper tooth row, 6.5; diastema, 9.3; length of incisive foramina, 7.

Two other specimens from Fort Hall complete the series of this race which represents altitudinal as well as inland limits of this coast species.

ACOMYS IGNITIS MONTANUS, new subspecies

Marsabit Spiny Mouse

Type from the north slope of Mount Marsabit, British East Africa; altitude 4,600 feet; adult female; number 182901 U. S. Nat. Mus.; collected February 26, 1911, by A. Blayne Percival; original number, 309.

Characters.—Resembling *Acomys ignitus* in general features as well as in quality of the pelage but coloration much grayer and duller and size larger. Dorsal coloration vinaceous-drab, the sides brighter or pure vinaceous but not sharply marked from the darker mid-dorsal region. Underparts and feet pure white, the hair white to the roots. Tail and ears drab-gray.

Flesh measurements of the type: head and body, 90 mm.; tail, 92; hindfoot, 17; ear, 16.5. Skull wanting. Another topotype also with skull missing is in the collection. The race is a mountain form living at an elevation of 4,000 feet or more and is larger and duller colored than the low desert forms to which it is related all of which are confined to the lower desert levels below 2,500 feet in altitude.

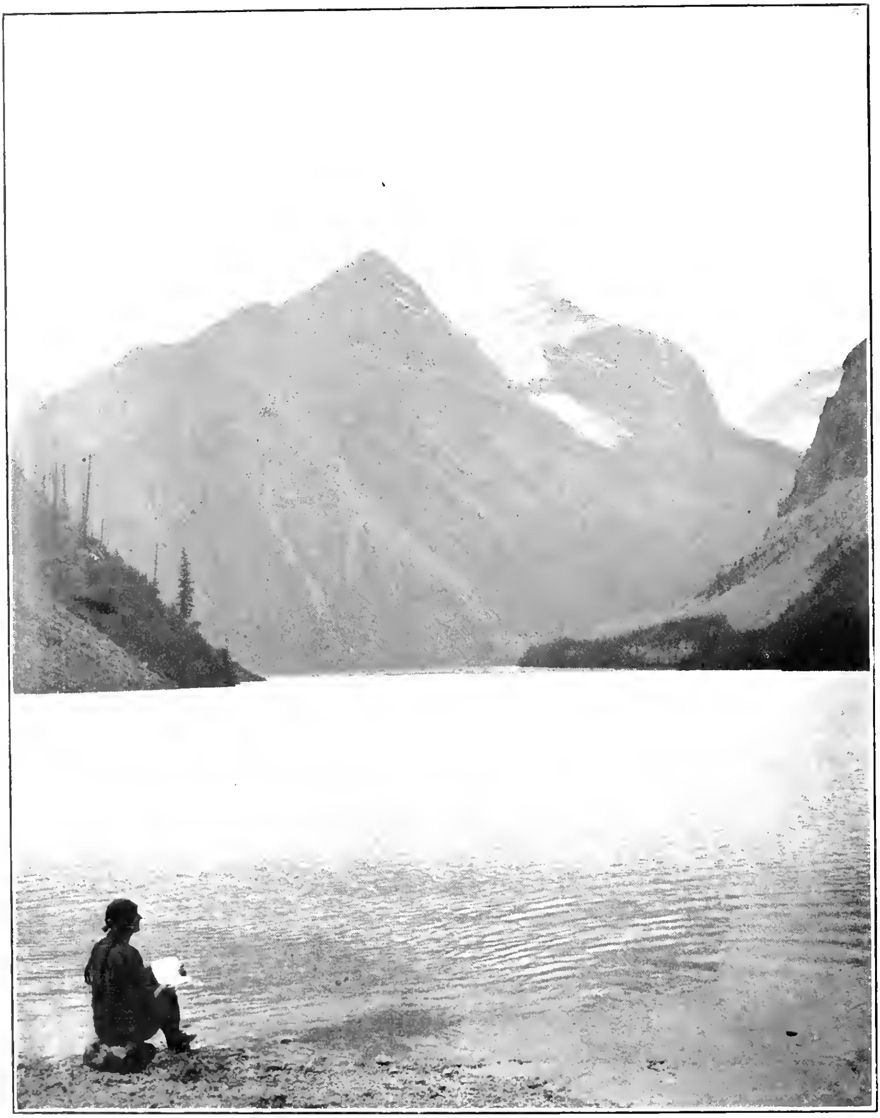
SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 63, NUMBER 8

EXPLORATIONS AND FIELD-WORK OF THE SMITHSONIAN INSTITUTION IN 1913

(Publication 2275)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
1914

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.



Looking north from foot of Kinney Lake toward Whitehorn Peak. On the right the cliff at the foot of Robson Peak. Miss Helen B. Walcott on beach in foreground. Robson Park, British Columbia, Canada. Photograph by C. D. Walcott, 1913.

EXPLORATIONS AND FIELD-WORK OF THE SMITHSONIAN INSTITUTION IN 1913

INTRODUCTION

There is here presented a general account of the exploration and field-work conducted by the Smithsonian Institution and its several branches, including the United States National Museum, in various parts of the world during the calendar year 1913. These explorations were made by means of allotments from the Smithsonian funds, from Congressional appropriations, and through the coöperation of other institutions and of individuals engaged or interested in geological, biological, or anthropological investigations.

The Institution and its branches were thus represented in a large number of field parties whose researches have tended to increase the general knowledge in various subjects, and have added much valuable material to the collections of the National Museum. Owing to its limited funds, the Institution was unable to participate in several additional enterprises in which opportunities for representation were offered.

In the preparation of the present account the direct statements of those who participated in the field-work have been employed, with one or two exceptions, while nearly all the photographs were made by the explorers themselves.

Some of the work carried on in 1913 was in continuation of operations begun in previous years and reported in part in accounts heretofore published by the Institution.[1]

Three Government branches of the Institution are represented in this report: The National Museum, although having no specific funds for exploration work, avails itself as far as possible of all opportunities presented for making collections in the field; the Bureau of American Ethnology engages largely in field-work, which is covered in detail in the annual report of that bureau; and the

---

[1] Expeditions Organized or Participated in by the Smithsonian Institution in 1910 and 1911. Smithsonian Misc. Coll., Vol. 59, No. 11, 1912.

Explorations and Field-Work of the Smithsonian Institution in 1912. Smithsonian Misc. Coll., Vol. 60, No. 30, 1913.

Astrophysical Observatory at times conducts special expeditions both in the United States and abroad, in connection with its regular work of studying the physical properties of the sun and their effect on the earth.

Both the National Museum and the National Zoological Park received during the year many donations and accessions presented or collected by collaborators in this country and abroad who have no official connection with either branch. The remaining branches under the Smithsonian Institution were not represented by any field parties, and therefore are not mentioned in this account.

FIG. 1.—Looking northeast toward the top of Robson Peak from Rainbow Brook, one-quarter mile south of Lake Kinney, Robson Park, British Columbia, Canada. Photograph taken while clouds and mist were drifting over the upper part of the peak. The summit of the peak is 8,800 feet above the camera. The view shows the southwest face of the peak. Photograph by C. D. Walcott, 1913.

GEOLOGICAL EXPLORATIONS IN THE CANADIAN ROCKIES

In continuation of his previous geological researches in the Canadian Rockies, Dr. Charles D. Walcott, Secretary of the Institution, revisited during the field season of 1913, the Robson Peak district in British Columbia and Alberta, and the region about Field, British Columbia. At the latter place he received the members of the International Geological Congress.

FIG. 2.—Robson Peak from a ridge above and north of east end of Berg Lake, showing north side of peak. Robson Park, British Columbia, Canada. Photograph by C. D. Walcott, 1913.

FIG. 3.—Hunga Glacier from south slope of Mumm Peak, with Phillips and other mountains to the south. Robson Park, British Columbia, Canada. Photograph by C. D. Walcott, 1913.

On this trip to Robson Peak, Dr. Walcott approached from the west side, in order to study the local geological section which he considers one of the finest in the world. From the west foot of Robson Peak, Whitehorn Peak rises on the north to a height of 7,850 feet above Lake Kinney (frontispiece), and on the east the cliffs of Robson rise tier above tier from the surface of the lake to the summit of the peak, a vertical distance of 9,800 feet. The base of this geological section is shown on the right of the frontispiece, and the upper half by figure 1, while figure 2 illustrates a profile of 7,500 feet of the section.

FIG. 4.—Phillips Mountain, from Robson Pass, looking over the front of Hunga Glacier. Robson Park, British Columbia, Canada. Photograph by C. D. Walcott, 1913.

From beneath the base of the mountain at Lake Kinney, the strata slope gently upward so that more than 4,000 feet in thickness of beds, which pass under Robson Peak, are exposed in ledges to the north and south. A considerable portion of this thickness is shown in the dark peak to the left of Whitehorn Peak in the frontispiece.

Owing to exceptionally good climatic conditions, the season of 1913 proved unusually favorable for viewing Robson Peak. Frequently in the early morning the details of the snow slopes on the summit of the peak were beautifully outlined. Toward evening,

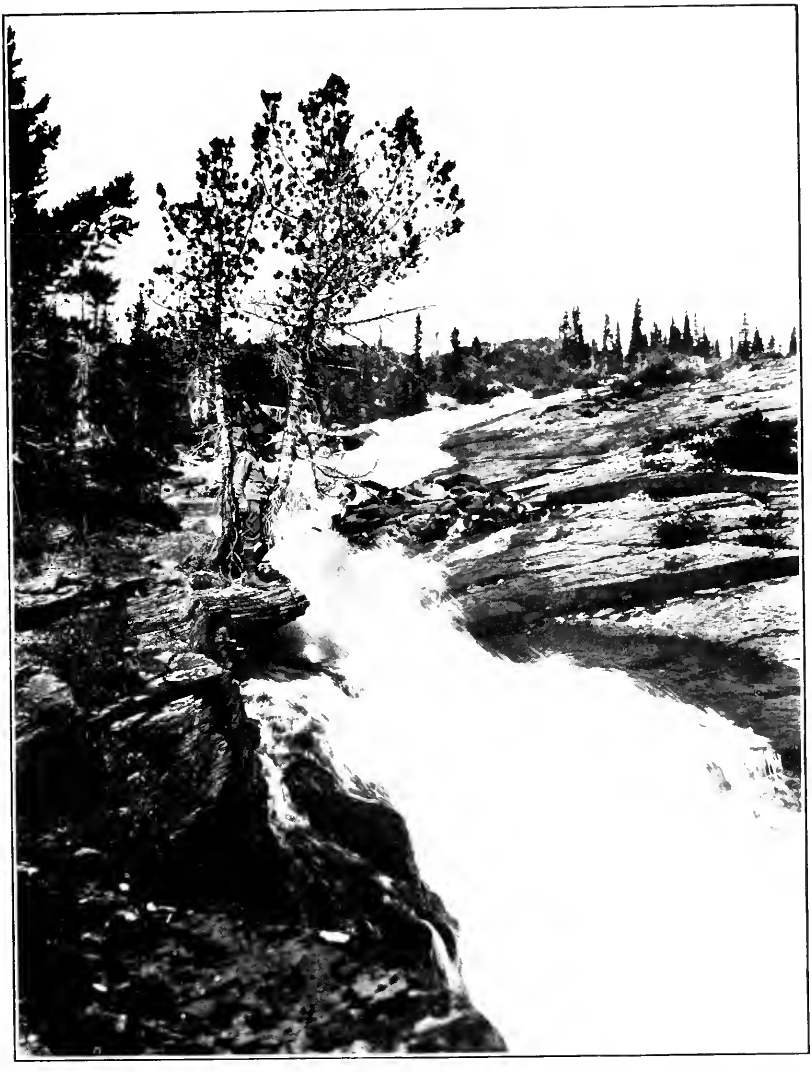


FIG. 5.—Brook entering Berg Lake, one mile southwest of Robson Pass. View taken about half a mile from the lake. Robson Park, British Columbia, Canada. Photograph by C. D. Walcott, 1913.

however, the mists driven in from the warm currents of the Pacific, 300 miles away, shrouded the mountain from view (fig. 7).

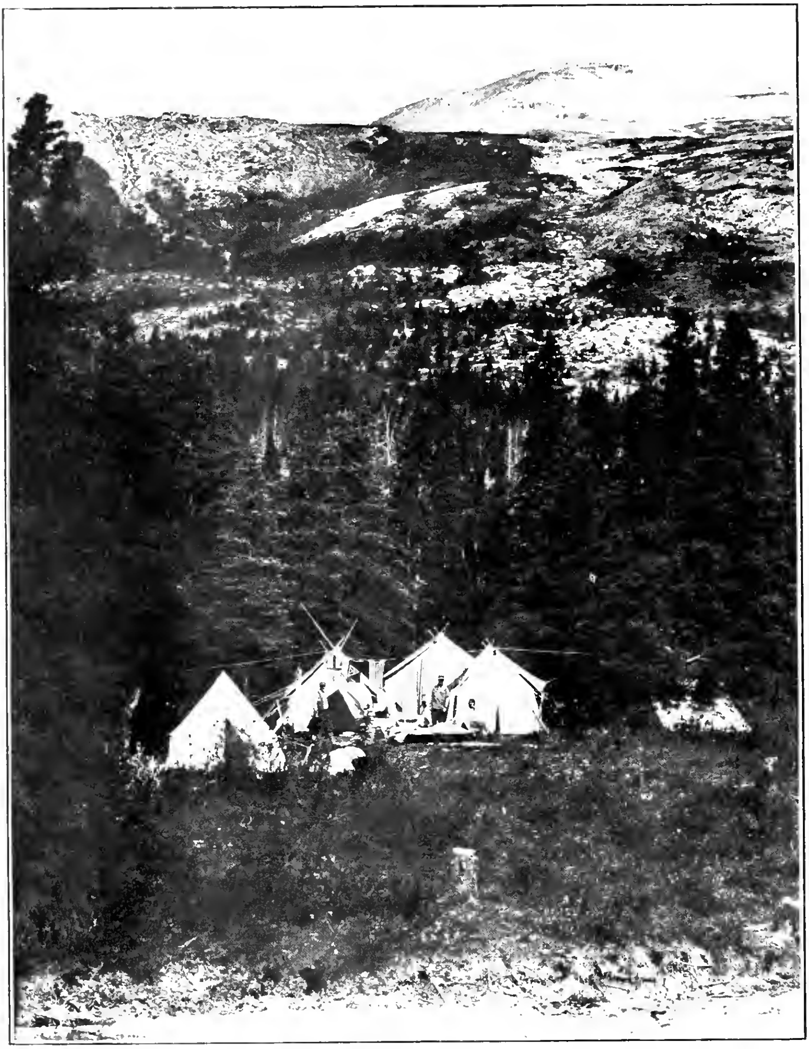


FIG. 6.—Camp on the north side of Robson Pass.
Photograph by C. D. Walcott, 1913.

From the slopes of Titkana Peak, west of the great Hunga Glacier (figs. 3 and 4), a wonderful view is obtained of the snow fields and falling glaciers east of Robson Peak. The glacial streams come

FIG. 7.- View from Walcott Camp, looking westward over President Range after sunset when the mist is driving eastward over the mountains. Near Field, British Columbia, Canada. Photograph by C. D. Walcott, 1913.

FIG. 8. Panoramic view of west side of foot of Hunga Glacier where the stream forming the head-waters of Grand Fork comes from beneath the ice and flows westward into Berg Lake. Robson Park, British Columbia, Canada. Photograph by C. D. Walcott, 1913.

FIG. 9.—View looking out from the fossil quarry over Burgess Pass, to the right of the mountain, the Van Horne Range in the distance, the President Range and Emerald Lake. On the left the Kicking Horse Valley, Mount Dennis, and in the distance Mount Vaux. Near Field, British Columbia, Canada. Photograph by C. D. Walcott, 1913.

FIG. 10.—North end of the fossil quarry above Burgess Pass on the slope of the ridge between Mount Wapta and Mount Field, 4,000

tumbling down the slopes (fig. 5) and often disappear beneath the glacier to reappear at its foot with the volume of a river (fig. 8).

At Field, British Columbia, work was continued at the great Cambrian fossil quarry, where a large collection of specimens was secured. The conditions were such that it was necessary to do much heavy blasting to reach the finest fossils which occur in the lower layers of rock. Figure 10 shows the north end of the quarry below the sharp summit of Mount Wapta, and, in the distance, the President Range with Emerald Lake at its base. The south end of the quarry is illustrated by figure 11; here the solid beds were blasted out to a depth of 22 feet.

FIG. 11.—South end of fossil quarry, where many of the most beautiful specimens were secured from the lower three feet of beds. Near Field, British Columbia, Canada. Photograph by C. D. Walcott, 1913.

Owing to the presence of a fault line, just north of the quarry, and the twist and compression of the rocks south of it, the available area for successful collecting is limited to about 200 feet. In other localities where the shale outcrops on the ridges in the vicinity, com-

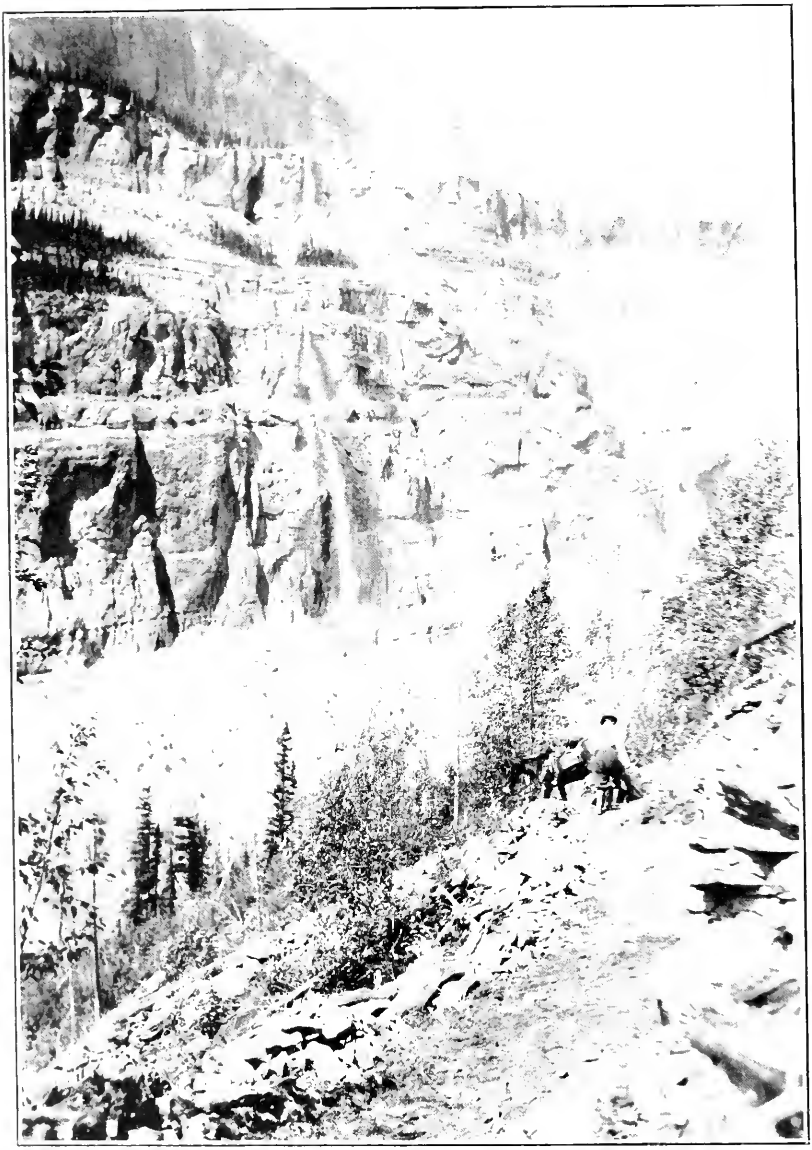


FIG. 12.—View of the west cliff of the valley of the Thousand Falls. On the trail from Lake Kinney to Berg Lake. Photograph by R. C. W. Lett. Grand Trunk Pacific Railway, 1913.

FIG. 13.—Summit of Mount Resplendent, with the mist driving over the three members of the Alpine Club of Canada. Photograph by P. L. Tait, British Columbia, 1913.

pression and shearing have so changed the character of the rock that it is impossible to obtain fossils in a condition to be of service.

The collections of 1913 contain a number of very important additions to this ancient Cambrian fauna, and many fine additional examples of species found in 1912.

FIG 14.—Bowlder train on the surface of the west side of Hunga Glacier, overlooking the Robson Pass, British Columbia. The Secretary of the Smithsonian Institution is standing beside the bowlder. Photograph by Miss Helen B. Walcott, 1913.

GEOLOGIC HISTORY OF THE APPALACHIAN VALLEY IN MARYLAND

Dr. R. S. Bassler, curator of paleontology in the U. S. National Museum, spent a month during the summer of 1913, in the Appalachian Valley of Maryland and the adjoining States, studying the Postpaleozoic geologic history of the region, as indicated by the present surface features. His studies, which were under the joint auspices of the U. S. National Museum and the Maryland Geological Survey, were in continuation of work carried on during the previous summer when the sedimentary rocks of the region were mapped in detail, the final object being the preparation of a report on the Lower

Paleozoic strata of Maryland, to complete a series of memoirs published by that State. Owing to the brevity of this account, only a few points in the physiographic history will be noted here.

Since Carboniferous time western Maryland has been above the sea, and its rocks have accordingly been subjected to a long period of aerial erosion. During Jurassic time, the area remained stationary for so long a period that the surface of the land in the Appalachian province was reduced to a rolling plain. Later uplift raised this plain still higher above sea level, and in Maryland only remnants of the old surface are preserved in the flat skyline of the highest mountains. This ancient plain, or Schooley peneplain, as it is termed, is well preserved on the top of the Blue Ridge, as shown in figure 15.

FIG. 15.—Jurassic (Schooley) peneplain, preserved in the Blue Ridge of Maryland. Photograph by Bassler.

A second great period of erosion occurred in early Tertiary time, the effects of which were chiefly in the Appalachian Valley proper, where the erosion is indicated by a pronounced plain at an elevation of about 750 feet. This plain was formed only on the softer Paleozoic rocks, and, because of its prominence near Harrisburg, Pennsylvania, is known as the Harrisburg peneplain. Conococheague Creek traverses the Harrisburg peneplain in Maryland, and has dissected it considerably, as shown in figure 16, but the even skyline of the ancient plain is still clearly evident.

Other factors in the geologic history of Maryland are recorded in the well defined gravel terraces along the major streams of the area and in great alluvial fans of large and small bowlders, spreading out at the foot of the larger mountains and sometimes reaching a depth of 150 feet. All of these phenomena have been plotted and will form a part of the geologic map of the region.

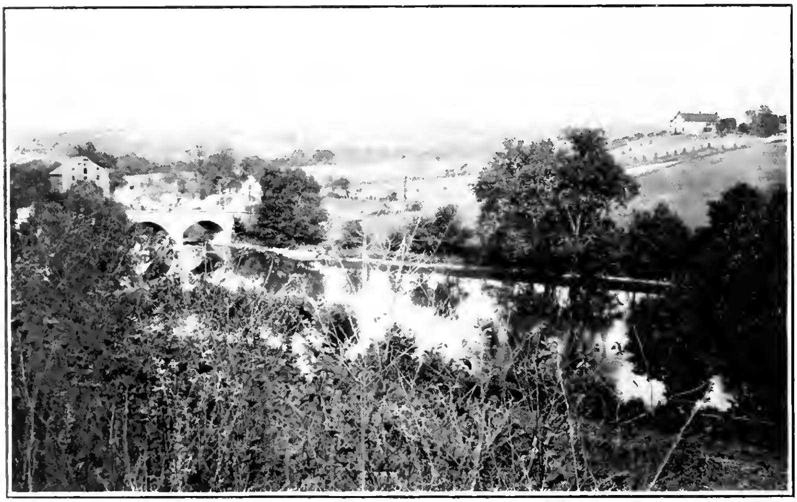


FIG. 16.—Dissected Early Tertiary (Harrisburg) peneplain, west of Hagerstown, Maryland. Photograph by Bassler.

COLLECTING FOSSIL ECHINODERMS IN ILLINOIS

The special field explorations maintained by Mr. Frank Springer, associate in paleontology in the U. S. National Museum, were continued during the season of 1913 by his private collector, Frederick Braun. The purpose of these explorations is to obtain additional material for use in Mr. Springer's monographs upon the fossil crinoidea, now in course of preparation, but they also result in important accessions of excellent specimens for the completion of the exhibition series in the hall of Invertebrate Paleontology in the National Museum.

The investigations of the past summer were confined to the Kaskaskia rocks of Monroe and Randolph Counties, Illinois. They were systematically carried on in connection with the geological work for the State of Illinois, in progress at the same time under the direction of Professor Weller, in order to have the benefit of accurate determinations of the horizons from which the collections were made, with reference to the several subordinate formations into which the Kaskaskia of that region is divided. In this way it was hoped to rectify some confusion as to the stratigraphic relation of a number of species described in the Geological Reports of Illinois and Iowa. The operations were successful in this respect, and at the same time six large boxes of fine specimens were obtained. Among the specimens there are a number of slabs covered with Crinoids not hitherto found in that formation, in an excellent state of preservation. A portion of one slab, containing 22 specimens of 9 different species, is shown in the accompanying illustration (fig. 17). This specimen and

FIG. 17.—Portion of a slab of fossil Crinoids from Illinois.
Photograph by National Museum.

others of similar character, giving a complete representation of the Kaskaskia crinoidal fauna, are being prepared for installation in the exhibition hall of the National Museum.

FURTHER EXPLORATION OF THE CUMBERLAND PLEISTOCENE CAVE DEPOSIT

In May, 1913, Mr. J. W. Gidley, assistant curator of fossil mammals in the U. S. National Museum, made a second visit to the Pleistocene cave deposit near Cumberland, Maryland, which proved even more successful than the one of the previous year, reported in the account of the Smithsonian explorations of 1912.

FIG. 18.—Near view of part of excavation made near Cumberland, Maryland, by U. S. National Museum party. Photograph by Armbruster.

Many new forms were added to the collection, and much better material was obtained of several species represented only by jaw fragments in the first collection. The collection now contains upward of 300 specimens, representing at least 40 distinct species of mammals, many of which are now extinct. Among the better preserved specimens are several nearly complete skulls and lower jaws. The more important animals represented are two species of bears, two species of a large extinct peccary, a wolverine, a badger, a martin, two porcupines, a woodchuck, and the American eland-like antelope.

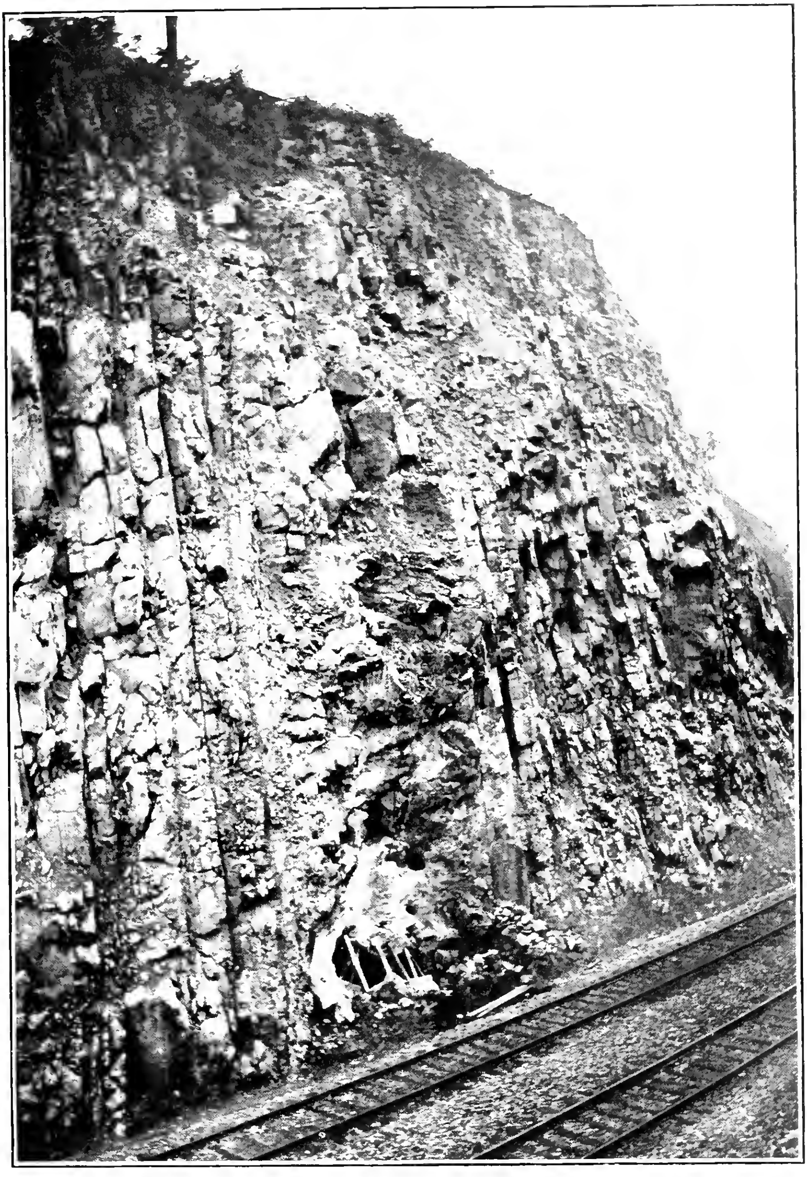


FIG. 19.—View from opposite side of railroad cut showing fossil deposits at bottom, near track, and traces of ancient opening at top of cliff. Photograph by Armbruster.

These species are all new and, with the exception of the American eland, the dog, and one of the bears, which Mr. Gidley has already described,[1] have not yet been named.

Other species represented by more fragmentary material include the mastodon, tapir, horse, and beaver, besides several species of the smaller rodents, shrews, bats, and others.

This strange assemblage of fossil remains occurs hopelessly intermingled and comparatively thickly scattered through a more or less unevenly hardened mass of cave clays and breccias, which completely filled one or more small chambers of a limestone cave, the material together with the bones evidently having come to their final resting place through an ancient opening at the surface a hundred feet or more above their present location. The deposit is at present exposed at the bottom of a deep cut through which the Western Maryland Railroad has built its tracks. The railroad excavation first brought to light the ancient bone deposit and incidentally made access to the fossils comparatively easy. It is proposed to continue work on this important deposit during the next season.

A FOSSIL HUNTING EXPEDITION IN MONTANA

While engaged in Geological Survey work in northwestern Montana in 1912, Mr. Eugene Stebinger discovered a promising locality of vertebrate fossil remains. The following summer (1913), under the auspices of the U. S. Geological Survey, Mr. Charles W. Gilmore, assistant curator of fossil reptiles in the National Museum, headed an expedition for the purpose of obtaining, if possible, a representative collection from this area.

In July a camp was established on Milk River, some thirty-five miles north and west of Cut Bank, Montana, on the Blackfeet Indian Reservation. Four weeks were spent here in collecting, the work being confined entirely to the Upper Cretaceous (Belly River beds) as exposed in the bad-lands for ten miles along this stream. Later, in August, camp was moved some fifty miles south on the Two Medicine River, and two weeks were spent working in the same geological formation.

Taking into consideration the short time at the disposal of the party, the results of the expedition were most gratifying. Between

---

[1] Smithsonian Misc. Coll., Vol. 60, No. 27, 1913.
Proceedings U. S. National Museum, Vol. 49, No. 2014, 1913.

500 and 600 separate fossil bones were obtained, many of them of large size. The most notable discovery was a new Ceratopsian[1] or horned dinosaur, the smallest of its kind known. There were portions of five individuals of this animal recovered, representing nearly all parts of the skeleton, so that it will be possible to mount a composite skeleton for exhibition. In this connection, it is perhaps of interest to know that, although Ceratopsian fossils were first discovered in the Rocky Mountain region in 1855, and portions of a hundred or more skeletons have been collected, this is the first individual to be found having a complete articulated tail and hind foot. It thus contributes greatly to our knowledge of the skeletal anatomy of this interesting group of extinct reptiles.

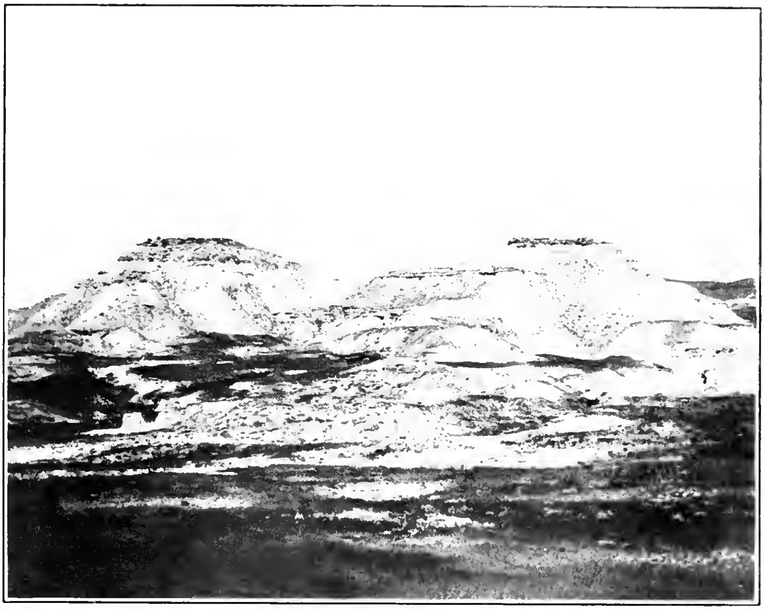


FIG. 20.—Fossil beds as exposed on Milk River, Montana. The small Ceratopsian dinosaur was found in the breaks in the foreground. Photograph by Gilmore.

Another noteworthy find was a partial skeleton of one of the Trachodont or duck-billed dinosaurs. This animal was only recently

---

[1] Mr. Gilmore's description of this extinct reptile is to be found in the Smithsonian Misc. Coll., Vol. 63, No. 3, 1914.

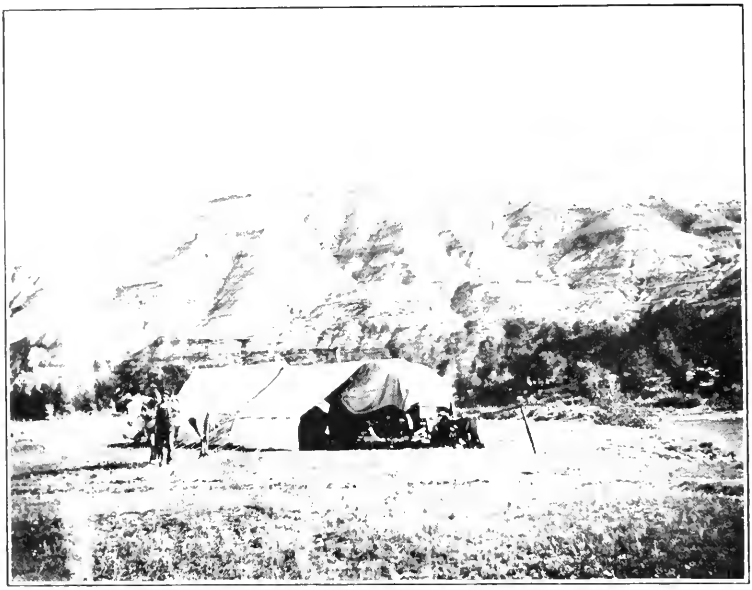


FIG. 21.—Fossil beds as exposed on Two Medicine River, Montana. Camp of fossil hunters in the foreground. Photograph by Gilmore.

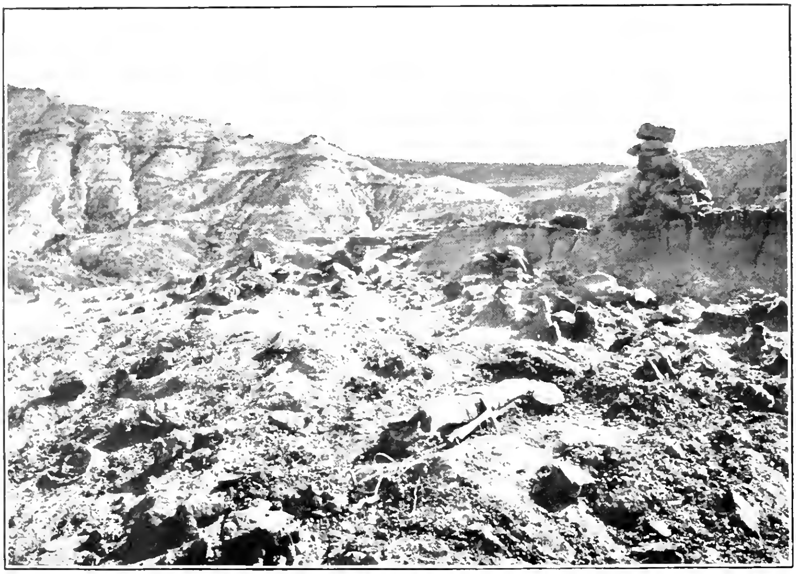


FIG. 22.—Fossil leg bone of a dinosaur shown as found in the ground, on Milk River, Montana. Photograph by Stebinger.

described from specimens obtained in Canada, and its discovery in Montana greatly extends its known geographical and geological range. The species was not before represented in the National Museum collections.

Less perfect skeletons of carnivorous and armored dinosaurs, turtles, crocodiles, and ganoid fishes were also obtained. Altogether the material is a most welcome addition to the fossil vertebrate collection in the National Museum, which has been deficient in representatives of this highly interesting but little known fauna.

LIFE ZONES IN THE ALPS

During the summer of 1904, Messrs. G. S. Miller, Jr. and Leonhard Stejneger, of the National Museum, visited the Western Alps in an endeavor to ascertain the limits of the life zones which, in that part of Europe, might correspond to those of North America established chiefly through the efforts of the U. S. Biological Survey. That a system of such life zones exists in Europe has long been more or less vaguely stated by authors, but although a definite correlation was established by the gentlemen mentioned, certain points, especially the interrelation of the zones corresponding to the so-called Canadian and Hudsonian life zones in America, were greatly obscured by the long continued interference of man and animals with Nature, such as the grazing of cattle in the high Alps, deforestation, and, more recently, artificial reforestation.

It was thought that the eastern Alps might show more primitive conditions, and in the spring of 1913, Mr. Stejneger took advantage of an opportunity to visit the mountain region between Switzerland and the head of the Adriatic, through a small grant from the Smithsonian Institution. Unseasonable and rainy weather interfered greatly with the carrying out of his investigation. He arrived in the town of Bassano at the foot of the Venetian Alps on April 20, 1913, it being his plan to study the life zones of the Val Sugana and the plateau of the Sette Comuni from that point. This plateau descends abruptly to the Venetian plain on the south, while to the east and north it is separated from the mass of the Eastern Alps by the Val Sugana, or the valley of the river Brenta, and on the west by the lower part of the valley of the Adige, or Etsch. It is intersected by the boundary line between Italy and Austrian Tirol.

From April 21 to May 6, he made a series of excursions from Bassano, Levico, and Trento as successive headquarters, during

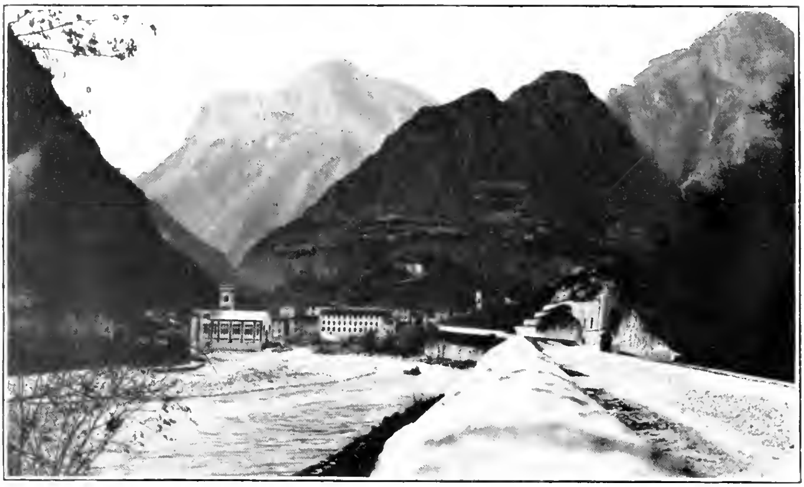


FIG. 23.—Mouth of Val Frenzela, at Valstagna, northern Italy. Photograph by Stejneger.

FIG. 24.—Plateau of the Sette Comuni, northern Italy, looking east from Gallio. Monte Grappa in the background. The valley is the beginning of Val Frenzela. Photograph by Stejneger.

which time he completely circled the territory, and crossed the plateau once on foot. In spite of the backwardness of the season, he was able to trace the boundaries of the Austral life zones in considerable detail, as well as to gather data which connect with the previous correlation of these zones in the Western Alps and with the corresponding zones in North America. It was found that the bottom of the entire Val Sugana belongs to the Upper Austral zone. Owing to the rainy and inclement weather the results were less satisfactory in the higher regions, though some important data corroborating previous conclusions were obtained.

The time from May 7 to May 20 was spent in a study of the Etsch Valley in Tirol, from Trento to Schlanders, and of its tributary, the Eisak, from Bozen to its source on the Brenner Pass.

The elaboration of the detailed observations will be incorporated with a general report on the biological reconnoissance of the Western Alps.

To this preliminary statement are appended two illustrations showing the character of the country in which the observations were made. Figure 23 is a view of the mouth of Val Frenzela, the narrow valley through which the descent from the Sette Comuni was effected, near Valstagna, a small town a few miles north of Bassano. Figure 24 represents the plateau near the commune of Gallio, about 3,500 feet above the sea, looking east toward Monte Grappa and showing the beginning of Val Frenzela.

DR. ABBOTT'S EXPEDITION IN DUTCH EAST BORNEO AND CASHMERE

In continuation of the exploring and collecting carried on through the generosity of Dr. W. L. Abbott, by Mr. H. C. Raven, in Dutch East Borneo, it may be said that the work is going forward with excellent results.

Dr. W. L. Abbott is continuing his personal explorations in Cashmere, which he undertook a year ago, and, although the Museum has received no detailed report, some fine specimens of mammals have been added to the collections and many more are expected.

In a letter received in January, 1913, Dr. Abbott says that in his last shipment the only really good specimen is a queer little silvery grey shrew about 74 millimeters long, quite different from anything he has before seen, of which there are four specimens from Skoro Loomba, east of Shigar. There is also a magnificent snow leopard with its complete skeleton.

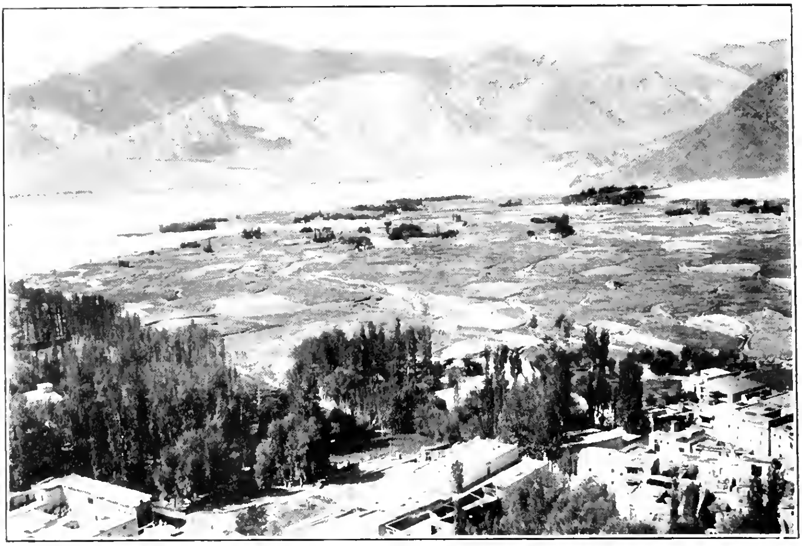


FIG. 25.—View from Leh, looking toward the Khardery Pass up the valley to the right. Observe the cultivation in terraces, all irrigated. The elevation is 11,200 feet. The hills in the background are from 20,000 to 21,000 feet elevation. Photograph from Abbott.

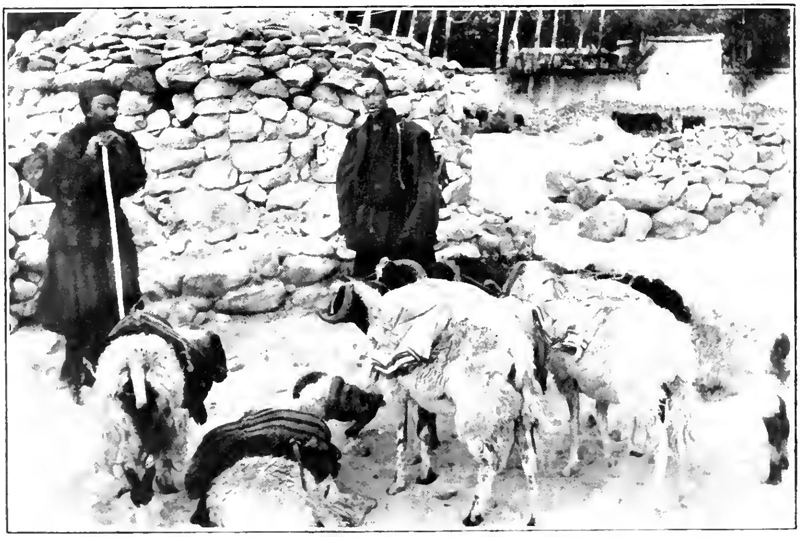


FIG. 26.—Shepherds with load-carrying sheep. Each animal carries from 12 to 30 pounds. They bring salt from Tibet to Ladak and carry back grain. Photograph from Abbott.

During the three months' trip which Dr. Abbott spent in Baltistan, in northwestern Cashmere, he secured about 289 skins which have been presented to the National Museum.

After a sojourn in England, he expected to return to Cashmere in May, and march to Ladak. He also intended to visit Nubra, and go east along the frontier to the Dipsang Plains where he hoped to secure specimens of a certain vole from Kara Korum Pass, as well as the little Tibetan fox, known to the Cashmere furriers as the "King Fox." At the time of the letter he anticipated a four months' trip during the summer of 1913.

This expedition, the results of which have been delayed in transit, was very successful. The small fox was obtained, also several wolves, lynxes, and many smaller mammals. The accompanying illustrations have been made from photographs sent by Dr. Abbott.

MARINE INVERTEBRATES FROM THE "EASTERN SHORE," VA.

In July, 1913, Mr. John B. Henderson, Jr., a regent of the Smithsonian Institution, and Dr. Paul Bartsch, of the National Museum, made a short trip to Chincoteague, on the Atlantic shore of Accomac County, Va., for the purpose of securing exhibition material of marine invertebrates and ascertaining the local marine fauna, particularly that of the mollusca. Owing to the inaccessibility of this strip of coast, generally known as the "Eastern Shore," collectors seem to have neglected it. At any event, there appear to be but few records and no critical lists published of the shallow water shells from any locality between Cape May, N. J., and Beaufort, N. C.

The chief objects of this trip were to determine of just what elements the molluscan fauna consisted; to see how many, if any, species of southern range lapped over from Hatteras, and what northern species still persisted in this faunal area. The collectors were fortunate in their somewhat haphazard choice of a locality, for they encountered at Chincoteague a greater variety of stations than can probably be found at any other point along this section of the coast.

Here there are interior sounds of very considerable extent which are very shallow (4 to 12 ft.), more or less thickly sown with oyster beds and with patches of eel grass, the bottom ranging from hard sand, through varying degrees of hard clay, to soft mud.

They found also the unusual feature of a bight or protected cove formed by the southward drift at the southern end of Assateague Island, protected from heavy wave action by a long, curved sand spit. This bight has a soft mud bottom, with a temperature possibly

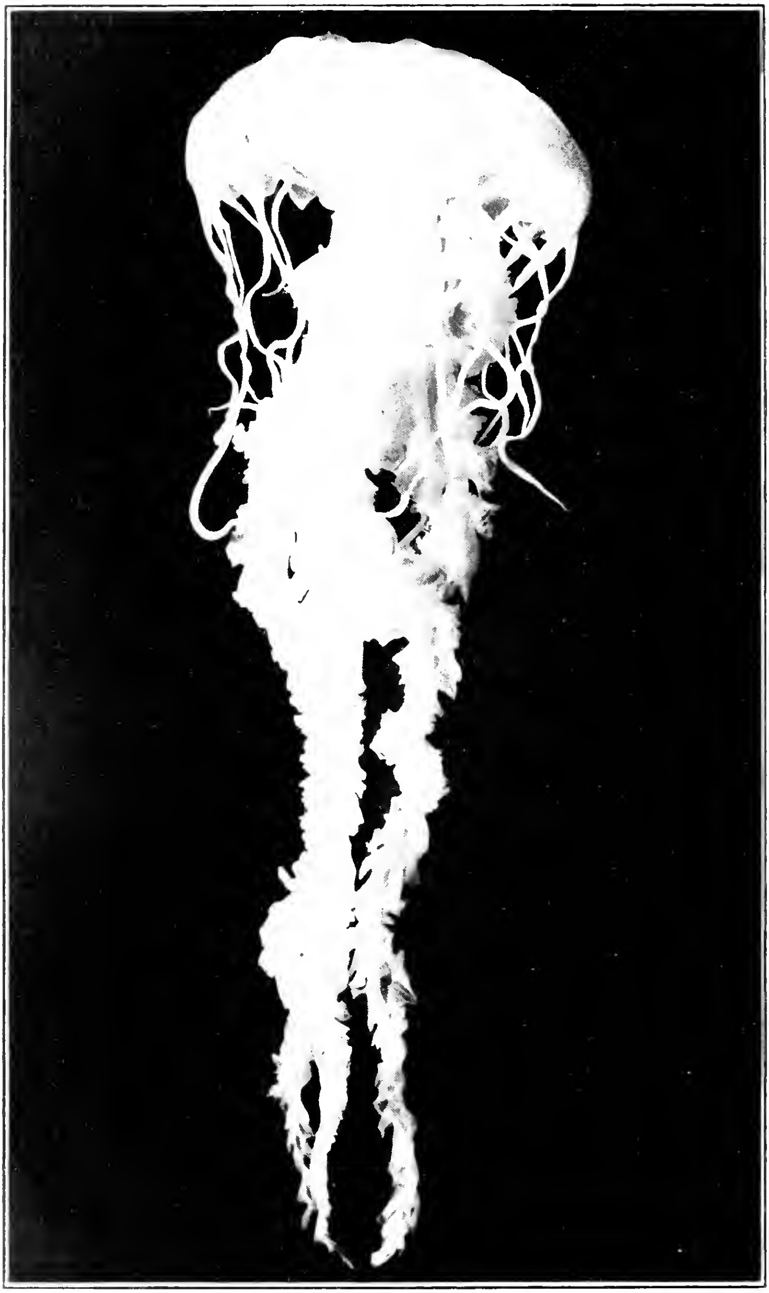


FIG. 27.—Medusa from Chincoteague, Virginia. Collected by Mr. Henderson and Dr. Bartsch. Photographed in alcohol by National Museum.

eight degrees less than that of the open sea. The mud brought up with the dredge seemed almost icy to the touch. This condition is probably produced by cold springs seeping through the floor of the bight. This colder water of the bight yielded to their dredge *Yoldia limatula*, large and fine, and *Nucula proxima*, whereas just around the protective spit of sand, on the ocean side, they found dead Terebras of two species, some young *Busycon perversa* and a valve of *Cardium robustum*; a somewhat startling association of species.

