PROCEEDINGS

OF THE

American Philosophical Society

HELD AT PHILADELPHIA

FOR

PROMOTING USEFUL KNOWLEDGE

VOLUME L

1911

PHILADELPHIA
THE AMERICAN PHILOSOPHICAL SOCIETY
1911

b

PRESS OF
THE NEW ERA PRINTING COMPANY
LANCASTER PA

c

CONTENTS

Symposium

OBITUARY NOTICES OF MEMBERS DECEASED

PROCEEDINGS
OF THE
AMERICAN PHILOSOPHICAL SOCIETY
HELD AT PHILADELPHIA
FOR PROMOTING USEFUL KNOWLEDGE

VOL. L JANUARY–APRIL, 1911 NO. 198

THE FORMATION OF COAL BEDS.

I.

AN HISTORICAL SUMMARY OF OPINION FROM 1700 TO THE PRESENT TIME.

BY JOHN J. STEVENSON.

(*Read April 21, 1911.*)

PRELIMINARY NOTE.

Preparation of a monograph on any subject which interests students in many lands requires thorough study of the literature as a preparatory step. But that literature has grown to such proportions that one often becomes discouraged and is burdened with the fear that life will be spent in making ready and that the grave will have been reached before the monograph has been begun. Yet such preliminary research is not without compensation, for one discovers that his own period is not so far in advance of days gone by as he had supposed; that his contemporaries, with all their advantages, have done little more, in many instances, than to place newer and finer clothing on the generalizations of earlier students who had worked within narrower areas.

This is not to say that modern workers have appropriated knowingly the results obtained by their predecessors. The writer has discovered very few instances of that sort. For the most part, generalizations have been made, *de novo,* in ignorance of those previously formulated. The literature has become vast; the papers are scattered in publications of many societies in six or more languages; many were merely separate pamphlets, now almost inaccessible. Great scientific libraries are few and they are beyond reach of the ordinary field-worker; while college professors and men connected with official surveys rarely have leisure needed for thorough research. The necessity for prompt publication, that fellow workers may have the advantage of one's results, makes long preliminary study almost impossible, in some cases almost unjustifiable.

The writer, looking forward to preparation of a monograph on formation of coal beds, has examined many hundreds of publications varying from mere notices to ponderous quartos and this preliminary work is still far from complete. During the examination, he has discovered not only that there is little new under the sun but also that much, which is good and important, soon passes from men's minds. He has discovered also that owing to quotation at second-hand, without verification, some conclusions offered by the earlier students have been misunderstood or even misinterpreted, so as to discredit the authors. He has become convinced that a systematic presentation of conclusions reached by his predecessors would not be useless or unacceptable; it would exhibit the gradual development of opinion and it would lead to proper appreciation of investigations made and conditions, which, in this day, would be regarded as unfavorable; it would aid the students hereafter by indicating the road along which to pursue his preliminary examination. Such presentation is offered in the succeeding pages.

In preparing this historical summary, the writer, recognizing the necessary limits of space, is compelled to note only such publications as deal especially with the topic under consideration; and of those, only such as are the outcome of direct study. The reader may be disappointed by the omission of some authors and by the admission of others; but this is unavoidable. Many important reflections have been made by writers incidentally; those will be noted in the final discussion. No reference to opinions respecting the origin of coal is given, except in cases where that question is basis of the author's conclusion respecting the mode of accumulation.

The plan of the summary may be open to criticism. The original plan was to arrange the synopses topically, but this separated the contrasting opinions of contemporaries; the chronological arrangement is open to the objection, that it breaks up the line of argument for or against an hypothesis. Yet the latter seems preferable as more in accord with the purpose of the summary. It has been followed, except where it would fail to show an author's final conclusions or where it seemed necessary to bring together widely separated observations upon a special phase.

The Hypotheses.

There has been little diversity of opinion respecting the origin of coal. Geologists and chemists, with rare exceptions, have recognized that the several types consist mainly of vegetable matter which has undergone chemical change. But no such consensus of opinion exists respecting the mode of accumulation in beds; geologists, for about one hundred and thirty years, have been divided into two opposing camps with here and there an individual warrior carrying on an independent strife.

The older hypothesis was suggested more than two centuries ago, prior to the era of investigation, and it remained unchallenged until the latter part of the eighteenth century, but it fell into disfavor early in the nineteenth century. Thereafter, it had few, but earnest defenders until within the last thirty years, during which it has been urged with great energy. This, the doctrine of allochthonous origin, conceives that coal beds are composed of transported vegetable matter deposited in the sea or in lake basins. The conception has assumed many forms but the essential feature of transport is common to all.

The other hypothesis, formulated in 1778 as the result of broad field observations gained general acceptance about one hundred years ago; since that time, it has been held in one form or another by a majority of geologists who have studied the coal measures. It is known as the doctrine of growth *in situ*, but von Gümbel's term, autochthonous, has come into general use. According to this hypothesis, the plants which yielded the vegetable matter grew where the coal is found, analogous conditions being found in great peat accumulations, especially those of the cypress swamps of North

America. That additional material may be brought in from time to time by transport is conceded, but the quantity thus added is comparatively unimportant. Equally the formation of a coal deposit by transport is conceded but not the formation of a typical coal bed.

The Synopses of Opinions and Results.

Woodward[1] explained all stratified rocks as deposits from the original menstruum. During the time of the deluge, the solid materials were wholly "dissolved." They were mingled with unconsolidated materials such as sand, earth as well as animal and vegetable matters and all were assumed and sustained by the water in a confused mass. In time, these materials subsided "as near as possibly could be expected in so great confusion, according to the laws of gravity," those having the least gravity settling last of all and covering the rest. "The matter, subsiding thus, formed the strata of stone, of marble, of cole, of earth and the rest." That Woodward thought coal to be of vegetable origin cannot be determined with certainty; his remark that vegetable materials, being of less specific gravity than mineral matter, would be precipitated last of all and so form the outermost "stratum of the globe" seems to suggest a contrary belief.

Whiston[2] took issue with Woodward and asserted that the hypothesis presented by that author "includes things so strange, wonderful and surprizing that nothing but the utmost Necessity, and the perfect unaccountableness of the Phenomena without it, ought to be esteemed sufficient to justify the Belief and Introduction of it." At the time of the Noachic deluge the earth passed through the "Chaotick Atmosphere of a Comet" and thus acquired a great amount of new material which mingled with the loose materials of the globe. These subsided according to the laws of specific gravity, giving the strata of stone, earth and coal; in all about 105 feet thick. Whether the coal is terrestrial or cometary in origin cannot be ascertained by study of this work. The author's conclusions are

---

[1] J. Woodward, "An Essay Toward a Natural History of the Earth and Terrestrial Bodies," 2d ed., London, 1702, pp. 73, 74, 77.

[2] W. Whiston, "A New Theory of the Earth," 4th ed., London, 1725, pp. 277, 278, 365, 419, 423, 425.

fortified by a wealth of mathematical proof which, apparently, leaves little to be desired.

Scheuchzer[3] described a deposit of black slate in the canton of Glarus, occurring in layers, one third of an inch thick, each consisting of a hard upper and a soft lower lamina. The phenomena observed in the quarry led him to assert "This is now certain that all rock beds were formed by precipitation, through subsidence of heavier earthy particles in a fluid menstruum, especially the waters of the Deluge. The observed difference of materials in every layer as well as the orderly parallelism of the layers is a sufficient proof of this. . . . At times all sorts of relics of the Deluge, fish and vegetables occur in these shales." Scheuchzer saw in the coal merely the remains of wood swept off during the deluge, "Wherefore here and there stone coals are found which were true wood"; and he notes the existence of deposits at 18 to 24 yards below the surface. This is his "Lignum fossile ex Sylva submersa."

De Jussieu,[4] about 1740, observed, near St. Chaumond in France, many impressions of plants very different from those now existing. He remarked that these represent true plants and that they lie flat as in a herbarium. In seeking their origin he was led to believe that they were vegetation of a warm climate and that they had been transported. The sea covered the continents; the currents carried and deposited the plants and shells which are found petrified.

Few writers prior to the middle of the eighteenth century dealt in other than *a priori* arguments but, after half the century had passed, there came numerous observers whose labors were utilized by Buffon.

Buffon[5] recognized the vegetable origin of coal and asserted that its excellent quality is due to the intimate mingling of vegetable matter with bitumen—the latter being only vegetable oil or animal fat impregnated with acid. He designates coal as "Charbon de

---

[3] J. J. Scheuchzer, "Meteorologia et oryctologia helvetica," Zurich, 1718, pp. 110, 111, 239, 240.

[4] A. de Jussieu, cited from Saporta by L. Lesquereux, 2d Geol. Survey of Penn., Ann. Rep. for 1885, p. 95.

[5] L. de Buffon, "Histoire naturelle, generale et particulière," Sonnini Ed., T. 9me., Paris, An IX., pp. 11, 14, 16, 35, 36, 42–46. The original publication was in 1778.

terre" and restricts the term "houille" to "the black combustible earthly deposits which are often found over and sometimes under the coal beds." These are simply mold mixed with a small amount of bitumen. The slime deposited in the sea, following the slope of the bottom and extending at times for several leagues along the coast is nothing other than the mold of plants and trees, which is drawn off by running water. The vegetable oil of that slime, seized by acids in the sea, will become in time bituminous coal but always light and friable; while the plants themselves, drawn off in like manner and deposited by the waters form the true beds of charbon de terre, of which the characteristics are very different from those of houille, the charbon being heavier, more compact and swelling in the fire.

The dips of the coal are due to the general law of deposit in moving water, while at the same time the materials have taken the inclination of the surface on which they were laid down. Occasionally the dip approaches the vertical, but even that great inclination gradually approaches the horizontal more and more as one descends and at last the horizontal plane, the plateur, is reached. A usual feature is that the thickness of a coal bed increases with the depth and the maximum is *en plateur*—which is in accordance with the law of deposit of materials carried by water and laid down on a sloping surface. The same law applies to other materials, whereby is explained easily the parallelism of coal beds to each other and to the intervening strata.

Von Beroldingen[6] published his work in the same year; it was based on broad field study. In it the author maintained that stone coals had originated from brown coals and those in turn from peat. This appears to be the first definite assertion of the peat-bog or *in situ* hypothesis.

De Luc[7] published the same theory during the next year in the

---

[6] v. Beroldingen, "Beobachtungen, Zweifel und Fragen, die Mineralogie betreffend," Erster Versuch, Hannover, 1778. The writer has been unable to find a copy of this work. It is cited by De Luc (1779), Mietzsch (1875) and by several other authors.

[7] J. A. De Luc, "Lettres physiques et morales sur l'histoire de la terre et de l'homme," Paris, 1779, Tome V., pp. 213–25. This 126th letter is dated Oldenburg, September 16, 1778.

last of five letters describing the peat deposits of northern Europe. During his journey across Germany and the Baltic he had made many exact observations on bogs; he had followed the great level marshes of the shores up the Weser river to the inland moors and had found the same general features throughout. He describes the slipping of the swamp into the river where, by swelling, it formed a hard dry rampart which prevented all further ingress of water to the swamp. He notes the great flood of Jutland, due to subsidence of the boggy area, which is covered at low tide. On the island of Bornholm in the Baltic is a swamp, surrounded by dunes, which shows many prostrate firs, pointing toward the center of the bog. These trees were overthrown by wind when the peat was soft. He observed that dry peat produces very fine trees, those growing on the peat ramparts of Oldenburg being beautiful. His observations led him to assert that

"The peat is the origin of the pit-coals or charbons de terre." He states in a footnote that he had been anticipated by v. Beroldingen, but that he had arrived at this conclusion independently while studying the immense peat bogs of Bremen. He recalls that islands had sunk below the ocean surface; some of them might contain peat as Bornholm. The waters would deposit matter on the peat giving the shaly roof mingled with leaves of vegetables which covered the peat at time of submergence. New sea deposits accumulated and the peat, compressed, enclosed as in a laboratory, underwent further change. He acknowledges that there may be difficulties in explaining the transmutation of peat and the arrangement of some coal beds, but he is confident that he is on the true road to the proper explanation of the origin of coal and of its occurrence in beds.

An anonymous writer,[8] in 1781, sums up the peatbog theory as presented at that time.

> It is a received opinion amongst many naturalists, that coal was originally peat moss, this fossil having been found in every intermediate state, nay, sometimes with wood in it, and often with the marks of leaves, roots, branches, and fruits of different plants, shrubs and trees, on the sides of broken fragments. To this doctrine we were made proselytes, being pre-

---

[8] "A Tour to the Caves in the Environs of Ingleborough and Settle in the West-Riding of Yorkshire," London, 1781, p. 68.

> sented with some pieces of coal that were got near the top of Whernside and the other mountains, that seemed more like dry clods of peat moss than coal, though distinguishable enough to belong to the latter class. The principal difference in their composition is that coals abound with the vitriolic, and peat moss with the vegetable acid. The vitriolic acid is diffused through every subterranean stratum; hence if a quantity of earth should be superinduced above a stratum of peatmoss, the vitriolic acid that would ouse through, must in time change its nature and turn it into coal: the deeper it lay below the surface of the ground, the more it would be impregnated with this fossil acid, and consequently be the more inflammable. If a stratum should lie near the top of a mountain, there is the less chance that it should be well fed.

Williams[9] was an uneducated man but an admirable observer, who summarized in his volumes the results of studies in much of Great Britain. He was a firm believer in the vegetable origin of coal and equally in the wide extent of the Noachic deluge. Thinking that he could identify in some coals the wood of modern species, he suggested that, prior to the deluge, only a small part of the globe was inhabited and that most of it was covered with tall trees. Those trees, swept off by the deluge, were carried by currents and deposited in limited areas. But this hypothesis does not satisfy all the conditions, for he had found coals which closely resembled peat. He says, "I will here beg leave to propose another probable source of coal. I believe I may call it a real one, and that is the antediluvian peat bog," and this is followed by a discussion of peat bogs, their structure and growth.

Williams argues strenuously against any hypothesis that the materials of the strata were formed by settling of particles from a heterogeneous mass in accordance with gravity, for the order of the beds is evidence to the contrary. At the same time, he finds in the structure of coal beds evidence that most of the beds were formed of transported timber. "I am of opinion that the antediluvian timber floated upon the chaos or waters of the deluge, . . . and that during the height of the deluge and the time in which the greatest part of the strata were forming, the timber was preparing and fitted for being deposited in strata of coal."

[9] J. Williams, "The Natural History of the Mineral Kingdom," Edinburgh, 2d ed., 1810, Vol. 1, pp. 510, 522–525. The first edition was in 1789.

Darwin[10] adhered to the doctrine of formation *in situ* but with modifications. "In other circumstances, probably where less moisture has prevailed, morasses seem to have undergone a fermentation, as other vegetable matter; new hay is liable to do so from the great quantity of sugar it contains. From the great heat thus produced in the lower part of the morass, the phlogistic part, or oil or asphaltum, becomes distilled and, rising into higher strata, condensed, forming coal beds of greater or less purity, according to their greater or less quantity of inflammable matter; at the same time the clay beds become poorer or less so as the phlogistic part is more or less completely exhaled from them."

Patrin,[11] cited by Parkinson, thought coal and the interposed beds of rock due to alternating ejection of bituminous and earthy materials by submarine volcanoes. In another work cited by Pinkerton he describes the characteristics of coal beds, that they have a boat-like form and that they are never single, there being many in each coal field. He thinks the deposit must have been made in still water. The occurrence of plant impressions in the roof shales has led several naturalists to think that coal is composed of vegetable remains. But Patrin thinks that this opinion presents great difficulties. The naturalist le Blond found beds of coal near Bogota at 13,200 feet above the sea. When the ocean reached that height there would be islands; and it cannot be seen how the small quantity of vegetables, which had been brought accidentally from those mountains, could have formed the thinnest bed of coal or even of peat.

Hutton's[12] opinions appeared in final form in 1795. They are not always stated clearly but the confusion may not be that of the author's mind; it may be only apparent and due to the somewhat involved method of presenting the case. The carbon of coal is evidently of organic origin. Bituminous coal and anthracite are parts

---

[10] E. Darwin, "Botanical Garden," Add. Notes, XVII., 1791. Cited by J. Parkinson; not seen by the writer.

[11] Patrin, Art. Houille, "Dict. d'hist. Naturelle," cited by Parkinson; "Mineralogie, V., p. 317. Cited by J. Pinkerton in "Petrology," pp. 567, 568.

[12] J. Hutton, "Theory of the Earth With Proofs and Illustrations," Edinburg, 1795, Vol. I., pp. 565, 566, 570, 575–581, 586.

of a series, the latter having been derived from the former by the influence of heat, which itself was the agent by which vegetable matter was converted into coal. Fuliginous matter is given off when vegetable materials are burned and it is just what is needed to compose coal beds. There are many charred coal beds, which have lost their volatile or fuliginous matter through subterranean heat. The volatile matter, diffused through the water, aided in formation of the strata, while smoke from burning bodies on the land found its way to the sea where it settled to the bottom. But this was not the only source. The rivers of Scotland carry brown water from the bogs; there must be some agency causing precipitation of this brown material, otherwise the sea would be impregnated with oily substance. The constant perishing of plants and animals would give a supply of oily or bituminous matter to the ocean, which would become pure coal unless earthy stuffs be in the water, which would render the coal impure. If the mixture be perfect and the subsidence uniform, a homogeneous substance resembling cannel would be formed.

> Therefore, with regard to the composition of mineral coal, the theory is this, that inflammable vegetable and mineral remains, in a subtilized state, had subsided in the sea, being mixed more or less with argillaceous, calcareous and earthy substances in an impalpable state. Now the chymical analysis of fossil coal justifies this theory; for in the distillation of the inflammable or oily coal, we procure volatile alkali, as might naturally be expected.

Kirwan,[13] indignant at Hutton's generally iconoclastic views, entered the lists evidently determined to annihilate the new doctrines as well as their author. He rejects the hypothesis that pit coal is merely earth or stone impregnated with petrol or asphalt, for Kilkenny coal contains neither petrol nor any other bitumen. He recognizes the vegetable origin of wood coal but maintains that it is chemically different from mineral coal, so different as to show that the latter was not derived from wood deposited in or out of the sea. As further arguments, he notes features in the mode of occurrence. Beds of mineral coal are uniform in thickness within great areas, beds of wood coal are not; beds of mineral coal show parallelism, which is unknown in wood coal beds; wood coal mines

---

[13] R. Kirwan, "Geological Essays," London, 1799, pp. 315–349.

have sudden elevations or depressions, not found in those of mineral coal; slips or dikes abound in true coal but do not occur in wood coal; wood coal is frequently, genuine coal never found in plains. Mineral coal is of distinctly inorganic origin.

> My opinion, therefore, is that coal mines or strata of coal, as well as the mountains or hills in which they are found, owe their origin to the disintegration and decomposition of primeval mountains, either now totally destroyed, or whose height and bulk, in consequence of such disintegration, are now considerably lessened. And that these rocks, anciently destroyed, contained most probably a far larger proportion of carbon and petrol than those of the same denomination now contain, since their disintegration took place at so early a period.

The seams of coal and their attendant strata must have resulted from the equable diffusion of the disintegrated particles of the primitive mountains carried down by the "gentle trickling of the numerous rills" and more widely diffused by more copious streams. The important sources of material for the coal beds were granite and trap, as those rocks contain natural carbon and hornblende, the latter mineral being an extremely important source. Kirwan's arguments are extremely ingenious and he finds no difficulty in explaining all known phenomena by means of his "supposition."

Playfair[14] attacked Kirwan's doctrine and defended that of Hutton. He regarded Kirwan's suggestions as deserving only ridicule. He showed that both wood and mineral coal occur in the same bed and that most of Kirwan's postulates were not in accord with fact. The quantity of hornblende and silicious schist to be decomposed in order to yield the coal would be vastly greater than Kirwan had supposed; Playfair suggested that it would have been better to imagine that the diamond existed so abundantly in the primeval mountains as to constitute great rocks. A single ridge might suffice to give material for coal beds of all the surrounding plains. He asserted that Kirwan's hypothesis trespasses on every principle of common sense.

Voigt[15] strenuously opposed v. Beroldingen's hypothesis that coal

---

[14] J. Playfair, "Illustrations of the Huttonian Theory of the Earth," Edinburgh, 1802, pp. 148–160.

[15] J. C. W. Voigt, "Versuch einer Geschichte der Steinkohlen, der Braunkohlen und des Torfes," Weimar, 1802, pp. 42–46.

beds originated as peat bogs. He believed that coal was formed chiefly from the harder species of reeds, and the vegetable matter had been dissolved in an oily substance. The fluidity of the material is proved by the occurrence of thin streaks in sandstone as well as by carbonaceous shale, which contains enough combustible matter to be utilized as fuel. The opinion that stone coal was at one time brown coal and that, in turn, originally peat deserves no consideration; it is merely the notion of a closet student and Voigt is surprised that Beroldingen, who had seen so many localities of stone and brown coal and peat, should offer the suggestion. Stone coal belongs to the oldest formations while brown coal and peat are of the newest; one might as well suggest that a child begat its mother, and the mother, the grandmother. It is sufficiently clear that Voigt conceived that the vegetable matter was first converted into bitumen and then transferred. His memoir was crowned by the Gottingen academy. The prominence thus given to it as well as the emphatic manner in which its assertions were made did much to repress the readiness shown by contemporaries to accept the Beroldingen hypothesis in whole or in part.

Faujas-St.-Fond[16] discussing the source of coals occurring in what he terms granitic regions, says that they were deposited in bays or vast basins excavated by the sea. Currents transported into these receptacles materials from the granites, which became beds of greater or less thickness. Sometimes the seas brought the plants which, along with animals so abound in them, and these accumulated pêle mêle with the products of terrestrial vegetation brought down by the rivers. At other times the tides deposited on these beds of combustible materials the quartz sand of the sea bottom; at later periods, wood and plants arrived again, were deposited on the sands or clays; thus were formed the alternating beds of vegetable material with combustible residues of fish, mollusks and marine plants.

Al. Brongniart[17] described in detail the various types of coal, lignite and peat. He evidently accepts Voigt's conclusion that there is no bond between coal and lignite, while at the same time he hesi-

---

[16] B. Faujas-St.-Fond, "Essai de géologie," Paris, 1803, p. 443.

[17] Alex. Brongniart, "Traité élémentaire de minéralogie avec des applications aux arts," Paris, 1807, t. 2, pp. 13, 14, 32, 36.

tates to accept the doctrine that coal is product of decomposition of organized bodies. Brongniart exhibits much caution in respect to generalizations but offers these conclusions which he thinks are derivable from actual observation: (1) That the coal is a formation contemporaneous with or posterior to the existence of the organized bodies; (2) that this combustible, when it was deposited or formed, was liquid, homogeneous and in a great degree of fineness, which is proved by the frequently parallelopipedonous structure and by the manner in which it is absorbed by the beds which enclose it; (3) that the cause, which has deposited or formed it, was renewed several times in the same place, with conditions almost the same; (4) that this cause has been the same for almost all the earth, since the coal beds present in their structure and their accessory conditions almost always the same phenomena; (5) that these beds have been deposited without violent disturbances, since the organized bodies which are found in them are often entire and since the leaves, which are impressed on the shales covering the coal, are expanded and are hardly ever rubbed or even folded.