Then there was the open sea, which here presumably differs in no manner from other open sea stations along the 200 miles or more of this coast. The bottom drops off very gradually to the edge of the continental shelf, some 75 or 100 miles out. The open sea stations which they occupied were, as might be expected, very poor. The smooth, hard sand bottom seemed almost barren of life, and the softer patches that were explored contained only many dead shells, mostly small bivalves. The work in the open sea was scarcely a good test, although the collectors made probably 20 hauls reaching out from the shore some 4 or 5 miles, but the chart soundings indicated more promising areas of pebbly bottom a few miles beyond what they considered the safety zone for a small motor boat.

The inner waters of the sound were found to be unexpectedly rich in molluscan life, the species, for the most part, not having been taken previously outside or in the bight.

Only two full working days were spent here, where the party was fortunate in securing an excellent boat and obliging skipper. The material has been identified with great care, and the results of the expedition will be published in the Proceedings of the U. S. National Museum.

EXPERIMENTS WITH CERIONS IN THE FLORIDA KEYS

In the second issue of the Smithsonian exploration pamphlet,[1] attention was called to experiments with Cerions, conducted by Dr. Bartsch, under the auspices of the Carnegie Institution. The plantings of Bahama Cerions made upon the Florida Keys were visited in the latter part of April and early June by Dr. Bartsch, and a de-

---

[1] Smithsonian Misc. Coll., Vol. 60, No. 30, 1913, pp. 58-62.

tailed report of his findings is published in the annual report of the Director of the Department of Marine Biology of the Carnegie Institution of Washington (Carnegie Year Book, 1913, pp. 217-219). The results of these experiments so far obtained may be summed up as follows:

FIG. 28.—"Peanut" shells on living vegetation, Key West, Florida. Photograph by Bartsch.

After looking over the entire plantings, Dr. Bartsch is inclined to believe that, with the exception of the Tea Table and Indian Keys, the colonies are doing as well as might be expected. It is also quite possible that when the young in the various colonies attain a larger size, a good many more will be found in the various places, in fact, a good many may be present in places where they were not discovered previously, for the nepionic shells are quite small and hard to find.

Judging from the young collected, which were born on these Keys, the first generation will be like the parent generation unless decided changes should take place in the later whorls, which have not as yet been developed. The largest specimens found have only seven post-nuclear whorls, leaving two to three whorls still to be developed, and these make up fully half of the length of the shell. If the present

FIG. 29.—"Peanut" shells on living vegetation, Key West, Florida. Photograph by Bartsch.

FIG. 30.—"Peanut" shells on dead stump, Key West, Florida. Photograph by Bartsch.

tendencies prevail in the adult shell, then it can be seen that the somaplasm has not at once responded to the change of environment. The reaction of the germ-plasm to the changed environment will await interpretation until the next generation presents itself.

Dr. Bartsch likewise kept a record of the birds seen on the various Keys visited between Miami, Florida, and the Tortugas, and has published this also in the Carnegie Year Book for 1913, pp. 220-222, with the hope that it may prove useful to students of bird migration.

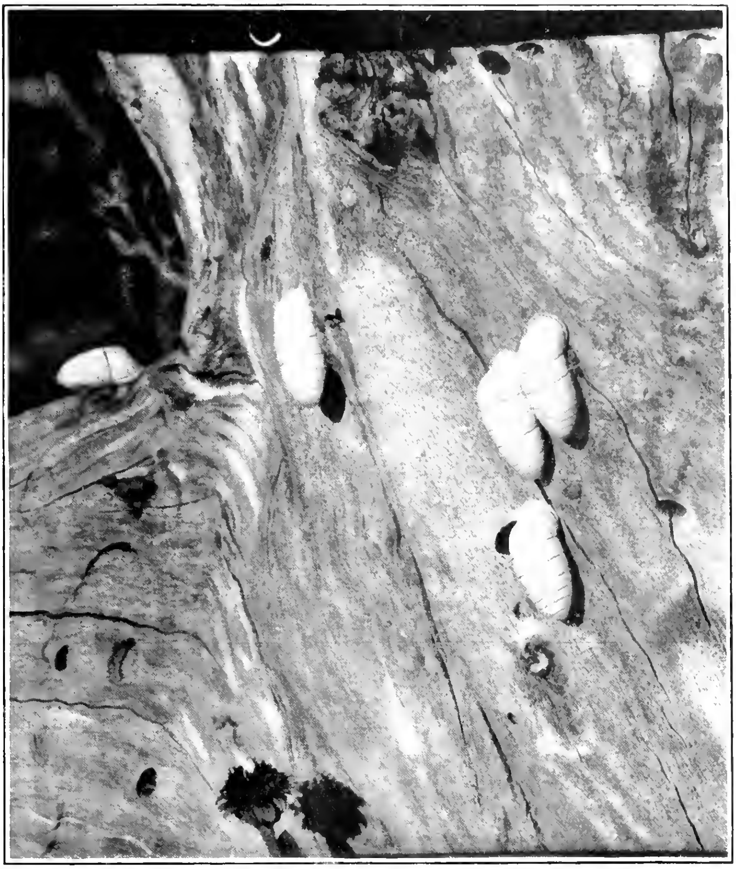


FIG. 31.—Detail view of "Peanut" shells on dead stump, Key West, Florida. Photograph by Bartsch.

BIRD STUDIES IN ILLINOIS

Mr. Robert Ridgway, curator of the division of birds, U. S. National Museum, has been working on the completion of National Museum Bulletin No. 50, Birds of North and Middle America, and has done some exploration work in the field in connection with this work.

Recently he made a trip to the Little Wabash River, about 16 miles southwest of Olney, Illinois, in order to ascertain what species of birds were wintering in the dense thickets of the bottom lands, and to obtain evidence as to the presence there of a decided element of the Austroriparian or Lower Austral fauna and flora.

Mr. Ridgway's residence in this locality during the winter has been of extreme interest; it is the first time he has had an opportunity to make natural history observations since his first trip to this region forty-seven years ago. He was thus enabled to compare present conditions with those existing on the occasion of his first visit, and has secured some valuable information for incorporation in his exhaustive monograph.

FISHES FROM THE REGION OF QUATERNARY LAKE LAHONTAN

The Museum has received through the Bureau of Fisheries a collection of fishes from the various river and lake basins that were at one time connected with the quaternary Lake Lahontan. Twenty-one species are represented, 15 of which are native fishes, including not only all that are now known to inhabit the basin, but also 5 that are as yet undescribed. The collection was made by John O. Snyder, of Stanford University, while engaged in an investigation of the region under the direction of the Bureau of Fisheries.

FIG. 32.—A breakfast catch of Tahoe Trout.
Photograph by Snyder.

Lake Lahontan, which in quaternary time was a large body of water, very irregular in shape, extended over a considerable part of

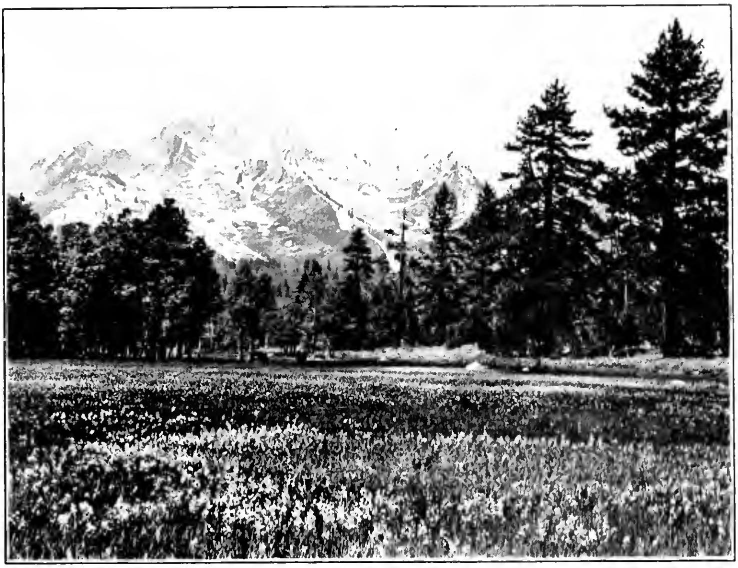


FIG. 33.—Mountain meadow in the high Sierra, one of the sources of the Truckee River. Photograph by Snyder.

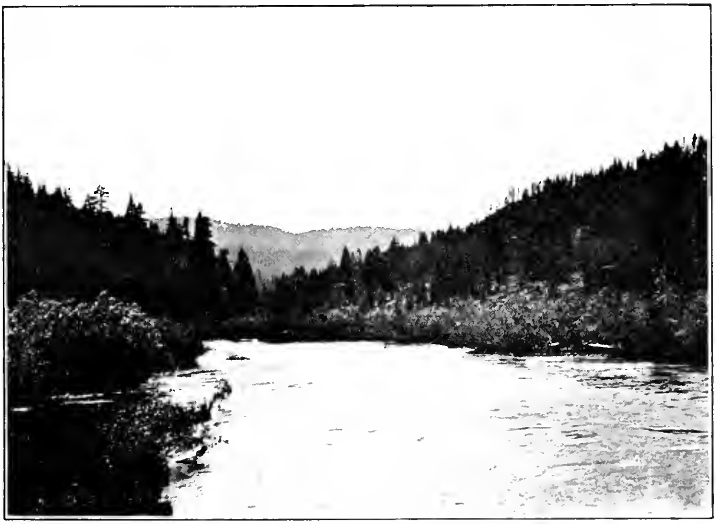


FIG. 34.—Truckee River, outlet of Lake Tahoe, California. Photograph by Snyder.

the region now included in northern Nevada and eastern California. It was no doubt a magnificent lake, including as it did a number of large and beautiful islands, with the great snow-capped wall of the Sierra on one side and the endless shimmering desert on the other. Even now, though dwindled and shrunken through desiccation, its glory has not all departed. For although one may travel for days over the wind-driven sands of its parched floor, the great terraces and castellated crags of its ancient shores tower at times hundreds of feet on either side, and there still remain a number of small though very beautiful lakes and several rivers of considerable size which were once tributaries of the greater lake. The waters of none of these reach the ocean but ultimately disappear through evaporation, or sink into the loose, dry sands of the desert.

FIG. 35.—Humboldt River near the Palisades, Nevada.
Photograph by Snyder.

Lake Tahoe, near the crest of the Sierras, 6,247 feet above the sea, has 195 square miles of clear water which reaches a depth of 1,645 feet. Its outlet, the Truckee River, plunges down 2,300 feet in a distance of about 100 miles, finally bifurcating and entering Pyramid and Winnemucca Lakes. The former is 30 miles long and 12 wide, the water having a depth of over 350 feet. It embraces some picturesque islands, two of which should be permanently reserved by the Government, for they shelter thousands of birds during the nesting season. Humboldt, Quinn, Walker, and Carson Rivers, and also Honey, Walker, and Carson Lakes are parts of this system.

FIG. 36.—The Needles, Pyramid Lake. Photograph by Paine.

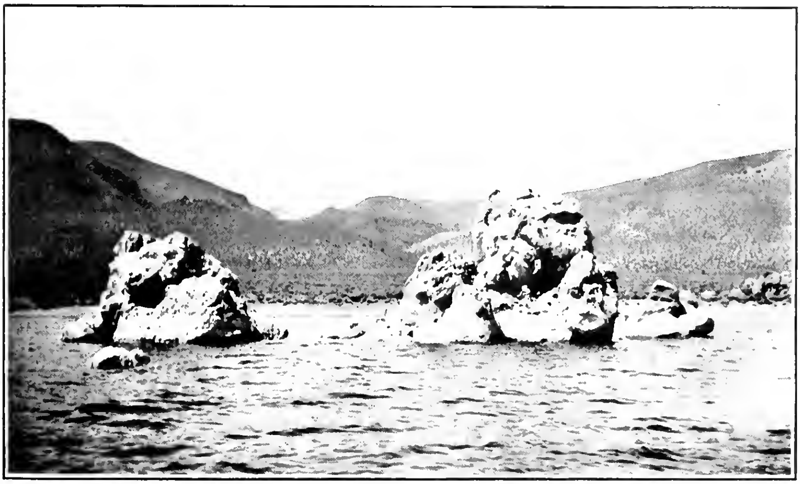


FIG. 37.—Tufa domes, Pyramid Lake. Photograph by Paine.

These rivers and lakes are well supplied with fishes, exceedingly abundant in number, although representing but a few species. Of chief interest and value among these are the trout which appear to have found here the most advantageous conditions for growth and development. At least 2 native species occur, *Salmo henshawi*, the large cut-throat which occasionally reaches a weight of over 20 lbs., and *S. regalis*, the royal silver trout, much smaller than the former, but a most beautiful fish, remarkable for the brilliant silver of its sides and the unparalleled blue of its dorsal surface. Formerly the lakes and rivers of the region fairly swarmed with trout, and during the spawning season they often entered the rivers in such numbers that it was difficult for them to find room in the channels. Several species of suckers and large minnows occur in countless numbers. Of these *Chasmistes cujus*, the Kouiewee of the Piute Indians, inhabits only Pyramid and Winnemucca Lakes. It lives in their depths, and is never seen until in the spring, when great schools suddenly appear at the mouth of the Truckee River, crowd up the channel and cover the bars, often pushing each other out of the water in their struggles to find room enough to deposit their eggs. Formerly this was an occasion of rejoicing among the Indians, for here were numbers of large, fat fishes which only need be kicked out of the water and hung on the bushes to dry. The Piutes still continue to cure them in large quantities for winter food. A small white fish abounds in favorable places. Some of the minnows reach a foot in length, bite

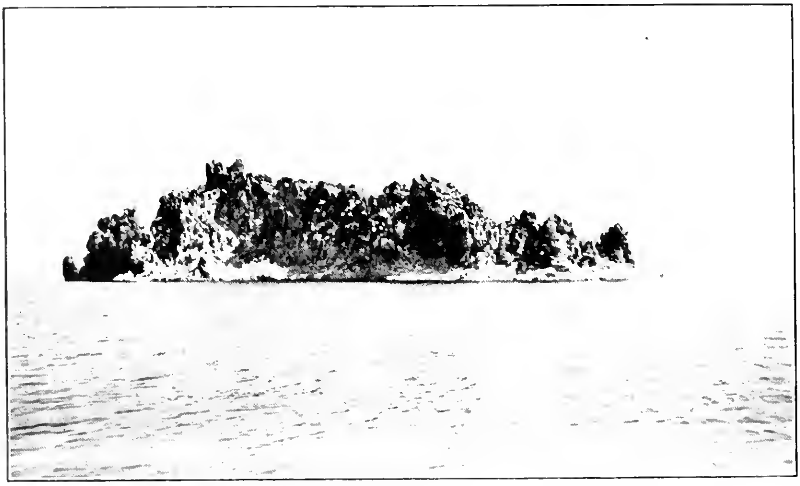


FIG. 38.—Bird Island, Pyramid Lake. Photograph by Paine.

a fly or small spoon, and occasionally contribute to the camper's breakfast.

A study of the fish fauna of the basin bears out the conclusions of geologists regarding its long isolation. Nearly all of the species are distinct from those of neighboring systems, and some belong to groups of very restricted distribution. An account of the fishes, their habits and distribution will appear in a future bulletin of the Bureau of Fisheries.

CACTUSES AND DESERT PLANTS FROM THE WEST INDIES AND SOUTHWESTERN UNITED STATES

Dr. J. N. Rose, associate in botany, U. S. National Museum (at present connected with the Carnegie Institution of Washington in the preparation of a monograph of the Cactaceae of America), accompanied by Messrs. William R. Fitch and Paul G. Russell, spent over ten weeks in travel and field-work in the West Indies in the spring of 1913. As this was an unusual opportunity to obtain very valuable material needed for the collections of the National Museum and for use in making exchanges, the Museum detailed Mr. Russell

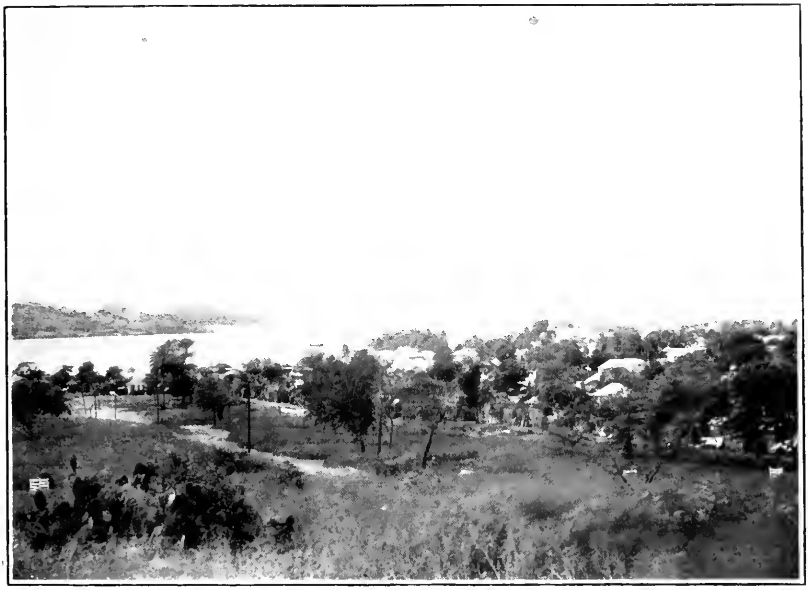


FIG. 39.—St. John's Harbour, British West Indies. The high point on the right is Rat Island, used as the Government Leper Asylum. Part of the town of St. John's is shown, the seat of government of the Leeward Islands under British control. Photograph by Russell.

for the trip. This expedition formed a part of the larger scheme of studying in the field the desert plants of both North and South America, which had been organized by Dr. N. L. Britton, Director of the New York Botanical Garden, and Doctor Rose, in connection with their Cactus Investigation for the Carnegie Institution of Washington. Doctor Britton also took a party to the West Indies.

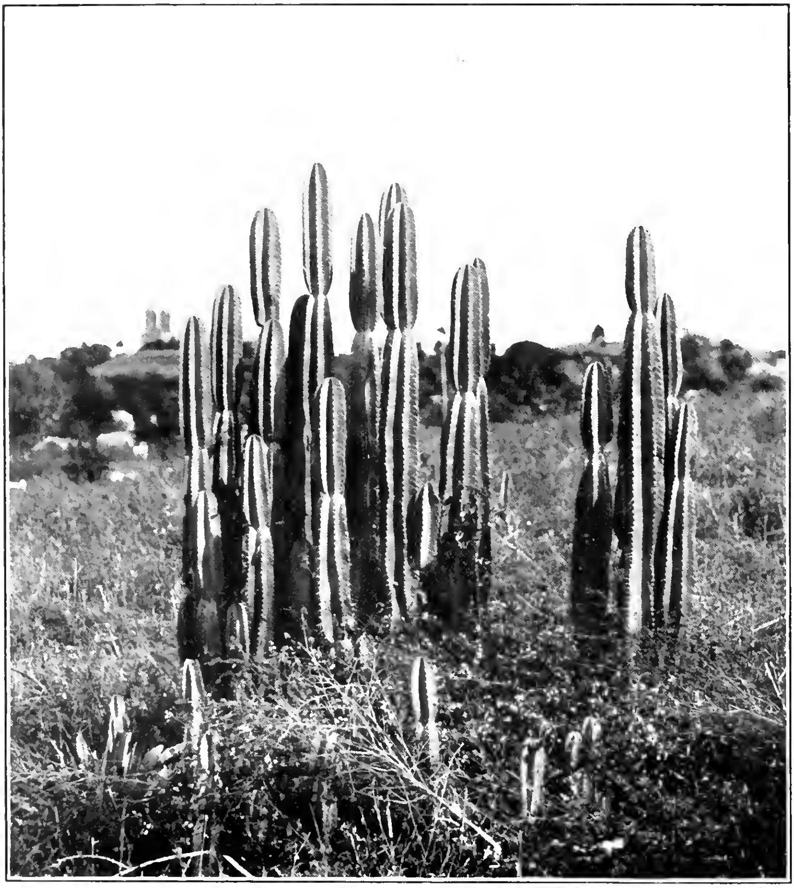


FIG. 40.—A Cereus (*C. lepidotus* Salm-Dyck) common on these islands. Near St. John's, Antigua. Photograph by Russell.

Both parties started from New York City January 25. Doctor Britton and his assistants explored St. Thomas, St. Jan and others of the Virgin Islands, Porto Rico, and Curacao. His collection consisted of more than 3,000 species, comprising two sets, one of which has been sent to the National Museum as an exchange.

FIG. 41.—A specimen of the Century plant (*Agave obducta* Trelease) showing an immature flowering stalk. Near English Harbour, Antigua. Photograph by Russell.

FIG. 42.—Specimens of the Melon-cactus (*Cactus intortus* Mill.) and Century plant (*Agave obducta* Trelease) on promontory near English Harbour, Antigua. English Harbour was once a fortified British stronghold. Admiral Nelson here fitted up part of his fleet for the Battle of Trafalgar. Photograph by Russell.

At the same time, Doctor Rose's party visited St. Thomas, St. Croix, St. Kitts, Antigua, and Santo Domingo. Knowing that the Museum greatly needed duplicates for exchange purposes, general collecting was done whenever possible. Dr. Rose's collection consisted of more than 1,200 species and about 7,000 specimens. Of these, one set has been mounted for the Museum and has become a part of the study series of the herbarium. A second set was sent to the New York Botanical Garden, while other sets have been sent to the Bureau of Science at Manila, and to the Royal Botanical Garden and Museum at Berlin, for use by Dr. I. Urban in the preparation of his Flora of Santo Domingo.

While especial attention was given to collecting the Cactus flora, a large general botanical collection was made. In this there are some new species, one in particular being a very remarkable Annona from the desert plain at Azua, Santo Domingo.

In addition to the herbarium material, 12 boxes and crates of living plants, chiefly Cacti, were sent from the West Indies by Doctor Rose, and two boxes of living plants were sent to Lady Katharine A. Hanbury's garden at La Mortola, Italy, in exchange for specimens and courtesies shown to Doctor Rose when in Europe in 1912.

Many packages of seeds, bulbs, cuttings, etc., were obtained for exchange purposes of the Museum or for study by the various workers in the U. S. Department of Agriculture.

PLANTS FROM SOUTHWESTERN UNITED STATES

In September and October, Doctor Rose, accompanied by Wm. R. Fitch, made extensive botanical collections in southeastern Colorado, New Mexico, and western and southern Texas. While the trip was made primarily for the purpose of collecting and studying the Cacti of this region, many other flowering plants were obtained, a full set of which has been mounted and placed in the National Herbarium.

THE FLORA OF WESTERN NORTH CAROLINA

During the latter part of August and early September, 1913, Mr. Paul C. Standley, of the Division of Plants, U. S. National Museum, and Mr. H. C. Bollman, of the Smithsonian Institution, spent four weeks camping in the mountains of western North Carolina, near Montreat, Buncombe County. Although undertaken primarily as a vacation trip, advantage was taken of the opportunity for study of the flora of this most interesting region. Over seven hundred specimens of plants were secured, besides small lots of some of the common and easily collected animals. Special attention was devoted to the mosses, hepatics, and lichens, in which the region abounds, and a representative collection of each of these groups was secured. Lists of the species of cryptogams have been prepared for publication.

FIG. 43.—Mountain brook near Montreat, North Carolina. Photograph by Standley.

The mountains of North Carolina are of great interest botanically, since they support a varied flora, many of whose components are not found elsewhere. Western North Carolina was visited by some of the earliest American botanists who collected here the types of many of the typically mountain plants. Although numerous botanists have explored the region, many of its divisions are still unexplored and yield rich returns to the collector.

About Montreat the mountains are covered with an almost virgin chestnut forest, traversed by numerous small, swift streams of clear, cold water, bordered with hemlocks. There is an abundant undergrowth of rhododendron and laurel, two of the handsomest of North American shrubs, which attain their greatest perfection in the southern Appalachians. The herbaceous vegetation consists of many species, some of them of limited distribution. A small sphagnum bog, in particular, yielded a large number of rare plants.

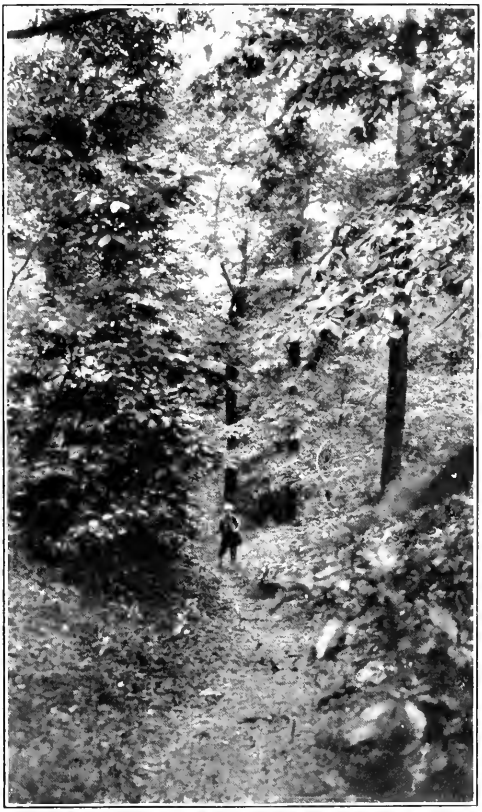


FIG. 44.—Chestnut forest near Montreat, North Carolina. Photograph by Standley.

The most interesting excursion made during the month's camp was to the summit of Mount Mitchell, the highest peak in eastern North America—6,710 feet. By trail, it is distant about sixteen miles from Montreat. The trail at first follows a logging railroad which is being extended into the mountains, then strikes through the heavy spruce and balsam forest covering the higher slopes. This primeval forest, which resembles in its general appearance those of the Rocky Mountains, unfortunately seems destined to disappear in the near future; indeed, it has already been removed from a large area, and desolation left in its stead. It is deeply to be regretted that as Mount Mitchell is made more accessible by the railroad its chief beauty will be destroyed.

A single night was spent on the summit of the mountain. A cabin was built here and maintained by the State some years ago, but it is now abandoned and has fallen into decay. At the summit of Mount Mitchell is a monument which marks the grave of the man whose name it bears, who lost his life while engaged in exploring its slopes. From this point at sunrise a wonderful view is obtained of the vast mass of mountains which cover the adjacent region, their valleys filled with a sea of clouds above which the higher peaks rise like rugged islands.

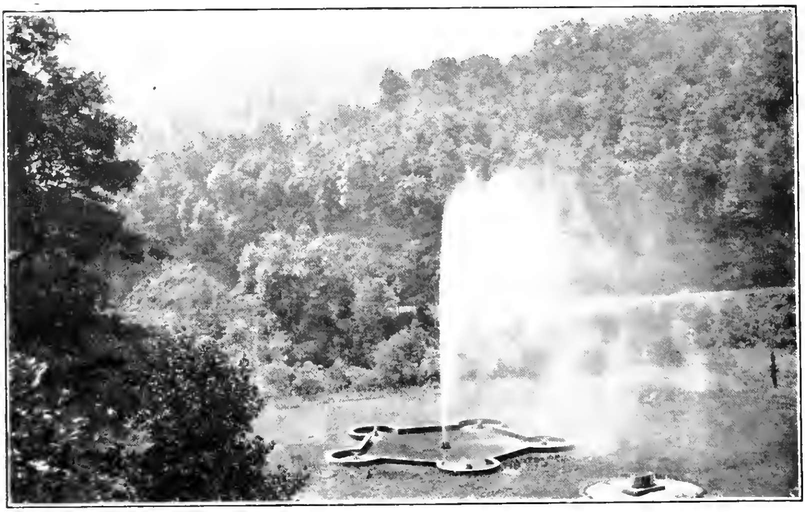


FIG. 45.—Artificial fountain near Black Mountain, North Carolina. It is fed from a reservoir on a neighboring mountain. Photograph by Standley.

A small collection of plants was made upon the peak, a locality whose flora is little known. The flora, strangely enough, is not particularly interesting, for it includes but few species. The vegetation is remarkable chiefly for the large number of introduced plants it includes. These have doubtless been transported by the visitors who ascend the mountain each year. In spite of the altitude of Mount

Mitchell, it yields none of the boreal plants which make the floras of the mountains of New England so interesting. The lower mountains of North Carolina, and some of the other high peaks, are much more interesting botanically than this, the loftiest of them all.

ANCIENT MICA MINES OF NORTH CAROLINA

In April, 1913, W. H. Holmes, head curator of the department of anthropology, visited the mica mines of western North Carolina, making such observations as seemed necessary for a reasonable comprehension of the nature and extent of the ancient operations.

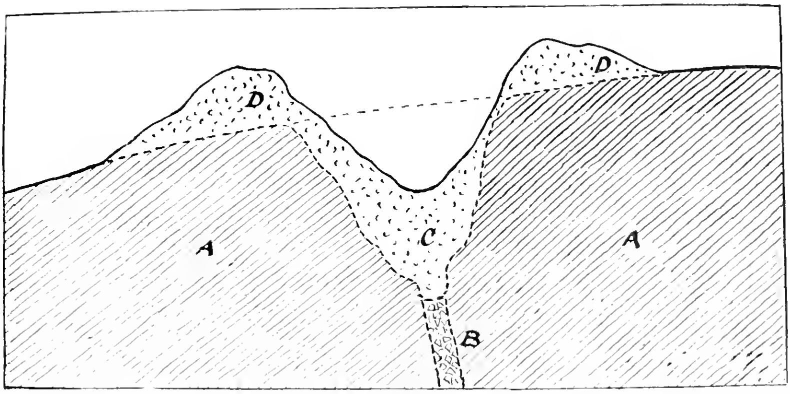


FIG. 46.—Section of an aboriginal mica mine: *A*, General schistose formation; *B*, Mica-bearing vein; *C*, Old digging partly filled up; D, Ancient dumps.

Mica was in very general use among the Indian tribes east of the Great Plains and was mined by them at many points in the Appalachian highlands from Georgia to the St. Lawrence River. From these sources it passed by trade or otherwise to remote parts of the country and is found especially in burial mounds, stone graves, and ordinary burials throughout the Mississippi Valley. The crystals of mica are of diversified shapes and sizes, reaching in some cases upwards of two feet in dimensions. They separate readily into sheets of very attractive appearance, which are transparent or translucent, displaying various silvery and amber hues. Mica crystals occur distributed through narrow veins of quartz and feldspar which extend at various angles through the inclosing schistose formations.

Although probably serving few practical purposes the sheets were highly prized by the aborigines for the manufacture of personal ornaments and for sacrificial and mortuary purposes. It is stated on good authority also that they were used as mirrors.

Mr. Holmes visited a number of mines in the vicinity of Sprucetree and Bandana, Yancey County, and near Bakersville in Mitchell County. The most important workings in the first mentioned locality are known as the Sink Hole mines, near Bandana. Although these mines have been operated extensively in recent years, sufficient traces of the old work remain to convey a fair notion of the nature and extent of the prehistoric mining. There are two main groups of pittings, each approximately 1,000 feet in length and 20 to 60 feet in width. The original depth in many cases was upwards of 40 feet, but recent operations of white miners have served to change their appearance, and to fill up the deeper excavations. The pittings are surrounded by a somewhat uneven ridge of detritus derived from the excavations, which has been added to in places by the modern miners, and has been dug into of late years to recover the mica rejected and thrown out by the aborigines.

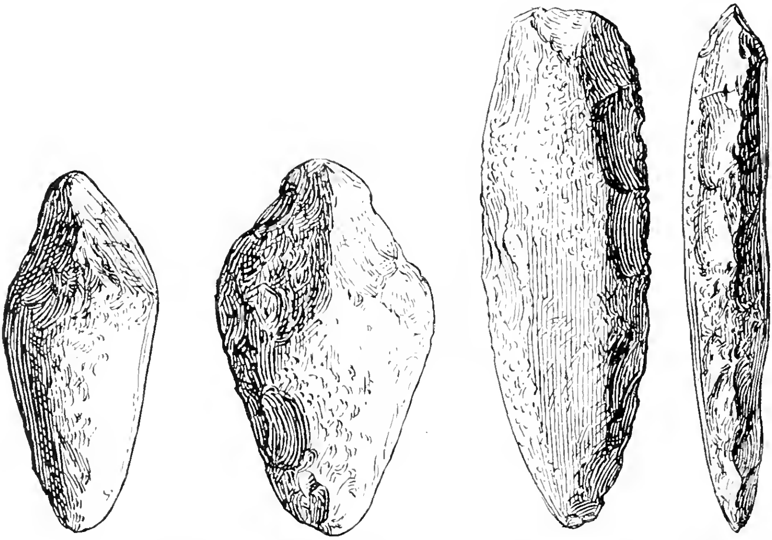


FIG. 47.—Stone picks used in excavating and freeing the crystals of Mica.

An important site of the ancient operations now known as the Clarissa mine, three miles east of Bakersville, Mitchell County, was also visited. This is probably the best preserved and most striking of the aboriginal workings in this general region, and serves to illustrate the importance of the mica industry in prehistoric times. Entering a low ridge at an oblique angle, the excavation reaches a depth of nearly 100 feet. The outer margin is buried beneath heavy bodies of ancient dump material which now supports numerous chestnut trees, the trunks of which are four or five feet in diameter. The modern operators of the mine who have worked the vein at the upper end to the depth of 300 feet have filled the old trenches deserted by the aborigines.

So far as could be determined, the implements used in excavating the decomposed schists and breaking up the vein material, thus freeing the mica crystals, were rude picks and hammers of stone, a few examples of which were found. Drawings of these are shown in figure 47.

Mr. Holmes extended his reconnoissance into South Carolina, where an ancient mound of large dimensions, situated twelve miles below Columbia on the Congaree River, was examined. A plan of the mound was made, and an examination of an ancient burial site on the edge of the mound yielded numerous relics of pottery and stone.

Near Waynesboro, Georgia, a number of ancient village sites and certain outcrops of flint, where the aborigines had obtained the material for their implements, were examined. Later, in the spring, Mr. Holmes visited St. Louis, Missouri, with the view of studying the very interesting collections owned in that city, and accompanied by Mr. Gerard Fowke spent a day at Mill Creek, Illinois, making collections on the ancient quarry and shop sites of that locality. He later extended his excursion to Davenport, Madison, Milwaukee, Chicago, and Columbus, for the purpose of making studies in the museums of those cities.

ANTHROPOLOGICAL EXPLORATION IN PERU

Dr. Aleš Hrdlička, of the National Museum, has made a second report[1] concerning his field-work in Peru during the past year, in connection with the Panama-California Exposition at San Diego, for which a very important exhibit in physical anthropology is being prepared. The investigations extended over several hundred miles of the Peruvian coast and over hitherto unexplored regions in the western Cordilleras. The objects of this trip, which occupied the first four months of 1913, were to determine the anthropological relations

---

[1] Anthropological Work in Peru in 1913, with Notes on the Pathology of the Ancient Peruvians. Smithsonian Misc. Coll., Vol. 61, No. 18, 1914.

of the ancient Peruvians of the mountains with those of the coast, and to extend the investigations which Dr. Hrdlička has carried on for many years, regarding Indian and especially pre-Columbian pathology.

The expedition was a very strenuous one, but proved remarkably successful. Over 100 ancient cemeteries and many ruins, a large percentage of which were previously unknown to science, were examined and over 30 boxes of skulls and other material for future study were collected for the U. S. National Museum and the Museum at San Diego.

FIG. 48.—The picturesque town of Huarochiri, in the western Cordillera of central Peru. Photograph by Hrdlička.

Dr. Hrdlička reports that skeletal material, which formerly abounded in Peru and is essential to scientific research, is fast disappearing, and in a few years can not be gathered without the expenditure of much time and money.

The results of the expedition will prove of unusual value to anthropology. While some of the links in the chain of evidence are still missing, it can now be said with certainty that the Peruvian coast from Chiclayo, in the north, to Yauca, in the south—a distance of over 600 miles—was peopled predominantly before the advent of the whites by one and the same physical type of Indian. These Indians were of medium height, with short and broad skulls, and moderately to strongly developed muscles according to the locality. The most important fact ascertained in this connection was that both the Chimu and Nascas, two of the foremost cultural groups of ancient Peru, were identical and, as regards physical characteristics, inseparable parts of this coast people.

FIG. 49.—The ruins of the Incaic Temple of the Sun, at Pachacamac, Peru. Photograph by Hrdlička.

According to their location, the people of old Peru were either fishermen or farmers. They seem to have been organized into numerous political groups, which developed smaller or greater cultural differences according to environment and other influences.

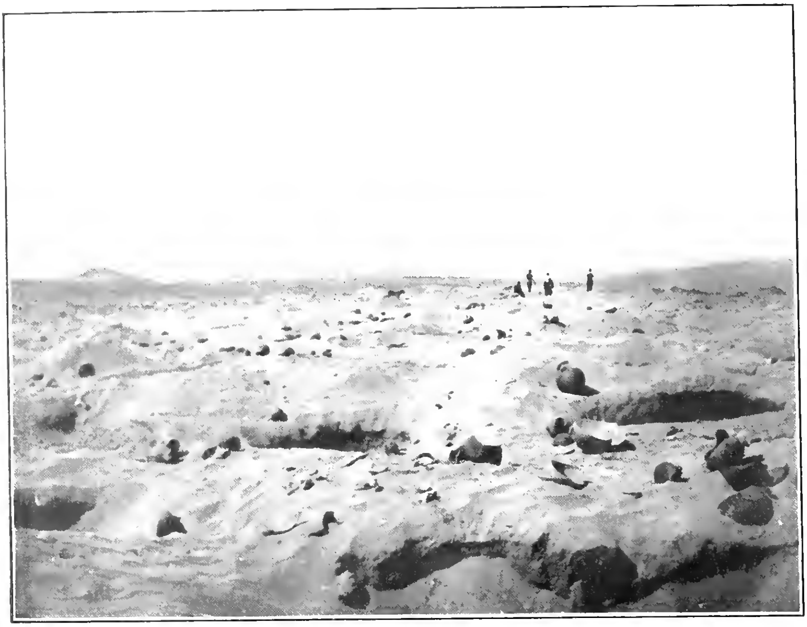


FIG. 50.—Ancient cemetery in Peru; a typical example of the waste of pottery and bones by the despoiling peons. Photograph by Hrdlička.

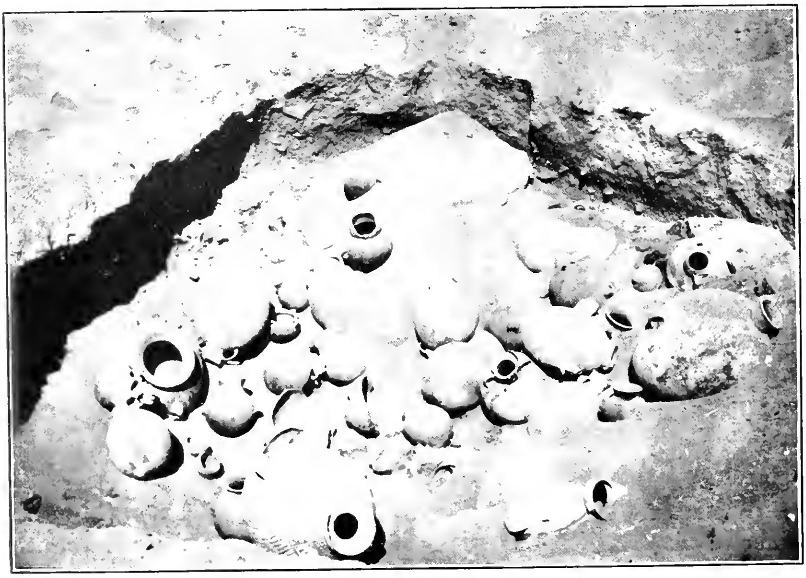


FIG. 51.—Cache, by the explorer, of ancient pottery left behind by vandals after despoliation of a cemetery south of Huacho, Peru. Photograph by Hrdlička.

Some of their smaller dwellings were made of reeds, while larger structures were built of small uncut stones, sun-dried brick, or blocks of adobe. Their knowledge of weaving, pottery-making, and decoration was surprising. They wove from native cotton and llama wool, and their designs indicate changes brought about by time and other influences. The native dress consisted principally of a poncho shirt, a loin cloth, and sandals, with occasionally a simple head-gear.

The pre-Columbian Peruvians of the coast knew the uses of gold, silver, and copper, and worked these metals to some extent, especially copper or "bronze" in the manufacture of weapons. Their common weapons were a metal or stone mace, a wooden club, a copper axe and knife, the sling, and in some regions the bow and arrow. Their implements were the whorl, weaving sticks, looms, cactus-spine or bone needle, bone needle-holders, sharpened sticks, copper knives and axes, hoes and fishing paraphernalia, including nets, sinkers, reed-bundle boats or balsas, and peculiar rafts which were paddled.

FIG. 52.—Indian hut and inhabitants, with a ruin-covered hill known at Llaxwa, in the rear, located in the Sierras, south-east of Nasca, Peru. Photograph by Hrdlička.

Throughout the whole territory along the coast the people deformed the heads of their infants by applying pressure to the forehead probably by means of pads and bandages, which process flattened the back of the head as well. They did not practice filing, cutting, or chipping the teeth, or other mutilations which would leave marks on the skeletons.

These natives seem to have been free from general bodily ailments before the advent of the white men; on the other hand they suffered from several peculiar local diseases affecting the hip-bone, the head, and the ear.

FIG. 53.—A party of vandals in an old cemetery on the railroad from Ancon to Huacho, Peru. Photograph by Hrdlička.

The people of the mountains possessed a good average development of the body and of the skull, and were even freer than the coast people from disease. Wounds were, however, common, and in some of the districts serious wounds of the head were frequently followed by the operation known as trepaning, and although this was often crudely done, it was successful in many cases. This practice was probably carried on even after the coming of the Spaniards.

The results of the expedition failed to strengthen the theories of any great antiquity of man in Peru, tending rather to prove the contrary. Aside from the cemeteries or burial caves of the common coast or mountain people, and their archeological remains, there was no sign of human occupation of these regions. Not a trace suggesting anything older than the well-represented pre-Columbian Indian was found anywhere; and neither the coast nor the mountain population, so far as studied, can be regarded as very ancient in the regions they inhabited. No signs indicated that any group occupied any of the sites for even as long as 20 centuries; nor does it seem that any of these people developed their culture, except in some particulars, in these places.

ARCHEOLOGICAL EXPLORATIONS IN WESTERN NEW MEXICO

Mr. F. W. Hodge, ethnologist-in-charge of the Bureau of American Ethnology, in the early autum of 1913 made a reconnoissance of a group of ruins on a mesa rising from the southwestern margin of the Cebollita valley, about 20 miles south of Grant, Valencia County, New Mexico, and only a few yards from the great lava flow that has spread over the valley to the westward for many miles. While no very definite information regarding the origin of this ruined pueblo

Fig. 54.—Character of masonry shown in one of the house-groups of the compound. Note the failure of the builders to "break" the joints and the consequent weakening of an otherwise excellent wall. The face of the stones is pecked to smoothness and all the stones are artificially squared. Photograph by Nusbaum.

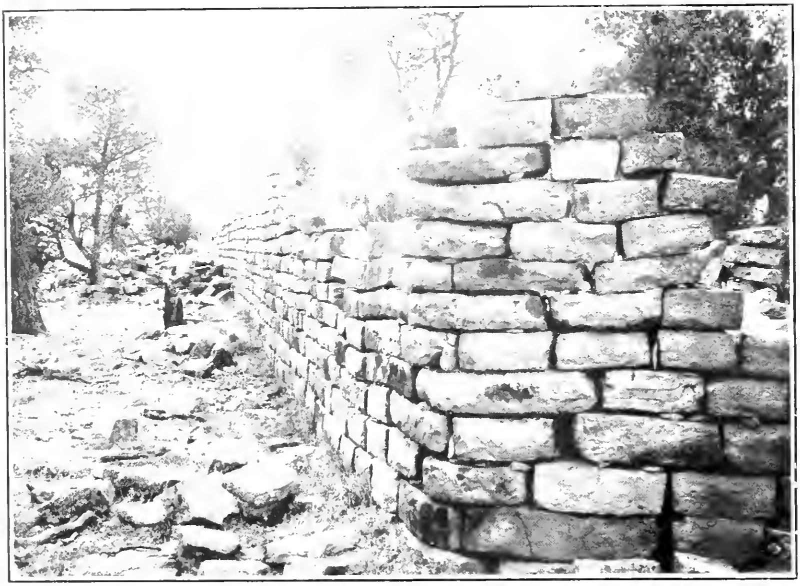


FIG. 55.—Stone outer wall of a defensive structure near the mesa rim. This wall is about 132 feet long in the clear, and is pierced only by small loopholes. Photograph by Nusbaum.

FIG. 56.—Skeleton, with burial accompaniments, found in a small cist. Photograph by Nusbaum.

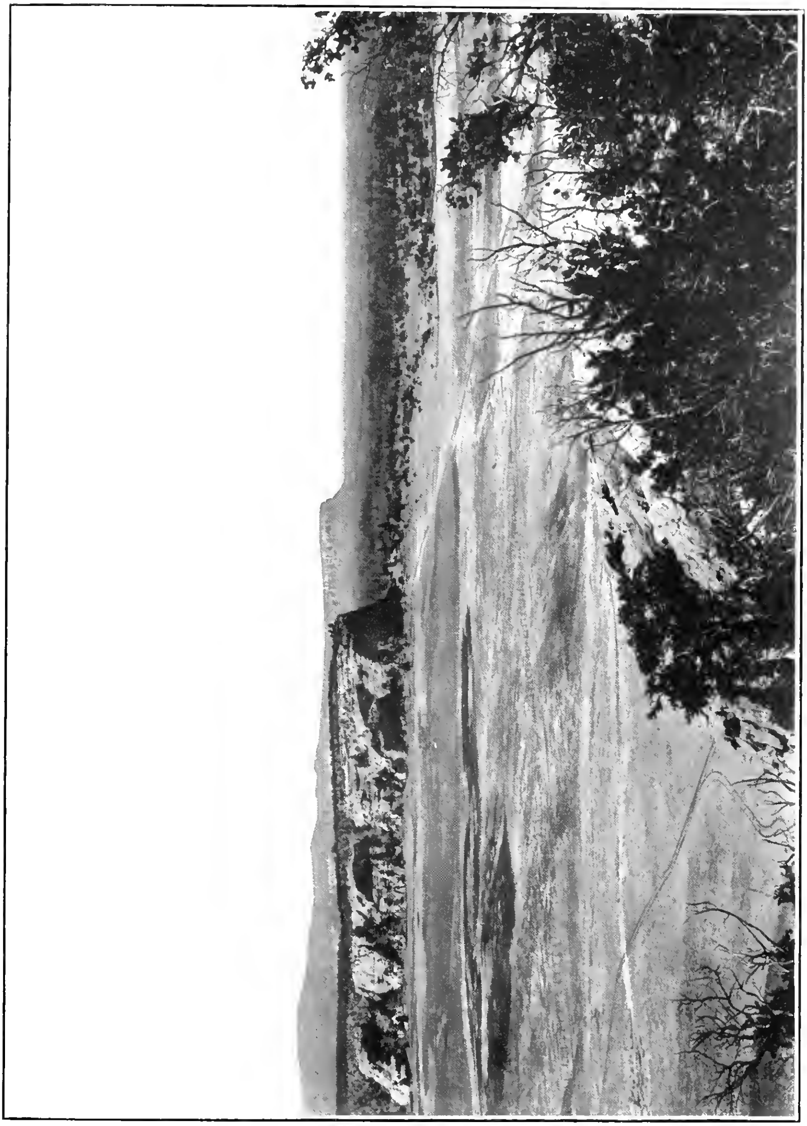


FIG. 57.—View southward across Cebollita valley, New Mexico. The lower mesa across the valley is that on the summit of which are situated the chief ruins described. Photograph by Nusbaum.