Parkinson[18] regarded coal as a product of vegetable matter reduced to fluidity by bituminous fermentation; this fluid suffered modification of its inflammability by deposition of carbon and by intimate admixture with various salts. The vegetable matter had been swept into the sea by the universal deluge.

Kidd[19] summarizes the doctrine of transport thus, "Powerful floods have swept away forests and subsequently covered them with the ruins of the soil in which they grew; whence those beds of clay and gritstone which so generally accompany the coal itself." His objections to this doctrine are that remains of trees and shrubs are wanting; that the plants are evidently those of many places; that the mechanical force, which uprooted the forests and swept away the vegetable matter as well as the greater amount of the earthy matter in the shales and gritstones, must have been extreme; yet the particles of the grit are not rounded and show no sign of attri-

---

[18] J. Parkinson, "Organic Remains of a Former World," London, 1811, Vol. I., p. 248.

[19] J. Kidd, "A Geological Essay on the Imperfect Evidences in Support of a Theory of the Earth," Oxford, 1815, pp. 126, 127, 128.

tion. He objects further that the theory does not account for the alternation of calcareous with argillaceous and siliceous beds, and asks on what principle one may expect that beds of earth spread out by the floods, should be periodically calcareous, argillaceous or siliceous, and how can it account for the alternations of clay beds with numerous coal beds; why should a second flood in its blind fury deposit a second series of beds on exactly the same spot where the first series is deposited?

Conybeare[20] adhered to the belief that vegetable matter alone was the source of coal and accepted Sternberg's suggestion that torrents tore off the vegetation from scattered primitive islands to deposit at the bottom of adjacent basins. He conceived at this early date a theory having not a few of the features characterizing one offered at a much later date. He thinks that the coal measures were deposited in estuaries and that the partial filling up of lakes and estuaries offers us the only analogies in the actual order of things with which the coal deposits can be compared. Respecting the deposit at Bovey Tracy, he says:

> We must here suppose the wintry torrents to have swept away a great part of the vegetation of the neighboring hills and buried them in the estuary with the alluvial detritus collected in its course; the latter would, from it's gravity, have sunk first and formed the floor; the wood would have floated till, having lost its more volatile parts by decomposition and become saturated with water moisture, it likewise subsided upon them, being perhaps loaded by fresh alluvium drifted down upon its surface; the re-iterated devastations of successive seasons must have produced the repetition and alternation of the beds . . . and if we suppose a like order of things to have operated more extensively and for a longer period during the formation of the coal strata, we shall find such an hypothesis sufficiently in accordance with their general phenomena.

Ad. Brongniart,[21] after long study of the fossil plants, concluded that in the Carboniferous time the dry land was confined to islands on which grew the plants whose remains are in the coal formation. Numerous proofs established that the plants grew in the very places where they are found or, at most, within only a little distance away.

---

[20] W. D. Conybeare, "Outlines of Geology of England and Wales," London, 1822, pp. 334, 345, 347.

[21] Adolphe Brongniart, "Prodromme d'une histoire des végétaux fossiles," Paris, 1828, pp. 183, 184.

The manner in which the plants are preserved in rocks accompanying coal beds as well as the presence of vertical stems in normal position are most convincing. He cannot attribute the formation of coal beds to accumulation of vegetable detritus transported from a distance and deposited in the condition of pulp (bouillée) as was supposed by Sternberg and Boue. In fact it would be difficult to understand how the causes, which reduced to a kind of pulp the plants which have formed the coal itself, failed to change the plants found in the neighboring beds; how it is that the coal formed in the sea contains no marine debris; how, finally, a substance thus deposited shows no more inequalities in thickness of the bed. He accepts De Luc's conception of vast swamps as best agreeing with observed conditions. The intervening rocks originated during periods of elevation of the sea-level or depression of the land.

Ure[22] could not believe that coal beds are the remains of uprooted forests or shattered trees. Reeds and ferns afforded most of the material and they grew not far from the place where the coal is found, as is shown by the state of preservation. The vegetable matter was reduced to a pasty condition, elaborated in the tepid waters of the primeval globe and was deposited in a semi-fluid condition where now found. The proof of this hypothesis is found in the great extent of very thin coal beds, the parallelism of the opposite faces, in the existence of narrow fissures filled with coaly matter, as well as in the homogeneous substance and texture and the cubical division in coal beds. The conversion of the buried matters into coal might continue ripening during many ages by percolation.

MacCulloch[23] devoted many years to actual investigations in both field and closet, the results being given in numerous brief papers. The outcome of his completed studies is presented in an elaborate discussion of the origin of coal and the formation of coal beds.

Peat, lignite and coal form a continuous series, the transition being sufficiently perfect. The character of the plants, the presence of tree trunks, their bark converted into coal, show that the plants from which coal was formed were terrestrial, not marine. Those

---

[22] A. Ure, "A New System of Geology," London, 1829, pp. 163–174.

[23] J. MacCulloch, "A System of Geology with a Theory of the Earth," London, 1831, Vol. II., pp. 311, 312, 336, 337, 339, 341, 359.

plants, being aquatic in type, grew in low moist forests in marshes on the borders of lakes or rivers. From the fact that peat occurs in only limited quantity within the tropics, he argues against the supposed tropical nature of the carboniferous plants. These embedded plants are so often in such state of preservation as to preclude the notion that they had been transported. MacCulloch's study of peat bogs led him to recognize four types. Marsh deposits are vast in area, uniting on one side with Lake deposits and on the other with Forest deposits, as they may be on either lowland or upland. They owe their origin chiefly to *Sphagnum palustre*. Two sets of plants aid in forming the lake deposits; shallow portions of the lake give floating plants, which, after flowering, sink to form a vegetable stratum; other plants fringe the pond, detain clay and detritus, supporting reeds and bulrushes; these gradually advancing form a marsh and eventually the lake is filled. The Forest peat contains submerged wood and is produced, for the most part, by plants after fall of the forest, so that it is a marsh peat. It is always forming in forests and the submerged tree-trunks are almost wholly in one direction, having been overthrown by the wind. Maritime peat is formed in estuaries by *Zostera marina,* which causes formation of sandbanks and bars; seaweeds may contribute even to shore peat, for *Fucus serratus* and *F. nodosus* are found in deep peat at some places in Holland. Transported peat is rare, occurring only in small quantities and as a fine powder; it is due to bursting of bogs. MacCulloch, after a detailed comparison of phenomena observed in peat bogs with those observed in coal deposits, concluded that by far the larger part of the coal deposits are now lying where the progenitor plants grew.

Mammatt[24] appears to have been the first to recognize that an underclay usually accompanies coal beds. "Seams of fireclay abound in the Ashby coal-field and there are very few coal-measures which do not rest upon it, as the sections will show." He remarks further: "From the circumstance, that so many cases occur, where a tolerably pure fireclay lies immediately under, and in contact with, a bed

---

[24] E. Mammatt, "Coal Field of Ashby de la Zouche," 1834, p. 73. Cited by H. D. Rogers, Assoc. Amer. Geol. and Nat., Boston, 1843, p. 454.

of coal, it may be inferred, that such clay stratum could not have been the soil, where grew the vegetable matter which produced the coal, unless this vegetable matter was a moss, a peat, or some aquatic plant; because in the clay, there is no appearance of trunks, or other vegetable impressions, beyond slender leaves, as of a long grass."

Lyell[25] about this time committed himself in part to both hypothesis, though evidently disposed to favor that of transport. "The coal itself is admitted to be of vegetable origin and the state of the plants and the beautiful preservation of their leaves in the accompanying shales precludes the idea of their having been floated from great distances. As the species were evidently terrestrial, we must conclude that some dry land was not far distant; and this opinion is confirmed by the shells found in some strata of the Newcastle and Shropshire coal-fields." The alternation of marine limestone with strata containing coal beds may be due to alternate rising and sinking of large tracts, which were first laid dry and then submerged again. He is clearly inclined to agree with the suggestion made by Sternberg and Ad. Brongniart, that the beds of mineral detritus were derived from waste of small islands arranged in rows and he thinks that the suggestion is supported by the observation that the Coal Measures flora is of insular type.

At a later period, Lyell accepted the autochthonous origin of the coal beds, as appears in the "Travels in America."

Buckland,[26] in 1836, accepted the theory of transport. "The most early stage to which we may carry back its origin was among the swamps and primeval forests, where it flourished in the form of gigantic *Calamites* and stately *Lepidodendra* and *Sigillariæ*. From their native bed, these plants were torn away, by the storms and inundations of a hot and humid climate and transported in some adjacent Lake or Estuary or Sea. Here they floated on the waters, until they sank saturated to the bottom, and being buried in the detritus of adjacent lands, became transferred to a new estate

---

[25] C. Lyell, "Principles of Geology," 5th ed., 1st Amer. ed., Philadelphia, 1837, Vol. I., p. 134.

[26] W. Buckland, "Geology and Mineralogy considered with Reference to Natural Theology, Philadelphia, 1837, pp. 362, 353, 354.

among the members of the mineral kingdom. A long interment followed, during which a course of Chemical changes, and new combinations of their vegetable elements have converted them to the mineral condition of Coal."

On an earlier page, Buckland referred to the existence of erect stems in the Coal measures rocks: he was convinced that none of those recorded, aside from some near Glasgow, could have grown where they were found.

From this date onward the discussion respecting erect stems, became increasingly important. The facts and the conclusions are alike contradictory. It is better to pass by this matter for the present and to treat it apart.

Sternberg[27] did not accept the hypothesis that coal was formed from peat. He thought that one should conceive of a forest in the ancient time, when neither man nor plant-eating animals existed; that this forest grew for an indefinitely long period in a warm, humid climate; that the offal of buds, leaves, seeds, fruits and decayed stems accumulated on the ground; many generations of plants grew, one on the other, and so a mass, consisting of mold from wood, fruits, seeds, leaves, with complete examples of smaller plants, would be produced, whose surface would be covered with still living vegetation. Conceive now of a cataclysm, when a hurricane casts down the living plants and is followed by a flood, loaded with sand and mud—thus one has a true picture of the mode in which the overlying deposits of the stone coal are formed. Cases are rare where one finds erect stems of trees between two coal beds, losing themselves above and below in the coals.

The water-cover would hold the mold in place, would bring about decompositions and changes in the different materials and would cover the whole with clay and sand. It is unnecessary to borrow carbon from the air or water in order to get a coal formation, since in this interval, as well in the dry as in the wet way, humus and other acids, bitumen and coal itself have been produced, as occurs even to-day in peat bogs. The material existed in abun-

---

[27] K. Sternberg, "Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt," Siebenstes und achtes Heft, Prag, 1838, p. 88.

dance and fermentation necessarily followed under the covering of water and sediment. It is unimportant to determine whether the water was fresh or salt.

In this way, he sees no difficulty in accounting for accumulation of stone coal deposits, even those of Saint-Etienne, which are 60 fathoms thick. He emphasizes the fact that the particular vegetation of the stone coal period produced colossal stems.

Link[28] was the first to study the texture relations of coals. He observes that two theories had been offered to account for the origin of coal beds; that of driftage does not commend itself to him, but that referring the coal beds to ancient peat bogs appears more reasonable. After summarizing the opinions of v. Beroldingen, de Luc, Steffens, Hutton and Leonhardt, he presents the results of his own investigations. Von Buch, feeling perplexed by some recent publications, had given him some specimens of coal from Bogota and had asked that he study them microscopically. The composition of one of those coals so resembled that of peat that he was led to a wide study of coals and peats from several horizons and regions.