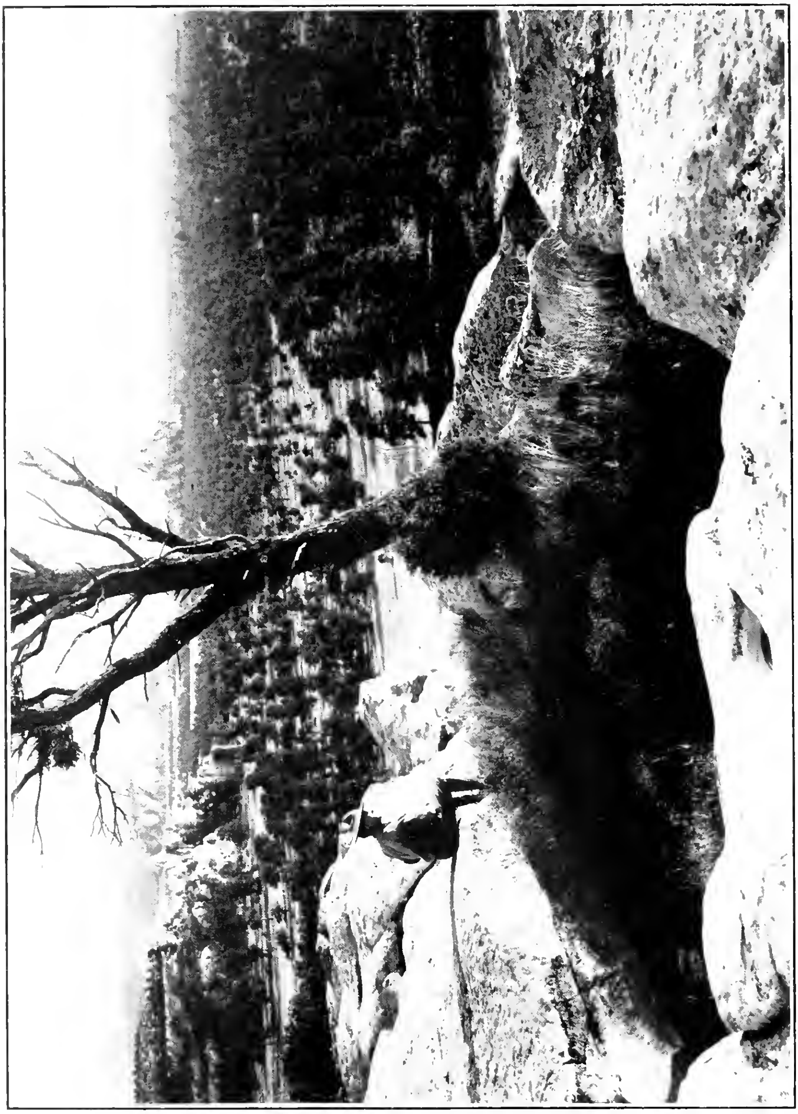


Fig. 58.—Smaller reservoir, probably chiefly a natural depression, in the rocky floor of the mesa-top; looking southward. Photograph by Nusbaum.

has yet been obtained, there is reason to suppose that it was occupied by ancestors of the Tanyi, or Calabash, clan of the Acoma tribe, and is possibly the one known to them as Kowina.

These ruins consist of a number of house-groups forming a compound, built on an almost impregnable height, and designed for defence; not only the groups but the individual houses have the form of fortifications, while the vulnerable point of the mesa rim is protected by means of a rude breastwork of stones.

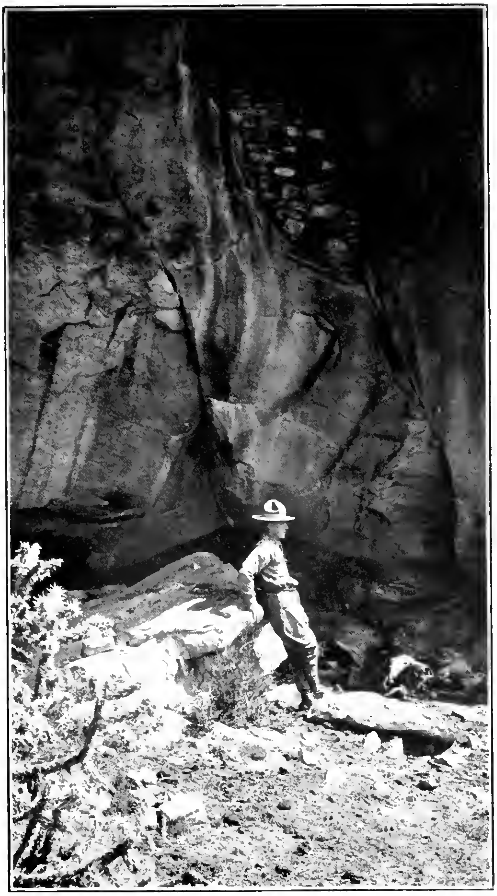


FIG. 59.—Small cliff-house on the northern side of Cebollita valley. Photograph by Nusbaum.

The outer wall, which protects the whole mesa, is built of exceptionally fine masonry, probably the finest work to be found in ancient pueblo ruins of the Southwest. The building stones have been dressed to shape, matched for size, and their faces finished by pecking, with such labor as to confirm the belief that this ancient village was designed for permanent occupancy. Altogether the work proves of great interest, and it is suprising to note the one failing, on the part of these early builders: they seem to have been unaware of the necessity of breaking the vertical joints in the courses of masonry, thus causing many weak points in the otherwise excellent walls.

Among the special features of interest which Mr. Hodge discovered were a burial cist where skeletons, pottery, and the remains of a mat were found; three small cliff lodges situated in the sides of the cliffs; several ceremonial rooms or kivas associated with the ruined houses, and the remains of the early reservoirs of the inhabitants.

A full report on the exploration of this interesting pueblo will be made by Mr. Hodge in a later publication.

ANTIQUITIES OF THE WEST INDIES

Dr. J. Walter Fewkes, ethnologist in the Bureau of American Ethnology, spent January, February, March, and part of April, 1913, in the West Indies, studying the prehistoric antiquities of the Lesser Antilles, and gathering material for a proposed monograph on the aborigines of these islands. He examined numerous local collections, and visited many village sites, prehistoric mounds, shellheaps, and bowlders bearing incised pictographs.

The most extensive excavations during these months were made at Erin Bay, Trinidad, in a shellheap of considerable size, where he found a valuable collection of animal heads made of terra cotta and stone, and other objects illustrating the early culture of that island. From Trinidad he went to Barbados, where he found evidences of the former existence of cave people living in a shell age or one in which stone was replaced by shell. Excavations were later made at a village site of the Black Caribs at Banana Bay, Balliceaux, a small island near St. Vincent, and a small collection was gathered from it.

He obtained many drawings of specimens in a rich collection from St. Kitts and Nevis, owned by Mr. Connell, and examined the shellheaps at Salt River, Christianstadt, St. Croix, and at Indian River, Barbados. The collection of prehistoric objects obtained from St. Croix, Danish West Indies, was ample to prove that the early culture of the inhabitants of this island was more closely related to the culture of Porto Rico than to that of St. Vincent. The material obtained in this field-work will be embodied in a report which Dr. Fewkes has in preparation on the magnificent collection of West Indian prehistoric objects owned by George G. Heye, Esq., of New York. The exploration was done in coöperation with the Heye Museum.

Field-work in the West Indian islands was supplemented by a visit to those museums in Europe where extensive Antillean collections exist. August, September, and October were devoted to studying prehistoric West Indian objects in Berlin, Bremen, Copenhagen, Vienna, and Leipzig. While in the first mentioned city he employed Mr. W. von den Steinen to make drawings of the originals of the Guesde Collection and many other objects from Hayti, Porto Rico, and the Lesser Antilles.

In the Bremen Museum a stone collar was found to have its knob modified into a reptilean head, an unique feature that would seem to shed light on the meaning of these objects. The Museum at Copenhagen has a rare ceremonial celt connecting petaloid stone axes with stone heads.

These field-studies and examinations of museum specimens have led Dr. Fewkes to the conclusion that in prehistoric times there existed in the Antilles a race of sedentary people having a form of culture extending from Trinidad to Porto Rico. This culture differed in minor details, in the various islands, as the style of stone implements, pottery, and other objects of material culture in all these islands shows. It was preceded by a life in caves which survived in western Cuba and the western peninsula of Hayti down to the time of the discovery by Columbus. The Caribs, who came comparatively late, brought a different culture that overlaid and, in a measure, absorbed the preceding culture in the Lesser Antilles. In other words, evidences were found of at least three distinct types of culture in the Lesser Antilles: cave, agricultural, and Carib. The second or agricultural type was found to have the subdivisions localized in the following groups of islands: Cuba, Santo Domingo, and Porto Rico; St. Kitts, including Nevis; the volcanic chain of islands from Guadeloupe to Grenada; Barbados; and Trinidad.

As with all other sciences, the highest form of research in culture history is comparative. It is universally conceded that the race inhabiting the New World, when discovered, had not advanced in autochthonous development beyond the neolithic age, whereas in Asia, Europe, and Africa a neolithic age was supplemented by one in which metals had replaced stone for implements. In the Old World this polished stone epoch had been preceded by a paleolithic stone age not represented, so far as is known, in America. The ethnology and archeology of our Indians therefore form only a chapter, and that a brief one, or a segment of a much more extended racial evolution, as illustrated in Asia, Europe, and Africa.

It is profitable to compare the neolithic stone ages in the New World and the Old in order to appreciate rightly the position of the American Indian in the advance of human history, and his relation to the dawn of human history.

In order to carry on comparative studies of the stone age of aboriginal America and the corresponding age in the Old World, Dr. Fewkes spent six months in field and museum work in Europe and Africa. He visited the prehistoric mounds, dolmens, and megalithic monuments at Stendal and Stöckheim in Altmark, a short distance from Berlin, and examined the finely installed collections from these localities in local museums. He also visited the island of Rügen, in the North Sea, where there are many prehistoric mounds, Huns' graves, workshops, and megalithic and other remains of the neolithic inhabitants. The many antiquities from this island in the museum at Stralsund furnished considerable data for a comparative study of artifacts from this part of Europe with similar objects from North America.

Dr. Fewkes believes that the time is past when the great ruins in our Southwest should be left to destruction by the elements, after smaller objects have been extracted from them. In order to protect these ruins he has inaugurated, under the direction of the Smithsonian Institution, at Casa Grande, Spruce-tree House, and Cliff Palace, a scientific method of excavation and repair. In order to improve his methods by becoming better acquainted with excavation and repair work adopted by the ablest European archeologists, he visited Egypt, Greece, and Italy (Pompeii).

He found in some cases that whereas repair work in the Old World is often neglected and cannot be called very scientific, and some of the excavated ruins have been left in very bad condition for future students, the majority are being carefully protected after excavation, in a manner well worth study by those who aspire to the most advanced standards.

The best archeological repair work in Egypt may be seen on the Temple of Amen Ra at Karnak, and the mortuary temples, the Ramesseum, Medinet-Habu, and the Seteum, from which were obtained valuable suggestions. The admirable repair of the hypo-style hall of the Temple of Amen Ra, by M. Le Grain, is the most important ever attempted on an ancient building.

Part of his time in Egypt was devoted to comparative problems, and he was also able to give some attention, all too limited, to evidences of convergence and parallelism in the neolithic or predynastic culture of the Nile Valley with that of the Gila. He investigated more especially remarkable lines of similarity in artificial methods of water supply, in both regions, and the influence of coöperation of predynastic villages in building great irrigation canals, on the development of a higher social organization. He had always in mind the collection of material bearing on interrelationship of climatic conditions and early culture in the Nile Valley.

AMONG THE EAST CHEROKEE INDIANS OF NORTH CAROLINA

Mr. James Mooney, ethnologist in the Bureau of American Ethnology, spent the summer of 1913, June 18 to October 4, inclusive, with the East Cherokee Indians in the mountains of western North Carolina, among whom he had made his first field studies in 1887. These Indians, numbering some 1,900, live upon a small reservation in Swain and Jackson Counties with several outlying settlements farther to the west. They are a part of the historic Cherokee Nation formerly holding the whole mountain region of the southern Alleghenies until removed by military force in 1838 to the Indian Territory, where they now number about 30,000 of pure or mixed blood. Those in North Carolina are the descendants of some hundreds who made their escape from the troops and were finally, through the good offices of their friend, Col. Wm. H. Thomas, allowed to remain and settle upon lands purchased for them with their share of the fund originally appropriated for their removal to the west. There are still living among them several who remember the removal.

Constituting from the beginning the most conservative and pure-blooded element of the tribe, protected by their mountain barriers from outside influences and never having been subjected to the shock of forced removal to a distant and strange environment, these East Cherokees remain to-day the conservators of the ancient traditions, and exemplars of the aboriginal life once common in varying degree to all the tribes of the Gulf States. Until 1881, when the first school was established, they continued virtually unchanged. Since then, schools, railroads, and lumber industries have made rapid advance, which, with the passing of the older generation, must before many years bring to a close the Indian period.

On this occasion, Mr. Mooney made headquarters in the largest and most conservative settlement, locally known as Raven Town or Big Cove, some 12 miles from the agency, over a very rough mountain road impassable for vehicles during a part of the year. Here, shut in by the highest peaks east of the Mississippi, some 500 Indians dwell in fairly comfortable two-room log cabins perched high up on the slopes of the mountains, always near a convenient spring. They till their fields of corn and beans, which extend sometimes even up to the crest of the ridge Some have oxen, and a few have horses, but the great majority cultivate their fields by hand, and travel always on foot.

FIG. 60.—Cherokee potter; Katâlsta, daughter of Yânagûski, "Drowning Bear," Head chief of the East Cherokee about 1838. Photograph by Mooney.

While many are nominally Christians, and most of the younger people can speak English, they still, as a community, adhere to their ancient rites of the Green Corn dance, the "going to water" at every new moon, the fishing and hunting charms, the medicine man, and the native ball game. Many of the women are expert in basket making, in a variety of patterns, but the pottery art, which flourished a few years ago, is now virtually extinct. The blow-gun, formerly used for shooting small game, is now almost a thing of the past, together with the head turban and the moccasin.

Although the outer life and semblance are thus altered, the possession of a native alphabet or syllabary, invented by a mixed blood of the tribe nearly a century ago, has enabled their priests and doctors to preserve their ancient ritual prayers and formulas without change and apparently almost without diminution from the remote past. By good fortune some twenty-five years ago Mr. Mooney was enabled to obtain some hundreds of these Cherokee manuscript formulas, the secret possession of their leading priests. Many others have been obtained on later visits, in addition to much miscellaneous ethnologic material, until the collection now numbers approximately 600 formulas, perhaps the equivalent of as many printed quarto pages, covering every occasion of Indian life, war, love, hunting, fishing, agriculture, medicine, games and ceremonials. This collection of aboriginal American literature is unique and without parallel. As a revelation of primitive psychology it is invaluable. The antiquity of the formulas is sufficiently indicated by the abundance of archaic forms and references, many of which cannot now be explained even by the priests, who simply say, "This is the way it was given to us." Many of these formulas are highly poetic.

The explanation of those originally obtained, almost one-half the whole collection, was procured from the principal recognized priests of that time, all of whom are now dead. At the same time, all the words of the formulas were glossarized, and all the plants mentioned in the medical prescriptions collected, and labeled with their Indian names, and later identified botanically by experts of the Smithsonian Institution. Other formulas have been translated and explained during subsequent visits. During the last summer the number was considerably enlarged by the best known teachers. All those then untranslated were translated and glossarized, and the additional plants named therein collected. The whole body was then revised from the beginning, so that nearly every formula has now had the interpretation of at least three recognized authorities. There is still a paucity in certain classes as compared with others, notably in the formulas relating to war and to the ball play, as compared with those relating to medicine and love. This deficiency may be supplied by future gatherings, but for the formulas already translated, it may be confidently affirmed that no important additional light is now procurable.

While the formulas constitute the largest body of aboriginal American literature extant, the plant collection constitutes probably the largest ethno-botanic collection from any one tribe, comprising some 700 species with Cherokee names and uses, nearly all of which have been scientifically identified by expert botanists. This collection represents the combined plant knowledge of the principal doctors in the tribe.

Opportunity was also afforded for special studies and observations, particularly of the ceremonial "going to water," and augury with the beads to forecast the health prospect and life-span of each member of the family, before partaking of the first corn of the new crop.

CEREMONIAL DANCES OF THE CREEKS IN OKLAHOMA

In July and August, Dr. John R. Swanton of the Bureau of Ethnology visited the territory of the old Creek Nation in Oklahoma, to attend several of the ceremonial dances or busks about which he had collected much information in previous years. He witnessed four of these ceremonials; that of the Eufaula Creeks near Eufaula, McIntosh County, those of the Hilibi and Fish Pond Creeks near Hanna, in Hughes County, and that of the Tukaba'tci near Yeager. Notes were taken on all of them and a number of photographs were obtained of the first three. Considerable supplementary information

FIG. 61.—The "Feather" dance, Fish Pond square ground. Photograph by Swanton.

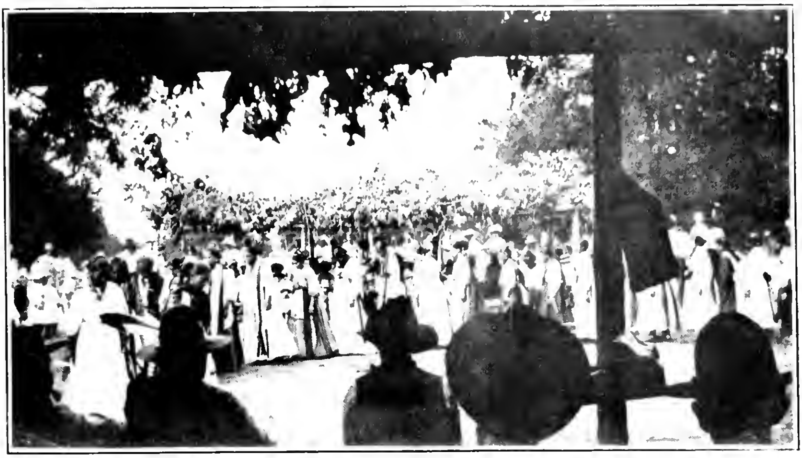


FIG. 62.—The women's dance, Fish Pond square ground. Photograph by Swanton.

FIG. 63.—"Feather" dance, Hilibi square ground. Photograph by Swanton.

was secured from the older men regarding the busk ceremonial and other ancient usages.

When the ceremonies were over Dr. Swanton visited the Indians in Seminole County, who still speak Hitchiti, a language formerly current throughout southern Georgia, and recorded several texts. He also secured the coöperation of a Hitchiti Indian, able to write in the missionary alphabet, to obtain other texts after his departure.

CEREMONIES AND RITUALS OF THE OSAGE

During the year 1913, Mr. Francis LaFlesche of the Bureau of American Ethnology secured the songs and rituals of five different Osage ceremonies. Two of these are practically complete; the others are fragmentary, but enough information was obtained to give a fair idea as to their significance. These rites are: Wa-dó-ka We-ko, Scalp Ceremony; Wa-zhiń-ga-o, Bird Ceremony for boys; Wa-wa-tho*n*, Peace Ceremony; Zhi*n*-gá-zhi*n*-ga Zha-zhe Tha-dse, Naming of a Child; and We-xthe-xthe, Tattooing Ceremony.

Owing to the superstitious hold these rites still have upon the people, together with the fact that every initiated person obtained his knowledge at a great expense, it was almost impossible to procure complete texts of any of the ceremonies.

The Tattooing Ceremony is of peculiar interest. It was more difficult to secure information concerning it than of any other ceremony. In earlier times only the warrior who had won war honors was entitled to have the ceremony performed and have the war symbols tattooed upon his body. If his means permitted it, they might also be placed upon any number of his relatives. These war symbols were his marks of distinction as a man of valor, for the strength and life of the tribe depended upon the prowess of the warriors. In those days there were but few who were entitled to have the ceremony performed, because war honors were not easily won and few were wealthy enough to afford the expense of the ceremonies. When, during the last century, wars between the various tribes ceased, the real significance of the rite vanished, but the superstitious belief that the symbolic figures meant long life to the individual so tattooed, remained prominently in the minds of the people.

About the time that the right of the honored warrior to the exclusive use of the Tattooing Ceremonies came to an end, a new condition arose which materially changed the character of the rite. From the sales of lands to the United States the Osage tribe acquired a wealth by which a greater number of its members were enabled to have performed the tattooing, as well as other ceremonies. It was then that this ancient rite became the means by which any individual could publicly display his affection toward a relative.

FIG 64.—An Osage Indian with tattooing.

Figure 64 shows designs tattooed upon the body of a man. Those on a woman are more elaborate and cover the upper part of her body, breast and back, and the lower part of her legs. Figure 65 shows three implements used in tattooing. Each of these is made of wood about the length of a pencil. To the lower end are attached needles arranged in a straight row, and to the upper end are fastened four small rattles made of the large wing quills of the pelican. This bird is referred to in one of the dream rituals as, Mo*n*-thi*n*-the-do*n*-ts'a-ge, He-who-becomes-very-old-while-yet-going. In certain passages of the ritual it is intimated that these implements were originally made of the wing bone of this bird and were used for doctoring as well as for tattooing.

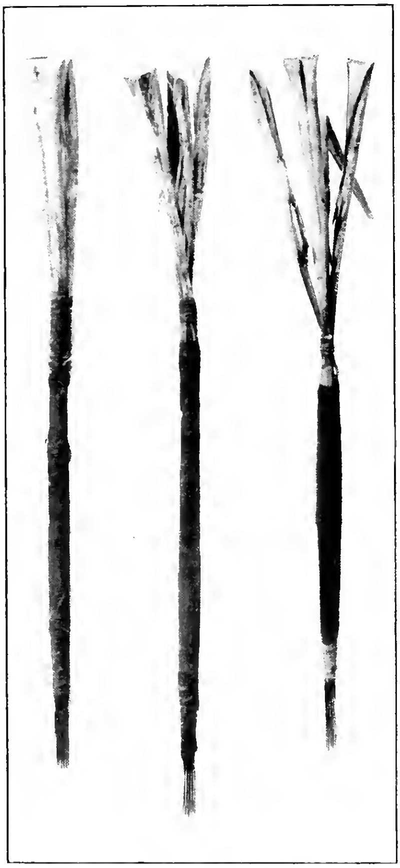


Fig. 65.—Three implements used in Osage tattooing. Photograph by DeLancey Gill.

The coloring matter employed in tattooing is made of charcoal mixed with kettle black and water. The charcoal is made from certain trees that serve as symbols of long life in the war ceremonies. Tail feathers of the pileated woodpecker are used for putting on the ink and drawing the lines.

On November 17, 1910, Wa-çé-to*n*-zhi*n*-ga, one of the prominent men of the Pa-çi-u-gthi*n* band (Hill-top Dwellers) died. It was learned that he had a Wa-xó-be-to*n*-ga, a Great Wa-xó-be. This is a white pelican, the bird which is supposed to have revealed, through a dream, the mysteries of tattooing and to have supplied the implements. On February 16, 1911, Wa-çé-to*n*-zhi*n*-ga's widow after much persuasion reluctantly consented to part with this sacred object (the Great Wa-xó-be), together with its buffalo hair and rush mat cases. It was thus secured by the writer, and now has a place in the United States National Museum.

A STUDY OF SIOUX MUSIC

The field-work of Miss Frances Densmore during the season of 1913 was concentrated on the southern portion of the Standing Rock reservation, which lies in the State of South Dakota. Many acquaintances had been made on a previous visit to the locality, and the earlier knowledge gained of the Indians opened the way for intensive work along the lines which had been selected, *i. e.*, songs of war, songs connected with the use of medicinal herbs, and songs of tribal social

FIG. 66.—Indians dancing the Grass Dance at Bull Head. Photograph by Miss Densmore.

organizations. As in previous years, the songs were recorded phonographically, about 130 songs being secured in this manner for the Bureau of American Ethnology.

In connection with this work Miss Densmore collected about 120 specimens, illustrating the old arts and industries as well as the customs of war and the practice of medicine. Twenty herbs said to have medicinal properties were secured from medicine men who use them in treating the sick. These herbs were identified at the Department of Agriculture in Washington, and a number of them were found to be in use among physicians of the white race.

Fig. 67.—Indian equipment for boiling meat without a kettle. Photograph by Miss Densmore.

During the celebration of July Fourth, at Bull Head, many old dances were given. Figure 66 shows the Indians at this celebration of the Grass Dance. A demonstration of the manner of boiling meat without a kettle was also given, Miss Densmore witnessing the process and afterward purchasing the entire equipment, shown in figure 67. This was of interest in connection with the subjects under investigation, as it was a method used in old times by Indians on the war path or buffalo hunt. The paunch of a freshly killed animal was suspended between three stakes, water was placed in it, and brought to the boiling point by means of heated stones. Meat was thoroughly cooked in this manner. A portion of the meat thus prepared was secured in connection with the apparatus.

Many of the war songs were illustrated by native drawings. Figure 68 shows a man known as Jaw, an old warrior with a wide reputation for stealing horses. Behind him is one of his drawings depicting such an expedition.

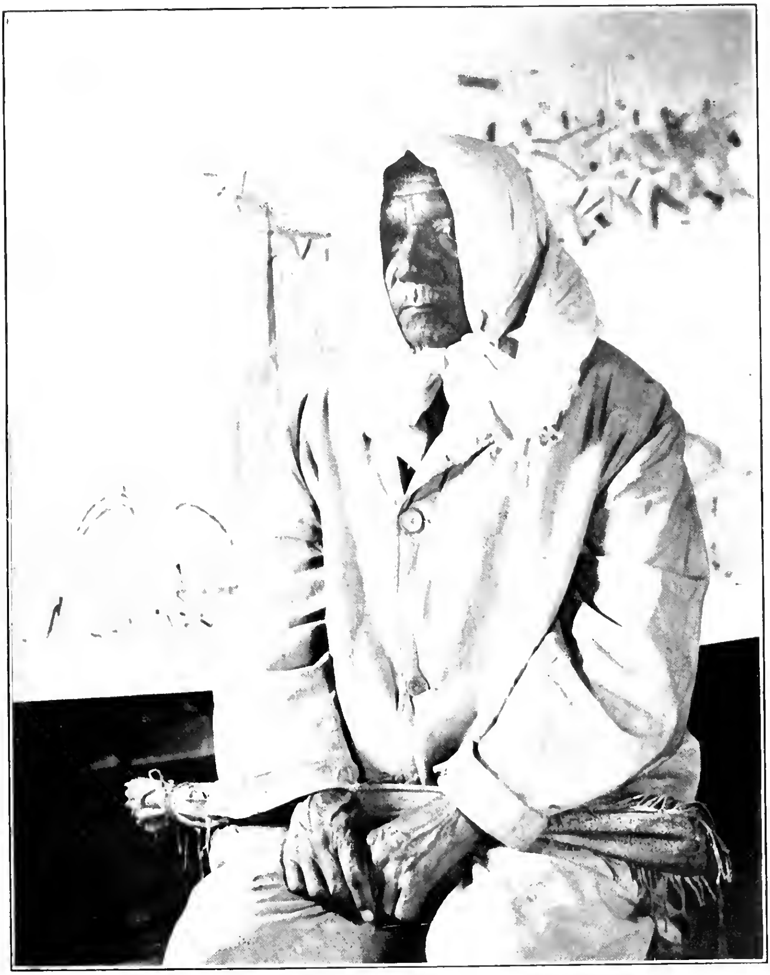


FIG. 68.—Jaw, an old Sioux warrior, whose horse-stealing expeditions are illustrated by his own drawings in the background. Photograph by Miss Densmore.

A medicine man with his drum is shown in figure 69. This man was named White Paw Bear, and proved a valuable informant to Miss

Densmore. He was a close friend of the famous chieftain Sitting Bull.

FIG. 69.—White Paw Bear, a medicine man with his drum. Photograph by Miss Densmore.

Miss Densmore attended a large feast given in her honor by Red Fox, the Sioux chief who adopted her two years previously in place of his daughter. This adoption was ratified later by the tribe.

STRANGE RITES OF THE TEWA INDIANS

Mrs. M. C. Stevenson continued her comparative study among the Tewa Indians of the Rio Grande valley, in behalf of the Bureau of American Ethnology. A close relationship was found to exist among all the Pueblo Indians, especially in their essential beliefs, resulting in a great brotherhood between them. Living in an arid land the cry of their souls was and is—"rains to water the earth."

Primitive man sought to define the mysteries of Nature, to account for its phenomena; thus primitive philosophy was born, and then religion and ritualism crept in. The Pueblo Indian began at an early period to create a pantheon of gods of his worship, gods to be appealed to for the good things of life, and angry gods to be propitiated, and thus, long ago, a most complicated system of religion and rituals developed among such peoples of the Southwest as had homes constructed of stone, clay, and plaster.

FIG. 70.—Plaza and kiva of the Sun people, San Ildefonso. X denotes the entrance to the kiva. Photograph by Mrs. Stevenson.

The more clever men of the past ages differentiated their gods into two classes, anthropic, principally ancestral, and zooic, and these men assumed to dominate the remainder of the people by asserting their direct communication with the gods. Through their power and influence with these gods they were next in importance to the gods themselves. Their doctrines taught that: The gods who bring good are exacting, and man must comply with the demands of his gods in order that the godly blessings may be bestowed upon him. He must not only perform the religious duties assigned him, but observe proper intelligence in the performance of these rites. "In the far past Avä^{n}'nyu, the great plumed serpent, whose home is in the depths of the lake of the departed, determined to take a journey over the upper plane so that he could look below and observe the people of this world.

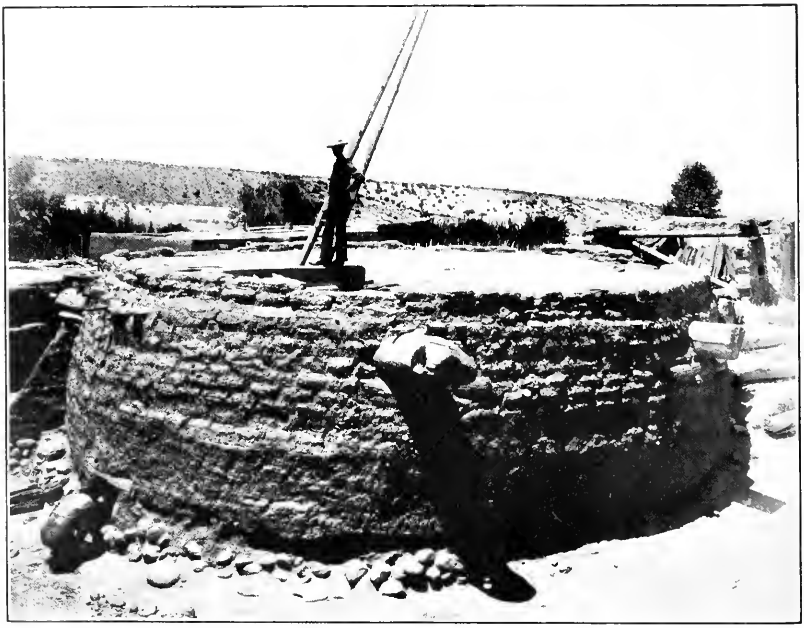


FIG. 71.—Circular kiva at Pueblo of Nambe, New Mexico. Photograph by Vroman.

Upon viewing a certain village on the summit of a mesa not many miles from the present pueblo of San Ildefonso on the Rio Grande, he discovered that though the people were devout, their rituals were all wrong and as a punishment for their ignorance he converted them into *si'de* (small bird), Mexican pajarito, and had them fly away. Since that time the deserted village has been called Si'de ge, small bird place. These ruins are known to the outside world as the Pajarito ruins.

Religion and ritual kept pace with the development of man. The peoples more remote from the long-continued influence of Roman

Catholic priests, retain more of their elaborate rituals and native paraphernalia than those who have been under the control of the Church.

FIG. 72.—Rain priest of Sun people of Nambe. Photograph by Mrs. Stevenson.

Priesthoods and fraternities were organized, and chambers were built in which to invoke and propitiate the gods. These chambers were circular and built under ground, symbolizing the innermost world whence the people came. As the people ascended from these chambers, they symbolized their emergence from the innermost world

FIG. 73.—Juan Gonzales, associate rain priest, and present governor of San Ildefonso. Photograph by Mrs. Stevenson.

into this world; and, although most of the kivas, or Hopi ceremonial chambers, at the present time, are above ground or partially so, they still represent the undermost world, the coming out still symbolizing the emergence from the undermost world, and the kiva the undermost world itself. The kiva is a prominent feature of the archeological remains of the Southwest, there is seldom a mesa, cliff, or cavate ruin where these ceremonial chambers are not to be found. They are the substantial evidence of the worship of the cliff dwellers. The underground structures have undergone changes since the oppression of the invading Spaniard. In the Tewa village of San Ildefonso, for example, the under-ground circular kiva was abandoned after the first departure of the Spanish invaders; in fact, there is not a pre-Spanish building in the village. The ruins of the old village are barely distinguishable in the fields, while the present village stands a short distance to the north. The first kiva constructed by these people after the coming of the Spaniards was round and built principally above ground, but before another kiva was constructed the people decided to build these chambers in rectangular form and in line with their dwellings, so that they would not be distinguished by the Spanish enemy. Many other pueblos adopted the plan of the rectangular kiva situated among the dwelling houses.

FIG. 74.—Zuñi personators of the rain gods.
Photograph by Mrs. Stevenson.

The Tewa are divided into the Sun and Ice peoples, therefore there are two kivas, one for each people. Every male child must be initiated into one of the kivas in order to be eligible to dance with the gods after death in the undermost world. The female child is passed through impressive ceremonies by a priest of the kiva, just after birth, and is carried into the presence of the rising sun on the twelfth day. As the tiny infant is held up facing the sun the following prayer is offered to the Sun father: "May the child grow to womanhood; may she speak with one tongue, be gentle and kind to all, and may all be gentle and kind to her. May her life be so full of love for all the world, and may her acts be so pure that she may be blessed with the love of the Sun father, so that her span of life may be complete, that she may not die, but live long, and become a child again, and so sleep, not die, to awake in the world with the gods. May she ever inhale more of the sacred breath of life."

FIG. 75.—Learning to photograph. A fine likeness of the rain priest of the Ice People. The woman at the tub is his mother. Photograph by Mrs. Stevenson.

In order that the rain priest may come into closer communion with the gods he must mortify the flesh. Semi-annually, at the winter and summer solstice, the rain priests of the Sun and Ice people retire, each with his associates, into the kivas for a retreat of four days and nights, to pray for rains, observing strict fasts, taking only meal-bread, and drinking popcorn water. Here it is that the rain gods are specially invoked. The rain priests do not pray with their lips—"hearts speak to hearts." While the priests practice deceptions upon the people and even delude themselves, when they leave their retreat, it is evident from their expressions that their minds and bodies have been elevated above worldly thoughts.

Whence come the rains so devoutly prayed for? By direction of the Council of the Gods, the shadow people fill their vases and long-necked gourd jugs from the waters of the six regions, and, ascending to the upper plane, provided there are sufficient clouds to protect the rain makers from view of the people of this world, they proceed to water such portions of the earth as have been assigned to them by the Council. The Tewa priests have given such close observation to the winds and clouds that they are quite weatherwise, and seldom select a time for a rain dance, when rains do not follow.

FIG. 76.—Kiva of the Ice People, San Ildefonso. X shows upper entrance. Two trees are by the lower entrance. This kiva is headquarters for the buffalo ceremonial. Photograph by Mrs. Stevenson.

Zoic worship has to do with the healing of the sick, the beast gods acting as mediators between man and the anthropic gods. The most shocking ceremony associated with the zooic worship of the Tewa is the propitiation of the rattlesnake with human sacrifice to prevent further destruction from the venomous bites of the reptile. The greatest secrecy is observed and the ceremonies are performed without the knowledge of the people except those directly associated with the rite which is performed quadrennially. Although many legends of the various Pueblos have pointed indirectly to human sacrifice in the past, it was a revelation to Mrs. Stevenson when she was informed that this rite was observed by the Tewa at the present time; and, while it is said to exist only in two of the villages, she has reason to believe that they are not exceptions. In one village the subject is said to be the youngest female infant; in the other village an adult woman is reported to be sacrificed, a woman without husband or children being selected whenever possible. The sacrificial ceremonies occur in the kiva. The subjects are drugged with *Datura meteloides* until life is supposed to be extinct. At the proper time the body is placed upon a sand painting on the floor before the table altar and the ceremony proceeds amid incantations and strange performances. The infant is nude, and the woman is but scantily clad. After the flesh has decomposed and nothing but the bones remain the skeleton is deposited, with offerings, beneath the floor of an adjoining room of the kiva. The entire ceremony is performed with the greatest solemnity.

FIG. 77.—Lucindra Jackson, Yonkalla tribe, Kalapuya family. Photograph from Frachtenberg.

NOTES ON THE ALSEA AND KALAPUYAN INDIANS

The opening of the year found Dr. Leo J. Frachtenberg in Siletz, Oregon, completing the linguistic and ethnological studies that were commenced in 1910 among the Alsea Indians. In addition to im-

Fig. 78.—Mary Harris, who died in 1910, the last of the Willapas. Photograph from Frachtenberg.

Fig. 79.—William Smith, an Alsea Indian, about 65 years of age. Photograph from Frachtenberg.

portant new linguistic material, he obtained a number of myths belonging chiefly to the Coyote cycle. This work was brought to a successful close towards the end of March.

In the early part of June he went to Bay Center, Washington, where he was told could be found, still extant, some members of the Willapa tribe, an important branch of the Pacific group of the Athapascan family. Unfortunately, upon close investigation, these reported Willapas proved to belong to the Chehalis tribe of the Salish family, a circumstance that substantiated his previously expressed belief that the Willapa Indians are entirely extinct. Upon his return to Siletz, Oregon, Dr. Frachtenberg began work on the Kalapuyan family, collecting linguistic notes and mythological material until the middle of September, when the work had to be discontinued for lack of funds.

FIG. 80.—William Hartless, a Kalapuya Indian about 65 years of age. Photograph from Frachtenberg.

FIELD-WORK AMONG THE CATAWBA, FOX, SUTAIO, AND SAUK INDIANS

From a study of Siouan and Muskogean languages, it appeared that these stocks resemble each other morphologically as compared with other American Indian languages. It therefore became a matter of importance that Catawba, a Siouan language of the Southeast, should be investigated to determine how close these resemblances were, and whether it was possible that both stocks were de-

FIG. 81.—The Brown Family, Catawba Indians. Photograph by Michelson.

FIG. 82.—Catawba Children. Photograph by Michelson.

rived from a common ancestor, but had differentiated at an early date. Accordingly, Dr. Truman Michelson of the Bureau of Ethnology left for South Carolina in May, 1913. Unfortunately, though a goodly number of individual words were collected, it was found that barely half a dozen persons were left who could give simple connected phrases, and only one or two who could give connected texts, but upon examination it was found that even the few texts which Dr. Michelson collected were extremely fragmentary. Under these conditions it is likely that it will not be possible to unravel the structure of the language in detail, and hence the problems presented above remain unsolved.

FIG. 83.—An old Cheyenne who remembers a little of the Sutaio language. Photograph by Michelson.

In July, Dr. Michelson arrived in Tama, Iowa, to renew his researches among the Fox Indians. After making arrangements for future work in August, he left for Montana to ascertain whether the Sutaio were a missing link connecting the Cheyenne with the normal Algonquian. The number of persons who remembered anything of the language were few, and none who could dictate connected texts were found. However, it seems clear from the individual words collected, that Sutaio will not shed any light on Cheyenne.

FIG. 84.—David A. Harris, Chief of the Catawba Tribe. Photograph by Michelson.

Upon his return to Iowa at the end of the month, he renewed his work with the Fox Indians. He was particularly successful in working out their social organization. A few more important myths were collected, and a number of those collected previously were translated. During his stay among the Foxes he also secured a number of ethnological specimens for the National Museum.

In October, Dr. Michelson left for Kansas to investigate the Sauk and Fox of the Missouri and adjacent tribes. A preliminary survey was all that was attempted owing to the inclemency of the weather. Some myths, obtained among the Foxes of Iowa, were also translated, and the investigator returned to Washington for office work.

FIG. 85.—A Catawba hearth with pottery. Photograph by Michelson.

EXPEDITION OF THE ASTROPHYSICAL OBSERVATORY

Mr. L. B. Aldrich proceeded to Mount Wilson in July, 1913, for the purpose of measuring the solar radiation. He was joined there at the end of August by Director Abbot. Several kinds of work were undertaken; first, the usual spectro-bolometric determination of the solar constant of radiation. This work has now been carried on during every summer at Mount Wilson from 1905 to 1913 inclusive, excepting the year 1907. It has resulted in showing an irregular variability of the sun from day to day, and a dependence of the sun's radiation on the number of sun-spots. It has also yielded a value of the solar constant of radiation believed to be correct within one per cent. Since there have been criticisms of the value, however, on the ground that it is impossible to correctly estimate the losses of radiation in the earth's atmosphere, it was felt desirable to check the result by sending up self-registering apparatus attached to free balloons to the highest possible altitudes.

This work was undertaken by Mr. Aldrich in July in coöperation with the United States Weather Bureau. Balloons were sent up on five days from Santa Catalina Island, carrying in each instance a self-registering pyrheliometer devised and tested at the Smithsonian Astrophysical Observatory, and a self-registering apparatus of the Weather Bureau, which records the temperature, pressure, and humidity of the atmosphere.

All the balloons carrying pyrheliometers were fortunately recovered, and in one instance the flight reached the altitude of about 33,000 meters, or 108,000 feet. The registering pyrheliometers behaved very well with the exception that their temperature sunk lower than was expected, so that in each case the mercury in the stem of the thermometers was frozen at an altitude of from 40 to 50 thousand feet, and therefore their records did not extend as high as the flights of the balloons. Nevertheless these measurements are obtained at altitudes above the highest clouds, and where the water-vapor and dust of the atmosphere is almost inappreciable. The results reached do not differ from what would be expected in view of the value of

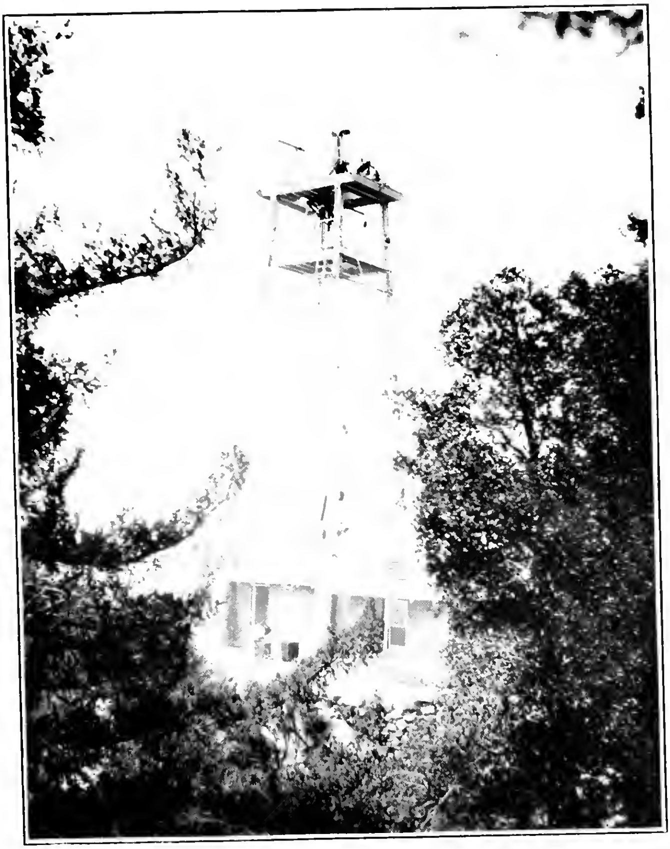


FIG. 86.—Observing station of Astrophysical Observatory on Mount Wilson with new tower telescope. Photograph by Abbott.

the intensity of the solar radiation outside the atmosphere, as computed from the ordinary measurements of the Astrophysical Observatory. It is expected that the observations will be repeated with improved apparatus in the year 1914.

After the arrival of Mr. Abbot, the new tower telescope was completed and prepared for observations of the distribution of brightness over the sun's disk. A solar image of about 9 inches in diameter is formed in this telescope by the use of mirrors, without lenses. The distribution of brightness along the diameter of the disk is observed at different colors of light by means of the spectro-bolometer. It is found that the sun is much brighter at the center of the disk than it is near the edge, and that this contrast of brightness is greater for red light than for violet light.

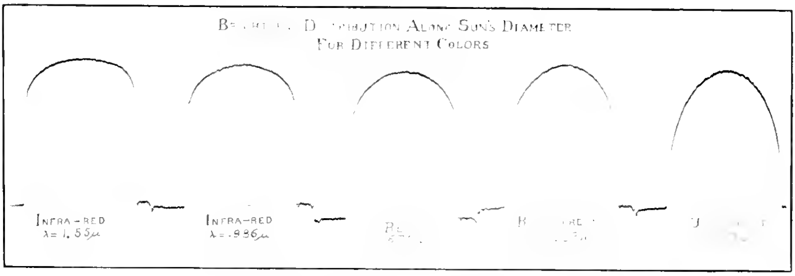


Fig. 87.—Diagram showing Brightness Distribution along Sun's Diameter.

The distribution of brightness along the sun's disk was observed on nearly 50 days, in connection with measurements of the intensity of the solar radiation as it would be outside the atmosphere. The results show in 1913, as in former years, a variability of the solar radiation from day to day. Along with this variability of the amount of the radiation, there is also shown a variability of the distribution of the brightness along the diameter of the sun's disk. This result is very interesting and important, for it enables the variability of the sun to be observed in two independent ways at the same observatory.

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 63, NUMBER 9

THE OLFACTORY SENSE OF INSECTS

BY

N. E. McINDOO, Ph. D.,
Bureau of Entomology, Washington, D. C.

(PUBLICATION 2315)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
NOVEMBER 21, 1914

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

THE OLFACTORY SENSE OF INSECTS

By N. E. McINDOO, Ph. D.,
BUREAU OF ENTOMOLOGY, WASHINGTON, D. C.

CONTENTS

INTRODUCTION

Since no one has ever collected the views of the various writers on the sense of smell in insects, the literature that bears directly on this subject is here briefly discussed for the use of students on this subject. Abstracts and translations of this literature have been made by the writer and his wife, Emma Pabst McIndoo, and the discussion is from these abstracts and translations. Minor details may have been incorrectly stated in some cases, but it is believed that each view as a whole is given correctly. The views of a few authors have been cited from others, because the original works were not accessible. After a short discussion of the sense of smell in general, the names of the various writers and their views are grouped under heads according to the seat of the olfactory organs which these writers favor. A few writers fail to advocate any particular view but they criticize certain ones. Such writers are placed under the head which they criticize.

This discussion was originally written as the second part of the author's (1914a) paper on "The Olfactory Sense of the Honey Bee." On account of the great length of this paper it was necessary to omit the discussion. Since the first part of the paper was published a few more references have been collected and the author (1914b) has written a second paper on the same subject concerning the Hymenoptera. Several letters have also been received requesting that a complete discussion be published. Another reason for publishing this discussion is to reveal the chaos which now exists on this subject, so that students may hereafter replace such chaos by facts.

The author is grateful in various ways to Dr. E. F. Phillips, in charge of bee culture investigations, and to Miss Mabel Colcord, librarian of the Bureau of Entomology, for invaluable aid in securing references.

SENSE OF SMELL IN GENERAL

Aristotle is the earliest author whose writings on the sense of smell in insects are available. He says:

> As for insects, both winged and wingless, they can detect the presence of scented objects afar off, as for instance bees and cnipes detect the presence of honey at a distance; and they do so recognizing it by smell. Many insects are killed by the odor of brimstone; ants, if the apertures to their dwellings be smeared with powdered origanum and brimstone, quit their nests; and most insects may be banished with burnt hart's horn, or by burning of gum styrax.

Virgil was a beekeeper as well as a poet. The ancients used roasted or burnt crabs in the treatment of certain bee diseases, but Virgil warned beekeepers that the odors arising from such materials are injurious to bees. He also reports that certain strongly scented plants were rubbed on the tree where a swarm of bees was collecting, so that these odors might prevent them from going farther.

Pliny states that the odors of origanum, of common lime, and of sulphur kill ants. Gnats hunt for acids and do not approach things which are sweet.

Varro (1735) infers that bees can distinguish odors, and that they are sensitive to perfumes which come from odoriferous objects; in this respect their preferences differ greatly.

Æliani (1744) asserts that bees smell anything with a foul odor or anything smeared with odors, and that they cannot tolerate an offensive smell, nor do they like sweet, delicious odors.

Rösel and Klemann (1747) remark that it is clearly understood that certain butterflies have a very acute sense of smell and that one sex certainly perceives the odor of the other from a distance.

Romanes (1877) is certain that moths smell, although they may detect the odor from ammonia through their whole system.

The Peckhams (1887) in their experiments on wasps used two essential oils—peppermint and wintergreen—maple syrup, and warm and cold chicken bones. They say:

> We conclude from these experiments that wasps have a strong sense of smell, but that they pay little attention to odors, however powerful, which do not denote the presence of something which they can utilize as food.

From the foregoing it is evident that the belief in a sense of smell in insects is general and that some insects are able to distinguish between various odors. From the time of Aristotle to the present no one has ever denied that insects can smell, yet no one has ascertained the relative sensitiveness for any particular species.

SPIRACLES AS SEAT OF OLFACTORY ORGANS

Sulzer in 1761, according to Lubbock (1899), was the first to suggest that the spiracles are the seat of the olfactory organs. Later, however, he abandoned this view and adopted the antennal theory in 1776.

Dumeril (1797) asserts that all insects possess a more or less acute sense of smell. He was the first to advocate strongly the view that insects, like all other animals that live in the air, have their olfactory organ located at the entrance of the respiratory system. The air charged with odoriferous particles passes into the tracheæ through the spiracles and here these particles stimulate multitudes of nerves and thus the sensation of smell is produced. He thought that the tracheal walls consist of a membrane which is clothed with olfactory nerves, against which the odoriferous particles from foreign bodies strike. Later the same author (1823) remarks that the perception of odors is then, like all the other sensations, physical—a kind of touch in which the bodies, should that be their nature, impinge upon the olfactory nerves. Dubois (1890) held the same opinion, saying that the first excitation is a mechanical one, like that which occurs in the sensation of touch. Hermbstädt (1811) asserts the opinion now generally prevalent, that taste and smell are chemical senses, while sight, hearing and touch are purely mechanical.

Baster (1798), cited from Perris (1850), believes that olfactory stimuli are received by the tracheæ, either at their apertures or throughout their whole extent.

Lehmann (1799), according to Lacordaire (1838), was the first who actually performed experiments to determine the location of the olfactory apparatus. He made a round aperture, surrounded by wax, in a glass bottle, in the center of which was a paper diaphragm. The antennæ or entire head of an insect was then inserted into this aperture. He next introduced into the bottle strongly odoriferous substances, such as burnt feathers, burning sulphur, etc. None of the insects subjected to this test reacted, but when the same substances were placed near the remaining part of the insect, the specimen made violent movements which showed the effect these substances had upon it. He concluded, therefore, that the head is not the seat of olfaction and that it must lie in the tracheæ near their external openings. As the antennæ are covered with hard chitin, while the tracheal walls are clothed with very thin, chitinous membranes, critics contend that such strong irritating odors mechanically irritate the tracheæ and that these odors cannot so affect the antennæ on account of the hard chitin.

Cuvier (1805) thinks that since all other air-breathing animals have the organs of smell located at the entrance of the respiratory organs, we should find it at the entrance of the tracheæ in insects, as Baster suggested. He added that the internal membrane of the tracheæ, being moist, appears properly to fulfill this office, and that in the insects in which the tracheæ form numerous vesicles these tracheæ appear to be excellently suited for the seat of smell. The antennæ do not seem to fulfill any of these required conditions.

Straus-Durckheim (1828) believed that the seat of olfaction is located at the entrance of the tracheæ because he discovered, in the environs of the spiracles, nerves which are large enough to belong to a special sense organ.

Lacordaire (1838), after discussing the experiments of Huber and Lehmann, says that from all the preceding we can conclude that we know nothing positive about the seat of smell and that the hypothesis which locates it in the respiratory organs is yet the most rational of all.

Brullé (1840), after briefly discussing the sense of smell in articulate animals, remarks that the organ of smell is not known in these animals, unless it is to be assigned to the apertures of the respiratory organs.

Of the foregoing six authors who advocate the theory that the spiracles are the seat of olfaction, Lehmann is the only one who experimented on the subject. The others seem to think that an analogy with higher animals is sufficient proof. Lehmann's experiments indicate that the seat of smell is not located in the head and assumes that the tracheæ are the only other place in which these organs could be located. No one has found any nerves or any kind of sense organ, which suggest an olfactory function, in the walls of the tracheæ or in the spiracles of the bee. This theory has been long since abandoned.

STRUCTURE NEAR SPIRACLES AS SEAT OF OLFACTORY ORGANS

Joseph (1877) postulated three conditions necessary for an olfactory apparatus: (1) It must come in contact with moving air; (2) it must be continually moistened, and (3) the olfactory substance must be in the form of a gas. If one of these three conditions is lacking, olfaction is impossible. According to these conditions no one has sought the seat of smell in any place other than at the entrance of the tracheæ, and the assumption that insects smell with their antennæ or buccal organs is completely inadmissible. In spite of the fact that their antennæ had been removed and in spite of their clumsy flying, a number of *Necrophorus vespillo* (carrion beetles) found a carcass wrapped in paper at a distance of 20 feet. The same result was obtained with the flesh-fly *(Musca) Sarcophaga carnaria* and with other insects. A short distance from the spiracles, toward the median line of the thorax and abdomen, he reports finding a peculiar structure which he called the "regio olfactoria." This olfactory region is completely covered by a delicate membrane perforated by pores, the largest of which are for gland exits and the smallest for hairs. Beneath this membrane lies a peculiar layer of cells.

Thus, not favoring the view that the spiracles are the seat of smell, and in order to comply with the above three conditions, Joseph assumed the existence of an organ near the spiracles which communicates with the air cavities of the tracheæ. Of course, being connected with the tracheæ and being continually moistened by the glands, it is easy to see that the necessary conditions would be fulfilled. No drawing of this organ is given and no such structure is found in the honey bee.

GLANDS OF HEAD AND THORAX AS SEAT OF OLFACTORY ORGANS

Ramdohr (1811) states that many species of insects, and among them the bee, have a well-marked sense of smell. He failed to find olfactory organs in the spiracles, but conceived the idea that odors come into the mouth through the lumen of the proboscis. He found behind the mouth a tube which is divided into three branches, the smallest of which runs along the œsophagus above the first thoracic ganglion and soon divides into two smaller tubes which pass into the thorax and seem to connect with the large tracheæ coming from the first spiracle. The other two branches pass at right angles into the sides of the head, where they expand into four small sacs which differ from air tubes in having walls that are soft, thick and transparent. A thick tissue of the finest tracheæ covers these various tubes. Ramdohr also mentioned nerves running to his supposedly olfactory organ. He was led to believe that air carrying odors passes through the lumen of the proboscis into these small sacs and, as their walls are soft and perforated with minute air tubules, that they act as an organ of smell. Referring to Snodgrass (1910) and judging from the foregoing description, Ramdohr probably mistook the thoracic salivary gland for the branch accompanying the œsophagus, and the salivary glands in the posterior part of the head for the other two branches.

ŒSOPHAGUS AS SEAT OF OLFACTORY ORGANS

Treviranus (1816) infers that the smelling organs in various families of insects are located in the throat. In all the insects discussed the œsophagus is dilated, as in the bee, in front of the stomach into a large sac-like reservoir, which he thought is perhaps for the purpose of drawing air into the throat. He believed that in the presence of strong-smelling substances the antennæ do not produce noticeable movements. He further stated that the olfactory apparatus of higher animals and the antennæ and palpi of insects are as different in structure as organs can ever be. In order to smell, higher animals must inhale the odoriferous particles. On the contrary, the antennæ and palpi do not conform with this general rule; in most insects these appendages are not coated with a mucous skin and the interior is carefully guarded against the entrance of odoriferous air. Treviranus therefore infers that the sac-like reservoir "honey stomach" in the bee, is for the purpose of drawing odorous air into the œsophagus.

"INTERNAL SUPERIOR SURFACE" AS SEAT OF OLFACTORY ORGANS

After discussing the various views concerning the location of the organs of smell, Burmeister (1836) concludes as follows:

> Thus insects, according to my opinion, would smell with the internal superior surface, if I may so call it, which is provided all over with ramifications and nets of nerves, since this is always kept moist by the blood distributed through the body and by transpired chyle, the same as is surmised of the superior Mollusca.

Further, the same authority wrote.

> Various authors consider the antennæ as olfactory organs, but with what right? A hard, horny organ, displaying no nerve upon its surface, can not possibly be the instrument of smell, for we always find in the olfactory organ a soft, moist, mucous membrane, furnished with numerous nerves.

What Burmeister means by "internal superior surface" is not clear.

DIFFERENT PARTS AS SEAT OF OLFACTORY ORGANS

Schelver (1798), cited from Lacordaire (1838), and Comparetti (1800), according to Perris (1850), place the seat of smell in different parts for different families, as follows: The club of the antennæ in lamellicorns, the proboscis in the Lepidoptera, and certain frontal cells, which have never been seen since by any one else, in the Orthoptera.

FOLDED SKIN BENEATH ANTENNÆ AS SEAT OF OLFACTORY ORGANS

Rosenthal (1811), cited by Burmeister (1836), "described a folded skin at the forehead, beneath the antennæ, to which two fine nerves passed, and which he considers the organ of smell in the flies *Musca domestica* and *(Musca) Calliphora vomitoria;* and he observed, after the destruction of the part, a deficiency of the function which had previously strongly exhibited itself."

The honey bee has no such structure as that described by Rosenthal.

RHINARIUM AS SEAT OF OLFACTORY ORGANS

Kirby and Spence (1826) regard the rhinarium as the location of the organs of smell. The rhinarium or nostril-piece is the foremost portion of the clypeus just above the labrum; it consists of circular pulpy cushions, covered by a membrane transversely marked with fine striæ. These fleshy cushions, like the upper surface of the tongue, are beset with minute black tubercles carrying bristles.

No such structure as the rhinarium exists in the bee.

PLATE BETWEEN EYES AND BENEATH ANTENNÆ AS SEAT OF OLFACTORY ORGANS

Paasch (1873) claims that no nerves coming from the brain lead to the tracheæ and that the olfactory organ need not necessarily be connected with the breathing apparatus. He reasons that its location should correspond with that found in higher animals. He found a peculiar plate situated between the eyes and beneath the antennæ and extending to the base of the proboscis. This plate possesses a groove whose edges are beset with stiff bristles, and many tracheal branches; it also has nerve connections. This he regards as the olfactory organ. This plate does not exist in the honey bee.

MOUTH CAVITY AS SEAT OF OLFACTORY ORGANS

After having cut off the antennæ of some queen bees, Huber (1807) was rather inclined to regard these appendages as the olfactory organ, but later (1814) after many experiments he concluded that the organ of smell resides in the mouth itself or in the parts depending upon it.

The following is a brief summary of his later work concerning the olfactory sense: Not only do bees have an acute sense of smell, but they possess the memory of sensations. For example, in the fall we placed some honey in a window and the bees came to it in great number. The honey was removed and the shutter of the window was closed all winter. The following spring, when we opened the shutter, bees returned to the same window, although there was then no honey at this place. They remembered that it had been there previously and an interval of several weeks had not effaced the acquired impression. Bees not eating appear more responsive to odors, while those eating honey are reluctant to move when odors are brought near them. To ascertain how different odors affect bees he used mineral acids and volatile alkalies presented on a pencil brush to the opening of the mouth; these did not affect them. Musk placed in front of the hives did not irritate the bees much. Assafœtida mixed with honey was put at the entrance of hives; the bees ate the honey and were not annoyed by this odor which is obnoxious to us. Bees are greatly affected by the odors from camphor and the poison from bee stings.

To locate the region of the body in which the olfactory organ is found, Huber brought a pencil brush, which had been dipped into turpentine oil, near the abdomen, thorax and head. He saw a response only when it was in the region of the head and decided that the organ of smell is located only in the head. He next placed an extremely fine pencil brush wet with the same oil near the eyes, antennae, proboscis and mouth cavity. The only response observed was when the brush came near the mouth cavity. He obtained the same result, only more pronounced, when oil of origanum was used. The mouths of several bees were filled with flour paste and when this was dry they were released. Honey, turpentine and oil of cloves, either in fixed or volatile alkalies, did not produce any response.

EPIPHARYNX AS SEAT OF OLFACTORY ORGANS

Wolff (1875) found many peculiar hairlike organs on the epipharynx of the honey bee; each organ consists of a small cone with a pit in the summit bearing a small hair. He regarded these cones as having an olfactory function and believed that the mandibular glands pour a liquid upon the surface of the epipharynx which keeps these cones moist and capable of absorbing odoriferous particles. He explained the inhalation of these particles into the preoral cavity as brought about through the contraction of the air sacs situated near the mouth.

Harting (1879), in discussing Wolff's olfactory organs, inferred that Wolff tried to homologize the epipharynx with the nose of higher animals whereas there is not the slightest reason for such an homology.

To determine whether the mouth cavity and the epipharynx are the seat of the olfactory organs, the author repeated Huber's experiment of filling the mouth cavity with flour paste. With the aid of a small pencil brush the mouth cavities of 20 worker bees were thus filled. When the paste had become perfectly dry, the bees were put into observation cases. They seemed otherwise entirely normal, but lived only 7½ days as an average, whereas unmutilated workers in the same cases lived 9 days and 3 hours. When tested with the oils of peppermint, thyme and wintergreen, their average reaction time was 2.68 seconds. The average for the same odors with normal workers was 2.64 seconds. It would seem that neither the buccal cavity nor the epipharynx has anything to do with olfaction.

PALPI AS SEAT OF OLFACTORY ORGANS

Lyonnet (1745) thinks that the palpi should be considered as the organs of smell rather than those of taste.

Bonnsdorf (1792) and Knoch (1798), according to Perris (1850), regarded the palpi as olfactory organs, but Knoch believes that the maxillary palpi only are for smell, while the labial palpi are for taste.

According to Marcel de Serres (1811), even if insects have their olfactory organs located at the entrance of the respiratory organs, the view that the palpi serve as organs of smell does not contradict the former view, because the palpi communicate both internally and externally with the air. This view resembles Duponchel's theory (1840), except that the latter author considers the antennæ of certain water insects as having a respiratory function. Duponchel thought that the antennæ were provided with minute perforations through which the air passed.

Newport (1838) performed many experiments with certain insects (Sylphæ) and he concludes that they find their food by smell but he did not think that the olfactory organs are found either in the antennæ or spiracles. He says:

> Hence, I think it must appear * * * from the motion of the palpi and the avidity with which the insect darted upon the food when held in front of it, it seems but fair to conclude that the sense of smelling must certainly reside in the head.

We may include Newport with those who believe that the palpi are the seat of olfaction.

Driesch (1839) favors the opinion that the seat of the olfactory organ is located in the palpi.

Perris (1850) found that after the amputation of the palpi insects showed none or only a very little sensibility to odors. In the articulates the sense of smell resides in the antennæ and in the palpi; but the antennæ are destined to perceive odors from both afar and near, while the palpi perceive odors from afar only. As far as the palpi are concerned he thinks that the seat of smell lies in their last joint. Cornalia (1856) also shared this view.

Plateau (1885) performed many experiments by cutting off the palpi. He ascertained that the amputation of both maxillary and labial palpi did not destroy the olfactory sense.

Wasmann (1889) favors the view that the group of delicate peg-like papillæ on the tips of the palpi probably function as olfactory organs.

To ascertain whether the palpi of the honey bee bear the organs of smell, the author cut off the labial palpi and maxillæ of 19 workers at their bases. When put into observation cases these bees appeared normal in all other respects, but certainly were not completely normal, for they lived only 24 hours on an average. When tested with the oils of peppermint, thyme and wintergreen, honey and comb, pollen and leaves and stems of pennyroyal their average reaction time was 4 seconds, whereas for the same odors with unmutilated bees the average was 3.4 seconds. Since these appendages carry several porelike organs, we may either attribute the 0.6 second difference in reaction time to the view that these appendages really aid in receiving odor stimuli, or to the injury caused by the operation, or to both of these views combined.

Breithaupt (1886) describes some porelike sense organs on the base of the proboscis of the bee. To determine whether these have an olfactory use, the author cut off the proboscides of 22 workers. These bees seemed normal in most respects, but lived only 7 hours on an average. When tested with the oils of peppermint, thyme and wintergreen the average reaction time was 2.9 seconds, while for the same odors with unmutilated bees the average was 2.6 seconds. We can probably attribute this difference of 0.3 second to the abnormality of the mutilated bees.

Janet (1911) describes a sense organ in the mandible of the honey bee which he thinks may have an olfactory function. To ascertain this experimentally, the mandibles of 20 workers were amputated close to the base by the author. These bees appeared completely normal, although they lived only 7 days on an average. When tested with the oils of peppermint, thyme and wintergreen, honey and comb, pollen, and leaves and stems of pennyroyal, they gave an average reaction time of 4.8 seconds, while the average for the same odors with unmutilated bees was 3.4 seconds. We may attribute this slight difference in reaction time either to the injury caused by the amputation, or to the view that the mandibles help to perceive odors, or to both.

ANTENNÆ AS SEAT OF OLFACTORY ORGANS

(1) WITHOUT EXPERIMENTS

Reáumur (1734) was the first to suggest that the olfactory organs of insects lie in their antennæ.

Lesser (1745) says that the sense of smell of some insects is more acute than that of man. He gives as two proofs of this, (1) that they find their food with this sense, (2) that they scent food farther than man does. He says that the antennæ are "noses" and that they enable their owners to smell odors near or far away.

Baster (1770) remarks that no one doubts that insects can smell, for flies, purely through olfaction, find their way to tainted meat. He also states that water insects can smell. Baster states that no insects, whether living in the air, under water, or in the earth, have the seat of smell in the antennæ.

Sulzer (1776) contends that insects have an acute sense of smell and spoke of bees coming for honey when it is placed in a spoon under a window. He believes that the olfactory apparatus is located in the antennæ.

Fabricius (1778) infers that the seat of smell belongs to the antennæ.

Bonnet (1781) asserts that diverse insects have the sense of smell exquisitely developed, but that we do not know where the seat of this sense lies. He suggests the antennæ as a possible location.

In discussing the probable uses of the antennæ, Olivier (1789) regarded them as olfactory in function.

Latreille (1804) regards the fact that many male insects have the antennæ better developed than the females of the same species as evidence that these appendages are the seat of olfaction. The greater number of insects that live in animal matter, in decayed vegetables, or in stagnant water generally have the antennæ better developed than those that live elsewhere. A more perfect olfaction would be necessary to these insects, and the organization of the antennæ seems to be adapted for this purpose.

After discussing Marsham's account of ichneumon flies, Samouelle (1819) states, "From these remarks may we not infer that the antennæ may be the organ of smelling?".

De Blainville (1822) and Robineau-Desvoidy (1828), cited from Perris (1850), state that the antennæ are olfactory organs.

After briefly discussing the various views concerning the seat of olfaction, Carus (1838) confesses that the opinion of Rosenthal, combined with that of Reáumur, appears to him to be the best. Hence he believes that the seat of olfaction lies in the folded skin beneath the antennæ as well as on the surface of the antennæ.

Since the antennæ of the male are often better developed than those of the female, Percheron (1841) states that the antennæ of the male aid the eyes in searching for the female. He infers that the antennæ are used for smelling.

Goureau (1841) thinks that the antennæ may be organs of olfaction besides being organs of touch and hearing.

Pierret (1841) also favors the view that the seat of olfaction lies in the antennæ.

Robineau-Desvoidy (1842) speaks of an olfactory apparatus as nothing less than an ordinary organ of touch which is capable of receiving invisible stimuli. By analogy he thinks that the antennæ must be the organs of smell.

Slater (1848) firmly believes that the antennæ are olfactory organs. He says that the antennæ seem to be the real organs for this sense or for a sense closely allied to it.

According to Dufour (1850) both the organs of audition and olfaction are found on the antennæ. The distal joints, which have a spongy texture, are the ones that bear the sense of smell, for here the odoriferous atoms can fall upon this special texture and the impulse can be transmitted to the cerebral ganglion.

Claparède (1858) asserts that absolutely nothing warrants us in locating in the antennæ the sense of hearing rather than that of olfaction or any other function, but he favors the view that the organs of smell are there.

Dönhoff (1861) from various experiments contends that bees learn the location of honey and of the queen through the antennæ. He placed a stick near the antennæ of a bee and these appendages remained quiet. When a stick wet with honey was similarly placed, the bee at once extended these appendages in the direction of the stick. When one places a foul-smelling substance like tobacco juice near the antennæ, the bee moves away. When one places a stick wet with honey or tobacco juice near a bee with amputated antennæ the insect shows no response of any kind. He thinks that the olfactory organ was removed by cutting off the tip of the antennæ.

Noll (1869) asserts that butterflies have a fine sense of smell as shown by the way in which they find prepared food when placed in a box covered with screen wire and having only a slit through which these insects may enter. This is shown by the way in which the males are able to find the females. He regards the antennæ as the olfactory organs, at least for the male.

Wonfor (1874) says:

> That it is the sense of smell which directs the blow-fly to the deposition of the larvæ is shown by the fact that she has laid them on *stapelias*, a carrion-odoured hothouse plant, and on silk with which tainted meat had been covered. Notwithstanding the view of Hicks he considers one of the functions of the antennæ as that of smell.

Fabre (1882) remarks that it is incontestable that insects have a very highly developed sense of smell. Carrion beetles run from all sides to the place where a dead mole lies. If we admit that the seat of smell lies in the antennæ he contends that it is difficult to comprehend how such an appendage of hard chitinous rings, articulated end to end, is able to fulfill the office of a nose. The organization of a true nose and that of the antennæ have nothing in common.

Henneguy (1904) state that the organ of olfaction is probably located in the antennæ and the buccal palpi.

(2) WITH EXPERIMENTS

Dugés (1838) was the first to experiment with the antennæ of insects. He cut off the antennæ of two male *(Bombyx) Eudia pavonia minor* and then these insects were unable to find a female that they had previously been able to locate while their antennæ were intact. Also, after having extirpated the antennæ of many blow-flies, *(Musca) (Calliphora vomitoria)*, and a large viviparous fly, *Sarcophaga carnaria*, he ascertained that they were unable to find putrid meat as before. He felt satisfied that olfaction resides in the antennæ.

Lefebvre (1838) was the first observer to experiment with a *bee*. He placed a long needle, whose end had been plunged into ether, near a piece of sugar which a bee was eating. The bee moved its antennæ towards the needle and then passed them several times between the legs. He brought this needle near the legs and spiracles, and since he noticed no response from these parts, he concluded that the antennæ are olfactory organs. As a control he used a needle without ether in the same manner. Next he mutilated the antennæ of several wasps *(Vespa)*. All their organs for perceiving odor stimuli seemed to be at the extremity of these appendages.

Küster (1844) declares that bees have a very acute sense of smell. He reports some that found a store of honey; even a week after they had carried away all the honey they still continued to come to the same place in search of more food. Since vertebrates carry their olfactory organs on the front of their head, under and between the eyes, he tried by analogy to locate the corresponding organs of the bee on the antennæ.

Perris (1850) repeated Dugés' experiment by holding many specimens of different families and genera over the mouths of vials containing alcohol, turpentine, or ether. At times he obtained the same results as did Dugés, at other times none at all, using the same individuals after intervals of one-half hour; but more often the antennæ or palpi exhibited more or less violent movement. He also repeated the experiments of Huber on various insects by stopping up their buccal cavities with wax, paste and gum. When they were set free he did not notice any signs of inconvenience. By such experiments he failed to locate the seat of the organs of smell in or near the mouth as Huber did. After having placed a brush dipped in turpentine, ether or wild thyme near the spiracles he concluded that odor-stimuli are not received by the respiratory apparatus.

In his summary Perris says: (1) By amputating the extremity of the antennæ the olfactory sense is not destroyed but it is weakened, and by cutting them off at the base the sense of smell is totally or partially destroyed; (2) covering the antennæ with a layer of india rubber renders these organs insensitive; (3) sometimes a little sensibility is shown when the palpi are amputated. Thus in the articulates the organs of smell reside in the antennæ and in the palpi, but the antennæ recognize odors from afar and from near by, while the palpi recognize only distant odors. In the plumose, flabellate or pectinate antennæ olfactory organs are present in all the branched parts. In the simple and setaceous or filiform antennæ the organs of smell are principally in the last joints and diminish toward the base. In antennæ terminated with a club the organs of smell are exclusively in the club. He believes that the organs of smell are present in the last joint of the palpi.

Cornalia (1856) says that the manner in which insects move the antennæ shows that these appendages serve for searching when the odor is scattered. He observed a male *Bombyx mori* that was trying to enter a small box in which a female was enclosed. After he had cut off the antennæ of this male it approached the box with uncertainty and sometimes did not go to the box at all. The same result was obtained by covering the antennæ. His view is similar to that of Perris in that the seat of olfaction lies in both the antennæ and palpi.

Garnier (1860) is certain that articulated animals perceive odors. Bees that go foraging for a long distance quickly recognize their hives without the aid of their acute vision. An organ of olfaction, wherever one may observe it, is an expansion of very fine skin, abundantly supplied with vessels and nerves, and moistened with a viscid fluid which permits the intimate contact of the odor. He does not state where the olfactory apparatus lies in insects, but he denies that the antennæ performs such a function, because when the knobs of the antennæ or the entire antennæ of individuals of the Genus *Necrophagus* were detached, the insects returned immediately to the body of a mole from which they had been temporarily removed.

Balbiani (1866) put unmutilated female butterflies in one box and in a second box he placed males of the same species. Some of the latter had their antennæ cut off. As soon as the box containing the females was placed under that of the males, the unmutilated males moved their antennæ, vibrated their wings and quickly moved their legs, while the mutilated ones remained perfectly quiet. In this experiment he says that sight and hearing were excluded and thinks that olfaction brought about by the antennæ is entirely responsible for these responses of the males.

Forel (1874, 1885) says that myricids (ants) appear to have the sense of touch highly developed in the antennæ, while in the antennæ of *Tapinoma* (ants) the sense of smell is better developed. If individuals of either genus are deprived of their antennæ they cannot guide themselves and are not able to distinguish companions from enemies or even to discover food placed at their sides. While deprived of the anterior part of the head and of the entire abdomen they preserve all their faculties. The same author (1878a) claims that the moving-back and forth of the wings enables insects to scent certain substances by means of their antennæ. Olfaction may cause certain flying insects to proceed in a given direction.

Forel (1878b) used three wasps that had previously fasted. The first was left intact, both antennæ of the second were cut off, and the anterior part of the head up to the compound eyes of the third was cut off. After a short rest a needle dipped in honey was brought near the first insect. It at once directed both antennæ toward the needle with rapid movements and followed the needle when it was slowly moved away. Exactly the same thing took place in the wasp with the anterior part of the head cut off, and thus with the nerve endings of the mouth, the pharynx, and Wolff's olfactory organs lacking. It was quite different with the one with the removed antennæ. It remained near the needle motionless, did not react to honey at all, and did not follow the needle.

Forel (1908, p. 92) cites some of his experiments performed in 1878. He found the putrid bodies of a hedgehog and a rat infested by a swarm of carrion-feeding beetles belonging to several genera. He collected more than 40 specimens from the carcasses and removed their antennæ. Then he placed them all at one place in the grass and moved the dead bodies a distance of 28 paces from the beetles and concealed them in a tangle of weeds. Examination the next day revealed the fact that not one of the mutilated beetles had found the carcasses, and repeated experiments gave the same results. No beetle without its antennæ was ever found on the dead animals, although at each examination new individuals of the several species were present. On the supposition that the mutilation itself might make the beetles abnormal to such an extent that they did not care to eat, Forel next cut off all the feet on one side of the body from a dozen beetles with their antennæ intact and changed the location of the dead bodies again. The next day five of this lot were found on the carcasses.

Trouvelot (1877) performed various experiments on the antennæ of many butterflies, several promethea silkworm moths, and some ants. From these experiments he concludes that the antennæ are the organs of smell, but he thinks that the sense of smell in insects is very different from that sense in the human species. He regards it as a kind of feeling or smelling at a great distance by some process now entirely unknown.

Layard (1878) relates the experiments of a certain French naturalist who immersed a long-snouted weevil in wax so that it was covered all over except the tip of the antennæ. When tested with oil of turpentine it became violently excited and endeavored to escape. Another had only the tips of its antennæ coated with wax, and neither turpentine nor any other strong-smelling substance affected it. From this he infers that the organ of smell is present in the tips of the antennæ of weevils.

Slater (1878) says:

> That wasps have an acute scent and seek their prey or their food by its means, will be generally admitted * * *. When a wasp is flying it keeps its antennæ advanced and extended, so as to be in the most favourable position for receiving an impression from odoriferous substances.

Chatin (1880) states that when one brings a needle wet with ether, creosote, essence of wild thyme, or clove oil near the head of a bee it moves its antennæ, vibrates them vigorously, and directs them away from the odorous substance; if one repeats the same experiments near the spiracles no such movements are manifested. Also, when the antennæ are cut off no responses occur.

Lubbock (1882) experimented with a large female ant. He placed a feather of a pen almost against the antennæ of this ant without it moving in the least. Next he dipped the pen in essence of musk and repeated the experiment. The antennæ were at once retracted. With a second ant he used essence of lavender and observed the same results. Many more of his experiments indicate that ants have a highly developed sense of smell.

Porter (1883) experimented on a butterfly with a piece of gum camphor on the end of a broom straw. He says:

> Whenever I put the camphor end near to its head and mouth parts, it would begin to struggle with all its might to get away from the fumes of the camphor; thus showing not only that it disliked the smell of camphor, but also that it did not smell with its antennæ. After experiments have shown the same thing of other insects.

This butterfly was affected little, if at all, by the extirpation of its antennæ while some humble bees become very sick after the loss of their antennæ; they, however, recovered after awhile. Some other humble bees are not affected at all by such an operation.

Graber (1885) severely criticizes the view that the antennæ are the seat of the olfactory sense. He experimented on many species with various odors, and makes the following claims: (1) Ants *(Formica rufa)* and flies *(Lucilia caesar L.)* without antennæ still possess the sense of smell; this fact shows that the perception of odors is not accomplished by the antennæ alone. (2) In *Silpha thoracica* deprived of antennæ, the odor of the essence of rosemary is manifestly perceived, while assafœtida does not affect the insects at all. Thus the antennæ are those parts of the body which are most sensible to odors. (3) From the comparative experiments on the excitability of the antennæ, the palpi, and the cerci (caudal styles) in *Gryllotalpa gryllotalpa* L. *(vulgaris)*, the palpi are more sensible to odors than the antennæ. (4) The palpi of *Lucanus* are sometimes the most easily excited, at other times the antennæ, according to the odors employed. From similar experiments on *Periplaneta*, some intact, others several days after they were operated on, it seems that the reception of odor stimuli is accomplished by the cerci. Graber is inclined to the view that insects do not have any special olfactory organ, and that when the odoriferous emanations are intense they may be perceived by the surfaces of the body that are covered with thin chitin and provided with terminal excitable nerves.

Plateau (1886) used four *Blatta* (cockroaches), two with their maxillary and labial palpi cut off and their antennæ left intact and the other two with the antennæ cut off and the palpi left intact. These four insects were put into a large circular dish 8 inches in diameter. This vessel contained a bed of fine sand and in the center there was a round pasteboard box 2 inches in diameter and 2 inches high. Food was put into this box, and these insects were observed each day for a month. Each day he saw one or two *Blatta* eating the food, and in every instance these were the insects with unmutilated antennæ, and he concluded that the antennæ are the olfactory organs in *Blatta*.

Graber (1887) repeated Plateau's experiments by using many cockroaches and declares that it is sufficiently proved that cockroaches deprived of their antennæ smell little or none at all, and that the antennæ in these insects actually function as olfactory organs. He also says that for cockroaches (and some other insects) it is shown that the olfactory sense lies in the antennæ but this is not the case in all insects.

Dubois (1895) touched the scent glands situated at the tip end of the abdomen of a female moth with a glass rod and then brought this rod, which had no odor perceptible to him, near a male of the same species that had its antennæ cut off. The male at once vibrated its wings and started toward the rod.

Fielde (1901a), who has made a special study of ants, claims in her various papers that ants have a keen sense of smell. The same author (1901b) asserts that,

> The power of perceiving the individual track lies in the tenth segment of the antennæ. When deprived of this segment the ant is no longer able to find her way in with the pupæ, but wanders about helpless and bewildered. Ants deprived of nearly all of the eleventh and twelfth segments continued to carry the pupæ through the runs of the maze, though with diminished physical vigor. The ant could pick up her scent so long as a tenth segment was intact, and no longer.

Miss Fielde clipped the antennæ with sharp scissors and 15 days after the operation about 40 per cent of the ants recovered from the effect of the shock.

> Before their recovery the ants were listless and abnormally irritable; and they attacked with self-destructive violence any moving thing that touched them. One antennæ performs all the functions of a pair. * * * Every *Stenamma fulvum piceum* has an odor manifest in all parts of her animate body, and discerned by herself and by other ants through the eleventh segment of the antennæ.

The commingled odors of all the ants in the nest constitute what she calls the " aura " of the nest.

> It is diffused in air or ether from the animate occupants of the nest, and it is discerned by the ant through the twelfth, the distal, segment of the antennæ.

When deprived of the distal segment the ants were not alarmed when introduced into the nest of aliens; they did not flee, nor did they endeavor to hide; thus their behavior is strikingly different from that of unmutilated ants. Also she found (1907) that queens deprived of their antennæ did not behave normally.

> So long as the eighth and ninth segments of the antennæ are uninjured, the ant may continue to lift and care for the eggs, larvæ, or pupæ, but after the removal of these segments she loses all interest in the young and performs no further work in the nursery. * * * Marked ants of two hostile colonies, when clipped across the tenth segments, associated freely and amicably with one another during several days in the care of the pupæ belonging to one of the two colonies.

A paper by the same author (1903a) summarizes the foregoing and adds observations on some of the segments not heretofore mentioned. The following perceive these particular odors: The eleventh or distal segment, the nest odor; the tenth, the colony odor; the ninth, the individual track; the eighth and seventh, the inert young; the sixth and fifth, the odor of enemies. Miss Fielde (1903b) claims that feuds between the same species living in different communities are caused by a difference of odor. Also, (1904) fear and hostility are excited by a strange ant odor. She (1905) decides that ants have a specific and progressive odor; the former is received by organs near the proximal end of the funiculus, while the latter is received among ants by organs in the penultimate joint of the funiculus.

Piéron (1906), basing his conclusion on the interpretations of Fielde and others, remarks that recognition in ants by odor is well established, and that sections of the antennæ have shown that the organs of smell are those of recognition.

Wheeler (1910) believes that the olfactory organs of ants are located in the antennæ, but he refutes Miss Fielde's theory that each segment of the antenna perceives a particular odor. He asserts:

> She says: "The organ discerning the nest-aura, and probably other local odors, lies in the final joint of the antenna, and such odors are discerned through the air; the progressive odor or the incurred odor is discerned by contact, through the penultimate joint; the scent of the track by the antepenultimate joint, through the air; the odor of the inert young, and probably that of the queen also, by contact, through the two joints above, or proximal to those last mentioned, while the next above these also discerns the specific odor by contact."
>
> This statement not only lacks confirmation by other observers, but seems to be the only one which implies that the olfactory organs of an animal may exhibit regional differentiations. This has not even been claimed for dogs, which nevertheless possess extremely delicate powers of odor discrimination and association. This would be no serious objection, however, if we were able to discover the slightest support for Miss Fielde's hypothesis in the structure of the antennæ. We do, indeed, find in the funiculi a variety of sensillæ, as has been shown in Chapter IV, but none of these is confined to a single joint or to two joints. Miss Fielde, moreover, completely ignores the tactile organs of the antennæ and makes this surprising statement:
>
> "During five years of fairly constant study of ants I have seen no evidence that their antennæ are the organs of any other sense than the chemical sense."
>
> Many of her interpretations of the behavior of ants with mutilated antennæ are open to the obvious objection that she tacitly denies the existence of perception where there is no visible response or where the animal inhibits certain of its activities. If we add to this objection the very limitations of the method, *i. e.*, the necessity of removing all the joints distal to the one whose function is being tested, and the consideration that the hypothesis is not needed to explain the facts, it will be seen that we are not sufficiently justified in regarding the ants' antenna as an organ made up of a series of specialized "noses."

Barrows (1907) says:

> I have found that *Drosophila ampelophila* (the vinegar fly) has a large saclike pit, which contains sense cones, situated in the end of the terminal (third) segment of the antennæ.

Gum on the antennæ did not prove satisfactory for abolishing sense of odors, nor could they be burnt off without considerable injury to the fly. He etherized some flies and cut the joint off with fine scissors and declares that the ether did not affect the results of the experiments with odors.

> It, therefore, seems certain that the sense of smell is absent, or at least greatly reduced in flies that have lost the terminal joints of the antennæ.

He thinks that these flies when normal find their food wholly by smell.

> When one antenna is lost and the other antenna is stimulated by food odor, circus movements are carried out in such a way as to prove that the fly orients normally by an unequal stimulation on the antennæ.

Kellogg (1907) informs us that the female silkworm moth protrudes a paired scent organ from the hindmost abdominal segment. A male moth with antennæ intact and with eyes blackened finds a female immediately and with just as much precision as when his eyes are not blackened. A male with the antennæ extirpated and eyes not blackened does not find the female unless by accident. Males with antennæ intact become greatly excited when a female is brought within several inches of them. If the excised scent glands are laid near the female from which they were taken, the males always neglect the near-by live female and go directly to the scent glands and try to copulate with them. A male with its left antenna removed, when within 3 or 4 inches of a female with protruded scent glands, becomes greatly excited and moves in circles around her to the right. A male with right antennæ off circles to the left.

Sherman (1909) discusses the sense of smell in insects without even giving any references or without performing any experiments. He says: "The organs of smell are the antennæ." Insects that feed upon decaying matter find their food almost entirely by smell. When their antennæ are removed they are unable to find their food even though it is quite near and in full view. "This indicates that the sense of sight is defective and that of smell very acute."

To ascertain if the antennæ of honey bees, ants and hornets carry the olfactory organs, the author performed the following experiments. Worker bees with one antenna pulled off are much less pugnacious than are those with the antennæ intact, and they "pay less attention" to each other. They appear otherwise normal, except that their ability to communicate is considerably decreased. In observation cases they live only 6¾ days while workers with unmutilated antennæ live 9⅛ days under the same conditions. When tested with the three essential oils—peppermint, thyme and wintergreen—

their reaction time was 4.6 seconds, which is exactly double the reaction time when workers with unmutilated antennæ are used.

Bees with one antenna pulled off and with 2 to 8 joints of the other one cut off never "pay any attention" to each other and very seldom are seen fighting, but are just as apt to fight a hive-mate as a stranger. The greater the number of joints severed, the less number of days they live and the more abnormal are they. On an average they live only 5 days and 11 hours. When tested with the three essential oils the following reaction times were obtained:

	Seconds		Seconds
2 joints missing....	15	6 joints missing....	27
4 " "	44	7 " "	98
5 " "	56	8 " "	88

Bees with both antennæ pulled off live only 19 hours in observation cases and are completely abnormal in behavior. They always fail to respond to odors. When both antennæ are cut off at the bases, the bees live only 2 hours. They are also entirely abnormal and fail to respond to odors.

Bees with their antennæ covered with either shellac or celloidin do not live long and are quite abnormal. Bees with the antennæ covered with vaseline soon remove this substance and then behave normally again. Bees having the antennæ covered with liquid glue are abnormal until they remove the glue with their antenna cleaners. To prevent this removal the tarsi of the front legs including the antenna cleaners were burnt off with a red-hot needle. One-fourth of the bees so mutilated died within 12 hours, but the remainder appeared quite normal in every other way. On the second day the entire flagellum of each antenna was covered with liquid glue. These workers were quite abnormal and most of them did not live long. However, after gluing the flagella of many bees, 21 were finally obtained that were fairly normal and their reaction time to the three essential oils was 2.9 seconds, while the reaction time of the same odors for unmutilated bees was 2.6 seconds. These 21 workers lived only 24 hours on an average. The odor from the glue did not affect these results.

Both antennæ of 95 workers were burnt off with a red-hot needle. These workers were quite abnormal and lived only 17 hours. Seven of them recovered sufficiently from the operation to respond to odors; while the others failed to respond. The reaction time of the 7 workers used to the three essential oils was 4 seconds.

Since the effect of the shock caused by mutilating the antennæ may have produced the abnormality in all the bees experimented with, 30 workers were immersed in water for 15 minutes. When removed they appeared entirely lifeless and the antennæ were pulled off at once. They revived and lived thereafter only 19 hours. When tested with odors they failed to respond and like all the other bees made completely abnormal, they scarcely moved when touched with a pencil.

Since bees whose antennæ are mutilated after they become adults are abnormal, the antennæ of 400 worker pupæ were cut off. Several days later these workers emerged normally from their cells, but lived thereafter only 5 days.

The funiculi of 12 workers of *Formica* were cut off. These ants were then returned to a Fielde nest. They were slightly hostile to each other and to their unmutilated sisters. They failed to eat food and to catch flies, but their unmutilated sisters continually ate food and soon caught flies. The funiculi of 50 more workers of *Formica* were cut off. When returned to their cage, these ants were quite irritable and invariably attacked one another, and as a result several were killed.

The funiculi of 2 soldiers, 10 large workers and 7 small workers of *Camponotus* were cut off. When returned to their nest these ants attacked one another for three hours, then they became very inactive and responded to odors only slowly. The next day they were still quite inactive and " paid no attention " to anything, except when they came in contact with each other, they still fought one another. When tested with odors they failed to respond. At no time did they eat or drink.

The funiculi of 30 winged virgin females of *Formica* were cut off. When placed in experimental cases they were quite abnormal. Five of them failed to respond to odors and scarcely moved when touched with a pencil. These ants were discarded from the experiments. When tested with the three essential oils, the other 25 gave a reaction time of 4.38 seconds, while the reaction time for unmutilated sister females was 2.12 seconds. Confined in a Fielde nest, these mutilated ants lived only 19 hours.

The funiculi of 30 winged virgin females of *Formica* were covered with liquid glue. These ants were completely abnormal and five of them failed to respond to odors. When tested with the three essential oils the other 25 gave a reaction time of 5.78 seconds. They lived 6 days on an average.

The flagella of 25 *Vespula maculata* were cut off. In behavior these mutilated hornets were abnormal and lived only 1 day and 13 hours in observation cases. When tested with the three essential oils some of them responded promptly; some responded slowly, and a few failed to respond at all. All of those which failed to respond to odors scarcely moved when touched with a pencil. These were discarded and the flagella of the others were cut off. The 25 used in these experiments gave a reaction time of 3.09 seconds which is 0.66 second greater than the same reaction time for normal hornets.

In conclusion under this head it is seen that about four-fifths of the writers cited advocate the view that the antennæ are the seat of the organs of olfaction. Most of these observers have not said whether the mutilated insects that they used were normal. The inactivity or state of rest of many of these speciments indicates abnormality. In regard to Miss Fielde's ants, only 40 per cent recovered from the effect of the shock and in all probability all of these were more or less abnormal. When the antennæ of ants, hornets and bees are mutilated in the slightest degree, as ascertained by the author, the insects are more or less abnormal. The results obtained by using any insect with mutilated antennæ are, therefore, in all probability more or less erroneous. Judging from the author's experiments there is no reason to assume the presence of the olfactory organs in the antennæ, because the differences in reaction times between the reaction times of the mutilated insects and those of unmutilated ones may be attributed to the abnormality of the insects which is probably always caused by the operations. At most it can be claimed only that the antennæ may assist in the receiving of odor stimuli.

Since the organs in the antennæ of ants, hornets and bees, and probably all insects, fail to receive most, if not all, odor stimuli, the true olfactory organs must be looked for elsewhere.

VARIOUS STRUCTURES ON THE ANTENNÆ AS OLFACTORY ORGANS

Before entering into a discussion of the antennal organs of insects, a brief description illustrated with drawings of the antennæ of the honey bee and their organs will first be given.

The antenna of the bee consists of two portions: the proximal part, called the scape, and the distal portion, the flagellum. Each portion is more or less cylindrical in shape. The scape consists of a single long, slender joint, while the flagellum consists of 11 short joints in the worker and queen and of 12 in the drone.

When an antenna is examined under the microscope with a strong transmitted light its surface is seen to be covered with small bright spots and also various kinds of hairs. In order not to overlook any of these peculiar structures, several pairs of these appendages from young bees just emerged from their cells were removed and perma-

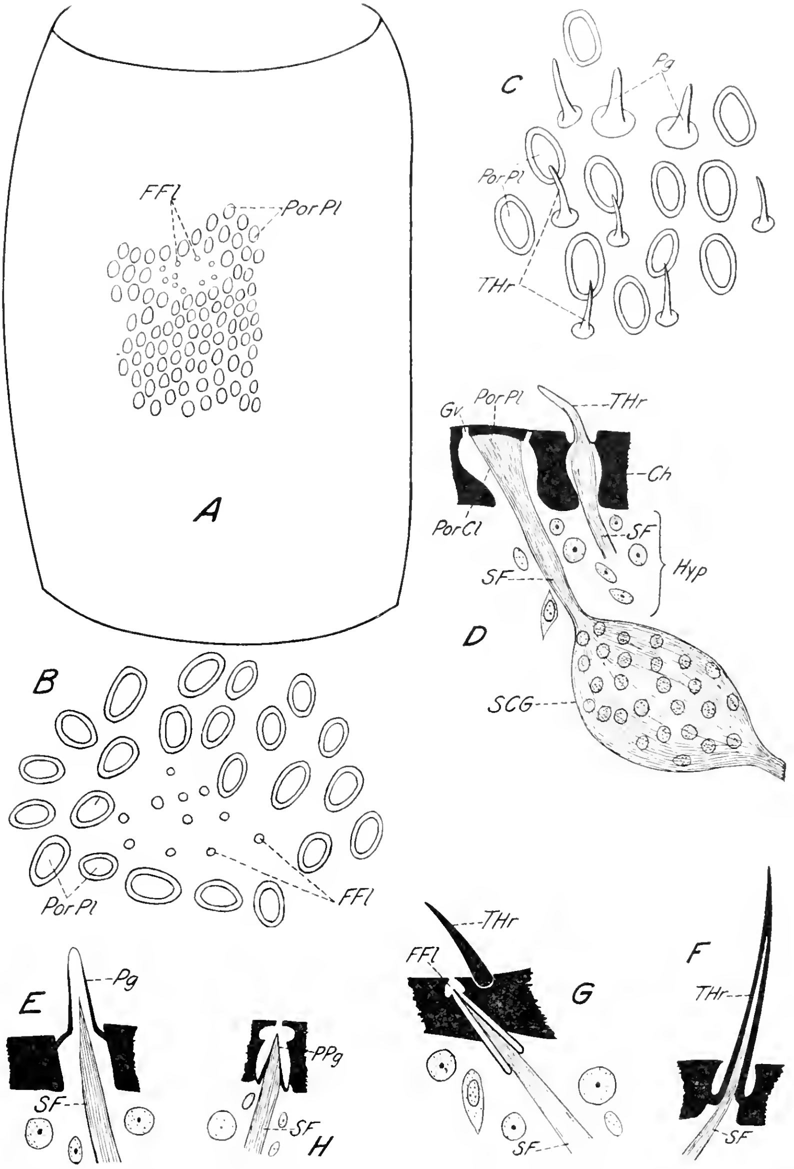


FIG. 1.—Antennal organs of the honey bee copied from Schenk. A, an antennal joint of a drone, showing a few of the many pore plates (*PorPl*) and a group of Forel's flasks (*FFl*), x 150; B, pore plates and Forel's flasks from a drone's antenna, x 600; C, pore plates (*PorPl*), pegs (*Pg*), and tactile hairs (*THr*) from a worker's antenna, x 600; D, internal anatomy of a pore plate and of a tactile hair; E, the same of a peg; F, the same of a tactile hair; G, the same of a Forel's flask; H, the internal anatomy of a pit peg. D-H, x 600.

nently mounted. In these antennæ there is no dark pigment to obscure any of the antennal organs. To illustrate these various structures modified copies of Schenk's drawings (1903) are given (fig. 1).

Figure 1, A, shows the small bright spots *(PorPl)* on the drone antenna magnified 150 times. This drawing also shows still smaller bright spots *(FFl)* which are difficult to find. Formerly the larger bright spots were termed " pits " but later they were called " pore plates," " pore canals," and " sensilla placodea," while the smaller spots bear the names " Forel's flasks " and " sensilla ampullacea." In this discussion the former will be known as *pore plates* and the latter as *Forel's flasks*. Figure 1, B, represents these organs of the drone bee enlarged 600 diameters. Figure 1, C, shows the pore plates *(PorPl)* and two kinds of hairs from the antenna of a worker, enlarged 600 diameters. The stouter of these hairs *(Pg)* bear the names, " pegs," " clubs," and " sensilla basiconica," and the more slender ones *(THr)* " hairlike structures " and " sensilla trichodea." In this discussion the stout hairs are designated *pegs* and the slender ones *tactile hairs*. A fifth antennal organ whose external opening is not drawn by Schenk has the same superficial appearance as Forel's flasks and probably cannot be distinguished from them externally. These structures have been termed " pit pegs," " champagne-cork organs," and " sensilla cœloconica." They are here designated *pit pegs*.

Figure 1, D-H, show the internal anatomy of the five antennal sense organs. Figure 1, D, shows the structure of a pore plate and of a tactile hair. The chitin *(Ch)* is solid black, the sense fibers *(SF)* and sense cell ganglion *(SCG)* are represented by fine broken lines. Since the sense fibers in Schenk's drawing are defective and are not attached to the plate *(Pl)* as the writer has observed them many times in his sections, and as Schenk represents them in *Vespa*, they are here drawn as they really exist. The plate is a hard and comparatively thick chitinous disc completely covering the pore canal *(PorCl)*. However, at its margin there is a deep groove *(Gv)* entirely surrounding the plate. To stimulate the sense fibers attached to the plate the odors must first pass through this hard chitinous plate.

Figure 1, E, shows a peg with its sense fibers running half-way to the tip of the hair. At its base the chitin is relatively thick while at the tip it is thin. If this structure is an olfactory organ, the odors must first pass through the thin chitin at the tip of the peg to stimulate the sense fibers. Figure 1, F, is a tactile hair. Figure 1, G and H, represent a Forel's flask and a pit peg respectively. Both of these are nothing less than hairs inside of pits, and the only difference between them is the shape of the flask. If they are olfactory organs, odors must enter the small apertures and pass through the thin chitin at the tip of the hairs inside the pits, to stimulate the sense fibers.

In drones, the antennal organs are found on only the distal nine joints of the flagellum and in workers and in queens on the distal eight joints. According to Schenk, the pore plates are present on all of these joints, and while they are abundant on both the dorsal and ventral sides of the male antennæ, in the female antennæ nearly all of them occur on the dorsal side. On both antennæ of a male there are about 31,000 and on those of a female only about 4,000; however, those of the female are considerably larger. Pegs are entirely absent from the drone antennæ, while they are abundant on those of workers and of queens. As a rule they are at the distal end of the joint on the dorsal side. The male antennæ are always devoid of tactile hairs whereas those of the female have many. Forel's flasks and pit pegs are moderately numerous in both sexes, but slightly less abundant in the female antennæ.