In all peats, whether loose or compact, cell tissues form the body of the mass; the difference in quality of the peats being due probably to difference in the plants; the stone coals resemble peat in structure, some recalling the comparatively loose *Linum* peat used as fuel in Berlin, while others are more like the dense, almost wood-like peat from Pomerania; the Mesozoic coals vary, one from the Muschelkalk closely resembles peat, but the Liassic coals appear to be composed largely of woody fiber; the brown coal of Greenland is like the *Linum* peat, while that of Meissner in Saxony is similar to the dense Pomeranian material.

Link observes two quarto plates illustrating the vegetable structures observed in each of the peats and coals examined.

Logan's[29] notable memoir on underclays appeared in 1841. He

---

[28] H. Link, "Uber den Ursprung der Steinkohlen und Braunkohlen nach mikroskopischen Untersuchungen," *Abhandlungen d. k. Akad. d. Wiss. Berlin*, 1838, pp. 33–44.

[29] W. E. Logan, "On the Character of the Beds of Clay Lying Immediately below the Coal Seams of South Wales," *Proc. Geol. Soc. London*, Vol. III., pp. 275, 276.

had found almost one hundred coal beds in the South Wales coalfield and, with rare exceptions, each overlies a clay bed from six inches to ten feet thick. The clay varies much in composition but it is a persistent deposit, so that coal beds which have thinned out in the workings have been found again by following the clay. Ordinarily, *Stigmaria* occurs abundantly in the clay and Logan thinks that plant was the source of most of the coal.

Soon after the field work of the Virginia and Pennsylvania surveys was completed, H. D. Rogers[30] gathered the salient facts bearing upon the origin of coal beds and presented them in a paper which has become classical. It bears the impress of the time, but it was based on broad observations by the author and his equally celebrated brother, William B. Rogers, aided by a corps of able assistants; the studies, lasting six years, were in detail for an area of somewhat more than 20,000 square miles, but in addition less detailed studies had been made in Ohio and Kentucky, so that the region under consideration was not far from 40,000 square miles. The discussion was the first serious attempt to account for the origin of the Coal Measures, which was based on actual study of a vast area.

At the outset, Rogers pronounced against any theory of delta formation, as according to his belief the Appalachian ocean deepened toward the west and northwest.[31] The deposits are traceable coastwise for 900 miles, so that it seems improbable that fluviatile currents could have assembled them.

The sandstones decrease in thickness and coarseness as they recede from the ancient shoreline at the east; the shales increase in that direction for a time and then decrease, while the limestones, wholly wanting near the shore line, increase in thickness and purity so as to become imposing before the Ohio River has been reached. The animal remains found in the limestones are marine. There

---

[30] H. D. Rogers, "An Inquiry into the Origin of the Appalachian Coal Strata, Bituminous and Anthracitic," Reps. of Amer. Assoc. of Geologists and Naturalists, Boston, 1843, pp. 434, 459, 463–467.

[31] It should be noted here that when Rogers wrote the conditions on the west side of the Appalachian basin were not known; but does not affect the general argument.

were many alternate periods of movement and of total or comparative rest. Limestones indicate periods of comparative tranquillity. Some of the coal beds are of great extent. The Pittsburgh bed had been traced around an area of 14,000 square miles and there are isolated basins holding that bed far southeast from the main area, so that the Pittsburgh coal must have covered a surface of not less 30,000 square miles. The uniformity in thickness and the absence of abrupt variations are as remarkable as the area. These features "seem strongly adverse to the theory which ascribes the formation of such deposits to any species of drifting action."

The alternation of laminæ of bright and dull coal; the lenticular form of the bright layers; the predominance of mineral charcoal in the dull laminae seem to be almost conclusive arguments in favor of belief that the vegetable matter grew where it was deposited. He finds it difficult to understand why the coal does not consist principally of the larger parts of trees if any drifting agency brought the materials together. The leaves and smaller parts would be detached before the trunks could become waterlogged.

But the beds have subordinate divisions, coal, clay, impure coal, so persistent in great areas that miners can recognize their bed at great distance from their own locality; only one method of accumulation can explain this. "I cannot conceive any state of the surface, but that in which the margin of the sea was occupied by vast marine savannahs of some peat-creating plant, growing half immersed on a perfectly horizontal plain, and this fringed and interspersed with forests of trees, shedding their offal of leaves upon the marsh. Such are the only circumstances, under which I can imagine that these regularly parallel, thin and widely extended sheets of carbonaceous matter could have been accumulated." The purity of the coal is inconsistent with any notion of drifting of the vegetable matter, "which according to any conceivable mode of transportation, would be accompanied by a large amount of earthy matter, such as abounds in all delta deposits and even mingles with the wood as in the raft of the Atchafalaya."

The underclay, irregular in structure, accompanies nearly every coal bed in the Appalachian basin and usually contains *Stigmaria* *ficoides* with its fibrous processes. The roof contrasts with the underclay and is, normally, a laminated shale due to more or less rapid current and it contains vast numbers of plant impressions.

When the roof is sandstone there is evidence of tempestuous currents and the vegetable fragments are trunks and stems of large plants. Occasionally limestone forms either roof or sole of the coal bed but there is usually a very thin layer of calcareous shale parting them.

No hypothesis, thus far presented seemed satisfactory to Rogers, and he presented his own to account for origin of the Coal Measures.

He imagined extensive flats bordering a continent, the shore of ocean or bays, beyond which was open sea. The whole period of the Coal Measures was characterized by a general slow subsidence of the coasts, interrupted by pauses and gradual upward movements of less frequency and duration, and these merely statical conditions alternated with great paroxysmal displacements of the land. During gentle depression, the coast was fringed by marshes while arborescent plants were on the land side. The meadows would give pulpy peat; leaves blown in or moved by higher tide would rest on the peat; some would be buried and become pulpy, or, in some cases, by rapid removal of volatile constituents would remain as mineral charcoal. An earthquake comes. Water is drained from the swamps and their tributaries; muddy water draws from swamp and swampy forests leaves and the rest to distribute them with the mud over the bog. This is the laminated shale. The sea returns, rolls over the swamp to the dry land; withdrawing, it brings uprooted trees, and washed off soil, strewing the land stuff in a coarse promiscuous stratum. Repeated waves would add to the mass. The disturbance ends; coarse materials sink, then the less coarse and last of all the finest sediment, light vegetable matter and the buoyant stems of *Stigmaria,* would sink together. A new marsh would be made and once more the savannahs would be clad with vegetation. This he terms the paroxysmal theory.

Petzholdt[32] found two questions involved in the problem; were coal beds formed during a brief period and were they formed *in situ*

---

[32] A. Petzholdt, "Geologie," Zweite Auflage, Leipzig, 1845, pp. 413–417.

or from transported vegetable material. The answer to the first question is certain—a great period of time was required for formation of the coal beds and their associated strata; but the second question is more complex and he is inclined to believe that both methods are possible, though there may be difficulty in determining which prevailed at a given locality. Vertical stems are not decisive, for they are found at times in rocks formed by transport, while prostrate stems occur in deposits clearly made *in situ*.

He believed that there were no continental areas during Carboniferous times, that the dry land consisted only of islands. For this reason, it is impossible to accept the hypothesis that coal was formed in great lakes or at the mouths of rivers. The only method of formation by transport would be the driving of great masses of vegetable matter against an island, which would collect in the quiet eddy on the opposite side, where, becoming waterlogged, they would sink and be covered with mud. He clearly prefers the doctrine of origin *in situ*.

An island, heavily forested for an indefinitely long period, becomes covered by a mass of bark, wood, etc., and similar remains of small plants. If the island be flooded by the outburst of granite and consequent elevation of the sea-level, the vegetation will be prostrated. By frequent outbursts the sea-level will be raised permanently and the island remains submerged. Deposits of sand and mud bring the island again to the surface of the water; a new forest rises on the grave of the old one. He thinks the alternation of strata and the formation of coal *in situ* can be explained very simply in this way.

Murchison,[33] after his study of the Donetz field in Russia, was convinced that the doctrine of transport alone could explain the conditions. The sections in southern Russia show "that the hypothesis of the formation of coal beds by masses of vegetation which there grew having subsided *in situ* (the truth of the application of which to some basins we do not deny) cannot be applied to the cases in question any more than to the pure marine coal beds of the northern districts, Northumberland and the northwestern parts of York-

---

[33] R. I. Murchison, "The Geology of Russia in Europe and the Ural Mountains," London, 1845, Vol. I., pp. 112–114.

shire, etc." Limestones with marine fossils are found at various horizons in the Donetz section. The presence of an underclay proves nothing—even though *Stigmaria ficoides* be the only plant present for a confused assemblage of plants is seen above and below the coal beds and the fossil beds are exclusively marine. The fine underclay indicates only that the sea bottom was covered with detritus of plants washed in by floods; the heavier earthy matters, accompanying the detritus, sank to the bottom, while the plants floated and formed the upper stratum. Those plants, thus left on the muddy slime, were covered afterwards by other sediment. Much of the coal, in strata alternating with marine sediments, may have come from the washing away and sinking into the sea of floating masses of matted earth and plants.

At a later date,[34] he discussed the question more broadly. He refers to the terrestrial conditions exhibited in the Upper Carboniferous of England and to the lack of a physical break there between the Lower and the Upper Measures, such as appears in Germany and France. In those countries, the later accumulations may well be accounted for by depressions of low woodlands and jungles beneath freshwater, followed by elevations and depressions. There is no physical break in Britain, but there is the same passage from marine to terrestrial conditions, of which the coal beds offer positive evidence; for the roots of *Sigillaria* are found in the underclay, which was the soil of a primeval marsh or jungle. The view, which supposes many and successive subsidences of vast swampy jungles beneath the level of the waters, best explains how the different organic masses became so covered with beds of sand and mud, as to form the sandstone and shale of such coal fields. But this theory of oscillations . . . can scarcely have an application to those other seams of coal, which, as before mentioned, are interstratified with beds containing marine shells, the animals of which, such as *Producti* and *Spirifers,* must have lived in comparatively deep water."

He conceived that the latter class is to be explained only by the supposition that great rivers, flowing through lowlands, transported vast quantities of trees, etc., entangled in earth, and de-

---

[34] "Siluria," 3d ed., London, 1859, pp. 315–317.

posited them on the bottom of the estuaries, or that vast heaps of organic matter were carried as floating masses to the sea. The Northumberland deposits, large tracts of Scotland, as well as the Donetz field in Russia offer fine proofs of these conditions. There were at least two modes in which coal measures were formed, one terrestrial, the other subaqueous.

Goeppert[35] in his elaborate work on the formation of coal beds gave the results of many years of study in the Silesian coal fields. A large part of the volume is devoted to determination of the materials forming coal; it will be considered in another connection. The chapter on the formation of coal beds is supplemented by a mass of illustrations drawn from the coal fields of Silesia, the whole discussion being so compact, so free from unnecessary detail that to make a just synopsis is difficult. The standpoint in Goeppert's work differs much from that in the discussion by Rogers, the only preceding study with which it can be compared. Rogers knew little about the intimate structure of coal itself and reasoned wholly from stratigraphical conditions; Goepert was a skilfull palæobotanist as well as stratigrapher.

The important question for Goeppert is, were the coal beds formed of plants growing in place or of plants brought in from other localities.

There were many islands, mountains, valleys, rivers, etc., in the Coal Measures time. The organic matter was deposited on plains which were covered with sand, clay or mud. The extent of the deposits, their occurrence as plains or as basins show that they were laid down on the sea-bed, on slowly changing coasts or in enclosed sea or lake basins. The few marine products found in coal beds do not favor the opinion that the coal-forming material was collected from distant places and deposited in the depths of bays; everything indicates the utmost quiet; the vegetation covered

---

[35] H. R. Goeppert, "Abhandlung eingesandt als Antwort auf die Preisfrage—'Man suche durch genaue Untersuchungen darzuthun, ob die Steinkohlenlager aus Pflanzen entstanden sein, welche an den Stellen, wo jene gefunden werden, wachsen: oder ob diese Pflanzen an anderen Orten lebten, und nach den Stellen, wo sich die Steinkohlenlager befinden, hingeführt wurden?" Amsterdam, 1848, pp. 119–131, 136–139, 141–160, 278, 279.

the low-lying horizontal sea-strand. Changes of level, elevation and subsidence, led to burial of the plants under the ocean; sand and clay were deposited on the plant covered surface; dunes were formed, on which plants grew to run the same course. Through repetition of this process, the different beds were formed, separated by sand and clay. The conditions were like those of the present day, for submerged bogs and forests have been observed at many places along the coasts of Europe and America.