Some of these antennal organs, or at least modifications of them are present in the antennæ of all species of insects with probably one or two exceptions. In butterflies and moths pore plates are entirely absent and pegs are almost wanting. However, the place of the pegs seems to be taken by end rods, which are very similar in structure but are more club-shaped. Butterflies and moths also have bristle-like tactile hairs.

Pore plates, pegs, Forel's flasks, pit pegs and end rods have all been considered as olfactory organs by various authors, who, in trying to prove their views, assert that odors can pass through the hard chitin of these organs so that the nerve fibers inside may be stimulated. While these authors declare that this is possible in insects, they acknowledge that it would be impossible in the higher animals.

Erichson (1847), according to Hicks (1859c), first observed the pore plates and hairs on the antennæ of insects. He considered the pore plates as olfactory organs for two reasons: (1) He thought that the numerous hairs on the antennæ protect and keep these plates moist, so that odors can pass through them, and (2) they are more numerous in those insects whose smell is acute.

Burmeister (1848) describes the pits found on the antennæ of lamellicorn beetles. These are a variety of the pit pegs, and he attributes an olfactory function to them.

Vogt (1851), according to Wonfor (1874), discovered that the antennæ are covered with minute pores which are apparently filled with fine hairs. He thinks that these structures perform a function combining those of smell and touch.

Bergmann and Leuckart (1852) say that when one brings a drop of ether on the tip of a needle near the head of an insect it moves and strokes its antennæ. They speak of many pits on the antennæ; from the base of these pits arise small papillæ which they regard as olfactory organs.

Leydig (1860, 1886) made a thorough investigation of the pore plates discovered by Erichson. He found these pore plates not only in the antennæ of most insects but also discovered that they are modified into peculiar, peglike organs in the remaining insects, and in the crustaceans and myriapods. Leydig regarded these organs of questionable function as olfactory. In 1860 he thought that the palpi have a function similar to that of the antennæ.

Lespés (1858) compares the pore plates to the ears of higher animals and denies their olfactory office.

Hicks (1859b and c) thinks that the pore plates are cavities filled with fluid, closed in from the outer air by a delicate membrane to which a nerve is attached. He regards the pore plates as auditory organs and says:

> If we assign an olfactory function to these organs, one difficulty presents itself, viz: that for the odorous particles to affect the nerve they must reach it through a membrane and a stratum of fluid.

Landois (1868) experimented with the stag beetle *(Lucanus cervus)*. He does not doubt that this beetle can smell, for if exposed to the fumes of sulphuric acid, or ammonia or to tobacco smoke it draws in its antennæ quickly. If the ends of the antennæ are removed it still draws in the remainder of these appendages with the same rapidity as when the antennæ are intact. He found two kinds of sense hairs on the antennæ of this insect and pits filled with small hairs. He thinks, however, that olfaction is performed by none of these organs.

Grimm (1869) describes three kinds of hairs and a pitlike organ on the antennæ of beetles but does not regard any of these as an olfactory apparatus. He put a beetle with entire antennæ into a box which had a glass cover and an opening at the bottom covered with thin cloth. After this beetle had become quiet he put a piece of dung to the opening. The beetle at once came to the opening and tried to tear the cloth. Later he cut off its antennæ and repeated the experiment, and the beetle came to the opening as before. By repeating these experiments many times he concluded that the antennæ of beetles do not function as smelling organs. Also he infers, like Leydig, that there may be some olfactory rods or pegs on the palpi of this beetle.

Gegenbaur (1870) briefly discusses the antennal organs described by Erichson, Burmeister and Leydig but fails to express his own opinion concerning their function.

Lowne (1870) believes that the olfactory apparatus of the blowfly is located in the third antennal joint. This joint is remarkably dilated and is covered with minute openings which communicate with little sacs in the interior.

Müller (1871) found stiff hairs and pore plates on the flagella of the antennæ of a female bee, but only pore plates on those of the male bee. He thinks that the pore plates are olfactory organs and that male bees have a better olfactory sense than the females for the following reasons: (1) A male bee has one more joint in the flagellum; (2) all of these joints are longer, and (3) wider, and (4) the pore plates are so close together that they crowd out the stiff hairs.

Claus (1872) thinks that many insects have a well developed olfactory sense and that the surface of the antennæ is the seat of the sense of smell, basing this conclusion upon the work of Erichson and that of Leydig.

Chadima (1873), after examining the hairlike structures on the antennæ and palpi of crustaceans, insects and myriapods, which Leydig (1860) regarded as most probably olfactory organs, says that the smelling organs of arthropods have not yet been found. He states that none of these hairs is perforated at its tip. He thinks investigators will have more success in solving this problem if they look on the olfactory sense as being connected with the breathing apparatus.

Forel (1874) counted five different kinds of organs on the antennæ of ants—(1) olfactory knobs or pegs, (2) tactile hairs, (3) pore plates, (4) Forel's flasks and (5) pit pegs. Forel (1902) judging from the works of Hicks, Leydig, Hauser, Kräpelin and himself remarks that all the reputed olfactory structures of the antennæ are modified pore canals bearing hairs. They come under three chief forms—pore plates, olfactory knobs, and olfactory hairs. At times the last two can hardly be distinguished from one another. Chitin, even if very thin, always covers the end of the nerve. Forel's flasks and pit pegs have no relation to smell because they are lacking in the insects with acute smell (wasps) and are present in great abundance in insects (bees) with poor sense of smell. The same author (1908, pp. 95 and 96) still regards the pit pegs and Forel's flasks as a physiological enigma. They are generally absent, but are present in ants and aphidids, are quite abundant in the domestic bee, are present but not abundant in bumble bees, and are absent in wasps; nevertheless, he thinks they have nothing to do with olfaction. In dragonflies and cicadas the antennæ are rudimentary and the sense of smell is poor. The organs of smell of insects are in general situated in the antennæ, especially in their swollen or perfoliate parts where the antennal nerve ramifies. "These 'horns,' these 'ears' form, therefore, a famous nose in spite of Wolff and Graber." Thus Forel believes that the antennæ are the olfactory organs, yet he does not state what particular antennal organs receive the olfactory stimuli.

Bertè (1877) states that none of the antennal organs in fleas is for olfaction.

Lubbock (1877) discusses the antennal organs but does not venture to suggest their functions.

According to Vom Rath (1888), Lubbock (1883) found the same structures on the antennæ as did Forel (1874), although the details are somewhat different. Neither Forel nor Lubbock ventures to ascribe an olfactory function to any one of the five antennal organs, but by their many experiments, particularly on ants, both are thoroughly convinced that the antennæ carry the olfactory apparatus.

Graber (1878) describes a pitlike sense organ in the antennæ of flies. This was long before described by Leydig as an olfactory apparatus, but Graber regards it as an auditory organ.

Mayer (1878, 1879) regards the pitlike organs or pore plates as being most probably olfactory in function.

Reichenbach (1879) thinks that the small pits filled with hairlike structures are the olfactory organs in insects.

Hauser (1880) studied the behavior of various insects before and after the removal of the antennæ. When the antennæ were cut off many individuals soon became sick and died, although some of them lived thereafter for many days. In insects with their antennæ dipped in melted paraffin, the behavior was similar to that of those with the antennæ amputated. He placed 12 individuals (beetles) *Philonthus æneus* R. one at a time in an inverted beaker whose bottom was removed. He slowly placed a clean glass rod in front of the head and the insect gave no response. He then repeated the operation with a glass rod dipped in carbolic acid. When this was 4 inches away the insect was much affected, it lifted and moved its head in different directions and made quick forward movements with its antennæ. When the glass rod was brought nearer it moved away quickly and drew its antennæ through its mouth. The reaction to turpentine and acetic acid was more violent. Next he cut off the antennæ. On the second day after the operation he repeated the experiments, but the insects failed to respond to any one of these three strong odors. After the operation the beetles ate with a greater appetite and some of them lived more than two months thereafter. From these experiments he concludes that the beetles lost the olfactory sense by the removal of the antennæ.

Experiments with species of several other genera gave the same results but those with beetles of the genera *Carabus*, *Melolontha*, and *Silpha* were less satisfactory. These never completely failed to respond to strong-smelling substances. If they are exposed for a long time to the odors the insects deprived of their antennæ become restless and walk away from the glass rod, yet all the movements are less energetic. The entire reaction is indefinite and weakened. Experiments with Hemiptera gave a still less favorable result. After the loss of the antennæ these insects reacted almost as well as they did with their antennæ intact.

Hauser performed the following experiments to ascertain the value of the antennæ in the search for food. He placed beetles *(Silpha)* in a large box whose bottom was covered with moss. In one corner of the box he put a small glass with a small opening, the glass containing foul meat. As long as the insects possessed their antennæ they regularly found the meat in the glass after some time, while after the removal of the antennæ they never came in contact with it. Similar experiments were performed with flies of three genera. A vessel containing spoiled meat was placed on a table by an open window. Soon several flies came to the meat. Then he closed the window and cut off the antennæ at the third joint. Thereafter not one of these flies came in contact with this meat.

Hauser next ascertained the value of the antennæ to the male in finding the females. Male and female beetles and butterflies were placed in large boxes. As long as they were normal in every respect they mated freely, but when the antennæ were cut off they copulated only occasionally.

Hauser, who worked extensively and thoroughly on the antennæ of insects of all orders, found many differences in the various orders but among different Hymenoptera the differences in distribution and structure of the antennal organs are comparatively slight. According to him, *Vespa* (a wasp) possesses about three times as many pegs as does the honey bee, and for this reason *Vespa* has better olfactory perception. *Formica* (an ant) has far more pegs than pore plates, contrary to the rule in hymenopterous insects. In conclusion Hauser asserts that in almost all insects the olfactory organ consists of (1) a large nerve arising from the cephalic ganglion which runs out into the antenna, (2) a recipient end apparatus which represents rod cells modified from hypodermal cells with which the fibers of those nerves are connected, (3) a supporting and accessory apparatus which is formed by the pore plates and pegs filled with a serous fluid. When both pore plates and pegs are present they both function in smelling according to their number; when one of these organs is absent then the other one functions entirely as an olfactory receptor.

Kräpelin (1883), according to Schenk (1903), considers the pore plates and pegs as smelling organs and translating from Vom Rath (1888) Kräpelin thinks that the olfactory organ is also located in the palpi.

Schiemenz (1883) regards the pegs as touch organs, while the pore plates and Forel's flasks probably serve as olfactory organs.

Sazepin (1884) worked chiefly on the antennæ of myriapods, but he also spent some time in working out the anatomy of the antennæ of *Vespa*. By comparing the anatomy of the myriapods' antennæ and with that of *Vespa* he found that as a whole there is a great similarity, but while the olfactory pegs in *Vespa* are closed at their tip, they are open in what he calls the olfactory pegs in myriapods.

Witlaczil (1885) worked on the antennæ of certain bugs. Since their antennal pits, called olfactory pits by Hauser, are covered by a membrane he thinks that they can scarcely be called olfactory organs.

Vom Rath (1887, 1888), like most authors on this subject, regards the olfactory sense as located in the sense pegs of the antennæ and probably also in the pore plates. By making a comparative study of all the antennal organs in arthropods, Vom Rath (1895) found a great similarity in the structure of each set of organs. The sense pegs are not by any means confined solely to the antennæ but are found on all the mouth parts, in the mouth cavity, and even over the entire body. It is possible that many pegs serve for the reception of the stimuli of weak odors from a distant object and others for the olfactory perception of those nearer. It may be that the pegs of each kind, and also the pore plates, are especially responsive to certain kinds of odors. He believes that the pegs on the palpi possess an olfactory function and possibly for odors close at hand. Moreover, these pegs elsewhere may have the same function.

Ruland (1888), who made a thorough comparative anatomical study of insect antennæ, contends that only such hair structures as those which are perforated at the tips can be sensitive to chemical stimuli. Pegs are found in all orders of insects and, since myriapods and crustaceans possess similar structures, these organs may be considered as the chief form of olfactory organs in the arthropods. Ruland regards the pit pegs and Forel's flasks found in most insects as simple pit pegs, while the compound pits, as seen in the antennæ of flies and butterflies, he calls compound pit pegs. He believes that all three sets of these organs are organs for the reception of stimuli from certain olfactory substances. To determine whether all of the hair structures are perforated at their tips, he put the antennæ into boiling caustic potash. After such treatment he observed that they were all open at the end. In the investigations made by the author it was learned that caustic potash within a short time not only destroys all of the internal tissue but it soon dissolves thin chitin. All who have studied these structures before and since 1888 assert that these hairlike organs are tipped with very thin chitin through which the odorous particles must pass. In the observations made by the author these structures in the antennæ of the honey bee have not shown a single hair which is open in the slightest degree at the tip and it is probable that in Ruland's treatment the caustic potash dissolved the thin chitin at the tip.

Nagel (1892, 1894, 1909, the views set forth in the first reference being cited by various authors,) states that, in his opinion, the antennæ are generally the olfactory organs of insects—not, however, without exception. That insects, after amputation of the antennæ, seem incapable of perceiving odors is not sufficient proof that the antennæ are olfactory organs. He declares (1894) that organs with thick chitinous walls cannot function in smelling, but he thinks that the olfactory pegs, being tipped with thin chitin, are capable of receiving olfactory stimuli. He asserts that these olfactory pegs are found on other parts of the body besides the antennæ. He (1909) does not doubt that in many insects the palpi may assist in smelling. In the antennæ of a May beetle there are four different kinds of pitlike organs (varieties of pit pegs), all of which may be olfactory in function. In the Hymenoptera the antennæ are the only seat for their highly developed olfactory sense. In some Hymenoptera both pore plates and pegs, while in others only the pore plates, function in smelling. In ants the pegs and knee-shaped bristles probably serve this purpose; in Lepidoptera the pit pegs function for smelling when the insect flies, the end rods serving such a purpose while the insect is resting; in Diptera the pit pegs, similar to those of butterflies, are the olfactory organs. Nagel repeated most of Hauser's experiments and seems to be convinced that the antennæ are almost always, if not always, the seat of the organs of olfaction. When one or more of these organs are absent the next best, histologically considered, must perform the olfactory work; and when all the antennal organs are wanting, as in *Ephemera vulgata*, a pseudoneuropteron, he imagines that the insect cannot smell.

Dahlgren and Kepner (1908) regard the knob-shaped, pitlike antennal organs of *Necrophorus* as the olfactory organs. They found glandlike cells beneath the hypodermis which they believe to be associated with these pits and perhaps aid in receiving odor stimuli.

Nearly all of the foregoing observers have overlooked the sense organ found in the second antennal joint of insects. This is called Johnston's organ. In *Vespa* the upper end, or the nerve rod, of the organ penetrates the articulating chitin between the second and third joints and comes to the surface. From its structure an olfactory sense might be attributed to it. According to Child (1894a and b), who experimented extensively with mosquitoes, this organ serves as a combined touch and auditory apparatus and has nothing to do with olfaction.

Lubbock (1899) says:

> Forel and I have shown that in the bee the sense of smell is by no means very highly developed. Yet their antenna is one ot those most highly organized. It possesses—besides 200 cones [pegs], which may probably serve for smell—as many as 20,000 pits [pore plates]; and it would certainly seem unlikely that an organization so exceptionally rich should solely serve for a sense so slightly developed.

From this fact and his numerous experiments Lubbock regards the antennæ as the seat of the organs of olfaction, yet he does not commit himself as to the particular antennal organs which receive the odor stimuli.

Börner (1902) states that only a few of the hair structures on the antennæ of Collembola may be regarded as olfactory organs.

Schenk (1903) claims that the fact that the males of Apidæ (bees) do not possess any pegs does not argue against the view that these structures are olfactory organs for (1) the pit pegs, which certainly have an olfactory function, are common to the antennæ of males, queens and workers, and (2) in hunting for the females the olfactory sense appears to be of second place to sight. In the summary of his observations on Lepidoptera Schenk asserts that the pit pegs function as smelling organs, because they are more highly developed and more advantageously distributed on the antennæ in the males so that they may be of the greatest use in scenting the females. The end pegs also aid in olfaction, particularly when the insect is resting. He does not think that the pore plates in Hymenoptera have an olfactory use, and he regards this view as based on insufficient data. Olfaction in the Vespidæ (wasps) is accomplished by the pegs, because the pit pegs are almost absent, while in the bees the pegs and pit pegs both are olfactory in use; but since the male bees do not have these pegs, the sense of smell is entirely performed by the pit pegs.

Röhler (1905) made a special study of the antennal organs in a grasshopper, *(Tryxalis) Acridella nasuta* L. On the antennæ he found only three kinds of organs, viz: bristles, pegs and pit pegs. Of these three he regards only the pit pegs as olfactory in function, and the females have only about two-thirds as many of them as have the males. This additional number of pit pegs greatly aids the males in finding the females.

Cottreau (1905) discusses the sense of smell of insects in a popular way, without performing any experiments or citing any references. He says that the olfactory organs are the pits and papillæ, distributed abundantly on the antennæ and without doubt in certain regions on the mouth parts.

In discussing olfaction and antennal sense organs of insects Berlese (1906) seems to infer that there can be no doubt that the antennæ are really the seat of the smelling organs.

In a comprehensive study of the morphology of the chitinous sense organs of *Dytiscus marginalis*, a water beetle, Hochreuther (1912) finds seven different kinds of organs. Of these seven only the hollow pit pegs (hohle Grubenkegel) are probably olfactory in function. They not only occur on the antennæ and mouth parts, but a few are found on the thorax and perhaps a few on the coxæ of the first two pairs of legs.

CAUDAL STYLES ("ABDOMINAL ANTENNÆ") AS SEAT OF OLFACTORY ORGANS

Packard (1870) discovered that the caudal styles of the female *Chrysopila* (a fly) possess a peculiar sense organ. On the posterior edge of the upper side of each style there is a single, large, round sac with quite regular edges. Its diameter is equal to one-third of the length of the style. Dense, fine hairs project inward from its edge, and the bottom of this shallow pit is a clear, transparent membrane devoid of hairs. Since this same insect possesses no antennal organs

Packard believes that this structure is an olfactory apparatus. He calls this a " simple nose," while in the caudal styles of the cockroach there is a " compound nose."

ORGANS ON BASES OF WINGS AND ON LEGS AS OLFACTORY ORGANS

While examining the organs on the halteres of flies, Hicks (1857) discovered on the bases of the wings peculiar structures which he called vesicles, arranged in a single row extending some little distance up the vein on both sides of the wing, but principally on the upper side. By examining insects of other orders he ascertained that these organs are not confined to the Diptera. He believes that they are found in all insects, and they were present in all specimens examined by him. They exist on both sides of the wing, but chiefly on the upper side of the base on the subcostal vein and in the Hemiptera on the costal vein. Those on the hind wing are generally larger in size and greater in number.

> In Moths they are very apparent, being greatest in the Noctuæ [Noctuidæ] and Bombycidæ. There are about 100 vesicles on the upper surface of the posterior wing, and half that number beneath, besides some few on the nervures [veins]. In the butterfly they are smaller, but arranged in more definite groups, about three in number. In Coleoptera and Neuroptera they are arranged in long rows along the subcostal nerve; they are more apparent in Coleoptera than in Neuroptera. In the Hymenoptera, for instance the bee, they are found in a rounded group of about forty on each side.
>
> Are they organs of smell, as suggested by Mr. Purkiss? As the olfactory organ has never yet been decided on, it seems to me not improbable that they be the organs of that sense; for, first, it is not likely that they should be the organ of hearing, as they are in constant motion, and situated near the source of the hum of the wings, so that other sounds would be drowned, 2ndly, it is not necessary that the power of smell should be in the head. It is situated in the commencement of the air passages in the upper animals probably because the current of air or water passing the olfactory nerves is there most powerful; but in the spiracle-breathing insects the greatest currents are in the neighborhood of the wing, and near the greatest thoracic spiracle. The motion of the halteres also permits a greater exposure to odors floating in the air.

He claims that the organs on the halteres and on the base of the wings are similar in structure and probably have the same function, that of smell. He was able to trace a nerve to each group of organs, the one going to the hind wing being the larger.

Hicks (1859a) presented a second paper concerning these organs in which he asserts:

> I may here repeat that each of these structures consists of very thin and transparent, hemispherical or more nearly spherical projections from the

> cuticular surface, beneath which the wall of the nervure is deficient, so as to allow a free communication with its interior; these organs are arranged in rows on the halteres and in variously shaped groups in the wings.

He examined one or more species of about two dozen genera representing all of the insect orders. He observed these organs in the honey bee, in *Vespa*, and in all other species examined by him except *Corysus* [*Corizus*], the bedbug *(Cimex lectularius)*, an apterous beetle, and the flea *(Pulex irritans)*. Usually these structures consist of two groups on the upper, and one scattered group on the under side of the subcostal vein, amounting in *Ophion* to from 200 to 300 above, and perhaps 100 beneath, with a smaller group at the end of the vein. In the Diptera these vesicles are found both on the wings and halteres. In the Coleoptera they are highly developed and occur in numerous groups on the subcostal vein, mostly at the widest part, but are also scattered along it to the joint of the wing. In *Carabus* (a beetle) they are found on veins other than the subcostal. In many beetles the vesicle is overarched by a hair, which probably protects the organ. He could distinguish no differences in the sexes except that the vesicles were slightly larger in the females, due to their greater size. These organs are most perfectly developed in the Diptera, slightly less perfectly developed in the Coleoptera, rather less so in the Lepidoptera, only slightly developed in the Neuroptera, scarcely at all in the Orthoptera, and only a trace of them exists in the Hemiptera. He gives several drawings, but they represent only the superficial appearances.

Hicks (1860) discovered these same vesicles on the trochanter and femur, chiefly on the former, in all the insects he examined. In *Formica rufa* (an ant) these structures are numerous and exist both on the trochanter and femur. A few small groups of these vesicles are also present on the proximal end of the tibia in this ant. In the honey bee these organs are not so abundant on the legs but are located at the same places as on the ant. The vesicles on the legs, like those on the wings, consist of a thin, delicate membrane

> stretching over, and closing in from the air, a tubular aperture in the chitinlayer of the part. This aperture may be circular or oval, the tube varying in length according to the thickness of the integument, curved as in the Hornet, or forming a globular cavity as in Silpha. The delicate membrane which covers over this aperture is generally level, sometimes leaving a ridge or a minute papilla in its center.

Hicks gives drawings showing the disposition of these vesicles or pores on the wings and legs of many of the species examined. He saw nerves running to all of these organs and gives a very good idea concerning their structure, although since our modern technique of making stained sections was entirely unknown in his time we should not expect his drawings to represent the finer anatomy of these pores. He used the following technique:

> After cutting off the wing and washing it well in water or spirits of wine, and draining off the major part by blotting paper, I immerse it in spirits of turpentine for a week or two, after which it is placed in Canada balsam between glass in the normal way, taking care not to heat it, as that renders the nerve too transparent. In those parts which are too dark for observation, I have been enabled to render them colorless by Chlorine.

In regard to smell in insects and the function of the pores on the legs Hicks says:

> The delicacy with which odours are perceived by many insects argues an olfactory apparatus of considerable perfection; and it seems to me not impossible that these latter named organs [those on the legs] may be in some way connected with the sense of smell, or perhaps with some sense not to be found in the Vertebrata.

To summarize Hicks' three papers, he discovered these pores on the halteres and on the bases of the wings of all Diptera examined; on the bases of all four wings of the four-winged tribes; on the trochanter and femur of all insects, and occasionally on the tibia. He examined many species representing various insect orders and found these pores even on the lower insects, such as the earwig. In such wingless insects as the worker and soldier ants, he infers that these pores are much more abundant on the legs than they are on these appendages in the winged insects. Hicks suggested an olfactory function for all of these pores, whether on the legs or wings, but he performed no experiments of any kind.

Weinland (1890) and several others have made a special study of the halteres or balancers of flies and the sense organs on the bases of these appendages. Weinland distinguishes four kinds of structures on the halteres, all of which are similar in most respects and differ only in minor details. Their internal anatomy is similar to that of Hicks' vesicles. Of these four structures Weinland calls only one of them Hicks' papillæ, and neither he nor anyone else except Hicks and Bolles Lee (1885) has ever attributed an olfactory sense to any of the structures on the balancers.

Guenther (1901) studied the nerve endings found in butterfly wings. He spent a short time on the anatomy of Hicks' vesicles but failed to recognize them as the ones which Hicks first described in 1857. Guenther calls them sense domes (Sinneskuppeln). He describes the external appearance of them as being light spots whose thin chitin is arched in the shape of a dome. Each light spot is surrounded by a dark, chitinous ring. The internal anatomy consists of a sense cell, sense fiber, and a flasklike cavity with its chitinous cone. All of these parts are almost identical to those in Hymenoptera described by the author but Guenther failed to see the sense fiber join the aperture at the bottom of the flask. Thus his drawing shows a thin chitinous arch or dome which completely closes the external end of the flask, the sense fiber running up against this chitinous dome. If he had prepared more sections and used light colored stains such as safrain and not dark stains like hämatoxylins, he could certainly have seen the sense fiber join the aperture in the dome. Guenther tries to liken these pores to the membrane canals of Vom Rath. A similar dome-shaped membrane was found in the antennæ of lamellicorn beetles by Hauser, Kräpelin, Vom Rath, and others, but these bear a little hair at their center. Hauser attributes an olfactory function to such structures, but Guenther shares the opinion with Vom Rath and Graber that they have an auditory rôle.

Janet (1904) found porelike sense organs in large numbers in all the ants that he examined. These pores are either widely separated or, more frequently, united into groups. They occur on the labial palpi and on the tongue, and there are some on the pharynx, besides many on the legs. Janet recognizes those on the legs as the same vesicles or organs that Hicks describes in 1860. In a wasp *(Vespa)* and an ant *(Formica)* their disposition is almost identical with that in the honey bee. Janet's drawings of the superficial aspects of these pores are very similar to those of the author but on account of the small size of the specimens he seems to have had trouble in understanding their internal anatomy. According to him, all the pores, whether on the mouth parts or legs, have a similar structure, and they resemble the structure of the olfactory pores found in the honey bee; however, there are a few slight differences. He calls the chitinous cone an umbel, which is always separated from the surrounding chitin by a chamber. This chamber communicates with the exterior by means of the pore. The sense fiber, or his manubrium, runs into the umbel, and he thinks that it spreads out over the inner surface of the umbel and does not open into the chamber. Thus the umbel forms a thin layer of chitin which separates the end of the sense fiber from the external air. The rôle of these organs is evidently to permit the end of the nerve to become distributed on a surface relatively large and separated from the air only by a thin layer of permeable chitin. Janet fails to give drawings that show the sense fibers running all the way to the umbel and apparently has not seen the way in which the nerves actually end in the umbels.

Janet (1907) describes and gives a drawing of one of these same organs that he found near the articulation of the wing of a queen ant. Its morphology is the same as described above. Thus in ants, according to Janet, we see that Hicks' vesicles are not only found on the legs, but also near the wing articulations and probably also on the mouth parts. According to their anatomy, as Janet describes it, these organs function as some kind of a chemical sense and in fact are as suitable to perceive olfactory stimuli as are the antennal organs, if not more suitable.

Wesché (1904) remarks that a certain bot-fly has a highly developed sense of smell, equal to that of many mammals. This fly has large antennæ containing sense organs that are larger than those in some other flies; some of these organs are known to function as a keen olfactory sense.

> I think that where the antennæ are not particularly sensitive, the palpi have this structure to compensate. We thus see that the palpi, like the antennæ, can bear organs of three senses—touch, taste, and smell; but I do not think that any one palpus has more than two of these senses developed at the same time.

Besides making such broad statements concerning the senses of insects, the same writer describes and gives drawings of some sense organs that he thinks entirely new. Some of these he found on the legs, which are without doubt Hicks' vesicles. He observed these organs in *Vespa* and in many Diptera and his description of their superficial appearance fits what has been seen by the author. Wesché remarks that these organs are possibly auditory or for some unknown sense; however, he says nothing about their internal anatomy or any literature relating to them.

Freiling (1909) spent a short time studying the anatomy of Hicks' vesicles as found in the wings of butterflies. While Guenther found these sense domes (Sinneskuppeln) in great numbers, irregularly scattered on the veins near the base of butterfly wings, Freiling regards them as regularly distributed in the same location. The superficial appearance, as he has drawn it, is similar to that of the bee. He shows a large bipolar sense cell with its sense fiber running to the apparent opening in these organs but he thinks that the sense fiber ends [clublike] just beneath the apparent aperture. He worked three weeks trying to get good sections of these organs and succeeded in getting only one specimen from which he obtained fairly good sections. Freiling gives only one drawing each of the external and the internal structure of these organs, and the latter is drawn diagrammatically. In this he fails to show the chitinous cone, and the end of the sense fiber is represented as separated from the exterior by the thin layer, forming the dome. On this incorrect interpretation of the anatomy, he, like Guenther, speculates on their probable function and concludes that these sense domes may serve as some kind of a barometric device or as an apparatus for measuring the force of the air against the wing.

Berlese (1909, pp. 678-684) calls all the dome-shaped organs of insects "sensilli campaniformi o papilliformi." The campaniform type is found on the mandibles, antennæ, legs and wings. Their domes never project above the general surface of the surrounding chitin. The papilliform type occurs only on the halteres. Here the domes project above the surface of the chitin. In schematic drawings he shows how the domes may have been derived from a portion of the chitin originally not arched. Berlese regards the function of these organs as unknown.

While studying the morphology of the chordotonal organs in the honey bee and ants, Schön (1911) found two rows of small cones on the proximal end of each tibia. A sense cell lies just beneath each cone and the peripheral end of the sense fiber runs into the cone. These sense cells connect with the chordotonal organ located in the middle and distal end of the tibia. Schön has certainly mistaken Hicks' vesicles for cones, because the external appearance of these vesicles often resembles cones when observed without the cylindrical tibia being properly rotated. These organs always lie near the edge of the tibia, and when one looks down upon them their apertures look like cones, but when the tibia is rotated slightly, so that they lie on the median line of the tibia, the optical illusion becomes evident.

Hochreuther (1912) describes and gives drawings of the dome-shaped organs (kuppelförmigen Organe) in a manner somewhat similar to that of Janet. Each organ is located at the bottom of a chitinous flask, the mouth of which communicates with the exterior. Instead of the peripheral end of the sense fiber coming into direct contact with the air in the flask, it apparently stops just beneath the chitinous dome. No true chitinous cone is present, but his terminal strand (Terminalstrang) resembles it somewhat in general appearance. He finds a few of these dome-shaped organs on the epicranium near the margin of the eyes, 11 on the first and second joints of the antennæ, a few on the dorsal side of the labrum, very few on the dorsal side of the mandibles, several on the maxillæ, about 18 on the first four joints of the first legs, about 10 on the first three joints of the second legs, and a few on the trochanter of the third legs. He evidently has not examined the wings. Thus according to Hochreuther these organs are rather widely distributed. Since the peripheral ends of the sense fibers do not come into contact with the outside air, but connect with the tops of the domes, he suggests that they receive some kind of mechanical stimuli, although he performed no experiments to determine their function.

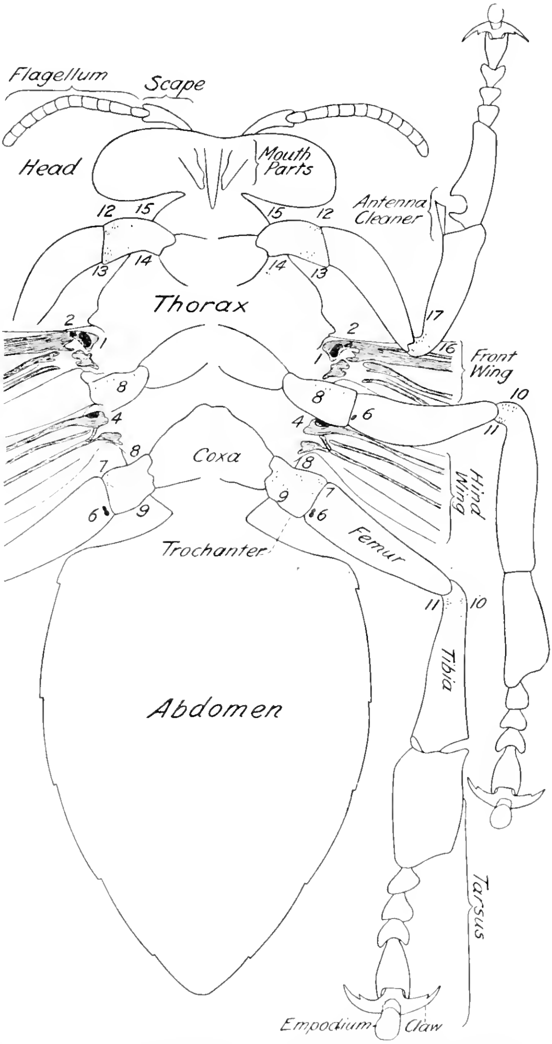


FIG. 2.—Diagram of ventral view of a worker bee, showing the location of the different groups of olfactory pores as indicated by the numbers.

The following results were obtained by the author. The disposition of Hicks' vesicles (called olfactory pores by the author) is best understood by referring to the numbers in figures 2, 3 and 4 of the honey bee. Groups 1 to 5 lie on the bases of the wings as indicated by the numbers 1 to 5. Groups 6 to 18 lie on the legs. Group 19 to 21 lie on the sting of the worker and queen (fig. 4). The same organs are found on the mouth parts of all the hymenopterous insects

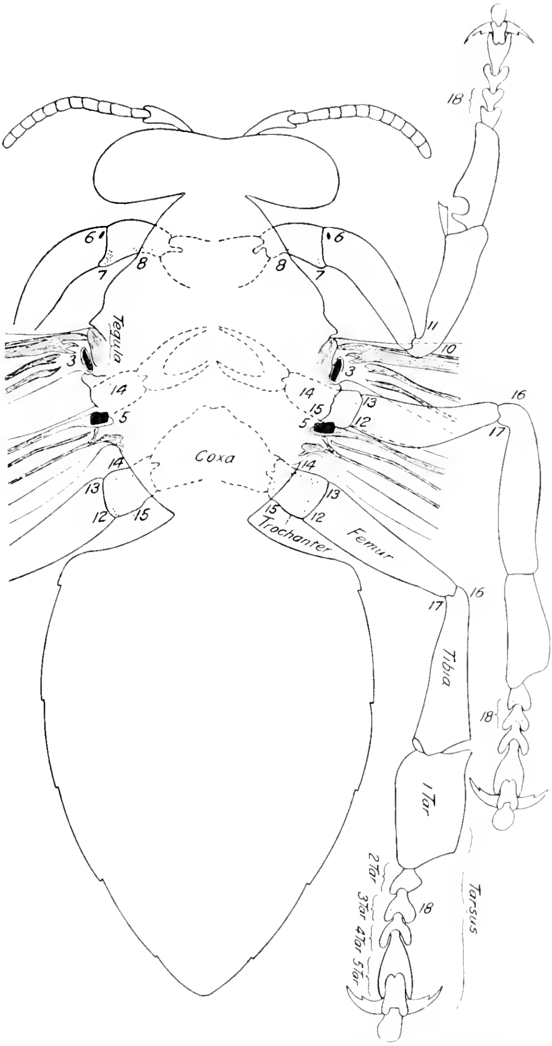


FIG. 3.—Diagram of dorsal view of a worker bee, showing the location of the different groups of olfactory pores as indicated by the numbers.

examined, but they have not yet been thoroughly studied. The antennæ of the honey bee and probably the antennæ of all Hymenoptera do not carry any of the organs first described by Hicks.

The olfactory pores in other hymenopterous insects are similar in position to those of the honey bee. Among the 29 species examined, these pores vary much in the number of groups and in the number of pores contained in the individual groups. As a rule, the lower the insect the fewer the groups and more isolated are the pores. *Cimbex,* regarded as the lowest hymenopteron, has the least number of groups of all the species examined, but it stands fourth in regard to the number of isolated pores. Its total number of pores is larger than that of many of the higher forms. Among ants the variations are also great. For the legs of ants the number of pores varies from 211 to 356 and for the winged ants the total number varies from 463 to 1,090. The smallest specimen among the ants and the second smallest one of all the Hymenoptera examined is a female with 463 pores as the lowest number. The drone honey bee with 2,608 pores has the highest number. The smallest specimen examined is a wasp with 688 pores. The following table including 6 of the 29 species examined will illustrate the variations in the number of olfactory pores as found on the three pairs of legs and the two pairs of wings. The letters "F," "M," "H" and "G" stand for front, middle, hind and grand, in the order named. The "Total" means all the pores found on all 6 legs, and the "G. total" means all the pores found on all 6 legs and all 4 wings combined.

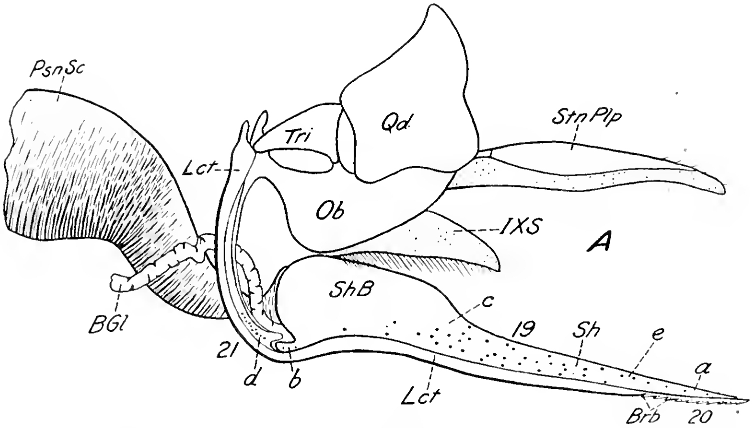


FIG. 4.—Diagram of lateral view of a worker bee's sting and its accessory parts, showing the location of the olfactory pores as indicated by the numbers.

TABLE I

Average number of olfactory pores on the legs and wings of Hymenoptera

	Apidæ.									Bombidæ.			Vespidæ.			Formicidæ.									Braconidæ.			Cimbicidæ.		
	Apis mellifica Linn.									Bombus sp.			*Vespula maculata* Linn.			*Formica obscuriventris* Forel.									*Microgaster mamestræ?* Vier.			*Cimbex americana* Leach.		
	♂			♀			☿									Winged. ♂			Winged. ♀			Major. ☿								
	No. of isolated pores.	No. of pores in groups.	No. of groups.	No. of isolated pores.	No. of pores in groups.	No. of groups.	No. of isolated pores.	No. of pores in groups	No. of groups.	No. of isolated pores.	No. of pores in groups.	No. of groups.	No. of isolated pores.	No. of pores in groups.	No. of groups	No. of isolated pores	No. of pores in groups.	No. of groups.	No. of isolated pores.	No. of pores in groups.	No. of groups.	No. of isolated pores.	No. of pores in groups.	No. of groups.	No. of isolated pores.	No. of pores in groups.	No. of groups.	No. of isolated pores.	No. of pores in groups.	No. of groups.
F. legs.	119	77	6	96	57	6	128	96	8	132	95	8	90	67	6	41	79	8	32	80	8	40	71	8	21	42	6	112	17	2
M. legs.	111	75	5	99	60	6	146	86	8	72	88	8	102	70	6	37	79	8	33	83	8	32	76	8	39	30	6	92	12	2
H. legs.	140	88	7	89	51	6	137	101	8	53	83	8	80	64	6	38	82	8	31	83	8	36	77	8	36	43	6	118	24	3
Total.	610	....	....	452	....	....	694	....	....	523	....	....	473	....	....	356	....	....	342	....	....	332	....	....	211	....	....	375	....	....
F. wings.	....	1232	6	....	840	6	....	970	6	....	704	6	....	1036	6	...	402	6	..	320	6	...	...	...	....	319	6	....	468	6
H. wings.	....	766	4	....	470	4	....	540	4	....	400	4	....	448	4	...	134	4	...	98	4	...	...	...	....	92	4	....	373	4
G. total.	2608	....	28	1762	...	28	2204	...	34	1627	...	34	1957	....	28	892	...	34	760	...	34	...	...	...	622	...	28	1216	...	17

In size the olfactory pores vary much. Those of an ant vary more in size than do those of the hornet or honey bee. The pores on the wings are always much smaller than are those on the legs and they vary less in size. In proportion to the sizes of an ant and of a worker honey bee, the pores of the ant are much larger.

Under the microscope with transmitted light the olfactory pores appear as bright spots. At the first glance they resemble hair sockets (fig. 5, PorApHr) from which the hairs have been pulled, but after a closer examination a striking difference is usually seen. Each bright spot is surrounded by a dark line, the pore wall (figs. 5 and 6, PorW). Outside this line the chitin (fig. 5, PorB) may be light or dark in color, but inside the line the chitin (figs. 5 and 6, ChL) is almost transparent, and at the center there is an opening, the pore aperture (figs. 5 and 6, PorAp).

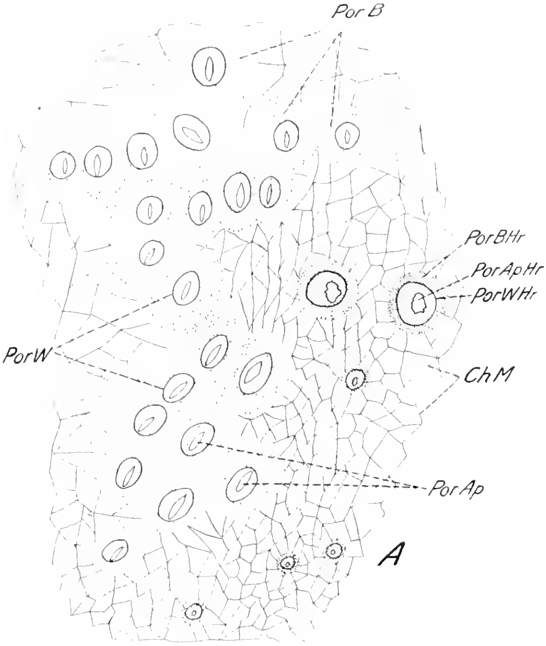


FIG. 5.—Group 6 of the olfactory pores from the hind leg of a worker bee, showing the external appearance, x 700.

The olfactory pores consist of inverted flasks in the chitin and of spindlelike sense cells lying beneath the mouths of the flasks (fig. 6). About two-thirds of the space at the bottom of the flask is occupied by a hollow chitinous cone (fig. 6, Con) which is not separated from the surrounding chitin, but only stains less deeply. In a typical olfactory pore the neck (NkFl) of the flask is wide and the mouth (MFl) is flaring. The sense fiber (SF) of the sense cell (SC) pierces the bottom of the cone and enters the round, oblong, or slitlike pore aperture (Por.Ap). The nerve fiber (NF) soon runs to a nerve. It is thus seen that the cytoplasm (Cyt) in the peripheral end of the sense fiber comes in direct contact with the air containing odorous particles and that odors do not have to pass through a hard membrane in order to stimulate the sense cells as is claimed for the antennal organs.

To determine the function of these pores the wings, legs and stings of many worker honey bees were mutilated. The behavior of the mutilated bees was carefully studied, and they were tested with odors in the same manner as were unmutilated ones. The stings of 100 workers were pulled out. These bees lived 30 hours on an average. Twenty of them were tested with odors. They responded only slightly more slowly than unmutilated bees. The wings of 28 workers were pulled off. When tested with odors, these bees responded one-eighth as rapidly as normal bees. The bases of the wings of 20 workers were covered with liquid glue. When tested, these bees responded also one-eighth as rapidly as unmutilated ones. The pores on the legs of 20 workers were covered with a mixture of beeswax and vaseline. When tested, these bees responded two-fifths as rapidly as unmutilated workers. The wings were pulled off and the pores on the legs of 20 workers were covered with the beeswax-vaseline mixture. When tested with odors, these workers responded one-twelfth as rapidly as unmutilated workers. All of the workers with mutilated wings and legs lived just as long in the observation cases as did unmutilated workers, and they were absolutely normal

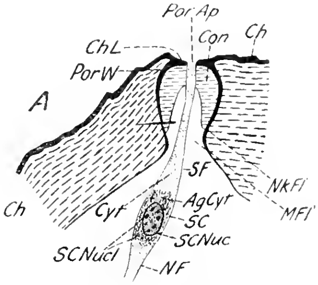


FIG. 6.—Cross section of a typical olfactory pore with its sense cell (*SC*) from the tibia of the hind leg of a worker bee, x 700.

in all respects except that they reacted to odors more slowly. Controls proved that the odors themselves from the glue and beeswax-vaseline mixture did not affect the reaction times.

The preceding experiments were repeated by using ants and hornets with mutilated wings and legs. When tested with the odors from the oil of peppermint, oil of thyme, oil of wintergreen, honey and comb, leaves and stems of pennyroyal, and formic acid from other ants, four deälated females of *Formica* gave a reaction time of 2.89 seconds. The reaction time for winged females of the same species is 2.45 seconds. The niches from which wings of these four females arises were examined. In seven of the eight niches, pores were seen.

All four wings of each of 25 virgin females of *Formica* were pulled off. When tested with the above six odors, these ants gave a reaction time of 2.85 seconds. After an examination it was found that 62 per cent of the detached wings had broken off just beyond the groups of pores, thus the pores on only 38 per cent of the wings were lost. When the wings are shed naturally only 21 per cent of the pores are lost, while 79 per cent are not prevented from functioning, because the wings devoid of pores always break off at a weak place in the chitin just distal to the groups of pores. Furthermore, sections through the stubs of the wings of deälated females show that the sense cells are normal.

The wings of 7 males of *Formica* were pulled off. When tested with the six odors, these ants gave a reaction time of 3.50 seconds, while the reaction time for the same ants before the wings were pulled off is 2.63 seconds. They were normal in all respects other than their slowness in responding to odors. Only 8 per cent of the pores belonging to the wings were left intact while 92 per cent were pulled off with the wings.

The bases of the wings of 25 winged females of *Formica* were covered with liquid glue and the pores on the legs were covered with the beeswax-vaseline mixture. Confined singly these ants were not able to remove the glue, but they did remove much of the vaseline and smeared some of it over their spiracles, which certainly accounts for their short lives. When tested, they gave a reaction time of 5.21 seconds, which is slightly more than twice the reaction time for their unmutilated sister females.

When tested, 25 deälated females of *Camponotus* gave a reaction time of 3.25 seconds. Their wing niches were filled with liquid glue thus covering the pores on the stubs of the wings, and the pores on the legs were covered with the beeswax-vaseline mixture. These females now appeared normal in all respects other than their slowness in responding to odors. When tested, they gave a reaction time of 7.94 seconds, which is more than twice the reaction time obtained before using the glue and vaseline.

The wings of 25 males of *Camponotus* were pulled off. These ants appeared normal in all respects except their slowness in responding to odors. When tested, they gave a reaction time of 3.49 seconds, which is one and a fourth times the reaction time of unmutilated males. Only 12 per cent of the pores on the wings were left intact.

The wings of 21 workers of *Vespula maculata* were pulled off. These hornets appeared normal in all respects other than their slowness in responding to odors. When tested with the three essential oils, they gave a reaction time of 6.35 seconds, which is almost three times the reaction time for sister hornets with wings intact. Only 22 per cent of the pores on the wings were left intact.

OLFACTORY ORGANS ON THE APPENDAGES AND STERNUM OF SPIDERS

In 1878 Bertkau noticed some slitlike cuticular organs on the legs of spiders. Since that date five other observers, including the present writer, have studied these structures. They are called lyriform organs on account of their shape.

The author (1911) made a special study of the morphology and physiology of the lyriform organs of spiders. He used in his studies 39 species representing 27 of the 38 families. These organs in spiders exist both as isolated slits and as groups containing several slits, and their position is relatively constant. The groups are located at the distal end of each joint of the legs, pedipalpi, chelicera (mouth parts), pedicle, and spinnerets. They exist on both sides of the foregoing appendages and as a rule each joint of the legs and pedipalps possesses the following number of groups: Coxa 1, trochanter 3, femur 2, patella 3, tibia 3, metatarsus 1, and occasionally the tarsus 1; each cheliceron usually has 4, each pedicle 2, and only occasionally is a group present on one of the spinnerets. The isolated slits not only occur irregularly scattered on the joints of all the above-named appendages, but also on the remaining mouth parts, on the sternum, and a few on the ventral side of the abdomen. Thus it is seen that the disposition of the lyriform organs is similar to that of Hicks' vesicles; however, the vesicles are situated at the proximal instead of the distal ends of the joints and less seldom exist as isolated structures irregularly distributed, as are the isolated slits. A few of Hicks' vesicles exist on the mouth parts but none is found on the sternum and abdomen, except those in the sting, which might be compared in position to the lyriform organs on the spinnerets of spiders. Since spiders have no wings, possibly all the slits on the mouth parts, sternum, pedicle, and the ones on the abdomen exclusive of those on the spinnerets, replace all the pores that exist on the wings of insects.

A great difference in the number of groups and isolated slits was found in the different species. The spiders that hunt for their food and use no webs in capturing their prey, without exception have the most slits, while those that live in caves and catch their food entirely by means of webs have the least number. The common cobweb spider (*Theridium tepidariorum*) catches its prey wholly by webs; it does not live in caves and may be considered as intermediate between hunting spiders with highly developed lyriform organs and cave spiders with degenerated lyriform organs. By counting all the slits on the surface of this cobweb spider, we find that an average spider possesses 1,770 slits, whereas considering an average worker bee, we have already seen that it possesses 2,270 pores. As stated by the other observers, lyriform organs have now been found in 7 of the 9 orders belonging to the Arachnida.

A lyriform organ is composed usually of several single slits which lie side by side and more or less parallel with each other. This group of slits is generally surrounded by a border, produced by a difference in pigmentation, which gives the lyre shape to the organ. Inside the border the pigmentation is usually much lighter than outside; hence a group appears as a light spot, while the superficial appearance of a slit reminds one of a long, slightly bent spindle that has an aperture either at the center or nearer one end than the other. A cross section of a slit shows that the aperture passes entirely through the cuticula and unites with the sense fiber of a large spindlelike sense cell lying at the base of the thick hypodermis. Thus a cross section of a slit with its sense fiber may be likened to a greatly flattened funnel. The innervation of a lyriform organ is identical with that of a group of olfactory pores, except that in the former the sense fibers unite with the base of the apertures, whereas in the latter the sense fibers connect with the top of the apertures.

So far as the writer knows, structures similar to lyriform organs and Hicks' pores have never been looked for in crustaceans. It is very probable, however, that this class of arthropods possesses some kind of organs that take the place of lyriform organs and Hicks' pores.

While experimenting with odors, it was found that spiders possess a true olfactory sense. Many individuals of two species representing two widely separated genera were used. They responded not only to five different essential oils, which are sometimes regarded as irritants, but also to both fresh and decayed buttercup flowers, decayed snails, squash bugs, and Phalangids. The usual reaction is to move away from the odor, but they also quickly moved their pedipalpi, chelicera and legs, and very often rubbed their legs and other appendages. The average reaction time of a ground spider (*Lycosa lepida*) to oils of peppermint, thyme and wintergreen was 9 seconds and for a jumping spider (*Phidippus purpuratus*) 4.6 seconds, while for the worker bee the same average is only 2.6 seconds. The differences in reaction time may be explained by the fact that *Lycosa* is rather sluggish, *Phidippus* is very active, while the bee is extremely lively. However, as a worker bee possesses 500 pores more than a spider and since it responds about twice as quickly it would appear that its sense of smell is more highly developed.

All the lyriform organs (single slits not included) on the legs, pedipalpi, chelicera, mouth parts, and sternum were carefully varnished with yellow vaseline. The following day they were tested with the five oils—peppermint, thyme, wintergreen, clove and bergamot. Thus it was ascertained that they responded nine times more slowly after varnishing than before.

Hindle and Merriman (1912) proved experimentally that Haller's organ is olfactory in function and that it is a means by which ticks are able to recognize their hosts. In *Hæmaphysalis punctata* this organ consists of a minute cavity, containing sensory hairs, and is associated with a specially modified region of the hypodermis. In ticks (Acarina) it is always located on the external dorsal surface of the tarsus of the first pair of legs. Hansen (1893) found a few scattered lyriform organs in acarinids which may also aid in receiving odor stimuli.

SUMMARY OF AUTHOR'S EXPERIMENTS

The following table is a tabulated summary of the author's experiments with spiders and Hymenoptera to determine the location of the olfactory organs. The odors used for the spiders are those from the essential oils of peppermint, thyme, wintergreen, clove, and bergamot. The "three odors" used for the Hymenoptera are those from oil of peppermint, oil of thyme, and oil of wintergreen. The

TABLE II

Summary of author's experiments with spiders and Hymenoptera to determine the location of the olfactory organs

Species.	Experiment.	Average reaction time.		No. of individuals tested.	Average length of life in captivity.	
		for three odors.	for six odors.			
		Sec.	Sec.		Days.	Hrs.
♀ Phidippus....	Unmutilated. Normal in behavior.	......	5.0	11	......	......
♀ "	Pedipalpi pulled off. Normal in behavior.	......	5.2	11	......	......
♀ "	Pedipalpi and maxillæ pulled off. Normal in behavior.	......	6.0	11	......	......
♂+♀ Lycosa....	Unmutilated. Normal in behavior.	......	7.0	15	......	......
♂+♀ " ...	Lyriform organs covered with vaseline. Normal in behavior.	......	61.0	15	......	......
♀ Formica......	Unmutilated. Winged, normal in behavior.	2.12	2.45	25	14	10
♀ "	Funiculi cut off. Abnormal in behavior.	4.38	......	25	0	19
♀ "	Funiculi glued. Abnormal in behavior.	5.78	......	25	6	0
♀ "	Dëalated. Normal in behavior.	2.50	2.89	4	142	0
♀ "	Wings pulled off. Normal in behavior.	2.32	2.85	25	10	0
♀ "	Bases of wings glued and legs covered with vaseline. Normal in behavior.	4.73	5.21	25	3	0
♂ "	Unmutilated. Winged, normal in behavior.	2.21	2.63	17	Used below.	
♂ "	Wings pulled off. Normal in behavior.	3.00	3.50	7	5	0
♀ Camponotus..	Dëalated. Normal in behavior.	2.32	3.25	25	Several months.	
♀ " ..	Glue in wing niches and legs covered with vaseline. Normal in behavior.	5.70	7.94	22	Several months.	
♂ " ..	Winged. Normal in behavior.	2.29	2.74	25	23	9
♂ " ..	Wings pulled off. Normal in behavior.	2.91	3.49	25	7	2
☿ Major Camponotus	Unmutilated. Normal in behavior.	2.32	3.22	25	26	8
☿ Minor Camponotus	Unmutilated. Normal in behavior.	2.27	3.09	25	26	8
☿ Vespula	Unmutilated. Winged, normal in behavior.	2.43	......	25	9	7
☿ "	Flagella cut off. Abnormal in behavior.	3.09	......	25	1	13
☿ "	Wings pulled off. Normal in behavior.	6.35	......	21	4	8

TABLE II—Continued

Summary of author's experiments with spiders and Hymenoptera to determine the location of the olfactory organs

Species.	Experiment.	Average reaction time.		No. of individuals tested.	Average length of life in captivity.	
		for three odors.	for six odors.			
		Sec.	Sec.		Days.	Hrs.
☿ Apis	Unmutilated. Winged, normal in behavior.	2.64	3.40	37	9	3
☿ "	Maxillæ and labial palpi cut off. Abnormal in behavior.	3.3	4.0	19	1	0
☿ "	Proboscis cut off. Abnormal in behavior.	2.9	......	22	0	7
☿ "	Mandibles cut off. Abnormal in behavior.	3.5	4.8	20	7	0
☿ "	Flour paste in mouth. Abnormal in behavior.	2.68	......	20	7	12
☿ "	Wings cut off beyond pores. Normal in behavior.	3.0	......	17	9	23
☿ "	Stings extracted. Normal in behavior.	2.86	......	20	1	6
☿ "	Glue on thorax as control. Normal in behavior.	2.76	......	19	9	3
☿ "	Vaseline on abdomen as control. Normal in behavior.	2.73	......	18	9	3
☿ "	Flagella burned off. Abnormal in behavior.	4.00	......	7	0	17
☿ "	Flagella glued. Abnormal in behavior.	2.90	......	21	1	0
☿ "	Wings pulled off. Normal in behavior.	22.20	27.10	28	9	20
☿ "	Bases of wings glued. Normal in behavior.	18.50	28.20	20	9	3
☿ "	Pores on legs covered with vaseline. Normal in behavior.	5.20	8.00	20	9	3
☿ "	Wings pulled off and pores on legs covered with vaseline. Normal in behavior.	36.90	40.00	20	9	5

" six odors " used for the ants and hornets are those from oil of peppermint, oil of thyme, oil of wintergreen, honey and comb, leaves and stems of pennyroyal, and formic acid. The " six odors " used for the honey bees are the same as those used for ants and hornets, except pollen was employed instead of formic acid.

The preceding table shows the following: (1) When the pedipalpi (slightly comparable to the antennæ of insects) of spiders are pulled off, the arachnids are normal in behavior and the reaction time is practically the same as when unmutilated individuals are used. (2) But when the antennæ of Hymenoptera are mutilated in the slightest degree, the insects are abnormal, and the reaction times are slower than when unmutilated individuals are used, although it is quite possible that the slower reaction times are caused by the abnormal behavior of the insects rather than due to the theory that some of the olfactory organs are prevented from functioning. (3) When the maxillæ of spiders are pulled off, no abnormal behavior results, but the reverse is true for the honey bee. In both cases the reaction time is slightly slower. (4) When the mouth parts of honey bees are mutilated, the insects are abnormal and the reaction times are slightly increased, which may be due to the abnormality of the insects, or to the view that the pores on these appendages are prevented from functioning, or to both of these conditions combined. (5) When the wings are pulled off artificially, most of the pores on these appendages are lost and the reaction times are considerably increased. (6) When the pores on the wings are covered with glue the reaction times are much increased. (7) When most of the pores on the legs are covered with vaseline, the reaction times are greatly increased. (8) When either spiders or Hymenoptera are so mutilated that most of the olfactory pores are prevented from functioning, the reaction times are increased many times, and the mutilated individuals used are absolutely normal in all respects other than their ability to smell.

DISCUSSION

The following criticisms concerning the physiological experiments performed with the antennæ of various insects may be offered. Most of the previous observers have studied the behavior of the insects investigated in captivity for only a short time, while the remainder have paid no attention at all to the behavior of their unmutilated insects. They cut off either a few joints of both antennæ, or these entire appendages, or varnished them with paraffin, rubber, etc. When a few joints are severed the sense of smell is apparently weakened. This is true for bees also as ascertained by the author. When both antennæ are amputated or varnished the insects, as a rule, fail to respond to substances which normally affect the olfactory sense. They generally fail to respond to odors held near them and fail to find food in captivity, and do not return to putrid meat and dead bodies when removed from such food. Males so mutilated do not, as a rule, seek females and show no responses when females are placed near them. Such experiments were seriously criticised until Hauser in 1880 presented his apparently conclusive results. Many of the insects on which he experimented with the antennæ amputated became sick and soon died. Most of them failed to respond when the antennæ were mutilated, although *Carabus*, *Melolontha*, and *Silpha* responded slightly, while all the Hemiptera that he used responded almost as well with their antennæ off as they did with them intact. Only 40 per cent of the ants from which Miss Fielde cut the antennæ recovered from the effect of the shock. Not one of these observers has studied the behavior of the species under observation sufficiently to know exactly how long they live in captivity with their antennæ either intact or mutilated. No one, except Miss Fielde, has kept a record of the death of the mutilated and normal insects accurate enough so that one might know what percentage died from the operation. To cut off some other appendage or even the lower part of the head, as Forel did, is not a fair test, because such operations seldom expose sense cells and never any nerve equal in size to that of the antennæ, unless one pulls off the wings. When the wings are pulled off the large nerve is severed between the masses of sense cells and thorax, and the sense cells are not exposed to the air, as they are when antennæ are cut off. Even if the antennæ are cut through the scape, the large masses of sense cells belonging to Johnston's organs are severed. When the lower part of the head or the tarsi are cut off, as Forel did, no nerves are exposed to the air except ends of small nerves. From the foregoing it is only reasonable to assume that when the antennæ of any insect are injured in the least degree, the insect is no longer normal and if it fails to respond to odors placed near it, this negative response may be caused by the injury.

The following criticisms based on a consideration of the morphology of the antennæ may also be offered. In the honey bee the pore plates can scarcely be considered as olfactory organs, because the drone has almost eight times as many as the queen, and responds to the odors presented in slightly more than one-half the time. It is true that those of the queen are considerably larger, but even on this basis the reaction times are not comparable. The pegs may be entirely eliminated as olfactory organs, because they are absent in the drone, but are abundant in the worker and the queen. Drones, queens and workers have about the same number of Forel's flasks and pit legs. Schenk's view that the pegs receive odor stimuli in the queens and workers, while Forel's flasks and the pit pegs function in this way in the drones is inconsistent, because if the latter two structures function for such a purpose in the drones why should they not also in the females? Since these two structures are few in number and many times smaller than the pegs, we cannot compare them physiologically. Thus it is seen that not one of these antennal organs of the honey bee offers a solution for the ratios obtained with the use of the various odors. If the reaction time of each caste of the honey bee is compared with the total number of olfactory pores a consistent inverse ratio is obtained. A drone has 2,600 pores and responds in 2.9 seconds; a worker possesses 2,200 pores and responds in 3.4 seconds and a queen has 1,800 pores and responds in 4.9 seconds.

Pore plates are not the olfactory apparatus in all insects, because they are entirely absent in the Lepidoptera. The pegs cannot be the olfactory organs in all insects, for they are absent in many male bees and almost wanting in Lepidoptera, although possibly the end rods in butterflies and moths are homologous. According to Vom Rath, pegs are found not only on the antennæ and mouth parts but also all over the body, and Nagel found them elsewhere than on the antennæ. If the pegs are the olfactory organs and if insects with amputated antennæ are normal, then why do not such insects respond positively at least slightly to odors instead of negatively, as most observers claim?

It is certain that spiders can smell, yet they have no antennæ nor any organs that may be compared to the antennal organs of insects. Hence, this is another argument against the antennæ as being organs of smell. All insects either have antennal organs like those described for the bee, or modifications of them, yet no two authors who have studied them have agreed concerning their function. Such chaos can be replaced by facts, only when the behavior of the insects investigated is thoroughly studied and when experiments are performed in ways other than on the antennæ alone. Then it will be realized that the antennæ can no longer be regarded even as a possible seat of the sense of smell in insects.

In conclusion, it seems that the organs called the olfactory pores by the author are the true olfactory apparatus in Hymenoptera and possibly in all insects and that the antennæ play no part in receiving odor stimuli.

LITERATURE CITED

The authors marked with an * were not accessible to the writer, and their views are cited from the writings of others.

ÆLIANI. 1744. De Animalibus, quæ Apibus inimica sunt. Natura Animalium, Londini, t. I, Lib. I, Cap. 58, p. 60.

Aristotle. The works of Aristotle, translated into English. vol. 4. Historia Animalium by Thompson, Oxford, 1910. Book 4, 8, p. 534a.

Balbiani, E. G. 1866. Note sur les antennes servant aux insectes pour la recherche des sexes. Ann. Soc. Ent. France, t. 6, (4), Bul., p. xxxviii.

Barrows, W. M. 1907. The reactions of the pomace fly, *Drosophila ampelophila* Loew, to odorous substances. Journ. Exp. Zool., vol. 4, pp. 515-537.

Baster, Job. 1770. Over het Gebruik der Sprieten by de Insecten. Hollandsche Maatschappye der Weetenschappen te Haarlem, 12 Deel, pp. 147-182.

*——— 1798. In Lehmann's De sensibus externis animalium exsanguinum, etc. Goettingue.

Bergmann und Leuckart. 1852. Anat.-physiol. Uebersicht des Theirreichs, pp. 453-454.

Berlese, Antonio. 1906-1909. Gli insetti, vol. 1, pp. 610-633.

Bertè, F. 1877. Contribuzione all'anatomia ed alla fisiologia della antenne degli Afanitteri. Atti Reale Accad. dei Lincei, vol. 2, serie terza, Roma 1877-1878, pp. 24-29, with 1 pl.

Bonnet, Charles. 1781. Collection des œuvres, t. 7, pp. 124-125.

*Bonnsdorf. 1792. De fabrica, usus differentiæ palparum in insectis. Dissertatio, Aboæ.

Börner, Carl. 1902. Ueber das Antennalorgan III der Collembolen, etc. Zool. Anz., Bd. 25, pp. 92-106.

Breithaupt, P. F. 1886. Ueber die Anatomie und die Functionen der Bienenzunge. Arch. f. Naturgesch., Bd. 52, pp. 47-112, with 2 pls.

Brullé. 1840. Introduction à l'histoire naturelle des Insectes Coléopteres by Castelnau, t. 1, pp. 78-79.

Burmeister, H. 1836. Manual of entomology, translation by W. E. Shuckard, pp. 297-298.

——— 1848. Beobachtungen über den feineren Bau des Fühlerfächers der Lamellicornien, als eines muthmasslichen Geruchswerkzeuges. D'Alton u. Burmeister's Zeitung f. Zool. Zoot. u. Paläozool., Bd. 1, pp. 49-56, 67.

Carus. 1838. Traité d'anatomie comparée, t. 1, paragraph 411, pp. 216-217.

Chadima, Jos. 1873. Ueber die von Leydig als Geruchs-Organe bezeichneten Bildungen bei den Arthropoden. Mittheil. d. naturwissenschaft. Ver. für Steiermark, Graz, pp. 36-44.

Chatin, J. 1880. Les organes des sens dans la série animale, Paris, pp. 274-281.

Child, C. M. 1894a. Beiträge zur Kenntnis der antennalen Sinnesorgane der Insecten. Preliminary communication. Zool. Anz., 17 Jahrg., pp. 35-38.

——— 1894b. Ein bisher wenig beachtetes antennales Sinnesorgan der Insekten, mit besonderer Berücksichtigung der Culiciden und Chironomiden. Zeitsch. f. wiss. Zool., Bd. 58, pp. 475-528.

Claparède. 1858. Zur les prétendus organes, auditifs des antennes chez les Coléopteres lamellicornes et autres insectes. Ann. Sci. Nat., Zool., t. 10 (4), pp. 236-250.

Claus, C. 1872. Grundzüge der Zoologie, Zweite Auflage, p. 570.

*Comparetti. 1800. Dinamica animale degli insetti, 2, Padoue, p. 442.

Cornalia. 1856. Monografia del bombice del gelso. Memoria dall' I. R. Instituto Lombardo di Scienze, Milan, pp. 304-305.

Cottreau, Jean. 1905. L'odorat chez les insectes. La Nature, Ann. 34, Sem. 1, p. 39.

Cuvier. 1805. Leçons d'anatomie comparée, t. 2, p. 675.

Dahlgren Ulric and Kepner, W. A. 1908. Principles of animal histology. New York. MacMillan Co., pp. 264-266.

De Blainville. 1822. Principes d'anatomie comparée, vol. 1, p. 339.

Dönhoff. 1861. Vom Geruchsorgan der Bienen, Bd. 1, Bienenzeitung, Theoretischer Theil, pp. 507-509.

Driesch. 1839. Odorat des insectes. Journ. l'Institut, Paris, t. 7, No. 294 p. 279.

Dubois, R. 1890. Sur la physiologie comparée de l'olfaction. Comptes Rendus. Acad. Sci. Paris, t. 111, pp. 66-68.

——— 1895. Sur le role de l'olfaction dans les phénomènes d' accouplement chez les papillons. Assn. France pour l'Avancement des Sci., 24^e session, Bordeaux, pp. 293-294.

Dufour, Léon. 1850. Quelques mots sur l'organe de l'odorat et sur celui de l'ouie dans les insectes. Ann. Sci. nat., Zool., t. 14 (3), pp. 179-184.

Dugés. 1838. Traité de physiologie comparée, t. l. pp. 160-161.

Duméril. 1797. Extrait d'une dissertation sur l'organe de l'odorat dans les insectes. Bul. Soc. Philom., Paris, vol. 1, second part, p. 34.

——— 1823. Considérations général sur les insectes, pp. 25-30.

Duponchel. 1840. Réflexions sur l'usage des antennes dans les insectes. Revue Zoologique de M. Guerin Méneville, Paris, pp. 75-79.

*Erichson. 1847. De fabrica et usu antennarum in insectis Berolini, typis fratrum Unger, 4, (15 pag., 1, Kupfertafel).

Fabre, J. H. 1882. Nouveaux souvenirs entomologiques. Paris, pp. 29-32.

Fabricius, I. C. 1778. Philosophia Entomologica.

Fielde, A. M. 1901a. A study of an ant. Proc. Acad. Nat. Sci. Phila., vol. 53, pp. 425-449.

——— 1901b. Further study of an ant. *Ibidem.* pp. 521-544.

——— 1903a. Artificial mixed nests of ants. Biol. Bul., vol. 5, no. 6, November, pp. 320-325.

——— 1903b. A cause of feud between ants of the same species living in different communities. *Ibidem.* pp. 326-329.

——— 1904. Power of recognition among ants. Biol. Bul., vol. 7, no. 5, October, pp. 227-250.

——— 1905. The progressive odor of ants. Biol. Bul., vol. 10, no. 1, December, pp. 1-16.

———. 1907. Suggested explanations of certain phenomena in the lives of ants, with a method of tracing ants to their respective communities. Biol. Bul., vol. 13, no. 3, August, pp. 134-137.

Forel, Auguste. 1874. Les fourmis de la Suisse. Ouvrage Soc. Helvétique des Sci. Nat.

——— 1878a. Beitrag zur Kenntniss der sinnesempfindungen der Insekten. Mittheil. d. Münchener Ent. Ver., 2 Jahrg., 1 Heft, p. 21.

——— 1878b. Der Giftapparat und die Analdrüsen der Ameisen. Zeitsch f. wiss. Zool., Bd. 30, Supplementary note on p. 61.

——— 1885. Etudes myrmécologiques en 1884. Bul. Soc. Vaudoise Sci. Nat., vol. 20 (2), no. 91. p. 334.

——— 1902. Die Eigentümlichkeiten des Geruchssinnes bei den Insekten. Verhdlgn. v. internat. zool.-Congr., Berlin, pp. 806-815.

——— 1908. The senses of insects. English translation by Yearsley, London, pp. 95-96.

Freiling, Hans H. 1909. Duftorgane der weiblichen Schmetterlinge nebst Beiträgen zur Kenntnis der Sinnesorgane auf dem Schmetterlingsflügel und der Duftpinsel der Männchen von Danais und Euploea. Zeitsch. f. wiss. Zool., Bd. 92, pp. 210-290 with 17 text figs. and 6 pls.

Garnier, M. J. 1860. De l'usage des antennes chez les insectes. Mém. d'Acad. des Sci. d'Amiens, t. 1 (2), pp. 489-501.

Gegenbaur, C. 1870. Grundzüge der vergleichenden Anatomie, Zweite Auflage, pp. 387-388.

Goureau. 1841. Ann. Soc. Ent. France, t. 10, Bul. pp. xii-xv.

Graber, Veit. 1878. Ueber neue otocystenartige Sinnesorgane der Insekten. Arch. f. Mikr. Anat., Bd. 16, pp. 36-57.

——— 1885. Vergleichende Grundversuche über die wirkung und die Aufnahme-stellen chemischer Reize bei den Tieren. Biol. Centralblatt. Bd. 5, Nr. 13, pp. 385-398.

——— 1887. Neue Versuche über die Function der Insektenfühler. Biol. Centralblatt, Bd. 7, Nr. 1, pp. 13-19.

Grimm, O. v. 1869. Beitrag zur Anatomie der Fuhler der Insekten. Bul. l'Acad. Imp. des Sci. de St. Pétersbourg, t. 14, pp. 66-74.

Guenther, Konrad. 1901. Ueber Nervenendigungen auf dem Schmetterlingsflügel. Zool. Jahrb., Anat., vol. 14, pp. 551-572, with 1 pl.

Hansen, H. J. 1893. Organs and characters in different orders of arachnids. Entomologiske Meddelelser, pp. 136-251.

Harting, P. 1879. Reukorgaan der insekten. Album der Natuur, Haarlem. Wetensch. Bijblad, p. 71.

Hauser, Gustav. 1880. Physiologische und histologische Untersuchungen über das Geruchsorgan der Insekten. Zeitsch. f. wiss. Zool., Bd. 34, Heft. 3, pp. 367-403, with 2 pls.

Henneguy, L. F. 1904. Les insectes, Paris, pp. 138-139.

Hermbstädt, Fried. 1811. Ueber die Gerüche und die physischen Ursachen ihrer Erzeugung. Der Gesellschaft Naturforschender Freunde zu Berlin, Jahrg. 5, pp. 111-124.

Hicks, J. B. 1857. On a new organ in insects. Journ. Linn. Soc. London, Zool., vol. 1, pp. 136-140, with 1 pl.

——— 1859a. Further remarks on the organs found on the bases of the halteres and wings of insects. Trans. Linn. Soc. London, Zool., vol. 22, pp. 141-145, with 2 pls.

——— 1859b. On a new structure in the antennæ of insects. *Ibidem*, pp. 147-154, with 2 pls.

——— 1859c. Further remarks on the organs of the antennæ of insects. *Ibidem*, pp. 383-399.

——— 1860. On certain sensory organs in insects, hitherto undescribed. *Ibidem*, vol. 23, pp. 139-153, with 2 pls.

Hindle, E. and Merriman, G. 1912. The sensory perceptions of *Argas persicus*. Parasitology, vol. 5, no. 3, September, Cambridge Univ. Press, pp. 214-216.

Hochreuther, Rudolf. 1912. Die Hautsinnesorgane von *Dytiscus marginalis* L., ihr Bau und ihre Verbreitung am Körper. Zeitsch, f. wiss. Zool., Bd. 103, pp. 1-114.

Huber, Francois. [Quoted by Jurine L., 1807.] Nouville Méthode de classer les Hyménoptères, t. 1. Genève, Introd., pp. 8-9.

——— 1814. Nouvelle observations sur les abeilles, t. 2, sec. édit. pp. 375-393.

Janet, Charles. 1904. Observations sur les fourmis. Limoges, pp. 17-22.

——— 1907. Anatomie du corselet et histolyse des muscles vibrateurs, après le vol nuptial, chez la reine de la fourmis (*Lasius niger*). Limoges, pp. 46-48.

——— 1911. Organes sensitifs de la mandibule de l'abeille. L'Apiculteur, 55^e^ Année, no. 3, Mars, pp. 107-108.

Joseph, G. 1877. Ueber Sitz und Bau der Geruchorgane bei den Insecten. Ber. 50 Vers. Deutscher Naturf. und Aerzte, München, pp. 174-176.

Kellogg, V. L. 1907. Some silkworm moth reflexes. Biol. Bul. vol. 12, no. 3, February, pp. 152-154.

Kirby and Spence. 1826. Introduction to entomology, vol. 3, pp. 455-456 and vol. 4, pp. 249-255.

*Knoch. 1798. In Lehmann's De sensibus externis animalium, etc.

*Krapelin, Karl. 1883. Ueber die geruchsorgane der Gliederthiere, Hamburg.

Küster. 1844. Zool. Notizen. (Die Fühlhörner sind die Riechorgane der Insecten.) Isis von Oken, pp. 647-655.

Lacordaire. 1838. Introduction à l'entomologie, t. 2, pp. 228-234.

Landois, H. 1868. Das Gehörorgan des Hirschkafers (*Lucanus cervus*). Arch. f. Mikr. Anat. Bd. 4, pp. 88-95.

Latreille. 1804. Histoire naturelle des crustacés et des insectes, t. 2, pp. 49-51.

Layard, Consul E. L. 1878. Smell and hearing in insects. Nature, vol. 18, pp. 301-302.

*Lee, A. Bolles. 1855. Les balanciers des Diptères. Rec. Zool. Suisse, t. 2.

Lefebvre, Alex. 1838. Note sur le sentiment olfactif des antennes. Ann. Soc. Ent., France, t. 7, pp. 395-399.

*Lehmann. 1799. De usu antennarum, Leipsig, p. 27.

Lespes, Ch. 1858. Mémoire sur l'appareil auditif des Insectes. Ann. Sci. Nat. Zool., t. 9, (4), pp. 225-249.

Lesser, P. 1745. Théologie des insectes, translated from the German by Lyonnet, t. 2, pp. 7, 8, 11, 12.

Leydig, Franz. 1860. Ueber Geruchs und Gehörorgane der Krebse und Insecten. Arch. f. Anat. und Phys., pp. 265-314, with 3 tables.

——— 1886. Die Hautsinnesorgane der Arthropoden. Zool. Anz. 9 Jahrg., pp. 284-291 and 308-314.

Lowne. 1870. The organs of hearing and smell in insects. Amer. Naturalist, vol. 4, p. 127.

Lubbock, Sir John. 1877. On some points in the anatomy of ants. Monthly Micr. Journ., vol. 18, pp. 121-142.

——— 1882. Ants, bees and wasps. International Scientific Series, New York, pp. 234, 235, 288.

*——— 1883. Ameisen, Bienen und Wespen. Internat. wiss. Bibl., Bd. 57, p. 197 ff.

——— 1899. The senses, instincts and intelligence of animals. International Scientific Series, vol. 65, London, pp. 37, 43, 58.

Lyonnet, P. 1745. In Lesser's Théologie des insectes, t. 2, p. 9 in note.

Marcel de Serres. 1811. De l'odorat, et des organes qui paroissent en etre le siége, chez les Orthòpteres. Ann. du Muséum d' Hist. Nat., t. 17, pp. 426-442.

MAYER, PAUL. 1878. Sopra certi organi di senso nelle antenne dei Ditteri. Reale Accad. dei Lincei, Roma, pp. 3-12, with 1 pl.

——— 1879. Zur Lehre von den Sinnesorganen bei den Insecten. Zool. Anz. Jahrg. 2, Nr. 25, pp. 182-183.

McINDOO, N. E. 1911. The lyriform organs and tactile hairs of araneads. Proc. Phila. Acad. Nat. Sci., vol. 63, pp. 375-418, with 4 pls.

——— 1914a. The olfactory sense of the honey bee. Journ. Exp. Zool., vol. 16, no. 3, April, pp. 265-346, with 24 text figs.

——— 1914b. The olfactory sense of Hymenoptera. Proc. Phila. Acad. Nat. Sci., vol. 66, pp. 294-341, with three text figs. and 2 pls.

MÜLLER, H. 1871. Anwendung der Darwinschen Lehre auf Bienen. Leppstadt, pp. 63-68.

*NAGEL, W. A. 1892. Die neidern Sinns der Insekten. Tübingen.

——— 1894. Vergleichend phys. and anat. Untersuchungen über den Geruchs-und Geschmacksinn und ihre Organe. Bibliotheca Zoologica, Heft. 18, pp. 1-207, with 7 pls., two of which are colored.

——— 1909. Geruchs- und Geschmacksinn der Insekten. Berliner ent. Zeitsch., Bd. 54, pp. 21-26.

NEWPORT, GEORGE. 1838. On the use of the antennæ of insects. Trans. Ent. Soc. London, vol. 2, pp. 229-248.

NOLL. 1869. Feiner Geruch bei Schmetterlingen. Zoolog. Garten, Bd. 10, pp. 254-255.

OLIVIER. 1789. Article on "Antennes et Antennules." Encyclopédie méthodique, p. 142.

PAASCH, A. 1873. Von den Sinnesorganen der Insekten im Allgemeinen, von Gehör- und Geruchsorganen im Besondern. Troschel's Arch. f. Naturgesch., 39 Jahrg., pp. 248-275.

PACKARD, A. S. 1870. Abdominal sense-organs in a fly. Amer. Naturalist, Essex Institute, vol. 4, pp. 690-691.

PECKHAM, G. W. and E. G. 1887. Some observations on the special senses of wasps. Proc. Nat. Hist. Soc. of Wisconsin, pp. 91-132.

PERCHERON, A. 1841. Essai sur la valeur relative des organes dans les insectes, pour servir de base à une classification de ces animaux. Comptes Rendus Acad. Sci., Paris, t. 13, p. 1101.

PERRIS, ED. 1850. Mémoire sur le Siége de l'Odorat dans les Articulés. Ann. Sci. Nat., Zool., t. 14, (3), pp. 149-178.

PIÉRON, H. 1906. Le rôle de l'olfaction dans la reconnaissance der fourmis. Comptes Rendus Acad. Sci. Paris, t. 143, pp. 845-848.

PIERRET. 1841. Ann. Soc. Ent. t. 10, Bul. pp. 10-11.

PLATEAU, FÉLIX. 1885. Expériences sur le rôle des Palpes chez les arthropodes maxillés. Première partie, palpes des insectes broyeurs. Bul. Soc. Zool. de France, vol. 10, pp. 67-90.

——— 1886. Une expérience sur la fonction des antennes chez la blatte (*Periplaneta orientalis*). Bul. Comptes Rendus des Séances Ann. Soc. ent. Belgique, t. 30, pp. 118-122.

PLINY. Histoire naturelle de Pline, traduction nouvelle par M. Ajasson de Grandsagne, t. 7, Paris, 1830, Livre 10, 90 70, p. 351.

PORTER, C. J. A. 1883. Experiments with the antennæ of insects. Amer. Naturalist, vol. 17, pp. 1238-1245.

RAMDOHR. 1811. Ueber die Organe des Geruchs und Gehörs der gemeinen Biene. Magazine der Gesellschaft naturf. Freunde zu Berlin, 5 Jahrg., pp. 386-390.

RÉAUMUR. 1734. Mémoires à l'histoire des insectes, t. 1, Paris.

REICHENBACH, H. 1879. Allgemeines über Sinnesorgane. Vortrag. Bericht über die Senkenberg. naturf. Ges., p. 136.

*ROBINEAU-DESVOIDY. 1828. Recherches sur l'organisation vertébrale des crustacés et des insectes.

——— 1842. Sur l'usage réel des antennes chez les insectes. Ann. Soc. Ent. France, t. 11, Bul., pp. xxiii-xxvii.

RÖHLER, ERNEST. 1905. Beiträge zur Kenntnis der Sinnesorgane der Insecten. Zool. Jahrb. Anat., 22, pp. 225-288, with one text fig. and 2 pls.

ROMANES, G. J. 1877. Smell and hearing in moths. Nature, vol. 17, p. 82.

RÖSEL und KLEMANN. 1747. Insecten Belustigung, Theil I, p. 19 under "Geruch in Register."

*ROSENTHAL. 1811. Ueber den Geruchsinn der Insekten. Reil's arch. f. die Physiologie, T. 10, Halle, p. 427.

RULAND, FRANZ. 1888. Beiträge zur Kenntnis der antennalen Sinnesorgane der Insekten. Zeitsch. f. wiss. Zool., Bd. 46, pp. 602-628.

SAMOUELLE, GEORGE. 1819. Entomologist's Compendium, London, pp. 26-27.

SAZEPIN, BASIL. 1884. Ueber den histol. Bau und die Vertheilung der nervösen Endorgane auf den Fühlern die Myriopoden. Mém. de l'Acad. Impér. d. Sci. de St. Pétersburg, t. 32 (7), no. 9, pp. 1-20.

*SCHELVER. 1798. Versuch einer naturgeschichte der Sinneswerkzeuge bei den Insekten, in —8°, Gottingæ, p. 46.

SCHENK, OTTO. 1903. Die antennalen Hautsinnesorgane einiger Lepidopteren und Hymenopteren, mit besonderer Berüchsicktigung der sexuellen Unterscheide. Zool. Jahrb. Bd. 17, pp. 573-618, with four text figs. and 2 pls.

SCHIEMENZ, PAULUS. 1883. Ueber des Herkommen des Futtersaftes und die Speicheldrüsen der Bienen, nebst einem Anhange über das Riechorgan. Zeitsch. f. wiss. Zool., Bd. 38, pp. 71-135, with 3 pls.

SCHÖN, ARNOLD. 1911. Bau und Entwicklung des tibialen chordotonalorgans bei der Honigbiene und bei Ameisen. Zool. Jahrb. Anat. und Ont., Bd. 31, pp. 439-472, with 9 text figs. and 3 pls.

SHERMAN, FRANKLIN, JR. 1909. The senses of insects. Journ. Elisha Mitchell Sci. Soc., vol. 25, pp. 78-84.

SLATER, J. W. 1848. Ueber die Function der Antennen bei den Insecten. Froriep's Notizen, III, no. 155, p. 6.

——— 1878. The seat of the sense of smell in insects. Entomologist, vol. 11, p. 233.

SNODGRASS, R. E. 1910. The anatomy of the honey bee. U. S. Dept. of Agriculture, Bur. of Ent., Tech. Ser. 18, Washington, Gov. Printing Office.

STRAUS-DURCKHEIM. 1828. Anatomie des Animaux Articulés, pp. 420-422.

SULZER, J. H. 1776. Abgekürzte Geschichte der Insecten, Erster Theil, p. 16.

TREVIRANUS. 1816. Ueber den Sitz des Geruchssinns bey den Insekten. Vermischte Schriften anat. und physiol., Bd. 1, Göttingen, pp. 146-155.

TROUVELOT, L. 1877. The use of the antennæ in insects. Amer. Naturalist, vol. 11, pp. 193-196.

VARRO. 1735. Scriptores Rei Rusticæ Veteres Latini curante Gesnere, Lipsiæ, Lib. 3, Cap. 16, p. 378.

VIRGIL. Virgil's Georgics, Liber quartus, lines 47-50, 62-64.

*VOGT. 1851. Zool. Briefe, vol. 1, Frankfurt a. M., pp. 516-517.

VOM RATH, O. 1887. Ueber die Hautsinnesorgane der Insecten. Preliminary Communication. Zool. Anz. 10, Jahrg., pp. 627-631 and 645-649.

——— 1888. Ueber die Hautsinnesorgane der Insekten. Zeitschr. f. wiss. Zool. Bd. 46, pp. 413-454, with 2 pls.

——— 1895. Zur Kenntnis der Hautsinnesorgane und des sensiblen Nervensystems der Arthropoden. Zeitsch. f. wiss. Zool., Bd. 61, pp. 499-539, with 2 pls.

WASMANN, E. 1889. Zur Bedeutung der Palpen bei den Insekten. Biol. Centralblatt, Bd. 9, no. 10, pp. 303-308.

WEINLAND, ERNST. 1890. Ueber die Schwinger (Halteren) der Dipteren. Zeitsch. f. wiss. Zool., Bd. 51, pp. 55-166 with 5 pls.

WESCHÉ, W. 1904. Some new sense-organs in Diptera. Journ. Quekett Micr. Club, vol. 9 (2), pp. 91-104.

WITLACZIL, E. 1885. Die Anatomie der Psylliden (Hemiptera). Zeitsch. f. wiss. Zool., Bd. 42, p. 600.

WHEELER, W. M. 1910. Ants. Their structure, development and behavior. New York. Columbia Univ. Press, pp. 509-511.

WOLFF, O. J. B. 1875. Das Riechorgan der Biene nebst einer Beschreibung des Respirationswerkes der Hymenopteren, etc. Nova Acta der Kls. Leop-Carol. Deut. Akad. der Naturf. vol. 38, pp. 1-251, with 8 pls.

WONFOR, T. W. 1874. The antennæ of insects. Science-Gossip, pp. 29-31.

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 63, NUMBER 10

ARCHEOLOGY OF THE LOWER MIMBRES VALLEY, NEW MEXICO

(With Eight Plates)

BY

J. WALTER FEWKES

(Publication 2316)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
1914

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

ARCHEOLOGY OF THE LOWER MIMBRES VALLEY, NEW MEXICO

By J. WALTER FEWKES

(With Eight Plates)

Introduction

Evidences of the existence of a prehistoric population in the Lower Mimbres Valley, New Mexico, have been accumulating for many years, but there is little definite knowledge of its culture and kinship. It is taken for granted, by some writers, that the ancient people of this valley lived in habitations resembling the well-known terraced dwellings called pueblos, many of which are still inhabited along the Rio Grande; but this theory presupposes that there was a close likeness in the prehistoric architectural remains of northern and southern New Mexico. It may be said that while there were many likenesses in their culture, the prehistoric inhabitants of these two regions possessed striking differences, notably in their architecture, their mortuary customs, and the symbolic ornamentation of their pottery.

As the former inhabitants of the Mimbres Valley have left no known descendants of pure blood, and as there is a scarcity of historical records, we must rely on a study of archeological remains to extend our knowledge of the subject. Much data of this kind has already been lost, for while from time to time numerous instructive relics of this ancient culture have been found, most of these objects have been treated as "curios" and given away to be carried out of the country, and thus lost to science. Some of these relics belong to a type that it is difficult to duplicate. For instance, it is particularly to be regretted that the numerous votive offerings to water gods, including fossil bones, found when the "sacred spring" at Faywood near the Mimbres was cleaned out, have not been studied and described by some competent archeologist. The arrowheads, lance-points, and "cloud-blowers" from this spring are particularly fine examples, the most important objects of the collection being now in the cabinet of Mrs. A. R. Graham of Chicago.[1]

---

[1] In a letter to Professor W. H. Holmes, published in his paper, "Flint Implements and Fossil Remains from a Sulphur Spring at Afton, Indian Terri-

The valley of the Mimbres has never been regarded as favorable to archeological studies, but has practically been overlooked, possibly because of the more attractive fields in the regions to the north and west, so that only very meager accounts have been published.[1]

The present article, which is a preliminary report on an archeological excursion into this valley in May and June, 1914, is an effort to add to existing knowledge of the archeology of the valley. During this reconnaissance the author obtained by excavation and purchase a collection of prehistoric objects which have added desirable exhibition material to the collections in the U. S. National Museum.[2]

Historical

The recorded history of the inhabitants of the Mimbres is brief. One of the earliest descriptions of the valley, in English, is found in Bartlett's "Personal Narrative," published in 1854. In his account of a trip to the copper mines at the present Santa Rita, Bartlett records seeing a herd of about twenty black-tailed deer, turkeys and other game birds, antelopes, bears, and fine trout in the streams. He

---

tory," Mr. A. R. Graham gives an instructive account of cleaning out the Faywood Hot Springs where he found the following relics: (1) parts of skulls and bones of several human beings; (2) over fifty spearheads and arrowheads of every shape and style of workmanship, the spearheads being valuable for their size and symmetry; (3) nine large warclubs made of stone; (4) a large variety of teeth of animals as well as large bones of extinct animals; (5) the most interesting relics are ten stone pipes from four to seven inches in length; (6) flint hatchet and a stone hammer, together with stones worn flat from use; beads made of vegetable seed and bird bones; part of two Indian bows with which was found a quiver in which was quite a bunch of long, coarse black hair that was soon lost after being dried.—Amer. Anthrop., n. s., vol. 4, pp. 126, 127.

[1] The Santa Rita mines early attracted the conquistadors looking for gold, and were worked in ancient times by the Spaniards, the ores obtained finding an outlet along a road down the valley to the city of Chihuahua. The prehistoric people also mined native Mimbres copper, and probably obtained from these mines and from those in Cook's Range, the native copper from which were made the hawk-bells sometimes found in Arizona and New Mexico. From these localities also were derived fragments of float copper often found in Southwestern ruins and commonly ascribed to localities in Mexico. From here came also a form of primitive stone mauls used in early days of the working of the mines.

[2] The National Museum had nothing from the Lower Mimbres before this addition, although it has a few specimens, without zoic designs, from Fort Bayard, in the Upper Mimbres. The latter are figured by Dr. Hough, Bull. 87, U. S. National Museum.

says very little, however, about antiquities, although he passed through a region where there are still several mounds indicating ruins. Bartlett writes (*op. cit.*, vol. 1, p. 218):

> On April 29, hearing that there were traces of an ancient Indian settlement about half a mile distant, Dr. Webb went over to examine it, while we were getting ready to move. He found a good deal of broken pottery, all of fine texture. Some of it bore traces of red, black, and brown colors. He also found a stone mortar about eight inches in diameter. I have since understood that this was the seat of one of the earliest Spanish missions; but it was abandoned more than a century ago, and no traces remain but a few heaps of crumbling adobes, which mark the site of its dwellings.

This ruin was situated near the Rio Grande, twenty-three miles from Mule Spring, on the road to the Mimbres. Bartlett does not tell us how he learned that this was an early mission site, but from the pottery it is evident that it was an "ancient Indian settlement."

After having examined the configuration of the country through which Bartlett passed, and having compared it with statements in his description, the present writer thinks that Bartlett camped on May 1, 1853, near the Oldtown ruin and that the place then bore the name Pachetehu. This camp was nineteen [eighteen?] miles from Cow Spring and thirteen miles from the copper mines.

Bartlett records that he found, near his camp, "several old Indian encampments with their wigwams standing and about them fragments of pottery." Although not very definite, these references might apply either to the Oldtown ruin and some others a few miles up the river, or to more modern Apache dwellings.

Mr. F. S. Dellenbaugh claims that Coronado, in 1540, passed through the valley of the Mimbres on his way to Cibola, and that this place was somewhere in this region, instead of at Zuñi, as taught by Bandelier and others. The present writer recognizes that the question of the route of Coronado is one for historical experts to answer, but believes that new facts regarding the ruins in the Mimbres may have a bearing upon this question and are desirable. While it can no longer be said in opposition to Dellenbaugh's theory that there are no ruins in the valley between Deming and the Mexican border, we have not yet been able to discover whether the ruins here described were or were not inhabited in 1540.

The fragmentary notice of the ruins in the Upper Mimbres and Silver City region by Bandelier is one of the best thus far published, although he denies the existence of ruins now known in the great stretch of desert from Deming to the Mexican boundary. Regarding the ruins on the Upper Mimbres, Bandelier writes:[1]

> Toward this center of drainage the aboriginal villages on the Rio Mimbres have gravitated as far south nearly as the flow of water is now permanent. They are very abundant on both sides of the stream, wherever the high overhanging plateaux have left any habitable and tillable space; they do not seem to extend east as far as Cook's Range, but have penetrated into the Sierra Mimbres farther north, as far as twenty miles from the river eastward. . . . . The total number of ruins scattered as far north as Hincks' Ranch on a stretch of about thirty miles along the Mimbres in the valley proper, I estimate at about sixty. . . . . I have not seen a village whose population I should estimate at over one hundred, and the majority contained ten. They were built of rubble in mud or adobe mortar, the walls usually thin, with overwings, and a fireplace in the corner, formed by a recess bulging out of a wall. Toward the lower end of the permanent water course, the ruins are said to be somewhat extensive.

Professor U. Francis Duff, in an article on the "Ruins of the Mimbres Valley,"[2] adds a number of new sites to those mentioned above and contributes important additions to our knowledge of the prehistoric culture of the valley.

Dr. Walter Hough, who compiled from Bandelier and Duff, and made use of unpublished information furnished by Professor De Lashmutt and others, enumerates twenty-seven ruins in the Silver City and Mimbres region to which he assigns the numbers 147-174. Many more ruins[3] might have been included in this list, but it is not the author's purpose, at this time, to mention individual pueblo sites but rather to call attention to the evidences of ruins in the Lower Mimbres Valley as an introduction to the study of pottery there collected. The ruin from which the majority of the bowls here considered were obtained does not appear to have been mentioned by Bandelier, Duff, or Hough.

The last-mentioned author makes the following reference to figures on the pottery from the Mimbres region: "The decoration is mainly geometric. From the Mimbres he [Professor De Lashmutt] has seen a realistic design resembling a grasshopper, and from Fort Bayard another representing a four-legged creature. Mrs. Owen has a

---

[1] Archæological Institute of America, American Series, vol. 4, Final Report, Part 2, pp. 356, 357.

[2] American Antiquarian, vol. 24, p. 397, 1902.

[3] Bandelier (*op. cit.*, p. 357) speaks of sixty ruins in a small section thirty miles along the river.

specimen from Fort Bayard bearing what is described as a 'fish design.'"[1] Dr. Hough likewise points out that

> pottery from some sites [ruins] is also different from that of any other [Pueblo] region and is affiliated, in some respects, with that of the Casas Grandes, in Chihuahua which lies in the low foot-hills of Sierra Madre. This is especially true in reference to fragments of yellow ware found here [the Florida Mountains] which in both form and color of decoration is manifestly like that of Casas Grandes.[2]

The latest and thus far the most important contribution to our knowledge of the prehistoric people of the Mimbres we owe to Mr. C. L. Webster, who has published several articles on the antiquities of the Upper Mimbres, in "The Archæological Bulletin." He has made known several new village sites along the valley and has mentioned, for the first time, details regarding Mimbres ruins and the objects found in them. Practically nothing has thus far been recorded on the antiquities of the region immediately about Deming, nor of those south of that important railroad center to the Mexican border.

In an article on "Some Burial Customs Practiced by the Ancient People of the Southwest,"[3] Mr. Webster describes and figures a human burial on the Lower Mimbres not far from the "Military Post," situated near Oldtown. It was found in the plain some distance from any indications of prehistoric settlement. He says:

> An exploration of it [a burial] revealed that originally a circular excavation, perhaps three feet in diameter and slightly more in depth, had been made in the ground; and afterwards the body placed at the bottom of this excavation in a sitting posture with the knees somewhat drawn up and arms to the side, and then a very large earthen olla, of a reddish color, was set over it, bottom side up, thus protecting it from the earth which was afterwards thrown in, filling up the excavation.

Mr. Webster shows that the Mimbres aborigines did not always bury their dead in a contracted or seated posture. He speaks also of intramural or house burials in the valley of Rio Sapillo, a tributary of the Upper Gila, not far from the source of the Mimbres. In this region he dug down in one of the central rooms of a ruin about three feet below the surface, where he says (p. 73):

> Near the bottom of this excavation hard red clay was encountered, which on opening up proved to contain the well-preserved skeleton of an adult person

---

[1] Bull. 35, Bur. Amer. Ethn., p. 83. See also an article subsequently published on the Culture of the Ancient Pueblos of the Upper Gila River Region, Bull. 87, 1913, U. S. National Museum, in which several bowls with geometrical designs from Fort Bayard are figured.

[2] Bandelier found that Mimbres pottery resembles that of several regions, including Casas Grandes.

[3] The Archæological Bulletin, vol. 3, No. 3, p. 70.

which had been placed at length on its back with arms at its side. Over the face of this one [human burial] had been placed a rather large shallow dish, through the bottom of which a hole about the size of a five cent piece, or a little larger, had been carefully drilled. This hole was so located as to occupy a position between the eyes when placed over the face. This body was resting on a bed of red clay like that which had covered it. Near the first body was a second body which had been buried in exactly the same way, and had a similar perforated dish over its face. Under this first or upper tier of bodies a second tier of bodies was discovered which had been buried exactly the same way as the upper tier—each one resting separate and alone, though near together, each one tightly enveloped in stiff red clay.

All the vessels placed over the faces showed the action of fire, and it was plain to be seen they had once been used in cooking. . . . . The method practised here was to first spread down a layer of red plastic clay, then lay the body upon it, place the perforated dish over the face and finally plaster all with a covering of the same clay. This same method was followed in every case observed.

Sites of Ruins in the Lower Mimbres Valley

The portion of the Sierra Madre plateau called Lower Mimbres, or Antelope Valley, extends from where the Mimbres sinks below the surface at Oldtown to Lake Palomas in Mexico, twenty-five miles south of Deming. According to some writers this region has no prehistoric ruins, but several of the beautiful specimens described and figured in the present article came from this valley, and there are doubtless many others, equally instructive, still awaiting the spade of the archeologist. The purest form of the Mimbres prehistoric culture is found in the lower or southern part of this plain, but it extends into the hills far up the Mimbres almost to its source.