Well preserved stems are wanting because the plants lacked a dense interior structure. Filled stems are rare in Tertiary deposits because the trees were dicotyledonous; whereas they abound in the Coal Measures because the loose interior structure decayed quickly. Plants grew in these hollowed stumps; Goeppert found *Lepidodendron, Calamites* and ferns in decayed *Sigillaria;* in the stump of *Lepidodendron* he found the stem of a new genus, two feet long and vertical.

If the coal had become compact or if the quiet were undisturbed, the boundary between coal and the succeeding deposit is sharply defined; at most one finds only impressions of stems lying upon the upper surface. This latter condition occurs frequently in Upper Silesia, where the coal is composed chiefly of *Sigillaria.* It is quite true that filled stems occur even within the coal itself; Goeppert found them. He explains their presence by supposing that clay and sand were brought down by floods before consolidation of the coal, before the spaces between the stems had been obliterated by compression. In the same way he accounts for Brandschiefer or bituminous shale; the influx of muddy waters caused the alternation of laminae of bright coal, containing 2 percent of ash, with dull layers, containing much mineral charcoal and 20 to 25 percent of ash.

The overlying beds were deposited after complete formation of the coal bed and the time-interval between the two deposits is as variable as the intervals interrupting the formation of a coal bed itself. Partings in coal beds show how the time required for different types of deposits may vary. A parting, ten inches thick, may be equivalent in time to a sandstone deposit elsewhere, many fathoms thick. Perhaps one may regard layers containing great abundance of plants as equivalent to deposits in which the plants do not form beds, because in the latter case the plants were brought in contemporaneously with the sand and mud masses. He is convinced that the coal and the enclosing sandstone or shale beds are wholly independent deposits. And this belief is strengthened by the fact that the material, filling stems in coal, clay or sandstone, differs from that which surrounds them—an additional evidence of the extreme quiet prevailing during deposition. Goeppert was the first to recognize that the coating of the filled stems is the converted bark. The roots of *Sigillaria* and *Lepidodendron* were feeble, as are those of related plants to-day, and the trees were overthrown easily; and thus it happens that the stems, as in Upper Silesia, contribute to the formation of the coal. When overthrown, their cellular interior was squeezed out and converted into coal, as is seen near Dombrowa. All the phenomena indicate that the coal deposits were made during conditions of quiet, which would be impossible unless the plants grew where the coal is found.

The vast extent and constancy in structure exhibited by coal beds is important. He cannot think that such a mass could be floated in at once, yet how could it be deposited so regularly by any other means? He agrees with Lindley and Hutton and with Burat that the mass is too great for transport. He is unable to believe that the coal was the product of forests, because the amount is so vast; but the evidence satisfies him that the plants have not come from a distance. He prefers to accept the opinions presented by v. Beroldingen, De Luc, Ad. Brongniart, Link, and to believe that, if not all coal beds, at least the thickest originated as peat bogs—the more so because of the resemblance which a buried peat bog has to a coal bed.

He conceives that on the damp floor there grew lycopods, calamites, ferns, stigmaria and other plants, corresponding to the cryptogams and monocotyledons of present day bogs. Tree-like *Sigillariæ* and *Lepidodendra* grew on the borders of the bog and at times were uprooted by floods. He laid great stress on the preservation of the plants, as precluding the possibility of transportation; he finds the mode of decay of tree stems equally important, for the conditions observed in *Calamites* are the same with those found in his experiments with *Arum*. The presence of vertical stems is noteworthy, because they are so numerous. It is possible for floods to carry away whole trees and to deposit them in vertical position; that occurred in the great débâcle near Martigny in Switzerland. This explanation would suffice for an isolated instance; but the number of such stems in the Coal Measures is too great; the analogy is in submerged forests of our own day.

The distribution of plants, both vertically and horizontally, has an important bearing on the subject. At one locality the flora may consist almost wholly of one species and at another, almost wholly of another species. There is a group-like distribution, so to speak, a social occurrence. In Upper Silesia, the coal may be termed *Sigillaria* coal, while in Lower Silesia it is *Stigmaria* coal. He asserts that an observer, in viewing the coal bed, involuntarily thinks of a peat bog.

Lyell's volumes on his second visit to the United States appeared at this time and had material influence in moulding public opinion. They will be cited in another connection.

Naumann[36] recognized the distinction between deposits formed on the sea border and those in fresh-water lakes, as had been done by Elie-de-Beaumont and Burat. The former contain, especially in their lower portions, rock layers with organic remains corresponding to the marine mode of formation, while the latter, less extensive, have no traces of marine fossils or anything else to show co-working of the sea. These types he terms paralisch and limnisch. These terms are equivalent to pelagic and mediterranean of Elie-de-Beaumont, to *terrains houillers de haute mer* and *terrains houillers des lacs* of Burat. The coal deposits of Great Britain, Belgium, Westphalia, Russia and America are paralisch or pelagic; those of central France, Saxony and Bohemia are limnisch or lacustrian.

The prevailing rocks of the Carboniferous are conglomerate, standstone and clay shale, which occur in paralisch and limnisch alike. They are derived mostly from destruction of other rocks and their materials were transported. The land consisted not of small low-lying islands but mainly of great islands and continents

---

[36] C. F. Naumann, "Lehrbuch der Geognosie," Leipzig, 1854, Vol. II., pp. 451, 452, 571–580.

with mighty rivers, along whose coasts and in basin shaped depressions was deposited the vast system of sand and mud strata: This at length became marshland, offering the ground for the luxuriant vegetation of the first coal bed. In the Appalachian region, there may have been the flat coast of a land extending far to the east, from which great rivers carried sand and mud into the shallow sea at the west, in which, farther away, limestone was forming. Processes such as those now seen in the Nile, Mississippi, Hoangho and other rivers, continuing for many thousands of years, would raise the sea bed until it reached the water surface as a wide-spread marshland. Similar operations were going on in freshwater basins of the dry land leading to the formation of morasses, supporting *Calamites, Sigillariæ* and other Carboniferous plants, which would give a deposit of peat.

The alternation of a great number of coal beds with thick masses of sandstone and shale is not so easily explained as is the origin of the first coal bed. The causes in paralisch areas are different from those in limnisch basins.

Lyell, Lindley and others held the opinion that seacoasts, on which paralisch deposits were formed, underwent slow subsidence during Carboniferous time. If one suppose that this subsidence was interrupted periodically, we have a mechanism by which the formation of successive coal beds could be explained. A similar result would be secured by occasional elevations of the sea-bottom, according to Petzholdt's conception. There is necessary in each case a general rise of the sea-level to cover the plant deposit with the sandstone and shale needed to give another swampy surface. This alternating subsidence and stability of the sea-bottom explains why the shale, covering coal beds, encloses a mass of plant remains and also why paralisch territories may have many but thin coal beds.

This explanation is not wholly satisfactory for limnisch areas, since one can hardly suppose that all of those could have suffered the repeated subsidence. One must conceive that between longer periods of stability there were epochs in which increased fall of inflowing streams or a diversion of flow occurred. The greater carrying power of the streams would bring the plant deposit and at length form a new surface on which vegetation would begin once more. This would give a smaller number of beds. The, at times, great thickness and the frequent irregularity of coal beds in limnisch areas may be explained in part by supposing that they were not formed wholly as peat deposits, but received masses of uptorn vegetation, swept out by floods, and this leads to the question of the formation of a particular coal bed.

There are two theories, transport (Anschwemmung) and *in situ* (an Ort und Stelle). Both may be correct. The great beds, beyond doubt, are of *in situ* origin, but there are many deposits which can be explained only by transport of plant masses.

It is known that streams bring down astonishing quantities of plant material; that ocean currents carry driftwood far and that it accumulates in vast masses on shores. Currents of the olden time must have been similar. If the widespread masses were buried under sediments, they would be transformed into coal beds. Neumann thinks that repetition of this process at mouths of streams in lakes or on the sea-coast would give a system of strata like the present series of coal beds with intervening sandstones and shales. Such drift masses are irregular in extent and thickness, often as blocklike masses. Such transported material would give conditions like those observed in coal beds of some limnisch areas, great irregularity and variation in thickness, breaking up into separate benches, some of them excessvely thick. He thinks that under especially favorable conditions a coal bed might be formed in this way which would resemble one formed *in situ.* He considers also that this theory of transport explains many regular coal beds, such as those between limestones or other strata distinctly marine, as well as beds resting directly on granite, limestone, etc., without an underclay. He agrees with Murchison that in some cases the transport theory has value.

But for the greater part of the coal beds, the *in situ* theory must be accepted; their material was produced by vegetation an Ort und Stelle. All beds continuous over great areas, with regular and not too great thickness and with a stigmaria-filled underclay are to be explained in this way. But one must not think that there were real forests, which were thrown down in place, compressed by in-coming sediments and changed into layers of plant material. The Carboniferous was not a tree and forest flora; it was morass and strand vegetation, developed on great emerging plains of marshland. The prevailing forms suggest that formation of the widely extended coal beds was analogous to the formation of peat bogs.

The purity of coal substance, the continuity of the beds, their regular thickness, the arrangement in benches due to clay layers produced by inconsiderable inundations, the upright plant stems and all the remaining relations of most coal beds appear to find sufficient explanation only in this or a similar conception of the mode of their formation. When at length a permanent elevation of the sea-level comes, the bog is buried under sand and mud, in whose first layers, just as in the last conditions of peat vegetation, a great mass of plant remains is found, torn from the neighboring land; so that it is clear that the roof shale of a coal bed encloses as a rule a large number of isolated plant remains.

Newberry's[37] attention was attracted to the cannels and semi-cannels of Ohio at the beginning of his studies. Observations made in peat bogs of this country and Europe led him to believe that cannel was formed in lagoons, where completely macerated vegetable tissue, probably parenchyma for the most part, accumulated as vegetable mud. Among other arguments favoring his hypothesis, he urges that cannel is more nearly homogeneous than cubical coal; that it contains more volatile matter, with more hydrogen, and must have been deposited in a hydrogenous medium which prevented oxidation; that it contains aquatic animals, so abundant at times, as to prove that they inhabited pools in which cannel was a sediment; that the plant remains in cannel are usually skeletonized; and that in open water lagoons of modern peat marshes, fine carbonaceous mud accumulates, which when dried is very like cannel.

Le Conte[38] compared the peat bog and estuary theories. The arguments in favor of the peat bog theory are, the purity of the coal, the fine preservation of the tender and more delicate parts

---

[37] J. S. Newberry, *Amer. Journ. Sci.*, 1857. A synopsis of this paper with some additional notes was given by him in Geol. Survey of Ohio, Vol. II., 1874, p. 125.

[38] Joseph Le Conte, "Lectures on Coal," Ann. Rep. Smithsonian Inst. for 1857, Washington, 1858, pp. 131–137.

of plants, the position of these plants in the roof shale, the completely disorganized condition of materials in the coal, the presence of the underclay, with roots and the occurrence of vertical stems rooted in the underclay. The chief objection to the theory is the repeated alternation, in the same locality, of coal seams with marine and freshwater strata. There being as many as one hundred coal seams, it would appear as though the same spot has been raised above water level and had been depressed below it at least one hundred times.

The estuary theory was proposed to avoid this difficulty. As an estuary at the mouth of a great river is occupied now by salt- and again by fresh-water, it should contain alternating deposits of marine and fresh-water origin. In seasons of freshet, the salt water is pushed out and the river water, loaded with mineral detritus and timber rafts, makes its deposits; during low water, the sea returns and marine deposits follow.

Le Conte finds insuperable objections to the latter. He thinks that coal beds were formed as peat bogs at the mouths of large rivers. The analogy is to be sought, not in the bogs of Ireland, but in those of the Mississippi delta. He supposes a vast delta, with spaces protected by fringes of plants from influx of river muds. There pure vegetable matter would accumulate until during some violent flood the barrier would be broken down and the whole space covered by mud. The delta, like that of the Mississippi, subsided slowly and the covering of mineral detritus eventually became ground for a new marsh. If the subsidence were more rapid than the river deposits could overcome, the sea would take possession and limestone would be formed. There is no necessity for conceiving repeated upheavals and depressions. "Coal has almost certainly accumulated *in situ* in extensive peat swamps at the mouths of large rivers, upon ground which was slowly subsiding during the whole period."

Lesquereux,[39] after long study of peat bogs in Europe, came to the United States, where as palaeobotanist to several official sur-

---

[39] L. Lesquereux, Palæontological report on fossil flora of the Coal Measures, Third Ann. Rep. Geol. Survey of Kentucky, Frankfort, 1857, pp. 505–522.

veys, he examined coal beds within a large part of the Appalachian and Mississippi coal fields. His first report upon the work in Kentucky is prefaced by discussion of matters relating to the origin of coal beds as illustrated by conditions in the Appalachian basin.

Bog plants are partially immersed and ordinarily are woody. The trees are mostly resinous and are such as can thrive only in bog conditions. The Coal Measures plants are ferns, clubmosses, horsetails, reeds and rushes, in character much resembling the forms prevailing in modern bogs. The peat of the Great Dismal and Alligator swamps rests on white sand and fills the depressions, while its surface is covered by canes, reeds and shrubs; where there is a cover of water, the soft black mud supports cypress and magnolia, and a great mass of material is added each year. Some ponds were once covered with vegetation, now sunken, as in Lake Drummond, which has at its bottom a forest, probably carried down by its own weight. He found similar phenomena in Sweden, Denmark and Switzerland. The water, to permit formation of peat, must have a constant level and be stagnant. The clayey bottom of bogs was made by fresh-water mollusks and infusoria or by *Characeæ* and *Confervæ*. Peat always has this mud.

Comparing these conditions with those prevailing in the Coal Measures, Lesquereux finds: (1) The fireclay varies in thickness, color, composition and in the quantity of *Stigmaria;* sometimes no coal rests on it—the soil was ready but conditions did not favor accumulation. Yet fireclay, without coal at one place, is likely to bear coal elsewhere. (2) The coal varies abruptly in physical and chemical features, just as peat varies in all directions, horizontal and vertical; and these variations depend largely on the plants concerned as well as on the amount of foreign matter introduced. (3) The roof shales, usually very fine, are evidence of slow subsidence, sometimes without marine invasion, as shown by plant remains; sometimes with marine invasion, as where the shales contain shells of brackish water type. (4) The limestones, equivalent to or continuation of the shales, need quiet deep seawater. Influence of the sea is very distinct in erosions due to currents. (5) The sandstones were due in many cases to turbulent waters, as appears from the erosions and the mighty erect trees. The sand may have been derived possibly from dunes such as those on the Rhine or Elbe.

Lesquereux knows of no peat composed of fucoids and marine plants.

Jukes's[40] contribution to the discussion is not less important than those by Rogers and Goeppert, as it is the first presentation of the transport theory based on careful observation in an extended area. It covered the ground so thoroughly that little aside from detail or local coloring has been added since its publication.

Two opinions exist respecting the origin of coal beds; the first is that trees and plants were drifted into lakes, estuaries and shallow seas, where, becoming waterlogged, they sank to the bottom and became covered by the other accumulations; the second is that the plants were not drifted but grew and perished on the spot where they have formed the coal, just as our peat bogs would form coal if long buried under a great mass of earthy matters. While he does not purpose to range himself as an advocate of either opinion, he finds difficulties in the way of the latter which make him hesitate to accept it exclusively. These, observed in the South Staffordshire coal-field, he gives in detail.

1. The "rolls," "swells" or "horsebacks," which are ridge-like accumulations of clay rising sometimes eight feet above the floor, cannot be explained if the coal were formed at or above the level of the water; but if coal and "swell" alike were formed under water no difficulty exists.

2. The "rock faults" in the Thick coal. These are of two kinds. One, which he has not seen, is due to erosion of the coal after deposit, the hollow being filled with the material deposited on the coal. The other comes from contemporaneous deposition of silt or sand with the coal, so that they alternate at short intervals. The coal encloses cakes, layers or masses of sandstone, more or less intermingled with it. One such "fault" seen by Jukes, was 286 yards wide and it had been followed 400 yards without reaching the end. The upper part of the coal bed passes over the sandstone. At the

---

[40] J. B. Jukes, *Memoirs,* Geol. Survey of Great Britain. "The South Staffordshire Coal-field," 2d ed., London, 1859, pp. 34–42, 44–49, 201–206. The writer has not seen the first edition, published at least ten years earlier.

lateral border, both coal and sandstone split up so as to interlace. The condition is precisely similar to a cake of sandstone in clay. Jukes asks, if the sandstone was deposited in water, why not the coal also, for they are interstratified. The partings of sand in coal beds are of the same type. The laminæ of coal are obviously laminæ of deposition; their arrangement and their alternation with films of shale or with thicker partings of clay or sand would all be explained by the gradual deposition of laminæ and strata of different kinds of substances and by different degrees of mingling at the bottom of some body of water.

3. The extreme bifurcation of some coal beds; and here are phenomena extremely perplexing from the standpoint of the *in situ* theory. The great bed near Dudley, known as the Thick coal, is composed of numerous benches, each with its own persistent peculiarities. At two miles north from Dudley there are eleven benches, with 36 feet 6 inches of coal and 2 feet 11 inches of partings; while at one mile east from Dudley, there are thirteen benches with 28 feet 7 inches of coal and 1 foot 9 inches of partings. But at two miles east of north from Dudley, the upper two benches, there known as the Flying Reed coal, are at 84 feet above the Thick coal; at two miles farther, the interval has increased to 204 feet, while an intercalation of 10 feet appears midway in the Thick coal below. The benches retain their distinctive features throughout. Similar conditions prevail toward the west, where the interval between the Flying Reed and the other portion of the Thick coal increases from almost nothing to 128 feet within barely three miles.

There is a higher bed known as the Brooch coal. It is 95 feet above the Flying Reed, where that bed is 10 feet 6 inches above the Thick; but where the latter interval becomes 115 feet, the former is only 30 feet. Thus, while the Brooch and Thick are rudely parallel, the Flying Reed is oblique between them.

The normal section persists in the central southern part of the field to some distance south from Dudley; but toward the southwest the Thick coal breaks up, loses its structure and becomes worthless; toward the southeast, the bed thins out, has little good coal and is troubled by "rock faults" or "cakes of sandstone."

An additional difficulty is found in the expansion of the Thick and other coal beds toward the north. The expansion of the whole series and the splitting of the beds in that direction seem incompatible with the idea that the coal beds were formed at or above the surface of the water, while the intervening strata were deposited under it. Of the intervening rocks, those of coarse material are heaped up usually and thin out rapidly in all directions, while those of fine material have a greater area. This is true of superimposed beds forming a group; when material is fine, the disappearance of a bed is gradual. This law of area and thickness means only that fine materials were spread over a larger area "in consequence of their comparatively light specific gravity, or at least of their being more easily and therefore more widely transported by water, and being more generally diffused through it before finally coming to rest at the bottom. It was pointed out before, too, that beds of coal so far from forming any exception to this general rule, are its most marked example at the one extreme, while coarse sandstones and conglomerates form the most striking example at the other. . . . I wish merely to say as the result of an experience of a good many years, confirmed by the particular instance under examination, that the phenomena of the lamination and stratification of beds of coal, and their interstratification and association with other stratified rocks are explicable *solely by the relation of the specific gravity of their materials to the action of moving water,* and the consequent diffusion of their materials through the mass of that water."

The materials of the clays and sandstones were most largely deposited on the northern side of the coal field and sometimes failed to reach the southern part of the area, whereas the coal beds "were diffused equally, or at least more equally, over the whole area." He finds in the Bottom coal bed a notable illustration of these conditions—and it is only one of many. One "cannot fail to be struck with the obvious 'delta-like' or 'bank-like' form which the Coal Measures of South Straffordshire must have originally possessed, and the perfect resemblance they must have had to an undisturbed subaqueous accumulation. It seems to me then impossible to suppose otherwise than that the whole series of the Coal

Measures, coals included, were deposited by one connected operation of the same forces acting in obedience to the same physical laws on similar but slightly differing materials, through an indefinite but immensely long period of time."

Dawson spent many years in investigation of the Acadian coal fields, but devoted his attention especially to the South Joggins region where exposures are almost complete in a section of more than 11,000 feet thickness. He visited that locality with Lyell in 1852 and 1853 and afterwards made detailed study of each coal bed as well as of each ancient soil, subjecting samples from all to careful macroscopic and microscopic examination. The results of his studies were given in several memoirs and the details were published in the second edition of "Acadian Geology." In his first elaborate memoir[41] he called attention to the gradual passage from coal to the roof shales through laminæ composed of coaled leaves and flattened trunks, separated by clay. He expresses the opinion that erect forests explain to some extent the accumulation *in situ*. The sandstone casts of *Sigillariæ* are enclosed in bark converted into caking bituminous coal, while remains of the woody matter remain as mineral charcoal at the bottom of the cast. A series of such stumps with flattened bark and prostrate trunks may constitute a rudimentary bed of coal, of which many occur in the South Joggins section. He is convinced that the structure of the coal accords with the view that it accumulated by growth and not by driftage and that accumulation was very slow. He regards *Sigillaria* and *Calamites* as the chief contributors to the formation of coal. The woody matter remains mostly as mineral charcoal, while the cortex and such other portions as were submerged gave the compact coal. This memoir is concerned, for the most part, with the origin of coal.

In a later memoir,[42] he considered especially the subject of accumulation. After describing the formations and the physical condi-

---

[41] J. W. Dawson, "On the Vegetable Structures in Coal," *Q. J. G. S.*, Vol. XV., 1859, pp. 638, 640.

[42] "On Conditions of the Deposition of Coal, more Especially as Illustrated by the Coal Formations of Nova Scotia and New Brunswick," *Q. J. G. S.*, Vol. XXII., 1866, pp. 95–104.

tions observed in the numerous coal beds, he presents these conclusions:

(1) The occurrence of *Stigmaria* under nearly every bed of coal proves accumulation *in situ;* the sediments between the beds prove transport of mud and other materials, the conditions being those observed in swampy deltas. (2) True coal consists mostly of bark of Sigillarid and other trees, leaves of ferns and *Cordiates* with other débris, fragments of mineral charcoal, all grown and accumulated where they are found. (3) Microscopic structure and chemical composition of cannel and earthy bitumen as well as of the more highly bituminous and carbonaceous shales prove that they were fine vegetable mud as in the ponds and lakes of modern swamps. (4) A few underclays consist of this vegetable mud, but most of them are bleached by drainage. They contain not sulphide but carbonate of iron; rain, not seawater, percolated through them. (5) Most of the erect and prostrate trees had become hollow shells of bark before final embedding and their wood had been broken into cubical pieces of mineral charcoal; land snails, galley worms and reptiles were caught in them. There is much mineral charcoal on surfaces in all the larger coal beds. (6) *Sigillaria* roots have much resemblance to rhizomas of certain aquatic plants, but structurally are identical with cycad roots, which the stems resemble. *Sigillariæ* grew on soils supporting conifers, *Lepidodendra, Cordaites* and ferns, which could not grow in water. There is remarkable absence of aquatic vegetation. (7) The occurrence of marine or brackish water forms is no evidence of sub-aqueous formation. The same condition is observed in the case of submerged forests.