The plateau on which the prehistoric Mimbres culture developed is geographically well marked, and distinguished from other regions of the Southwest geographically and biologically, facts reflected in human culture. The cultural gateway is open to migrations from the south rather than from the east, north, or west.

The evidences drawn from the poor preservation of the walls of the ruins, and the paucity of historical references to them, instead of indicating absence of a prehistoric population suggest the existence of a very ancient culture that had been replaced by wandering Apache tribes years before the advent of the Spaniards. Chronologically the prehistoric people belongs to an older epoch than the Pueblo, and its culture resembles that which antedated the true Pueblos.[1]

---

[1] During the author's stay in Deming he was much indebted to Dr. S. D. Swope for many kindnesses, among which was an opportunity to study his valuable collection, now in the high school of that city. He was also greatly

The ruins here considered do not belong to the same type as those of the Lower Gila and Salt, although they may be contemporaneous with them, and may have been inhabited at the same time as those on the Casas Grandes River in northern Chihuahua. Not regarded as belonging to the same series of ruins as those on the Upper Gila and Salt rivers, they are not designated numerically with them.

Although the indications of an ancient prehistoric occupancy of the Mimbres are so numerous, they are so indistinct and have been so little studied that any attempt here to include all of them would be premature. Remains of human occupancy occur in the plain about Deming, and can be traced northward along the river east and west into the mountains, and south into Mexico.

The author has observed many evidences of former settlements along the Upper Mimbres which have not yet been recorded. The indications are, as a rule, inconspicuous, appearing on the surface of the ground in the form of rows of stones or bases of house walls, fragments of pottery, and broken stone implements, such as metates and manos. These sites are commonly called "Indian graves," skeletons often having been excavated from the enclosures outlined by former house walls. There are also evidences of prehistoric ditches at certain points along the Mimbres, showing that the ancients irrigated their small farms.

No attempt is made here to consider all the ruins of the Mimbres or of the Antelope plain in the immediate neighborhood of Deming, but only those that have been visited, mainly ruins from which the objects here described were obtained.

Although few of the walls of the ancient buildings rise high above ground, they can be readily traced in several places. From remains that were examined it appears that the walls were sometimes built of stone laid in mortar and plastered on the inside, or of adobe strengthened at the base with stones and supported by logs, a few of which have been found in place upright. No differentiation of sacred and secular rooms was noticed, and no room could be identified as belonging to the type called kiva. The floors of the rooms were made of "caleche," hardened by having been tramped down; the fireplace was placed in one corner, on the floor, and the entrance to the room was probably at one side. To all intents and purposes these dwellings were probably not unlike those fragile wattle-walled structures found

---

aided by Mr. E. D. Osborn and several other citizens, and takes this opportunity to thank all who rendered assistance in his studies. The photographs reproduced in the present paper were made by Mr. Osborn.

very generally throughout the prehistoric Southwest, and supposed to antedate the communal dwellings or pueblos of northern New Mexico.

The two aboriginal sites in the Mimbres Valley that have yielded the majority of the specimens here figured and described are the Oldtown ruin and the Osborn ruin, a small village site twelve miles south of Deming and four miles west of the Florida Mountains. There are some differences in general appearance and variations in the minor archeological objects from these two localities, but it is supposed that specimens from both indicate a closely related, if not identical, culture area.

About a year ago Mr. E. D. Osborn, of Deming, who had commenced excavation in these ruins,[1] obtained from them a considerable collection of pottery and other objects. His letters on the subject and his photographs of the pottery, sent to the Bureau of American Ethnology, first led the author to visit southern New Mexico to investigate the archeology of the Mimbres.

VILLAGE SITE NEAR OSBORN RANCH [2]

A few extracts from Mr. Osborn's letters regarding this site form a fitting introduction to a description of the sites and the objects from them:

> At the present time [December 8, 1913] the nearest permanent water to this place [site of the cemetery] is either the Palomas Lake in Mexico, twenty-five miles south, or thirty miles north, where the Mimbres River sinks into the earth. . . . . This supposed Pueblo site is situated upon a low sandy ridge which at this point makes a right-angle bend, one part running south and the other west from the angle. The top and sides of the ridge, also the "flat" enclosed between the areas of the ridge, to the extent of about an acre, is littered all over with fragments, charcoal and debris containing bones to the depth of from one to three feet. There are also a great many broken metates and grinding stones. . . . . In digging on top of this ridge, near the angle, we occasionally found what appeared to have been adobe wall foundations, but not sufficiently large to determine the size or shape of any building. In digging on the ridge a few stone implements were found, including one fine stone axe, stone paint pots and mortars, and a few arrowheads, also two bone awls and a few shell beads and bracelets, the last all broken. The only article of wood was the stump of a large cedar post full of knots, badly decayed; it had been burned off two or three inches below the surface of the ground. The cemetery was found on the inner slope of the angle facing the southwest. . . . . In a

---

[1] Specimens were also found by Mr. Osborn at the Byron Ranch ruin, at the Black Mountain site, and elsewhere.

[2] This is the ruin called Osborn ruin in subsequent descriptions.

large proportion of cases the body was placed upon its back, feet drawn up against the body, knees higher than the head; sometimes the head was face up and sometimes it was pressed forward so the top of the head was uppermost. In other interments the body was extended its full length with face up. A large majority of the skulls had a bowl[1] inverted over them, though I judge twenty per cent were without any bowl. . . . . In a great many instances after the body had been placed in the grave with bowl over the head, a little soil was filled in, and about one foot of adobe mud was added and tramped down then filled up with soil. This adobe mud is almost like rock, making it difficult to dig up the bowl without smashing it. . . . . No article of any kind except the bowl over the head was found in any grave. In one case a bowl was found with a skull under it and under that skull was another bowl and another skull.

Few evidences of upright walls of buildings are found at or near this site. The surface of the ground in places rises into low mounds devoid of bushes, which grow sparingly in the immediate neighborhood, but no trees of any considerable size were noticed in the vicinity. Before work began at this place the only signs of former occupancy by aborigines, besides walls, were a few broken fragments of ancient pottery, metates, or a burnt stump protruding here and there from the ground. None of the house walls projected very high above the surface of the ground. Excavations in the floors of rooms at this point yielded so many human skeletons that the place was commonly referred to as a cemetery, but all indications support the conclusion that it was probably a village site with intramural interments.

The human burials here found had knees flexed or drawn to the breast in the "contracted" position, sometimes with the face turned eastward. The skeletons were sometimes found in shallow graves, but often were buried deeply below the surface. Almost without exception the crania had bowls fitted over them like caps. The graves as a rule are limited to soft ground, the bowls resting on undisturbed sand devoid of human remains. In some instances there appears to have been a hardened crust of clay above the remains, possibly all that is left of the floor of a dwelling. The indications are that here, as elsewhere, the dead were buried under the floors of dwellings, as is commonly the case throughout the Mimbres Valley. While there is not enough of the walls above ground to show the former extent

---

[1] On some of the skulls excavated at Sikyatki, Arizona, in 1895, the author found concave disks of kaolin perforated in the center. One of these disks is represented in Fig. 356, p. 729, 17th Ann. Rep. Bur. Amer. Ethnol. In an article on "Urn Burial in the United States" (Amer. Anthrop., vol. 6, No. 5), Mr. Clarence B. Moore, quoting his own observations and those of many others, records burials in which an inverted mortar, bowl, basket, or other object was placed over the skull of the dead, and shows the wide distribution of the custom.

of the dwellings, the indications are that they were extensive and have been broken down and washed away.

OLDTOWN RUIN

Near where the Mimbres leaves the hills and, after spreading out, is lost in the sand, there was formerly a " station," on the mail route, called Mimbres, but now known as Oldtown. Since the founding of Deming, the railroad center, the stage route has been abandoned and Mimbres (Oldtown) has so declined in population that nothing remains of this settlement except a ranch-house, a school-house, and a number of deserted adobe dwellings.

Oldtown lies on the border of what must formerly have been a lake and later became a morass or cienega, but is now a level plain lined on one side with trees and covered with grass, affording excellent pasturage. From this point the water of the Mimbres River is lost, and its bed is but a dry channel or arroyo which meanders through the plain, filled with water only part of the year. In the dry months the river sinks below the surface of the plain near Oldtown reappearing at times where the subsoil comes to the surface, and at last forms Palomas Lake in northern Mexico.

In June, when the author visited Oldtown, the dry bed of the Mimbres throughout its course could be readily traced by a line of green vegetation along the whole length of the plain from the Oldtown site to the Florida Mountains.[1]

The locality of emergence of the Mimbres from the hills or where its waters sink below the surface is characteristic. The place is surrounded by low hills forming on the south a precipitous cliff, eighty feet high, which the prehistoric inhabitants chose as a site of one of their villages; from the character and abundance of pottery found, there is every reason to suppose this was an important village.

The Oldtown ruin is one of the most extensive seen by the author during his reconnoissance in the Deming Valley, although not so large as some of those in the Upper Mimbres, or on Whiskey Creek, near Central. Although it is quite difficult to determine the details of the general plan, the outlines of former rectangular rooms are indicated by stone walls that may be fairly well traced. There seem to have been several clusters of rooms arranged in rows, separated by square or rectangular plazas, unconnected, often with circular depressions between them.

---

[1] A beautiful view of the valley can be obtained from the top of Black Mountain, above the small ruin at its base, that will be mentioned presently.

There is considerable evidence of "pottery hunting" by amateurs in the mounds of Oldtown, and it is said that several highly decorated food bowls adorned with zoic figures have been taken from the rooms. It appears that the ancient inhabitants here, as elsewhere, practised house burial and that they deposited their dead in the contracted position, placing bowls over the crania (fig. 1).[1]

The author excavated several buried skeletons from a rectangular area situated about the middle of the Oldtown ruin, surrounded on three sides by walls. The majority of the dead were accompanied with shell beads and a few turquoise ornaments, and on one was found a number of shell tinklers made of the spires of seashells. One of the skeletons excavated by Mr. Osborn appeared to have been enclosed in a stone cist with a flat slab of stone covering the skull. The remains of a corner post supporting the building stood upright on this slab.[2] In another case a skull was found broken into fragments by the large stone that had covered it. Several skeletons had no bowls

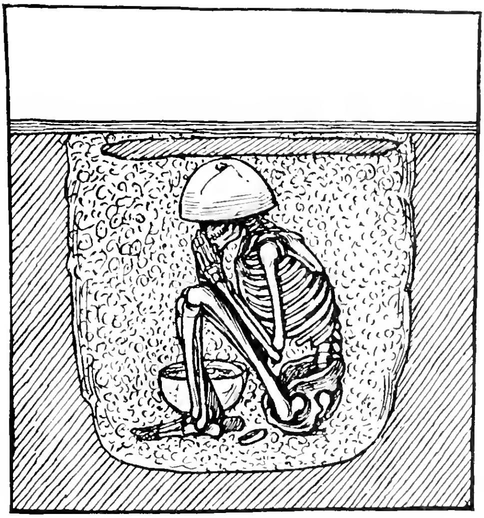


Fig. 1.—Urn burial. (Schematic.)

---

[1] The drawings of pottery designs in this article were made by Mrs. M. W. Gill; the stone and other objects were drawn by Mr. R. Weber.

[2] A significant feature in the Mimbres form of "urn burial" is the invariable puncturing of the bowl inverted over the head. The ancient Peruvians in some instances appear to have "killed" their mortuary bowls, and life figures depicted on Peruvian pottery are sometimes arranged in pairs as in the Mimbres.

over the heads, an exceptional feature in Mimbres burials; and in some instances the bowl had been placed over the face. In the case of numerous infant interments the bowl covered the whole skeleton.

RUIN ON BYRON RANCH

This ruin lies not far from the present course of the Mimbres near the Little Florida Mountains. The place has long been known as an aboriginal village site and considered one of the most important in the valley. The remains of buildings cover a considerable area. They have a rudely quadrangular form, showing here and there depressions and lines of stones, evidently indicating foundations of rooms, slightly protruding from the ground. Although this ruin has been extensively dug over by those in search of relics, no systematic excavations seem to have been attempted. It is said that valuable specimens have been obtained here, and fragments of pottery, arrowheads, and broken stone implements are still picked up on the surface.

The important discovery of burial customs of the ancient Mimbreños was made by Mr. Duff at this ruin. He excavated below the floor of one of the rooms and found a human cranium on which was inverted a food bowl pierced in the middle, the first example of this custom noted in the Mimbres region.

RUIN NEAR DEMING

About seven miles northwest of Deming, in a field on the north side of the Southern Pacific Railroad, there is a small tract of land showing aboriginal artifacts strewn over the surface, affording good evidence of prehistoric occupation. There are no house walls visible at this place, and only a few fragments of food bowls, but in the course of an hour's search several small mortars (fig. 2), paint grinders and other objects were procured at this place.[1]

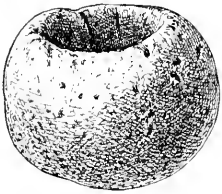


FIG. 2.—Paint mortar. Diam. 2½".

---

[1] Although not placed in the proper locality on his map, this ruin seems to be one of the "pueblos" (Nos. 162-164) mentioned by Dr. Hough.

PREHISTORIC SITE NEAR BLACK MOUNTAIN

Walls and outlines of rooms indicated by rows of stones mark remains of a prehistoric settlement at the base of Black Mountain, eight or nine miles northwest from Deming. Here occur many fragments of pottery, broken metates, and manos, and other indications of occupation by man. On top of Black Mountain there are rude cairns or rings of stones apparently placed there by human hands.

The fragments of pottery taken from the ruin at the base of Black Mountain are very different from those from Oldtown and other typical Mimbres ruins. Its color on the outside is red, with a white interior surface decorated with black geometric designs, the border is flaring often with exceptional exterior decoration. These bowls have broken encircling lines—a feature yet to be found in other Mimbres pottery—and none of the few pieces yet obtained from the ruin near Black Mountain has animal pictures. The whole appearance of this pottery recalls old Gila ware and suggests an intrusion from without the Mimbres region, possibly from the north and west.

The circles of stones on the top of Black Mountain have many points of resemblance to similar structures on hilltops near Swarts' Ranch on the Upper Mimbres, described by Mr. Webster, as follows:[1]

> The tops of nearly all the mountains of this valley, and particularly those here mapped, are occupied by hundreds of rock mounds, breastworks, pits, etc. The region shown in plate 3, and which represents an area about one mile in length and three-fourths mile in width, exhibits 240 of these structures. . . . . These rock mounds are composed of more or less rounded rocks gathered from the region, and generally weighing from four to eight pounds each; although many are smaller: and again others weigh from twenty-five to fifty pounds or more each. These structures are generally circular: although at times they are ovate, and again assume an oblong or linear marginal outline. They vary considerably in size, although usually being only from three to four feet in diameter: the linear ones being from six to eight feet or more in length. Some of the larger circular mounds assume a diameter of seven to eight feet. The height of these mounds varies considerably; but as a rule assume a height ranging from one to one and a half feet.
>
> The distance apart of these structures is variable; being as a general thing from five to fifteen feet; but not infrequently they are only two to four feet apart: at other times, however, they may be observed to be from sixty to ninety feet or more distant from each other.

---

[1] Archæological and Ethnological Researches in Southwestern New Mexico, Part 2, Ruin, Ancient Work Shop, Rock Mounds, etc., at Swarts' Ranch. (The Archæological Bulletin, vol. 4, No. 1, p. 14, 1913.)

Mr. Webster discovered on a rocky ridge near Swarts' ruin, somewhat higher on the Mimbres than Brockman's Mill, seven similar earthen pits of much interest, which remind the author of subterranean or half-sunken dwellings. They are saucer-shaped or linear depressions, averaging about two feet in depth; when circular they are from five to fifteen feet in diameter the linear form in one instance being fifty feet long. Some of these have elevated margins, others with scarcely any marginal ridge. The western margin in one instance has a " wall of rounded stones."

There are similar saucer-shaped depressions near Brockman's Mills and elsewhere in the Mimbres, almost identical with " pit dwellings " found by Dr. Hough near Los Lentes. These saucer-like depressions, often supposed to have been the pits from which adobe was dug, were also places of burial, the dead being presumably interred under or on the floors; the original excavation being a dwelling that was afterwards used as a burial place for the dead. Their form suggests the circular kiva of the Pueblos and has been so interpreted by some persons.

RUINS ON THE MIMBRES RIVER FROM OLDTOWN TO BROCKMAN'S MILLS

On low terraces elevated somewhat above the banks of the river, between Oldtown and Brockman's Mills, there are several village sites, especially on the western side.[1] The most important of these is situated about four miles north of Oldtown. The ruin at the Allison Ranch, situated at the Point of Rocks where the cliffs come down to the river banks, is large and there are many pictographs nearby. The ruins at Brockman's Mills on the opposite or eastern side of the river lie near the ranch-house. Many rooms, some of which seem to have walls well plastered, can be seen just behind the corral. North of the ruin is a hill with low lines of walls like trincheras. On some of the stones composing these walls and on neighboring scattered boulders, there are well-made pictographs.[2]

PICTOGRAPHS

Pictographs occur at several localities along the Mimbres. As these have a general likeness to each other and differ from those of other regions, they are supposed to be characteristic of the prehistoric

---

[1] For a description of ruins at Swarts' and Brockman's Mills see C. L. Webster, Archæological and Ethnological Researches in Southwestern New Mexico. (The Archæological Bulletin, vol. 3, No. 4.)

[2] It is said that a Spanish bell in the Chamber of Commerce at Deming, was dug up on this ranch near the ruin. This bell might indicate an old mission at this place.

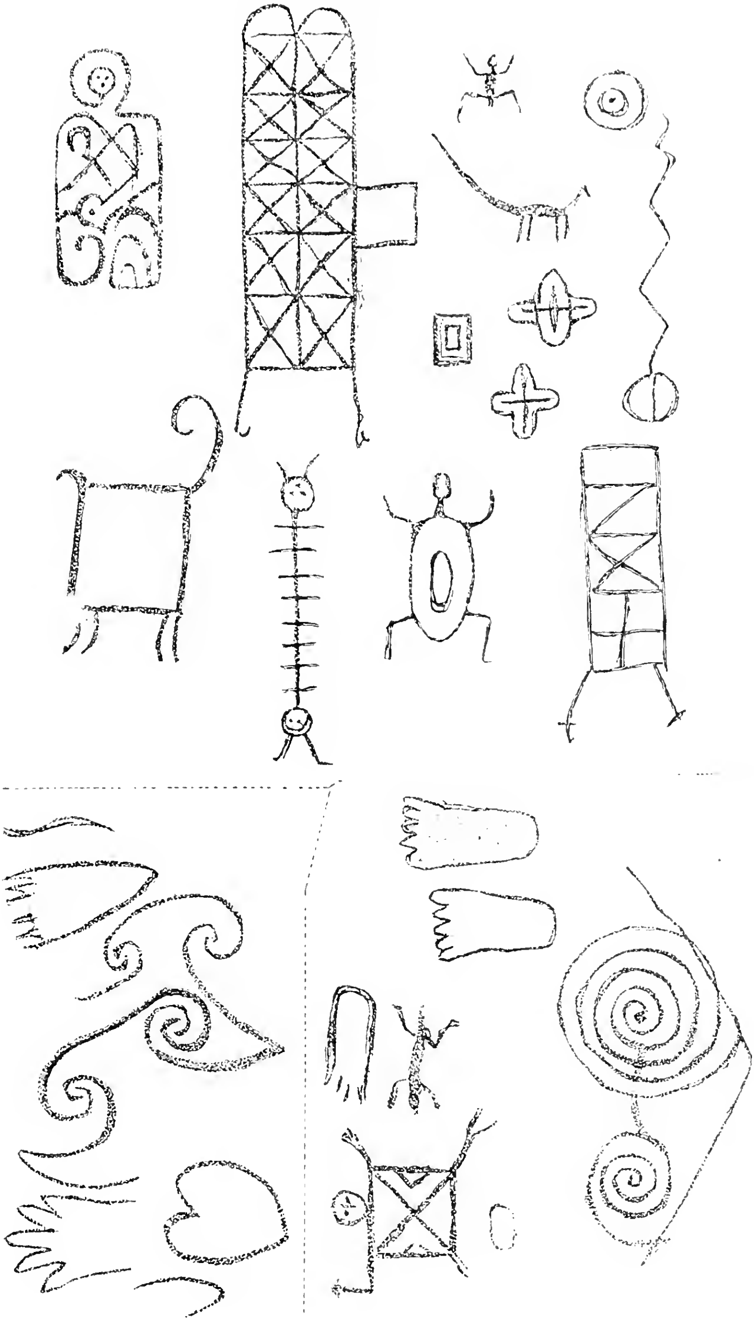


FIG. 3.—Pictographs.

people. They are generally pecked on the sides of boulders or on the face of the cliffs in the neighborhood of prehistoric sites of dwellings. Although there is only a remote likeness between these pictographs and figures on pottery, several animal forms are common to the two.

The most important group of pictographs (fig. 3) seen by the author are situated about nine miles from Deming in the western foot-hills of Cook's Peak.[1] Some of the pictographs recall decorations on bowls from Pajarito Park.

Another large collection of Mimbres pictographs, visited by the author, is found at Rock Canyon, three or four miles above Oldtown, at a point where the cliffs approach the western bank of the river. On the river terrace not far above this collection of pictures, also on the right bank of the river, lies the extensive ruin of a prehistoric settlement, the walls of which project slightly above the surface. This ruin has been dug into at several points revealing several fine pieces of pottery, fragments of metates, and other implements, which are said to have been found in the rooms. A mile down the valley overlooking the river there is another cluster of pictures at a ruin called "Indian graveyard," probably because human skeletons have been dug out of the floors of rooms.

MORTARS IN ROCK IN PLACE

One of the characteristic features of the Mimbres ruins, but not peculiar to them, are mortars or circular depressions worn in the horizontal surface of rock in place. They are commonly supposed to have been used as mortars for pounding corn, and vary in size from two inches to a foot in diameter, being generally a foot deep. We find them occurring alone or in clusters. Good examples of such depressions are found near the Byron ruin, in the neighborhood of the ruins along Whiskey Creek, at Oldtown, and elsewhere. There is a fine cluster of these mortars nine miles from Deming, near the pictographs in the Cook's Range. Similar mortars have been repeatedly described and often figured. Mr. Webster has given the most complete account of this type of mortars in a description of the ancient ruins near Cook's Peak.[2] On the surface of the southwestern

---

[1] The author visited these rocks in company with Dr. Swope, who has known of them for many years.

[2] Archæological and Ethnological Researches in Southwestern New Mexico, Part 4. (The Archæological Bulletin, vol. 5, No. 2, p. 21.)

point of a low hill to the north of an ancient ruin at Cook's Peak, according to this observer,

> occurs a feature which the writer had nowhere else seen, save on the east side of the same mountain. I refer to the great number of mortars which occur in this sandstone back a few feet to the north of the ruins, and which were made and long used by the ancient pueblo-dwellers. There exists at this one place fifty-three of these mortars, nearly all of them occurring in an area of surface not more than seventy-five or eighty feet in diameter. . . . . Nearly all the mortars are circular or sub-circular in outline, symmetrical and smooth inside, and the upper edge or margin usually rounded by the pestle. In a few cases, however, these mortars have an oblong or subovate outline, somewhat like some forms of metates found among the ruins.
>
> These mortars often contract to a point at the bottom, when circular in marginal outline, although at times are longer than broad, as just stated, and in this case have a more flattened bottom. They vary from two to eleven inches in diameter, the smallest forms being those apparently only just begun, and are few in number. The deepest mortar observed was seventeen inches, though the great majority of them would vary perhaps from four to ten inches in depth. Often the rock was smooth and polished around the margin of the mortars, and [their distances apart] vary from a few inches to several feet from each other.
>
> At times these mortars would be located on the top of a large block of sandstone which might happen to occupy this area; these boulders sometimes being four to five feet in diameter and perhaps four feet in height. It was plain to be seen that this ancient mill-site was long used by these peculiar people, but just why so many quite similar mortars should have been made here and used by these people is a matter of conjecture.
>
> It seems certain that a sufficiently large number of people could not have been congregated here, under ordinary conditions, to warrant the forming of so many mortars for the purpose of grinding food.[1]

The present writer accepts the theory that these rock depressions were used in pounding corn or other seeds, but their great number in localities where ruins are insignificant or wanting is suggestive. We constantly find arable land near them, indicating that communal grinding may have been practised, and suggesting a large population living in their immediate neighborhood, which may have left no other sign of their presence.

MINOR ANTIQUITIES

The artifacts picked up on the surface near ruins or excavated from village sites resemble so closely those from other regions of the Southwest that taken alone these do not necessarily indicate special

---

[1] Mr. Webster describes "ancient pueblos" on the western side of this group of mountains as well as on the eastern slope of Cook's Range. Certain cave lodges, or walled caves, in a wild canyon on the east side of Cook's Peak are supposed by him to be the recent work of Apaches.

culture areas. A few of the more common forms from the Mimbres are here figured for comparison, but, with the exception of the pottery, there is little individuality shown in the majority of these objects. Among other objects may be mentioned stone implements, mortars, idols, bone implements, shell ornaments, and pottery.

STONE IMPLEMENTS

The stone axes are not very different from those of the Rio Grande and the Gila, but it is to be noticed that they are not so numerous as in the latter region, and are probably inferior in workmanship, fine specimens indeed being rare. The majority of the axes (fig. 4) are single grooved, but a few have two grooves. In Dr. Swope's collection, now in the Deming High School, there is a fairly good double-bladed axe.

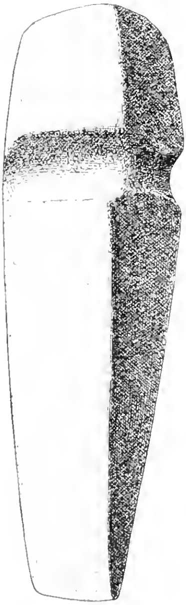


Fig. 4.—Stone axe. Length 8¾″.

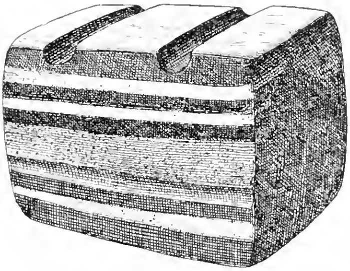


Fig. 5.—Arrow polisher. Length 3¼″, breadth 2½″.

Miss Alnutt, of Deming, has a remarkable collection of arrowpoints gathered from many localities in the valley, and also a few fine spearpoints, conical pipes, and other objects taken from the sacred spring at Faywood Hot Spring. A beautiful arrow polisher found near Deming is shown in figure 5.

The pipes from the Mimbres take the form of tubular cloud-blowers, specimens of which are shown in figure 6. Apparently these pipes were sometimes thrown into sacred springs, but others have been picked up on the surface of village sites or a few feet below the surface.

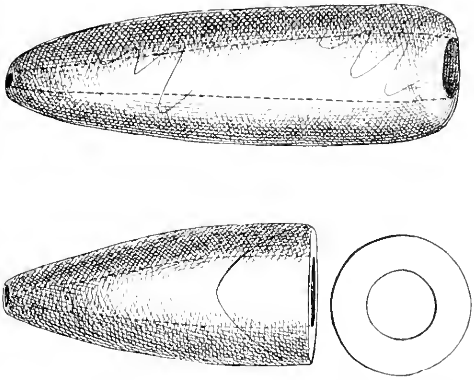


FIG. 6.—Cloud blowers. Faywood Hot Springs. (Swope collection.) ½ nat. size.

Lateral and top views of one of the characteristic forms of small stone mortars with a handled projection on one side is shown in figure 7. This specimen is in the Swope collection in the Deming High School. In the same collection there are also two beautiful tubular pipes, or cloud-blowers, from the same spring.

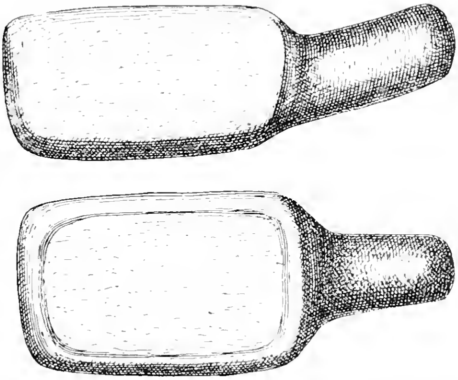


FIG. 7.—Handled mortar. (Swope collection.) Length 10¾″.

The stone mortars from Mimbres ruins vary in size. Many are simply spherical stones with a depression on one side; others are larger but still spherical, or ovate; while others have square or rectangular forms. The most remarkable feature in these is the presence of a handle on one side, which occasionally is duplicated, and in one instance four knobs or legs project from the periphery. These projections appear to characterize the mortars of the Mimbres, although they are not confined to them, as the form occurs in other regions of New Mexico and in California. One of the most instructive of these small spherical paint mortars, now owned by Mr. E. D. Osborn, has ridges cut in high relief on the outside.

Metates and manos, some broken, others whole, are numerous and can be picked up on almost every prehistoric site. While some of these metates are deeply worn, showing long usage, others have margins but slightly raised above the surface. The majority of metates found on the sites of habitations have no legs, but a typical Mexican metate with three knobs in the form of legs was presented to the National Museum by the Rev. E. S. Morgan, of Deming. Metates are sometimes found in graves with skeletons, presumably those of women. Several ancient metates are now in use as household implements in Mexican dwellings.

If the size of the population were to be gauged by the number of mortars and manos found, certainly the abundance of these implements would show that many people once inhabited the plain through which flows the Mimbres River. Narrow, flat stone slabs have an incised margin on one end. Their use is problematical. The frequency of stone balls suggests games, but these may have been used as weapons; or again, they were possibly used in foot races, as by the Hopi of to-day.

COPPER OBJECTS

Native metallic copper was formerly abundant at the Santa Rita mines, and there is every probability that the material out of which some of the aboriginal copper bells were made was found here, and that these mines were the source of float copper found in Arizona ruins. Although no copper implements were found by the author in the Mimbres ruins, he has been told that objects of copper apparently made by the aborigines have been found in some of the graves.[1]

---

[1] Elaborate metal objects of early historical times have been found at various places in the Mimbres. The best of these is a fragment of an elaborately decorated stirrup, now owned by Mr. Pryor of the Nan Ranch. A copper church bell was found near his house, and other metal objects belonging to the historic epoch are reported from various ruins in the valley.

STONE IDOLS

The author saw several stone idols that were reported to have been obtained from ruins in the Mimbres Valley. These idols represent frogs (fig. 8), bears, mountain lions, and other quadrupeds, and have much the same form as those from ancient ruins in Arizona.[1]

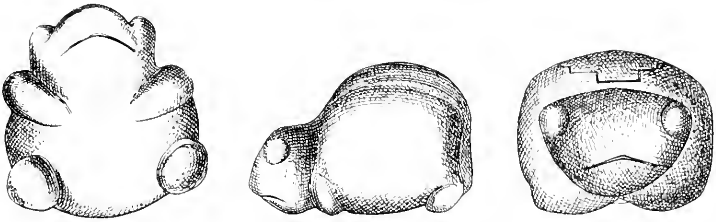


FIG. 8.—Frog fetish. Black Mountain Ruin. (Swope collection.) Length 3½″.

On the backs of several of these stone idols are incised figures, like arrowheads tied to Zuñi fetishes, or possibly rain-cloud figures. In one instance they were made on an elevated ridge, which unfortunately was broken. The author has also seen several small amulets, perforated apparently for suspension. The stone idols here figured (figs. 8, 9, 10) were presented to the Deming High School by Dr. Swope.

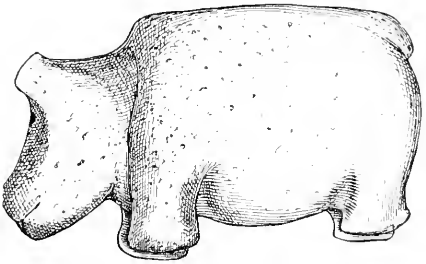


FIG. 9.—Fetish. Byron Ranch. (Swope collection.) Length 5¾″.

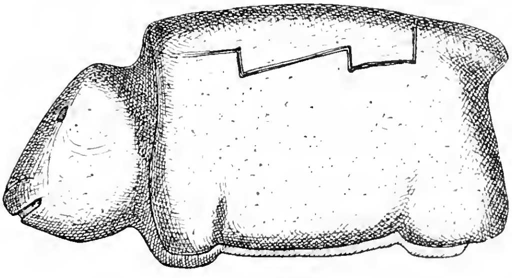


FIG. 10.—Fetish. Byron Ranch. (Swope collection.) Length 6¾″.

---

[1] Similar stone idols from the San Pedro Valley and other localities, in Arizona and New Mexico, have mortar-like depressions on their backs.

SHELL BRACELETS AND CARVED SHELLS

Two or three shell bracelets were excavated from Mimbres ruins, and there were also found carved shells and tinklers not unlike those of northern New Mexico ruins. Some of these when excavated were found near the head and are supposed to have been earrings. Five shell rings were still on the bones of the forearm of a child when found. One of the shell bracelets owned by Mr. Osborn was cracked but was pierced on each side of the break, indicating where it had been mended; another had figures incised on its surface, and a third had the edges notched, imparting to it a zigzag shape, like that of a serpent. Many shell beads, spires of shells used for tinklers, and other shell objects, all made of genera peculiar to the Pacific Ocean, were found during the excavations.

POTTERY

FORMS AND COLORS

The comparatively large number of vases, food bowls, and other forms of decorated smooth ware in collections from the Mimbres is largely due to their use in mortuary customs, and the fact that almost without exception they were found placed over the skulls of the dead. Although the largest number of vessels are food bowls, there are also cups with twisted handles (fig. 11), bowls (fig. 12), vases, dippers, and other ceramic forms found in pueblo ruins.[1]

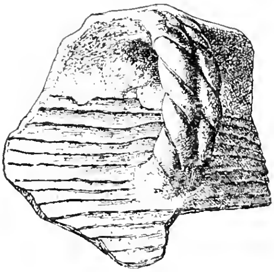


FIG. 11.—Braided handle.
½ nat. size.

FIG. 12.—Small bowl.
Diam. 3½″.

Coarse, undecorated vessels showing coils, indentations, superficial protuberances, and other rude decorations like those so well known in Southwestern ruins, are well represented. Some of these were

---

[1] One of the exceptional forms of pottery has a flat rectangular base, the four sides being formed by bending up segments of a circular disk (fig. 18).

used as cooking vessels, as shown by the soot still adhering to their outer surface. While the majority of bowls were broken in fragments when found, a few were simply pierced through the bottom; one or two were unbroken or simply notched at the edge.

The colors of Mimbres ware are uniform and often striking. There are good specimens of black and white ware; also red, black, and yellow with brown decorations are numerous. Some of the best pieces are colored a light orange. Many of the fragments are made of the finest paste identical in color and finish with ware from Casas Grandes, Chihuahua, which furnishes the best prehistoric pottery from the Southwest. No effigy jar, or animal formed vase, however, exists in any collections from the Mimbres examined by the author.

Ruins in the Lower Mimbres have thus far yielded a larger variety and a finer type of pottery than ruins on the banks of the river among the hills, which is in part due to the extent of excavations. The Oldtown potters developed a kind of pottery with characteristic ornamentation found both in ruins in the plain to the south and along the narrow valley of the Mimbres to the north.

The Mimbres pottery, like all other ancient ware from the Southwest, frequently shows evidences of having been mended. Holes were drilled near the breaks and fibers formerly united the parts thus holding the bowl together even though broken. As one goes south, following the course of the river, the character of the pottery changes very slightly, but if anything is a little better.

The food bowls generally have a rounded base, but one specimen is flat on the bottom. The edges of the bowls from the ruin at Black Mountain are curved outward, an exceptional feature in ancient Pueblo vessels but common in modern forms.

PICTURES ON MIMBRES POTTERY

The great value of the ceramic collection obtained from the Mimbres is the large number of figures representing men, animals, and characteristic geometrical designs, often highly conventionalized, depicted on their interiors. These figures sometimes cover a greater part of the inner surface, are often duplicated, and are commonly surrounded by geometrical designs or simple lines parallel with the outer rim of the vessel. It is important to notice the graceful way in which geometrical figures with which the ancient potters decorated their bowls are made to grade into the bodies of animals, as when animal figures become highly conventionalized into geometrical designs. Although these decorations are, as a rule, inferior to those of the Hopi ruin, Sikyatki, the figures of animals are more numerous, varied, and realistic.

The ancients represented on their food bowls men engaged in various occupations, such as hunting or ceremonial dances, and in that way have bequeathed to us a knowledge of their dress, their way of arranging their hair, weapons, and other objects adopted on such occasions. They have figured many animals accompanied by conventional figures which have an intimate relation to their cults and their social organization. Although limited in amount and imperfect in its teaching this material is most instructive.

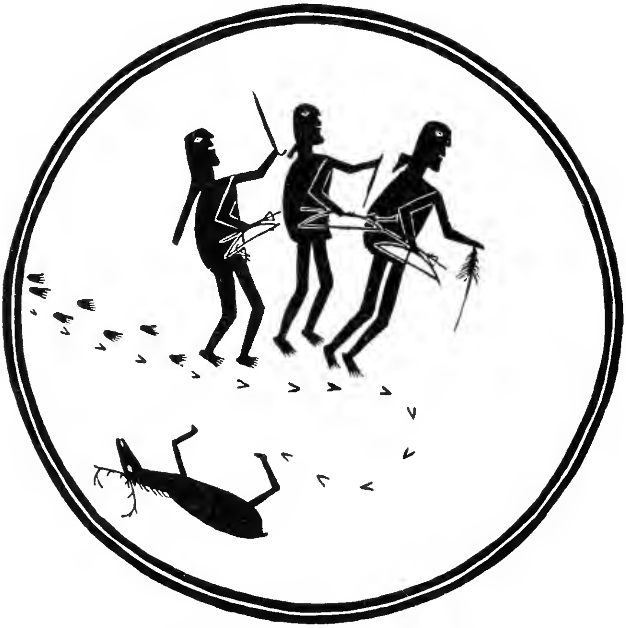


FIG. 13.—Hunters. Oldtown Ruin. (Osborn collection.)

GROUP OF HUNTERS

An instructive group of human figures is drawn on a deep red and white food bowl (fig. 13), which measures ten inches in diameter. It is evident that this design represents three hunters following the trail of a horned animal, probably a deer. This trail is represented on the surface of the bowl by a row of triangles, while the footprints of the hunters extend along its side. It may be noted that although there are three hunters, the trails of two only are represented, and that the hunters are barefoot. They have perhaps lost the trail and are looking the opposite way, while the animal has turned back on his path. The footprints of the deer in advance of the hunters are tortuous, showing want of decision on the part of the animal. The three hunters are dressed alike, wearing the close-fitting jacket probably made of strips of skin woven together like that found by Dr. Hough in a sacrificial cave at the head of the Tulerosa, New Mexico. Each carries a bow and arrow in his right hand, and in his left a stick which the leader uses as a cane; the second hunter holds it by one end before him, and the third raises it aloft. These objects are supposed to represent either weapons or certain problematic wooden staffs with feathers attached, like divining rods, by which the hunters are in a magical way directed in their search. The first hunter " feels " for the lost trail by means of this rod.

An examination of the pictures of the arrows these hunters carry shows that each has a triangular appendage at the end representing feathers, and small objects, also feathers, tied to its very extremity. The hair of the third hunter appears to be a single coil hanging down the back, but in the other two it is tied in a cue at the back of the head. The eyes are drawn like the eyes on Egyptian paintings, that is, the eye as it appears in a front view is shown on the side of the head. The right shoulders of all are thrown out of position, in this feature recalling primitive perspective. The information conveyed by this prehistoric picture conforms with what is known from historical sources that the Mimbres Valley formerly abounded in antelopes, and we have here a representation of an aboriginal hunt.

FIGURE OF A WOMAN

A black and white bowl (pl. 1, fig. 1) is twelve and one-half inches in diameter and six inches deep. Upon this bowl is drawn a figure of a human being, probably a woman or a girl, seen from the front. Although portions of the figure are not very legible, such details as can be made out show a person wearing a blanket that extends almost to the knees leaving arms and legs bare, the lower limbs being covered. The head is square, as if masked, with hair tied at each lower corner. Although these appendages may be meant to represent ear-pendants, it is more likely that they are whorls of hair, as is still customary in Pueblo ceremonies in personations of certain maidens. Across the forehead are alternating black and white square figures arranged in two series, recalling corn or rain-cloud symbols. The neck is adorned by several strands of necklaces, the outermost of which, almost effaced, suggests rectangular ornaments. The garment worn by the figure is evidently the ceremonial[1] blanket of a Pueblo woman, for no man wears this kind of garment. It has a white border and from its middle there hangs a number of parallel lines representing cords or a fringe, evidently the ends of a sash by which the blanket was formerly tied about the waist. It is instructive to notice that we find similar parallel lines represented in a picture of a girl from Sikyatki[2] where the blanket has the same rectangular form as in the prehistoric Mimbres picture. There can be no question that in this case it represents a garment bound with a girdle, or that the picture was intended for that of a girl or a woman. We have in this picture evidence that the same method of arranging the hair was used in the Mimbres Valley as in northern New Mexico. The leg wrappings suggest those used by Pueblo women, especially the Hopi, whose leggings are made of long strips of buckskin attached to the moccasins and wound around the lower limbs.

PRIEST SMOKING

The third human figure, found on a black and white bowl from a Mimbres ruin, is duplicated by another of the same general character depicted on the opposite side of the bowl. These figures (fig. 14) are evidently naked men with bands of white across the faces. The eyes are represented in the Egyptian fashion. In one hand each figure holds a tube, evidently a cloud-blower or a pipe, with feathers attached to one extremity, and in the other hand each carries a triangular object resembling a Hopi rattle or tinkler. The posture of these figures suggest sitting or squatting, but the objects in the extended left hand would indicate dancing. The figure is identified as a man performing a ceremonial smoke which accompanies ceremonial rites.

MAN WITH CURVED STICK

One of the most instructive food bowls found at Oldtown, now owned by Mr. Osborn, has on it a picture of two hunters, one on each side of an animal (fig. 15). One of these hunters carries in his hand a stick crooked at the end, its form suggesting a throwing stick.[3] Both hunters have laid aside their quivers, bows, and arrows, which are shown behind them. The picture of an animal between them has been so mutilated by "killing" or breaking the bowl that it is impos-

---

[1] Called also a "wedding blanket" since it is presented to a girl on marriage by her husband's family.

[2] 17th Ann. Rep. Bur. Amer. Ethnol., pl. 129, fig. *a*.

[3] The hand of the hunter pictured on a bowl already described (fig. 13), also carried a curved stick.

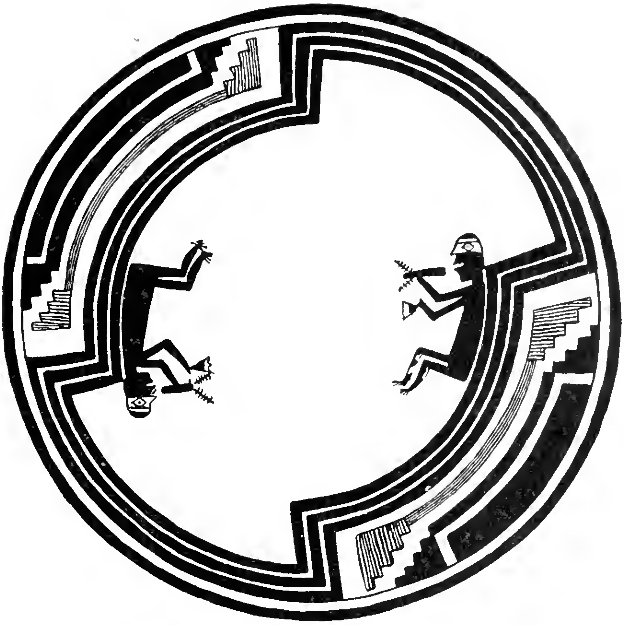


FIG. 14.—Priest smoking. Osborn Ruin.

FIG. 15.—Man with curved stick. Oldtown Ruin. (Osborn collection.) Diam. 5½″.

sible to identify it. From the end of this crook to the body of the animal there extend two parallel lines of dots indicating the pathway of a discharged weapon. Near the body of the animal these rows of dots take a new direction, as if the weapon had bounded away or changed its course. The rows of dots are supposed to represent lines of meal by which Pueblos are accustomed to symbolically indicate trails or " roads."

There is, of course, some doubt as to the correct identification of the crooked staff as a throwing stick, for as yet no throwing stick has been found in the Mimbres ruins. The resemblance of the crooked stick to those on certain Hopi altars and its resemblance to emblems of weapons carried by warrior societies is noteworthy. Crooked sticks of this character have been found in caves in the region north of the Mimbres.[1]

We find a survival of a similar crook used as sacred paraphernalia in several of the Hopi ceremonies, where they play an important rôle. As the author has pointed out, crooked sticks or gnelas (fig. 16) identified as ancient weapons surround the sand picture of the Antelope altar in the Snake Dance at Walpi, and in Snake altars of other Hopi pueblos, but it is in the Winter Solstice Ceremony, or the Soyaluña, at the East Mesa of the Hopi, that we find special prominence given to this warrior emblem. During this elaborate festival every Walpi and Sitcomovi kiva regards one of these gnelas as especially efficacious for the warriors, and it is installed in a prominent place on the kiva floor, as indicated in the author's account of that ceremony.[2]

The following explanation of these crooks was given him by the priests:

> These crooks or gnelas have been called warrior prayer sticks, and are symbols of ancient weapons. In many folk tales it is stated that warriors overcame their foes by the use of gnelas which would indicate that they had something to do with ancient war implements. Their association with arrows on the Antelope altars adds weight to this conclusion.

The picture from Oldtown ruin of the hunter who has laid aside the quiver, bow, and arrow, and is using a similar gnela,[3] corroborates this interpretation.

Not all crooked sticks used by the Hopi are prayer sticks, or weapons, for sometimes in Hopi ceremonials a number of small shells are

---

[1] Bull. 87, U. S. National Museum.

[2] The Winter Solstice Ceremony at Walpi. Amer. Anthrop., 1st ser., vol. 11, Nos. 3, 4, pp. 65-87, 101-115.

[3] An ancient crook found in a cave near Silver City is figured by Dr. Hough. Bull. 87, U. S. National Museum.

tied to the extremity of a crooked stick forming a kind of rattle. In the Flute Ceremony a crooked stick is said to be used to draw down the clouds when the rain they contain is much desired.

Figure 16 is a representation of one of the crooks which was specially made for use in the Soyaluña at Walpi, in 1900. Similar crooks were set upright in a low mound of sand on the floors of all the kivas. Extending from the base of the crook to the ladder there was sprinkled a line of meal called the road (of blessings), over which was stretched a feathered string attached to the end of the crook. Midway in the length of the crook was attached a packet of prayer meal wrapped in cornhusk and a feather of the hawk, a bird dear to warriors, and other objects, which indicated a prayer offering. At the termination of ceremonies in which these crooks are made and blessed as prayer emblems by the Hopi they are deposited in shrines as recorded.

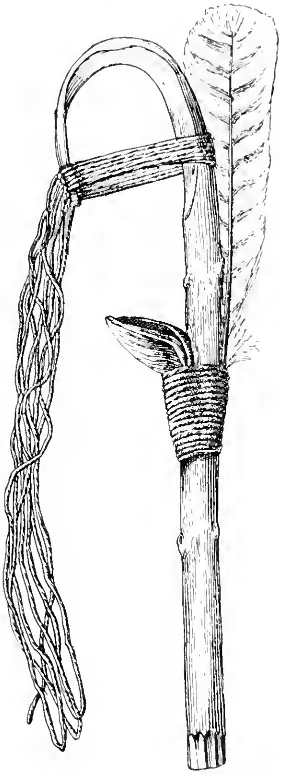


FIG. 16.—Hopi curved stick. Length 8″.

The crook (gnela) is used as a prayer emblem of warriors because it has the form of an ancient weapon, and while it assumes modifications in different Hopi ceremonies it apparently has one and the same intent, as in Soyaluña. This crook is sometimes interpreted as symbolically representing an old man with head bent over by age, but this interpretation is probably secondary to that suggested above, as so often happens in the interpretations given by primitive priests.

The true interpretation of the crooked prayer stick was pointed out by the author in his article on "Minor Hopi Festivals,"[1] as follows:

> This crook is believed by the author to be a diminutive representation of an implement akin to a throwing stick, the object of which is to increase the velocity of a shaft thrown in the air. Its prototype is repeatedly used in Hopi rites, and it occurs among Hopi paraphernalia always apparently with the same or nearly the same meaning.

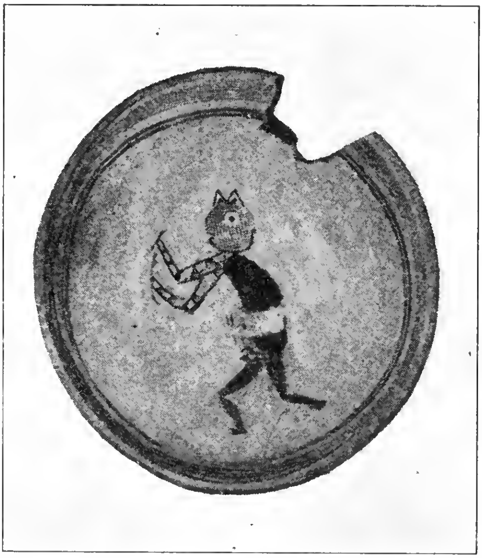


FIG. 17.—Human figure running. Oldtown Ruin. (Osborn collection.) Diam. 7½".

In figure 17 is represented a person running with outstretched banded arms, holding in the left hand a bow, and in the other a straight stick. The head is circular with cross lines, a round, dotted eye, and two triangular ears. Another representation shows a human figure with a bow and arrow before the hands, accompanied by three animals, the middle one being a bird and the two lateral, quadrupeds.