The channels, sand or gravel ridges, inequalities of floor observed in coal beds are familiar features of modern swamps. The lamination of coal is not aqueous lamination; it is the superposition of successive generations of more or less decayed trunks and beds of leaves. It is very different from the lamination observed in cannels and in the carbonaceous shales.

The doctrine that coal is composed of the débris of land plants, though maintained by nearly all students, did not pass unchallenged. As far back as 1815, Parrott suggested that seaweeds had contributed materially to the formation of coal and, at a later date, Bischoff conceived that the Sargasso sea might yield a coal bed. Mohr,[43] in 1866, presented this view with great energy, and his opinions received more or less support from some eminent students.

Mohr contrasts stone- and browncoal, the one being fusible the other infusible. Land plants with much woody fiber yield charcoal, which soon decays when exposed to air and moisture. But seaweeds, river and lake algæ, having no fiber, decay to slime, which hardens through loss of CO_2 and CH_4 the original composition being that of starch and the allied substances. He combats Bischoff's assertion that *Calamites* and other land plants were concerned in forming coal, for the mass of the coal is amorphous and no treatment gives trace of plant skeleton. Evidently, everything with recognizable structure is a foreign body. Coal did not originate from land plants but from water plants, whose growth is protected from air and decay.

Only one of these water plants, a grass of wide distribution, is a phaenerogam; the genera and species of the others are very numerous and their mass is inconceivable. The Sargasso sea alone has an area seven times as great as that of Germany and none of its material can escape. Here is ample material; contributions from land plants are only accessory. The ash from sea weeds contains no clay; that from coal, lignite and peat consists of silicates not belonging to plants and contains clay. This material is derived from land detritus. The ammonia in distillates from coal is of animal origin; no accumulations in landlocked basins could have animals enough to supply this ammonia, but Darwin and Meyen have described the vast numbers of mollusks and other forms attached to seaweeds.

Sea plants are swept away, decay and sink or are distributed by currents. They are heaped up to great thickness, there being 338 feet of coal in the Saarbruck basin. Darwin saw immense masses of seaweed, floating, so constant in position that they are mapped as reefs and sand banks. If a layer of leaf coal occur, it is evidence only of material brought in from the land. The absence of

---

[43] F. Mohr, "Geschichte der Erde," Bonn, 1866, pp. 82–100, 130, 137.

animal remains in stone coal is due to the solvent power of carbon dioxide coming from the decomposing seaweeds.

Muck[44] came strongly to support of Mohr's doctrine in the first edition of his work. The essential objections to the theory are: (1) That great accumulations of seaweed are not likely to reach the bottom; (2) that remains of seaweeds have not been found in dredgings, which bring up only inorganic materials and animal remains; (3) the poverty of earthy materials in stone coal; (4) the absence of sea plants, and (5) the rare occurrence of sea shells in stone coal.

The answers to these objections are:

That the first is based on supposition, originating in lack of knowledge; that, for the second, it may be well to wait for its invalidation by opposing facts; as for the third, it stands in close connection with the second and so may be of narrowly conclusive value, but it is to be remarked that the ash-poor glance coal alternates with the often very ash-rich matt- and cannel coal, whose ash does not proceed from beds intervening between the coals, but is so intimately mixed with the coal stuff that it can be due in only small degree to later infiltration; as for the fourth, absence of sea plants is explained by the fact that those plants, in dead or torn condition, with or without access of air, undergo decay very quickly, becoming, within a few weeks or months, a structureless mass, in which organic remains cannot be recognized; the fifth is answered very easily, for animal remains are calcareous and are removed by carbon dioxide which originates during the coal making process.

In the second edition of his work, Muck, though no longer urging the theory, argued that sea plants, embraced under the trivial term "Tang," offered and do offer enough material for stone coal formation. The disappearance of organic structure in stone coal is explained as easily for seaweeds as for land plants by a kind of peaty fermentation. The morphological differences between seaweeds and the land plants corresponds to chemical differences in composition.

Petzholdt[45] gave a more than halting adhesion to this doctrine

---

[44] F. Muck, "Die Chemie der Steinkohle," Leipzig, 1st ed., 1880; 2d ed., 1891. The citations are from the second edition, pp. 162–165, 168.

[45] A. Petzholdt, "Beitrag zur Kenntniss der Steinkohlenbildung," Leipzig, 1882, pp. 25, 26, 27.

though without mentioning Mohr in connection with it. Referring to the current opinion that the material for formation of coal may be wholly or at least in great part derived from land plants, he says that this is evidently pure hypothesis, for remains of undoubted land plants occur in coal only under exceptional conditions. As, at the time when stone coal and anthracite were formed, the land was sunken, it is doubtful if the then production of land plants could yield the vast quantity required for the coal beds, he is led to look elsewhere for suitable material—and that, the sea plants appear to have produced. Remembering that the fauna of the Coal Measure time was marine and that, for these vast numbers of genera and species, the nourishment could come only from algæ, he asks with Bischoff, "where are the remains of the vast masses of sea plants, which since the Plant Kingdom first appeared on earth, have grown and then perished?" He replies that they have been consumed in forming coal and anthracite beds; and he is compelled to admit the conclusion that algæ, not land plants, produced the chief material for coal-making. At the same time, he is careful to state that this is only hypothesis, without direct proof, since remains of algæ are as rare in coal as are those of land plants.

Mietzsch[46] devoted much space to discussion of this hypothesis, which he regarded as baseless. His objections are those tabulated by Muck in the work just cited. In the concluding part of his argument, he points out that the Challenger expedition crossed the ocean along several lines and that the results of dredging leave uncertain whether seaweeds, after death, reach the bottom, become decomposed at the surface or become covered with animal remains. The Challenger expedition found no seaweed on the way to coal, though, several times it crossed the area, where, if ever, such deposits might be expected. Not only the petrography of coal but also the palæontology opposes the hypothesis. Seaweeds have not been discovered and the forms known in earlier days as fucoids have proved to be land plants.

Lesquereux[47] referred to Mohr's hypothesis only to reject it.

---

[46] H. Mietzsch, "Geologie der Kohlenlager," Leipzig, 1875, p. 244.

[47] L. Lesquereux, Ann. Rep. 2d Geol. Survey of Penn. for 1885, p. 104. Same for 1886, p. 465.

Seaweeds have cellular structure alone. They decompose quickly whether exposed to atmospheric oxygen or protected from it. They are soon transformed into a fluid, black material which penetrates the sands along the seashore. He thinks it possible that remains of marine algæ may have been thrown casually on swamps and that their decomposition products, added to those of the decomposing materials, may have enriched them and may have given cannel.

J. Geikie[48] sees in the alternation of coal and limestone, evidence of prevailing subsidence, while the coal seams indicate frequent recurrence of land surfaces. The cannels and iron-stones show that many wide lakes and lagoons existed. He finds lines and ribs of cannel associated with splint and even ordinary coals, while the cannel itself passes into common coal or black shale or even into blackband ironstone. The varying conditions are due to the mode of accumulation. Cannel was formed under water, for it contains fresh or brackish water fossils. The expanse of fresh water was surrounded by wooded flats; slimy vegetable mud, with, in places, ferruginous matter, was deposited where the streams entered. Along the shores were marsh plants, while farther back were trees and fern undergrowth. The last gave ordinary coal, the marshy plants were converted into splint, while the slime became cannel, oil-shale or even iron-stone.

Stevenson,[49] as the result of studies in the Upper Coal Measures (Monongahela) of Ohio and West Virginia, came to the conclusion that at the close of the Lower Barren Measures (Conemaugh) the northern part of the Appalachian area basin was a half-filled trough separated from the western coal areas by the Cincinnati fold. He accepted the *in situ* doctrine without reserve. The conditions observed in the Upper Coal Measures prove a succession of gradual subsidences interrupted by intervals of repose, during each of which a lid of coal was formed over all or part of the basin. The subsidence could not have been paroxysmal, for, as the shore line sank,

---

[48] J. Geikie, "On the Geological Features of the Coal and Iron-stone-bearing Strata of the West of Scotland," *Journ. Iron and Steel Inst.*, Vol. III., 1872, pp. 13, 14.

[49] J. J. Stevenson, "The Upper Coal Measures West of the Alleghany Mountains," *Ann. Lyc. Nat. Hist.*, N. Y., Vol. X., 1873, pp. 226–252.

the great marsh, which became the Pittsburg coal bed, crept up the shore—and this perhaps to the very close of the epoch. Thus it is, that though giving origin to many subordinate seams, the great bed diminishes westward. The Pittsburg coal bed began at the east and advanced westwardly. There is evidence in the distribution of sandstones and shales that a delta formation at the east pushed out into the basin, so that conditions favorable to coal-making existed first on the east side of the great basin. His summary is:

(1) The great bituminous trough west from the Alleghanies does not owe its basin-shape primarily to the Appalachian revolution. (2) The coal measures of this basin were not united to those of Indiana and Illinois at any time posterior to the Lower Coal Measures (Allegheny) and probably were always distinct. (3) The Upper Coal Measures (Monongahela) extended as far west as the Muskingum river in Ohio. (4) Throughout the Upper Coal Measures epoch, the general condition was that of subsidence, interrupted by longer or shorter intervals of repose. During subsidence, the Pittsburgh marsh crept up the shore, and in each of the longer intervals of repose it pushed out upon the advancing land, thus giving rise to the successive beds of the Upper Coal Measures. (5) The Pittsburgh marsh had its origin at the east.

Two years later,[50] after further studies in West Virginia, he offered additional arguments in favor of his suggestions and extended the scope of his hypothesis. The Appalachian basin at the beginning of the Upper Coal Measures was closely landlocked, communicating with the ocean at the southwest by a comparatively narrow outlet. At the east and southeast, rivers brought in their loads of detritus to be spread over the bottom of the basin; on the opposite side, few and sluggish streams flowed from the low Cincinnati fold. During periods of repose, deltas were formed and the marsh advanced on the newly formed land. If the period of repose were long enough to permit the filling of the bay, the marsh would extend across if begun on one side, or to the middle if passing out from all sides. The basin in West Virginia was never so filled with detritus as to permit coal beds to cross it. The Appalachian basin was never

---

[50] "On the Alleged Parallelism of Coal Beds," *Proc. Amer. Phil. Soc.*, Vol. XIV., 1875, pp. 283–295.

united with those at the west, anywhere north from Kentucky and he leaves to others to decide if there was at any time a connection farther south.

Still later,[51] after very detailed studies in southwest Pennsylvania, he discussed the question Are coal beds continuous? He describes the Pittsburgh, Waynesburgh, Waynesburgh A and Washington coal beds as practically continuous in the northern portion of the Appalachian basin within Ohio, Pennsylvania and West Virginia—that is to say, that they are almost invariably present wherever their horizon is reached. But that is not true of the intermediate beds, which frequently are wanting in considerable areas; yet they are constant in many great spaces of from 100 to 1,000 square miles: he cannot resist the conviction that these beds are not in isolated patches but that for the most part these apparently separate areas are merely parts of a connected whole. The barren spaces mark localities which did not present conditions favorable to accumulation of coal. Respecting coal beds older than those of the Upper Coal Measures, he is convinced by the evidence of borings, that all, with possible exception of two, merely fringed the border of the basin.