---

[1] Amer. Anthrop., n. s., vol. 4, p. 502.

By far the most unusual group of human forms consists of two figures, one male, the other female, depicted on another bowl. The action in which these two are engaged is evident. The female figure has dependent breasts and wears a girdle. One hand is raised and brought to the face and the other carries a triangular object. The female figure has three parallel marks on the cheek, like the Hopi war-god. Behind the woman are several curved lines depicting unidentified objects.

The figure shown on one bowl (fig. 18) has several marked features, but the author is unable to suggest any theory of identification. It seems to be a seated figure with a human head, arms, and legs, the toes and fingers being like hands and feet. The forearm is drawn on the shoulder in the same way as in the one of the hunters (fig. 13).

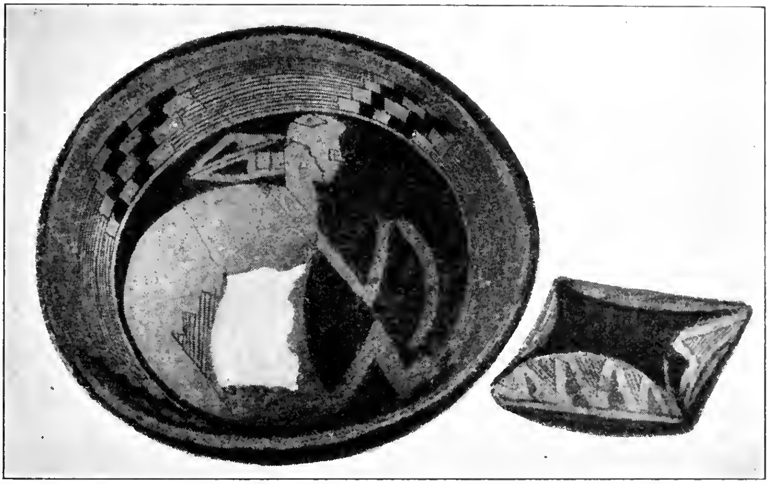


FIG. 18.—Unidentified animal and bowl of unusual form. Oldtown Ruin. (Osborn collection.)

The eye, nose, and mouth are also human, but the body is more like that of an animal. The appendages back of the head are similar to those interpreted as feathers on the heads of certain animal designs.

On the theory that this is a seated human figure it is interesting to speculate on the meaning of the curved object represented on the surface of the bowl, extending from one hand to the foot. This object has the general form of a rabbit stick or boomerang, still used by the Hopi in rabbit hunting.[1]

---

[1] Rabbits are abundant in the Mimbres Valley and several well-drawn pictures of this animal are found on the pottery.

The well-drawn figure painted on a bowl (pl. 1, fig. 2) from Oldtown ruin represents a man with knees extended and arms raised as if dancing. This picture has characteristic markings on the face, but otherwise is not distinctive.

QUADRUPEDS

Wolf.—Although there are not sufficiently characteristic features represented in the next figure (pl. 2, fig. 1)[1] to identify it satisfactorily, the form of the head, tail, mouth, and ears suggests a wolf.[2] The square design[3] covering one side of the body seems to the author not to belong to the animal itself, for an Indian who could represent an animal as faithfully as those here pictured would not place on it such markings unless for a purpose. It resembles the small blankets sometimes worn by pet dogs or horses among white people, which is a lame explanation, as dog and horse blankets were

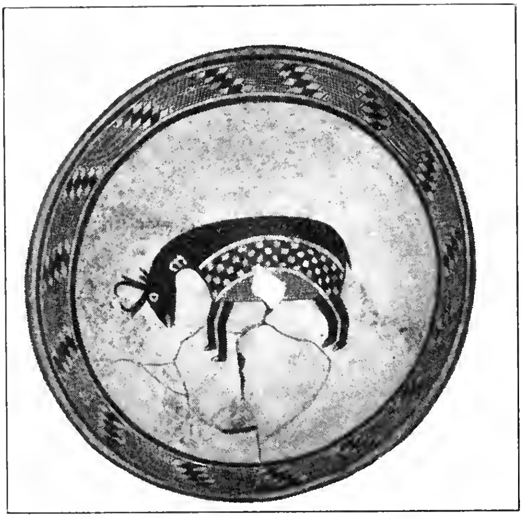


FIG. 19.—Antelope. (Osborn collection.) Diam. 10″.

---

[1] This picture resembles that of a wolf depicted on the east wall of the warrior chamber at Walpi. See Amer. Anthrop. n. s., vol. 4, pl. 22.

[2] Pictures of the mountain lion by Pueblo artists, at least among the Hopi, have the tail turned over the back. The animal on the Mimbres bowl having no horns is not a horned deer or antelope.

[3] The decoration of the bodies of animals with rectangular figures is a common feature in Mimbres pottery, as will be seen in pictures of birds soon to be considered.

unknown among Indians. The only theory the author has formed regarding this geometrical figure is that it is a variant of the Sikyatki habit of accompanying a figure of an animal with a representation of his shrine. This bowl is of black and white ware and is eleven inches in diameter by five and one-half inches deep.

Antelope.—There are two[1] figures of an animal with branching horns,[2] supposed to be an antelope, an animal formerly common in Mimbres Valley. In one of these (fig. 19) the head is held downward as if the animal were feeding; in the other (fig. 20) the neck is extended. A pair of markings on the neck are identical with those on pictures of the antelope still painted on modern pottery made by the Zuñi. A band, resembling a checkerboard, is drawn across the body of one; on the other are parallel lines.

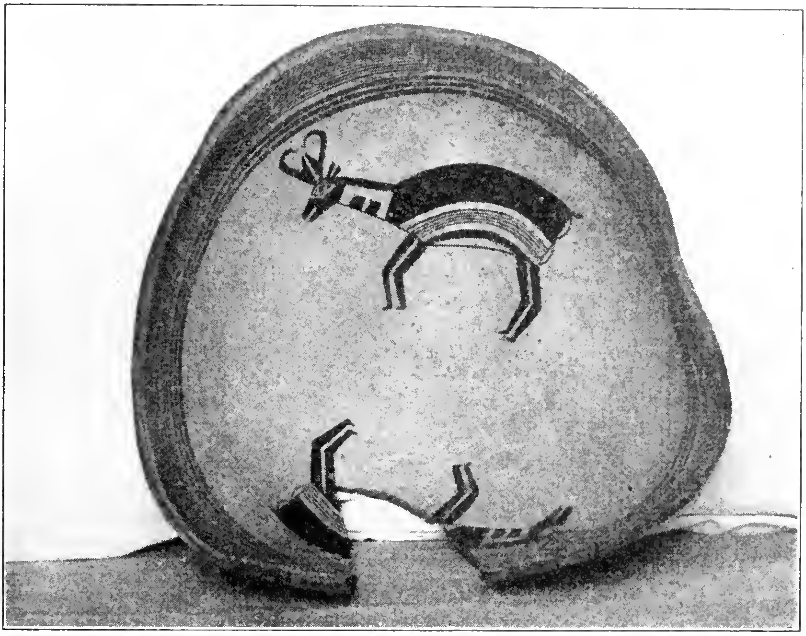


FIG. 20.—Antelope. Osborn Ruin. Diam. 10".

Another figure referred to as an antelope appears to represent a young fawn, since, while it has all the characteristics of this animal,

---

[1] In addition to the figure with the hunters which is probably a deer, as it has not the antelope marks on the neck.

[2] These horns are represented on a plane at right angles to that in which they naturally lie.

the horns are wanting. This specimen (fig. 21) was found at Oldtown. The rectangular shape so often given to the bodies of animals drawn on Mimbres pottery is well shown in this specimen.

Fig. 21.—Fawn. Oldtown Ruin.

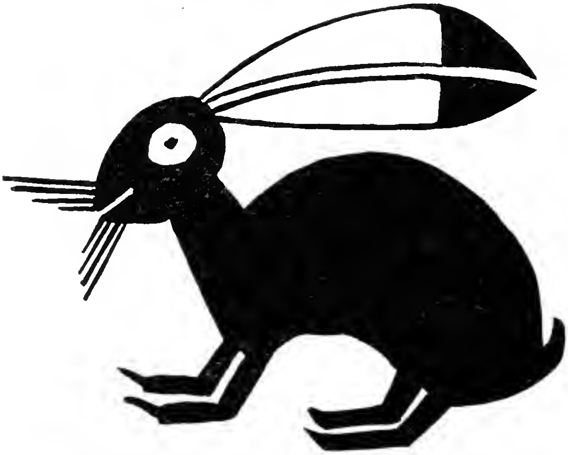


Fig. 22.—Rabbit. Oldtown Ruin. Diam. 7½".

Mountain Sheep.—It is evident from the form of the unbranched horns, the slender legs, and the head, that either a mountain sheep or mountain goat was intended to be represented in plate 2, figure 2.

The markings on the body are symbolic, suggesting lightning, and it may be added that the Hopi depict the lightning on the artificial horns mounted on caps and worn by them in presentations of dances in which they personate mountain sheep.

Rabbit or Hare.—The pictured representation (fig. 31) of a quadruped whose hindlegs are larger than the forelegs and whose long backward extending ears are prominent features, probably represents a rabbit or a hare. The eyes recall figures of birds depicted on bowls from the Little Colorado ruins in Arizona, where eyes are depicted on one side of the head in violation of a law of perspective in which only one eye can appear on a lateral view. The figure appears to have a tuft of grass in the mouth. The geometric markings on the body are different from those of any known species of rabbit and belong to the category of symbolic designs.

Fig. 23.—Mountain lion or wild cat.
(Osborn collection.)

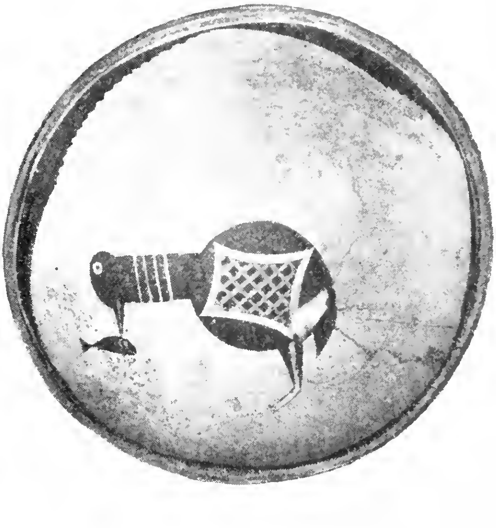


Fig. 25.—Bird E. Osborn Ruin.
(Osborn collection.)

The author excavated at Oldtown a food bowl, the figure on which was undoubtedly intended for a rabbit (fig. 22). The head, ears, body, legs, and tail are well made, leaving no question of the intention of the artist; but if there were any doubt of the identification it is dispelled by the representation of the mouth, on which the sensitive hairs or bristles are represented.

Mountain Lion.—One of the Oldtown bowls is decorated with a representation of the wild cat or mountain lion, and is a fair example of archaic design (fig. 23). The feature that distinguished this quadruped is the position of the tail which, like those of Pueblo pictures of mountain lions or cats, is bent forward over the back.

Both head and body are rectangular and the legs are short and stumpy with sharp curved claws. The ears, mouth, and teeth have characteristic features of carnivora and the tail is banded, especially near the end.

The geometric design on the side of the body consists of an angular, S-shaped design with two equal armed stars, the latter associated with the mountain lion in Pueblo symbolism. The single figure drawn on this bowl occupied the middle of the interior, but in the next bowl this figure is duplicated.

The two figures on another bowl also represent some cat, or mountain lion, but the geometric figure on its body differs so much from the first specimen that it may belong to a different genus. The geometrical designs occur on both the anterior and posterior extremities of the rectangular body and consist of triangular figures with parallel lines and terraces recalling rain-clouds. This bowl is owned by Mr. E. D. Osborn, and was found at Oldtown. The decorations on the two quadrants alternating with the animal figures are bands from which other markings radiate to the side of the bowl.

Badger.—The quadruped drawn on the inside of a bowl found at Oldtown, and now owned by Mr. E. D. Osborn, has some resemblances to a badger, especially in the head, ears, teeth, and tail. The geometrical design on the body of this animal consists of an unequal sided rectangle enclosing four triangles with angles so approximated as to form an enclosed rectangle. The head has two bands extending longitudinally, apparently conventionalized markings characteristic of this animal, as they do not occur on deer, wildcats, or mountain sheep.

Birds.—As has been pointed out in the author's identifications[1] of designs on Sikyatki pottery, those representing birds are among the most abundant. The same holds also in the pottery from the Mimbres, where several figures identified as birds occur on food bowls. Two of these are duplicated on the same vessel, practically the same figure being repeated on opposite sides. In the latter case each member of the pair faces in an opposite direction or is represented as if moving with the middle of the bowl on the left.[2]

---

[1] 17th Ann. Rep. Bur. Amer. Ethnol., p. 682.

[2] This is known as the sinistral circuit and is regarded as beneficial in Hopi ceremonials.

The various birds differ considerably in their forms, organs, attitudes, and appendages. Two of the pictures seem to represent the same bird, but the others belong to different genera. There are one or two figures in which feathers can be distinguished, but as a rule they are fewer in number and the feathers less conventionalized than in Sikyatki pottery.

Pending the difficulty in identifying the various designs representing birds, they are designated by letters A, B, C, D, etc.

Bird A.—The figure shown in plate 3, figure 1, is represented by two designs, practically the same, repeated so far as appendages go, but quite different in the ornamentation of their bodies. One of these has the same geometrical figure on its body as on one of the quadruped pictures, the second has a different design. Both birds have wings outspread as if in flight, in which the feathers are well drawn in detail, especially the wing on the side turned toward the observer. That on the opposite side is simply uniformly black. The feathers of its companion on the other side of the bowl are indicated by parallel lines. The tail is long and forked at the extremity, suggesting a hawk, and is decorated for two-thirds of its length with cross-hatched and parallel lines. A triangular appendage arises from the under side of the tail at the point where the line decoration ends, forming an appendage which is likewise represented in the companion picture.

Bird B.—Bird B (pl. 3, fig. 2) is painted on the interior of a food bowl of black and white ware, ten inches in diameter by five inches deep. Its body is oval, the head erect and undecorated, and the tail twisted from a horizontal into a vertical plane as is customary in representation of lateral views of birds from Pueblo ruins. The geometric figure on the body is unfortunately somewhat obscured by the plaster used in mending, but several parallel bars that may represent feathers of the wings show through it, and a number of other designs or parallel lines are apparent. An appendage of triangular form hangs from the lower margin of the body and indicates the position of one leg; the other leg is missing.

Bird C.—Bird C, shown in plate 4, figure 1, occurs on a black and white bowl that measures ten inches in diameter, five and one-half inches in depth. The figure occupies the circular zone in the middle of the bowl and is enclosed by parallel lines which surround the bowl near the rim. The top of the head, which is globular, is white in color, the beak projecting and the eyes comparatively large. The body is likewise globular and is covered by a square geometrical design the details of which are considerably obscured by the hole in the middle of the jar. A number of parallel lines of unequal length, turned downward, hang from the rear of the body and form the tail. The long legs suggest a wading bird, and the widely extended claws point to the same identification.

Bird D.—One of the most instructive figures of birds occurs on a bowl from Oldtown ruin. This bowl (fig. 24) is now owned by Mr. E. D. Osborn, by whom it was found. The bird depicted on it is seen from the back; its wings are drooping, and parallel lines indicate feathers. The legs, drawn backward, terminate in three toes, and the tail, slightly bent to one side, is composed of several feathers.

Fig. 24.—Bird D.
(Osborn collection.)

Fig. 29.—Unidentified animal. Oldtown Ruin.
(Osborn collection.)

The head is globular with two eyes on the back and a short pointed beak. As in all other zoic figures the geometric figures on the back of the body are the most characteristic. The middle of the body is occupied by an oval design through which may be seen the perforation with which the bowl was killed. At one end there is a triangular design with cross lines which extend partly over the oval figure where, except at one point, they are obscure.

Four quadrilateral designs are distributed at intervals around the oval figure. Each of these has sides of about equal length and a dot medially placed in a smaller figure contained in a larger.

Bird E.—The bird shown in figure 25 (p. 35) from the Osborn ruin has a body form not unlike that of plate 4, figure 1, but the geometric design on the body, although rectangular, has incurved sides and is covered with cross lines suggesting a net. Its neck is girt by four rings, head small, without feathers, eye minute, bill comparatively long and pointed recalling that of a snipe which is also suggested by long legs and in a measure by the form of the tail.

This bird is undoubtedly aquatic, as indicated by the figure of a fish which it appears to be on the point of capturing or devouring.

Bird F.—The bird shown in plate 4, figure 2, is different from any of the above and is distinguished readily by the four curved lines on the head suggesting the quail. The pointed tail is marked above and below with dentations, formed by a series of rectangular figures which diminish in size from body attachment to tip. The body itself is marked posteriorly with parallel lines, rectangular and curved figures suggesting wings.

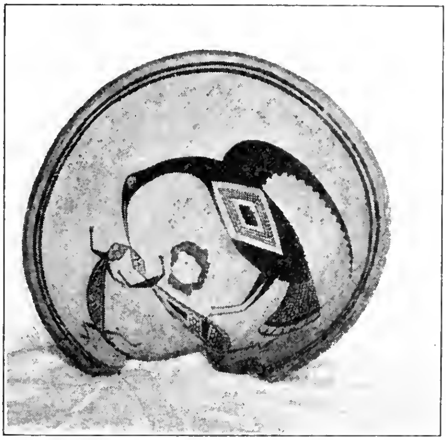


FIG. 26.—Bird G. Oldtown Ruin. (Osborn collection.) Diam. 10″.

The bowl (fig. 26) has three animals figured upon it forming a graceful combination. The most striking represents a long-billed bird with one wing notched on the inner margin. The tail of this bird is differently drawn from any of the other birds in the collection and has representations of six feathers. In front of this bird, with the point of the snout at the tip of the bill of the bird, is a lizard-shaped head covered with scales and two round eyes. The other remarkable figure also has extended forelegs, but the body is so broken that identification is quite impossible. Like the figure of the lizard, it also has a lozenge head and two eyes. The geometrical designs on the body are characteristic.

ANIMALS NOT IDENTIFIED

Unidentified Animal.—It is difficult to tell exactly what animal was intended to be represented by that shown in plate 5, figure 2. Its head and mouth are not those of any of the horned animals already considered, although it has some anatomical features recalling a mountain sheep. The extension back of the body has a remote likeness to a fish, but may be a bird or simply a conventional design. The geometrical figure covering the side of the body bears some likeness to one depicted on a bird, as shown in plate 3, figure 1. The same geometrical figure sometimes also occurs separated from any animal form in Sikyatki pottery.[1]

The bowl is ten inches in diameter, five inches in depth, and the figures are painted red on a white ground.

Unidentified Animal.—One of the most remarkable of many figures on bowls from Oldtown in the collection of Mr. E. D. Osborn is shown in figures 27, 29 (p. 38). Three colors enter into the decoration of this bowl, black, white, and brown, and there are two types of ornamentation, one zoic, the other geometric. The bowl itself was much broken when found, but not so mutilated as to hide the main designs.

The zoic figures represent animals with square bodies, four legs, ears, head, and tail like a young antelope. There is no design on the side of the body, but in its place four broad parallel bands extend from the belly across the bowl. Each group of parallel lines changes its direction, widening in their course or near the ends where they enlarge for the accompanying figure. The markings on the necks of these figures suggest those on fawns.

The elaborate geometric figure composed of a scroll and comma-like dot and eye is a highly conventionalized symbol, possibly of some animal, as a bird's head, common on Casas Grandes pottery.

There is a bowl on exhibition in the Chamber of Commerce at Deming with a picture of a quadruped resembling a deer, but the base is so fractured in killing that it is difficult to determine the shape of the body or its decoration.

Unidentified Animal.—One of the most instructive figures of the collection appears in duplicate on a large food bowl (pl. 5, fig. 1). This vessel is black and white in color and measures fifteen inches in

---

[1] 17th Ann. Rep. Bur. Amer. Ethnol., pls. 121*a*, 138*c*. There are one or two examples of Sikyatki pottery where a geometrical design is attached to an animal figure which leads to the belief that possibly the figure attached to the rear of the above may not represent a part of another animal but rather a geometrical design of unknown significance, in this particular recalling old time Hopi ware.

diameter by six inches deep. The two designs occur on the two sides of the interior of the bowl, the middle of which is left without decoration.

The body of this creature is elongated and tapers backward, being continued into a tail like that of the lizard. The head is long and the snout pointed. Only two legs are represented, and these are situated far back on the body near the point of the origin of the tail from the body. A lozenge-shaped symbol forms the geometrical design on the side.

FIG. 27.—Unidentified animal. Oldtown Ruin. (Osborn collection.)

The presence of only two legs in this figure would seem to indicate that a bird was intended, but no bird has a tail like this figure; and the prehistoric potters of the Mimbres certainly knew how to draw a bird much better than this would imply. The exceptional features of this drawing, doubtless intentional, belong neither to flesh, fish, nor fowl, rendering its identification doubtful.

GRASSHOPPER[1]

A figure on a bowl here represented (pl. 6, fig. 1) is painted in "black or brown on a background of bluish wash over a yellow color."

---

[1] This figure may also be identified as a locust.

This bowl is eleven inches in diameter, five inches in depth. The figure is a remarkable one, having features of several animals, but none of these are more pronounced than its insectiform characters, among which may be mentioned the antennæ, three legs on one side (evidently three pairs of legs, for that in the back is simply introduced in violation of perspective), and an extended segmented abdomen attached to the thorax and terminating in a recurved tip. The character of the appendages to the thorax, or the wings, leaves no doubt that a flying animal was intended, and the legs and head being like an orthopterous insect, it may be provisionally identified as a "grasshopper."[1]

While the general form of head, thorax, and body appear from an inspection of the figure, it may be well to call attention to certain special features that illustrate primitive methods of drawing. The most striking of these is seen in the abnormal position of the leg which arises from the thorax on the back in the rear of the so-called wings. This abnormal position was introduced by the artist to show the existence and form of the legs on the right side; the appendage corresponds with one of the three on the left side, which have the proper position but are much smaller. A similar delineation of organs out of place not seen or turned away from the observer was common among the prehistoric artists of the Pueblo region and is paralleled by the representation of two eyes on one side of the head already mentioned. The two "wings," each ending in white circles with dots or crosses, are supposed, on the theory that this is a grasshopper, to represent wing covers or elytra, which of course the prehistoric people of the Mimbres did not differentiate from folded wings. It is possible that wing cover and wing may be represented on one side and that corresponding organs on the right side of the body are omitted. The thorax is covered with regularly arranged rows of dots formed by parallel lines crossing at an angle, forming purely arbitrary decoration representing the geometric designs on the bodies of other animals.

FROGS AND BIRDS

One of the few bowls obtained on which animals of two species were depicted on the same vessel was excavated by the author at Oldtown. This remarkably fine specimen (pl. 7, fig. 1) has figures of

---

[1] Possibly depicted on a food bowl because grasshoppers were eaten by the prehistoric people of the Mimbres.

two birds and two frogs[1] drawn in opposite quadrants, being unique in this particular. The two birds and frogs are not very unlike those already described but have certain characteristic features, especially in the geometric designs on their bodies.

The bowl is warped into an irregular shape and made of thin ware, probably distorted in firing. It was found under the floor of one of the central rooms in the Oldtown ruin, almost completely covering the skeleton of a baby.

On another bowl (pl. 6, fig. 2) there is depicted a frog very like that last mentioned. The frog being an amphibian was undoubtedly greatly reverenced by the ancient people of the Mimbres Valley.

HORNED SNAKE

The serpent with a horn on the head is pretty generally regarded as a supernatural being, and its pictures and effigies occur on modern Hopi, Zuñi, and other Pueblo paraphernalia. It is an ancient conception, for it is figured on prehistoric pottery from all parts of the Pueblo area, having been found as far south as Casas Grandes in Chihuahua. It is to be expected that a people like the ancient Mimbreños who adorned their pottery with so many well drawn zoic figures would have included the horned serpent, provided this reptile was a member of their pantheon. The nearest approach to a figure of such a monster is found on a large pottery fragment found by Mr. Osborn twelve miles south of Deming. This fragment covered the cranium of a skeleton and was perforated or "killed" like a whole bowl.

A very large number of pictures of the horned snake from localities all over the Southwest might be mentioned, but a few examples are adequate to show how widespread the conception was in ancient times. They occur among the Tewa, Keres, Zuñi, Hopi and other Pueblos and vary greatly in details, but in all instances preserve the essential symbolic feature—a horn on the head and a serpentine body.

The horned serpent is known to the Hopi as the plumed serpent, and when represented by them has a bundle of hawk feathers as well as a horn attached to the head. Effigies of this being, also with horn

---

[1] A picture of a horned toad on a food bowl was recorded from Cook's Peak by Professor Webster, and there is a picture of what appears to be the same reptile in Mr. Osborn's collection. It is of course sometimes difficult to positively distinguish representations of frogs, toads, lizards, and Gila monsters, but the anatomical features are often well indicated.

and feathers, are used in several ceremonies, as the Winter Solstice,[1] and a dramatic festival[2] which occurs yearly in March. Wooden representations of the same horned snake are carried as insignia by a warrior society called the Kwakwantu,[3] in the New Fire Ceremony. The priests of the Tewan pueblo, Hano, among the Hopi also have effigies of the horned snake, the worship of which their ancestors brought to Arizona from New Mexico. These effigies are yearly made of clay and form conspicuous objects on the December altars of that pueblo.

FIG. 28.—Serpent. Osborn Ruin. (Osborn collection. E. D. O. Jr. del.)

The head shown in figure 28 has a horn curving forward almost identical with that on the head of a horned serpent on a bowl from Casas Grandes in the Heye collection. Its gracefully sinuous body is decorated with alternating geometric figures, curves and

---

[1] The Winter Solstice Ceremony. Amer. Anthrop., 1st ser., vol. 11, Nos. 3, 4, pp. 65-87, 101-115.

[2] A Theatrical Performance at Walpi. Proc. Washington Acad. Sci. vol. 2, pp. 605-629. Native pictures of the Hopi horned snake may be found, pl. 26, 21st Ann. Rep. Bur. Amer. Ethnol.

[3] The horned serpent cult at Walpi is said to have been introduced from the south.

straight lines.[1] Accompanying the figure of a serpent is a well-drawn picture of a turtle which is decorated on the carapace with a rectangular area on which is painted a geometric figure recalling that on bodies of birds and some other animals.

FISHES

One of the bowls (fig. 30) from the Oldtown ruin has two fishes depicted on opposite sides of the inner surface. These fishes resemble trout and are of different colors, black and reddish brown figures painted on a white ground. They are represented as hanging from two parallel lines surrounding the rim of the bowl. These fishes are so well drawn that there is no doubt what animal was intended to be here represented. On the interior of another bowl excavated by the author at Oldtown there is a picture of a fish which recalls the two

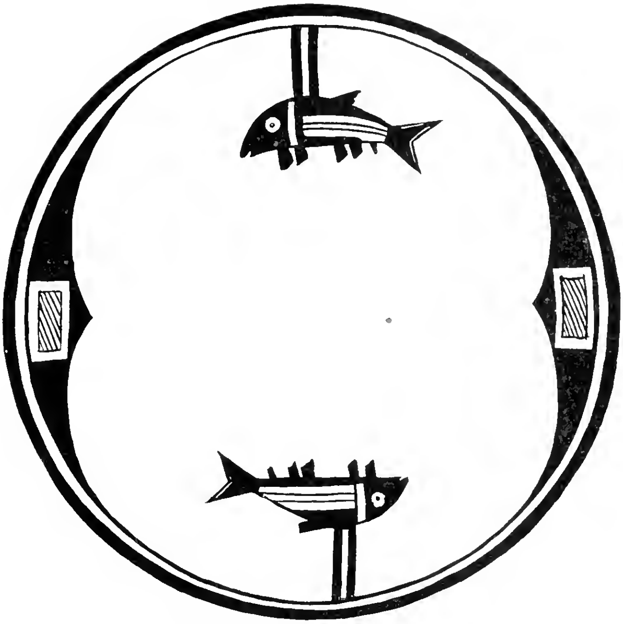


FIG. 30.—Fish. Oldtown Ruin. Diam. 9".

---

[1] Of all the designs representing the horned snake known to the author this picture from the Mimbres resembles most closely the pictures of this being on pottery from Casas Grandes. It has, however, the single horn found on the clay image in the Hano altar of the Winter Solstice Ceremony, although quite unlike figures on pottery from the Pajarito region. The bodily decorations in the Mimbres bowl are unlike those of the Hopi horned snake.

just mentioned.[1] It may be mentioned that fishes are not represented in the beautiful specimens of pottery from Sikyatki,[2] possibly for the simple reason that there are no streams containing fish in the neighborhood of Hopi ruins. In the Mimbres, however, fish are still found and were no doubt formerly abundant and well known to the prehistoric inhabitants,[3] being looked upon by them as water symbols in much the same way as the frog is at present regarded by Zuñi and Hopi.

Another fish figured on a bowl from Oldtown, is unfortunately broken near the tail. The accompanying decoration has apparently another figure behind this fish, but its complete form is obscured by the perforation made in killing the vessel.

The most problematical of all the life figures on the Mimbres pottery is shown in plate 7, figure 2. This figure occurs on a black and white food bowl, eleven inches in diameter, four and one-half inches in depth. In support of the theory that the two figures here depicted represent fishes, we have the pointed head without neck, the operculum as a white crescentic design, two fins (pectoral ventral, and anal), the median (adipose?) dorsal fin unpaired, and a long tail bifurcated at the extremity. The resemblance of these figures to the undoubted fishes on bowls previously mentioned is conclusive evidence that they represent the same animal.

GEOMETRICAL FIGURES

The geometrical designs on Mimbres pottery are rectangular, curved, and spiral, the first form being the most common. These units are arranged in twos or fours, and although they consist often of zigzag or stepped figures, the triangle and rectangle predominate. The geometrical designs are rarely colored, but commonly filled in with hachures and parallel lines. There are seldom decorations on the outside of the Mimbres bowls, in which respect they differ from ancient Hopi (Sikyatki) vessels elsewhere figured.[4] Conversely, that part of the interior of the bowl which surrounds the central design, oftentimes elaborately ornamented in Mimbres pottery, is very simply

---

[1] The Mimbres formerly had many more fishes than at present, and Bartlett records that his men often brought in fine trout for his camp. These, with turkeys, quail, deer and antelopes, led him to say that his "fare might be called sumptuous in some respects" (*op. cit.*, p. 236).

[2] Fishes are sometimes represented on Keresan pottery.

[3] As elsewhere mentioned in this paper, one of the bird figures (fig. 25) has a fish in its mouth.

[4] 17th Ann. Rep. Bur. Amer. Ethnol., Part 2, figs. 277-355.

decorated in Sikyatki pottery. Encircling lines on Mimbres pottery are continuous, whereas at Sikyatki they are broken at one or more points by intervals known as the "life gateways" or "lines of life."[1] The geometrical figures on the inside of every bowl sometimes surround a central region on which no figures of animals or human beings are drawn, but which is perforated.

The more strikingly characteristic forms of geometrical figures are shown in designs on plate 8. Certain of the geometrical figures drawn on the sides of animals as on the wolf (pl. 2, fig. 1), the antelope (figs. 19 and 20), the mountain sheep (pl. 2, fig. 2), the unidentified animal and bird (figs. 18 and 25), the reptile (fig. 28), also appear without the animals and probably have the same significance[2] in both instances.

Fig. 31.—Rabbit and geometrical designs.

No geometrical figures were identified as representing sun, moon, earth, or rain-clouds. A few crosses, circles, triangles, and irregular quadrilateral designs combined with zigzag stepped figures and interlocked spirals and highly interesting swastikas (fig. 31) form the

---

[1] Ceremonially, every piece of pottery is supposed by the Hopi to be a living being, and when placed in the grave of the owner, it was broken or killed to let the spirit escape to join the spirit of the dead in its future home. There is no evidence that the Sikyatki mortuary pottery was purposely broken when deposited in the grave, and probably no need of perforating it to allow free exit of the spirit, for the broken encircling line, "life gateway," absent in Mimbres pottery, but almost universally present in ancient Hopi pottery, answered the same purpose, in their conception.

[2] Following Hopi analogies, where these geometrical figures frequently occur with animals they may have the same symbolic meaning as when alone, and represent shrines or prayer-offering houses.

majority of the designs.[1] Several geometric designs, as those on the bodies of figures 25 and 26, appear on Sikyatki pottery (see 17th Ann. Rep. Bur. Amer. Ethnol., plate 121); others resemble Pueblo symbols of wide distribution, but the majority are unique. The geometric designs on the bodies of life-figures vary with the animal depicted, but the same genus of animals does not always have the geometric figure, although almost identical designs occur on the bodies of different genera. It is recognized that a comparison of designs on Southwestern pottery shows a general uniformity in geometrical pattern which renders it very difficult to distinguish different local areas of development, and may be the result of more extensive interchange of ideas and a greater uniformity of cultural conditions. The pottery of the Mimbres shares with the rest of the Southwest several well-known geometrical designs which no doubt date back to an earlier epoch than the evolution of animal figures, but it also has several decorations of geometrical patterns (fig. 32) that are peculiar to it and which, taken with the characteristic zoic figures, serve to differentiate it from other local areas. Mimbres pottery as pointed out by others has a general likeness to that from Casas Grandes Valley in Chihuahua, a resemblance which no doubt increases as we follow the river to Lakes Palomas and Guzman.[2] The resemblance is not close

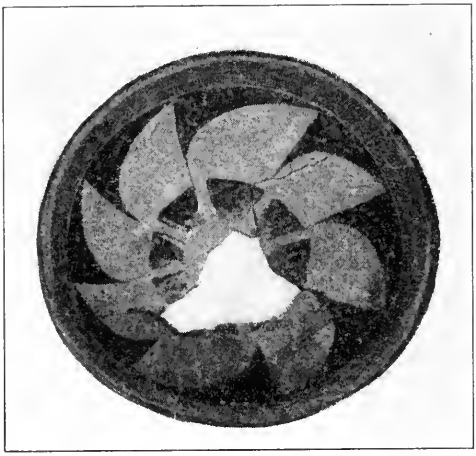


FIG. 32.—Geometrical figure. (Osborn collection.)

---

[1] Unfortunately there are few decorated vases represented in the collection, but exploration in the field may later bring many of these to light.

[2] The author brought to Washington fragments of a food bowl from the ruin near Byron Ranch, identical with Casas Grandes ware.

enough to indicate identity, but we have enough material to support the belief that the archeological area in which it occurs is Mexican, unlike that of any other ceramic area in Arizona or New Mexico. Here a specialized symbolism has been developed which is different from that of the Rio Grande, or the Upper Gila-Salt area, and that characteristic of the great Lower Gila in which lie the compounds like Casa Grande. The Mimbres Valley archeologically is the northern extension of a culture area which reached its highest development on Casas Grandes River.

CONCLUSIONS

Geographically the Mimbres Valley is the northern extension of the drainage area of the large interior plateau, the lowest level of which is occupied by Palomas, Guzman, and other so-called lakes. The Casas Grandes, Mimbres, and other rivers contribute their scanty waters to these lakes, which have no outlets into the sea. As a rule the thirsty sands along the course of the river drink up the surplus waters of the Mimbres or cause them to sink beneath the surface, to reappear when the configuration of lower clay or rock formations forces them from subterranean courses. Considering the similarity in climatic and geographical conditions in the northern and southern ends of this plateau, we would expect to find cultural likenesses in the prehistoric inhabitants of the Mimbres and Casas Grandes valleys, but such is not the case. The absence of relief decoration combined with painting, so common in the pottery from the Casas Grandes region, separates the Mimbres ware from that found far to the south.[1]

There are evidences that the course of the Mimbres River through Antelope Plain has from time to time changed considerably, and although a section of its bed now lies east of the Florida Mountains, the river probably formerly made its way to the west of the same in its course to Mexico. Modifications or changes in the bed of this river have had in the past much to do with the shifting of population and obliteration of prehistoric sites, either by washing them away entirely or burying them out of sight or deeply below the surface. This concealment of evidences of prehistoric occupancy has also been aided by frequent sandstorms, when considerable quantities of soil have been transported from place to place and deposited on walls or covered implements lying on the surface of the ground. It is also

---

[1] We must look to renewed explorations to shed light on this and many other questions which the paucity of material is yet insufficient to answer.

possible that there has been a slow change of climate, causing a desiccation which may have been so widespread that the inhabitants of the plain were driven up river into the hills where water was more abundant, but it is well to remember that abandoned settlements or ruins exist on the banks of the Mimbres where there is still abundant water, as well as in the plain which is dry.

The depth of the present water level, as shown by drilling for wells, varies in different places in the valley, but in the neighborhood of the hills there are many springs. The configuration of the surface of the hard clay strata lying beneath the soil here and there often forces the water to rise to the surface, and ruins occur at points where at present there are no signs of surface water, although at the time they were inhabited there may have been more water.[1] Whether or not this water was brought to certain ruins by a system of artificial irrigation, the canals of which have been obliterated, we cannot say, but there is only scanty evidence that the climate here, as elsewhere, has radically changed since man occupied the valley.[2]

Although there is a remote likeness between the terraced house or pueblo community of northern New Mexico[3] and the prehistoric houses of the Lower Mimbres, its closest resemblance is to an antecedent type, for it is possible that the terraced pueblo culture in the Rio Grande Valley was preceded by another. This earlier type of habitation of the Mimbres Valley was like the fragile-walled house of the natives inhabiting a large part of Arizona and New Mexico before the Puebloan, and we have evidence that this older style of building was scattered over the present Pueblo area. There is no evidence of a terraced dwelling or pueblo more than one story high

---

[1] In dry seasons the river flows under the superficial soil at a varying depth, but in floods it follows the surface bed.

[2] As the author has pointed out in several articles, the abandonment of Southwestern ruins is due to a variety of causes, chief of which are changes of climate. It is often due to other more local causes, as attacks by hostiles, salinity of soil, poor site for defence, presence of wizards, contagious diseases, etc.

[3] The designation "pueblo ruins" sometimes applied to any cluster of ancient house walls in Colorado, Utah, New Mexico, and Arizona, should be restricted to a well-defined architectural type which originated and reached its highest development in a small area in New Mexico. It was eventually carried by colonists in all directions from the center of origin, becoming intrusive as far west as the Hopi, Zuñi, and Little Colorado. The boundaries of this type never extended into Mexico in prehistoric times. The ruins along the Mimbres are not community houses of terraced character and should not be called pueblo ruins.

in the Mimbres or the inland basin in which it lies. In other words the ruins of the Mimbres may be regarded as older than true pueblo ruins, resembling an earlier type of dwelling that antedated, in the Rio Grande Valley, the terraced houses.

The author does not find any architectural features in the remains of the prehistoric habitations of the Mimbres Valley suggesting Casa Grande compounds, or those massive buildings with encircling walls which are characteristic of the plains of the Gila. Although the walls of the Casas Grandes, in Chihuahua, are constructed in the same way and out of material like those of Casa Grande on the Gila, the architectural feature, an encircling wall of the latter, has not yet been recognized on the Sierra Madre plateau.[1] Objects found in the Gila ruins are somewhat different in form from those of Chihuahua, while pottery from the Gila Valley ruins and that from the inland plateau in northern Chihuahua is markedly different, with very divergent symbolism. Not only do forms of stone implements of a shape unknown in southern Arizona occur in southern New Mexico, but also the methods of disposal of the dead differed among the two people. The latter practised inhumation only, the other both cremation and inhumation. The aborigines of the Mimbres Valley placed a bowl over the head or face of the dead, a practice which, so far as known, does not appear to have been so commonly in vogue in inhumation of the prehistoric people of the Lower Gila plains.

The conventional geometric symbols on prehistoric Mimbres pottery are readily distinguished from those on ware from Tulerosa, a tributary of the San Francisco. The most significant feature of the Mimbres pottery is that fifty per cent of the figures on it represent men or animals, while out of a hundred bowls from the Gila not more than two or three are ornamented with zoic designs. As we know comparatively nothing of the pottery of the sources of the Upper Gila and that part of its course which lies between the Tulerosa and the Mimbres, we can at present venture very little information on ceramic relations, but similarities or mixtures would naturally be expected, due to contact or overlapping, the type of the one valley overlaying that of the other or mingling with it.

The sources of the Upper Salt, the largest tributary of the Gila, lie far from the Mimbres, and close relationship in the pottery of the

---

[1] This statement is made with reservation, as the true architectural form of the Casas Grandes of Chihuahua is not yet known. The published plans show no encircling wall like that of Casa Grande on the Gila; probably the Casas Grandes of Chihuahua belong to a highly specialized type different from others.

ancient people inhabiting its banks is not found or expected. It is not known whether the pottery from the Upper Salt and that from the Upper Gila is similar, for our museums have no extensive collections from the latter region from which to make comparisons and draw conclusions. We know practically nothing of the prehistoric culture of the Upper Gila.

The aborigines of the Mimbres, like those of some of the former dwellers in Pajarito Park in New Mexico, practised a modified form of urn burial, but the latter rarely decorated their pottery with figures of animals. As compared with known Pueblo ceramics, the Mimbres pottery appears to be more closely allied to ancient Keresan than to old Tewan. Judging from what remains, the houses architecturally had little in common with true pueblos.[1] There are no evidences of circular subterranean kivas with pilasters, ventilators, deflectors, and niches, as in northern New Mexico, although there is a fairly large proportion of subterranean rooms or pit dwellings which may have been their prototypes. Architecturally the prehistoric habitations of the Mimbres Valley represent an old house form widely distributed in the Pueblo region or that antedating the pueblo or terraced-house type before the kiva had developed.

There are not sufficient data at hand to determine satisfactorily the kinship of the prehistoric inhabitants of Mimbres Valley, but as far as may be judged by pottery symbols it may be supposed that their culture resembled that of other sedentary people of New Mexico and Arizona in early times, as well as that of peoples of Chihuahua. It appears to the author that there are so many cultural similarities among the sedentary people which inhabited the Sierra Madre plateau, of which the Antelope Plain of Mimbres Valley is only a northern extension, that we may regard their culture as closely related. A specialized high development of this inland culture took place along the Casas Grandes River, culminating in Chihuahua. The Mimbres Valley was inhabited by people somewhat less developed in culture.

Although the ancients of the Mimbres were related on the one side to the Pueblos of New Mexico and on the other to more southern people, that relationship existed between the ancestors of the same rather than with modern Pueblos, and reached back to a time before

---

[1] While neither the terraced nor the "compound" type of architecture has been seen in the Mimbres for the reason that both were specialized in their distinct geographical areas, the fragile-walled, jacal type of habitation is identical in form, though not in time, in all three localities.

the terraced communal house type originated. This type of house arose in northern New Mexico and spreading from this center extended down the San Juan as far as the Hopi, while modifications are also found in certain ruins on the Gila and Little Colorado, which, like Zuñi, it profoundly influenced, but its influence never reached as far as the Lower Mimbres.

A comparison of the limited archeological material from the Mimbres with that from other localities in the Southwest suggests a provisional hypothesis that the prehistoric culture of this valley was not modified by terraced architecture nor greatly affected by that of the Lower Gila type, both of which evolved independently and locally, but belonged to an older type with which it had much in common.

1

2

FIG. 1.—WOMAN DANCER. BLACK AND WHITE WARE. 12 BY 6 INCHES. OSBORN RUIN
FIG. 2.—DANCING FIGURE. RED DECORATION. DIAMETER 5 INCHES. OSBORN RUIN

FIG. 1. TWO WOLVES. BLACK AND WHITE WARE. 11 BY 5½ INCHES. OSBORN RUIN

FIG. 2. MOUNTAIN SHEEP BLACK AND WHITE WARE. 11 BY 5½ INCHES. OSBORN RUIN

1

2

FIG. 1.—BIRD A. RED AND WHITE WARE. 9 BY 4 INCHES. OSBORN RUIN

FIG. 2.—BIRD B. BLACK AND WHITE WARE. 10 BY 5 INCHES. OSBORN RUIN

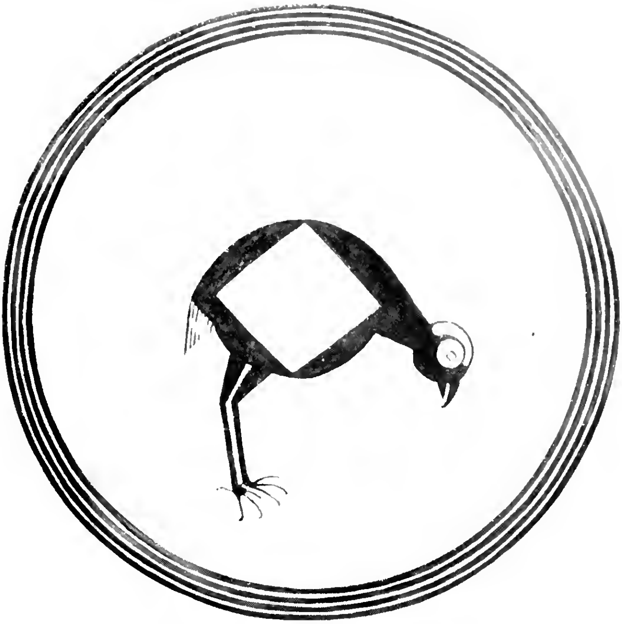


FIG. 1. BIRD C. BLACK AND WHITE WARE. 10 BY 5½ INCHES. OSBORN RUIN

FIG. 2. BIRD F RED AND WHITE WARE. DIAMETER 8 INCHES OSBORN RUIN

1

2

FIG. 1.—PROBLEMATICAL ANIMAL. BLACK AND WHITE WARE. 15 BY 6 INCHES. OSBORN RUIN

FIG. 2.—PROBLEMATICAL ANIMAL. RED DECORATION. OSBORN RUIN

1

2

FIG. 1.—GRASSHOPPER. RED FIGURE. DIAMETER 5 INCHES. OSBORN RUIN
FIG. 2.—FROG. DIAMETER 10 INCHES. OSBORN RUIN

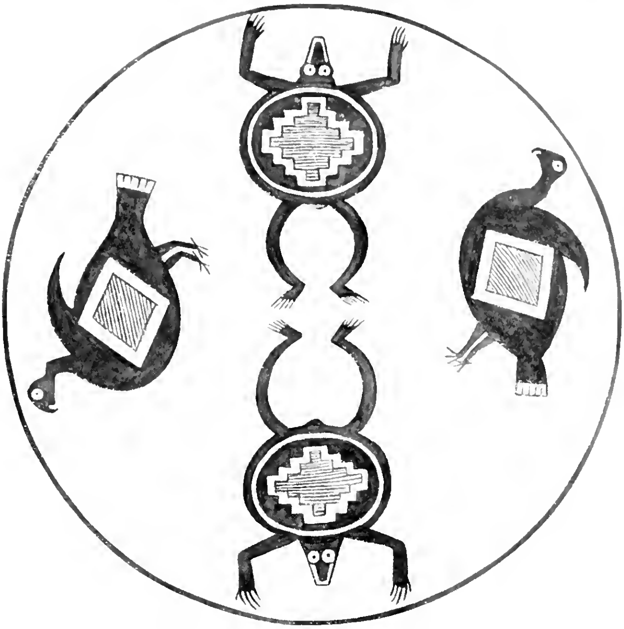
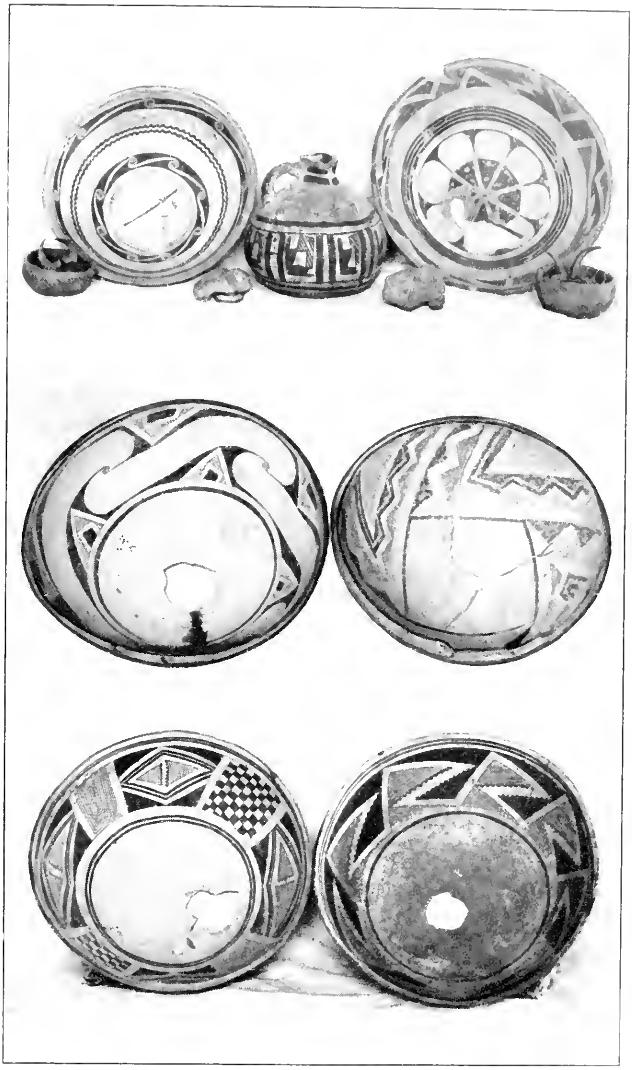


FIG 1. FROGS AND BIRDS. BLACK AND WHITE WARE. DIAMETER ABOUT 12 INCHES
OLDTOWN RUIN

FIG. 2. FISHES. BLACK AND WHITE WARE. 11 BY $4\frac{1}{2}$ INCHES



GEOMETRICAL DESIGNS. DIAMETER 1/7 NATURAL SIZE