Andrews,[52] in rendering the final report upon his work in southeastern Ohio, presented the conclusions respecting formation of coal to which he had been led by his many years study of the Ohio measures.

The Lower Carboniferous detrital rocks were deposited in shallow water; the sandstones show ripple marks, striæ and branches of marine plants (the indefinite *Spirophyton*). Some conglomerate appears in the early part of the Coal Measures, but it is confined to the shore side of the basin and disappears eastwardly [toward the center of the basin]. Rocks exhibit rapid variations laterally; sandstones pass into shales; limestones into shales and sandstones. Some marine limestones, formed in shallow water, indicate, as do the coal beds, pauses in the almost continuous subsidence; but the great limestones of the Upper Measures [Monongahela] are to be considered merely as calcareous muds, for they vary as do the other mud rocks.

---

[51] 2d Geol. Surv. Penn. Rep. KKK, Harrisburg, 1878, pp. 283–295, 301–303.

[52] E. B. Andrews, Geol. Survey of Ohio, Vol. I., Part I., Columbus, 1873, pp. 345, 347–351, 354, 357, 358.

They were deposited in shallow water, for they are close to coal beds and show the shrinkage cracks due to drying.

Andrews adheres to the doctrine of accumulation *in situ*, asserting that his studies leave no room for any other conclusion. The vegetation grew on marshy plains skirting the ocean or perhaps making low islands near the shore. Slates as coal partings are of great geographical extent, holding the same stratigraphical position throughout, thus implying a temporary overflow of the marsh by ocean waters, with an even distribution of the sediment. Some beds contain evidence of tidal flows, for beachworn sticks, replaced by pyrite, lie in the coal as they were drifted upon the marsh. After complete submergence of the bog, trees growing on the surface were overthrown by turbulent waters; thousands of trunks of *Pecopteris arborescens* are seen in the roof of the Pomeroy coal bed, bent or broken down by the sediment-carrying water; and with them are great trunks of *Sigillaria* and *Lepidodendron;* while, in sandstone, drifted and buried trees from upland areas are not rare. The continuity of coal seams was often interrupted, as should be expected in great areas.

Andrews's studies were confined chiefly to southeastern Ohio and the adjacent portions of West Virginia, where the coal area approaches the central part of the basin, the original western border having been many miles beyond the present western limit of the Coal Measures. The irregularities of deposit are comparatively insignificant and the important members show a remarkable parallelism. He was led by the phenomena of his region to deny the possibility of notable variations in thickness of intervals between coal beds and he refused to accept as correct the great variations reported from the anthracite areas.

There are many evidences of erosion and planation during deposition of sandstones. The great bed on Sunday creek shows erosion from one foot to entire thickness of the bed, the overlying sandstone filling the trench and resting unconformably on the eroded edges of the coal. The eroded surface is smooth, there being no traces of rough work such as one should expect to find, if the coal were still soft and unconsolidated at the time of removal.

Andrews thought that cannel was originally vegetable mud. He emphasizes the abundance of *Stigmaria,* saying that they fairly reveled in this ooze. They, with their rootlets, abound throughout; their existence in these beds for hundreds of miles almost necessitates the conclusion that they are *in situ.* If they are roots of *Sigillaria,* those trees must have grown in the wettest portions of the marsh, which, in that case, could not have been lagoons. The *Stigmaria* are evenly distributed. If they had been drifted in, he thinks they ought to have gone to muck with the rest.

Newberry,[53] in the following year, discussed the origin of the various deposits composing the Coal Measures. The coarse rock underlying the series contains rounded pebbles of quartz, igneous and metamorphic rocks, with rounded and angular sand of the same material as well as cherty pebbles from the Lower Carboniferous. The pebbles for the most part must have come from Archean areas at the east and north; but he finds difficulty in explaining how material from those areas could be distributed in sheets at hundreds of miles from the only possible sources of supply. It is difficult to conceive of rivers as the transporting agency and he is inclined to find the explanation in the drift deposits of the Mississippi valley, ice being the transporting agent. Where the rock is coarse, fragments of the tree trunks, of *Calamites* and of roots are present, all broken, and sometimes heaped in masses covering several rods. Fruits, like *Trigonocarpum,* occur in hollow calamites and the mass is like driftwood, everything broken and battered.

The fireclays sometimes contain stumps of *Sigillaria* and *Lepidodendron* in unbroken connection with *Stigmaria* roots. Coal is seldom wanting above fireclay, though at times it has been removed by erosion. Coal beds were formed *in situ.* Fine sediment accumulated in pools and these were invaded by vegetable growth, to be filled up finally by bitumenized remains of generations of plants. Aquatic plants remove alkalies, phosphorus, sulphur and silica from the soils, as is seen in peat bogs, where the underclays are often fireclays. The varying deposits are explained by alternate elevations and depressions of the surface. Limestones were formed in arms of the sea and their presence is proof of unequal subsidence.

---

[53] J. S. Newberry, Geol. Survey of Ohio, Vol. II., part I., Columbus, 1874, pp. 104–115, 118.

Newberry opposed the doctrine that spores of cryptogamous plants are important constituents of coal. Sporangia and spores are common enough in American coals but they are an inconsiderable part of the whole.

Dana,[54] reasoning from chemical analyses, objected to Dawson's suggestion that coal was derived largely from bark or material of that nature. Though nearer coal in composition than is true wood, bark resists alteration longer and is less easily converted into coal. The occurrence of stumps and stems outside of the coal beds, "while proof that the interior wood of the plants was loose in texture and very easily decayed, is no evidence that those trees contributed only their cortical portion to the beds of vegetable debris. Moreover, the cortical part of Lepidodendrids (under which group the Sigillarids are included by the best authorities) and of Ferns also, is made of the bases of the fallen leaves, and is not like ordinary bark in constitution; and *Equisetæ* have nothing that even looks like bark. This cortical part was the firmest part of the wood; and for this reason it could continue to stand after the interior had decayed away—an event hardly possible in the case of a bark-covered conifer, however decomposable the wood might be. Further, trunks of conifers are often found in the later geological formations, changed *throughout* the interior completely to Brown coal or lignite." He appears to be convinced that the whole plant material contributed to formation of the coal, which he regards as the product of marsh accumulation.

Dawson[55] returned to the discussion in view of Huxley's assertion that spores are an important constituent of the coal-forming mass. Referring to his study of more than eighty coal beds in Nova Scotia and Cape Breton, he asserts that the trunks of *Sigillaria* and similar trees constitute the great part of the densest portion of the coal and that cortical tissues, rather than wood, predominate. Spores and spore cases, though often present abundantly, constitute only an infinitesimal part of the great coal beds. Sporangites or bodies resembling them are present in most coals, but they are acci-

---

[54] J. D. Dana, "Manual of Geology," 2d ed., New York, 1874, pp. 361, 362, 366.

[55] J. W. Dawson, *Amer. Journ. Sci.,* 1874. Supplement to 2d ed. of "Acadian Geology," 1878, pp. 65.

dental rather than essential constituents, more likely to be found in cannel and shales, deposited in ponds near lycopod forests, than in the swampy or peaty deposits, whence the coal beds proceed. While giving credit to Huxley and his predecessors for calling attention to the importance of spores in coal, he is compelled to maintain that they have generalized on insufficient basis, that sporangitic beds are exceptional among coals and that cortical and woody matters are most abundant. The purest layers of coal are composed of flattened trunks; other coals are made up of finely comminuted particles, mostly epidermal tissues—not only from fruits and spore cases but also from leaves and stems.

Mietzsch[56] attempted to answer the question, how did the vegetable material accumulate in great beds? Was it brought down by rivers from forest covered areas or did the plants grow where the coal is now found? The mode of occurrence can be explained measurably by either supposition; at times one process may act alone, at time it may be permissible to regard both as contributing.

He describes the heaping up of driftwood along streams as well as on coasts, whither it has been carried by currents; and he thinks that in this way may have originated some tertiary deposits of lignite, composed almost wholly of stems stripped of their bark. But many deposits of lignite and brown coal contain stems with bark, twigs, leaves and fruit preserved. The Suterbrander lignite of Iceland was formerly supposed to be driftwood, because of the present conditions in that land; but Heer discovered well-preserved buds, leaves and twigs of the plants, represented by the stems, which still retain their bark. The same criterion must be applied to the black coals. Many deposits of these and the greater number of brown coals have numerous tokens, rendering improbable, in part impossible, the supposition that they were made of transported plant masses. It is difficult to understand the regularity and vast extent of coal beds on the theory of transport, for driftwood accumulations are irregular and of small superficial extent.

The composition of coal tells against the theory of transport, for in most beds the ash is very small—surprisingly small, for in the process of coalification no part of the mineral content of the plants

---

[56] H. Mietzsch, "Geologie der Kohlenlager," Leipzig, 1875, pp. 244–257.

disappears, aside from soluble alkaline compounds. Some have found proof of transport in the composition of ash from stone coal, since it is quite similar to clay shale. But Mietzsch points out that living *Lycopodiaceæ* contain from 22 to 26 per cent. of clayey earth in the ash and asks why one should suppose that the older types were different. But if the coal contain an abnormal proportion of ash, there is reason to recognize influx of fine mud.

The fineness of the materials, clay and sand, in contact with the coal, proves a long period of quiet; and the same may be said of the plant deposits themselves. Such a period can hardly be accepted for rivers or for currents along coasts. The conditions of the underclay; the resemblance of the clay in many cases, as Steffens showed, to vegetable mould; the interlacing of *Stigmaria* roots like wicker work; and the occurrence of erect trunks are all opposed to the doctrine of transport. In most cases the conditions can be explained only by the doctrine that coal beds owe their origin to plants which grew where their remains are now found. He accepts the peat bog theory as advanced by v. Beroldingen and presents many facts as additional evidence in its support. The advance of bogs into lakes is proved by the discovery of pile constructions in Swiss peat bogs; along the seashore, algae form dense floating felts on which bog plants grow and the mass sinks to the bottom. Zeeland was once cut by bays much longer than now and part of the former sea-area is filled with peat. He strengthens his argument by many references to phenomena observed in the great swamps of Europe and North America.

In order to explain the origin of coal-bearing strata, holding a number of coal beds, one must distinguish between those formed along a coast and those formed along rivers or in the interior of an island or continent. Those of the first type are explained by the subsidence of coasts bordering on the North Sea. The preliminary work for drainage of the Zuyder Zee, as well as similar work elsewhere, has proved the existence of peat bogs in extended areas of shallow sea; anchor flukes have brought up peat from depths of 200 meters on the English coast. Such bogs become covered by river sediments and in case of long-continued slow sinking, the shallow sea area is filled, so that a number of bogs may be formed successively. Among other illustrations, he refers to the discovery at Rotterdam of two bogs, 5 and 6 meters thick, separated by 4 meters of clay; to the presence of erect trees which, despite the long period which has passed since they sank below the water surface, are still standing on the sea bottom, partly surrounded by sediments; such trees on the coast of the islands of Sylt and Romo are of types which disappeared from that region many hundreds of years ago.

Changes in grade of rivers, caused by damming or by crustal movements, would lead to covering of bogs with sand or mud and to the accumulation of rock masses. He finds confirmation of this view in Livingstone's statements respecting the floods of African rivers and in the observations of others elsewhere.

Lesley[57] in prefaces to reports by geologists of the Pennsylvania survey, made frequent references to hypotheses respecting formation of coal beds. Ordinarily, he preferred to present the matter, as it were judicially, giving the difficulties in the way of accepting the hypotheses and leaving the decision to the reader. But in two of the prefaces he offers some important suggestions.

W. G. Platt described a little basin, barely a mile and a half across, in which three sections of Coal bed D were obtained. In all of them, the bottom bench is 2 feet 7 inches thick and composed of brilliant coal; but the upper part is a dull cannel or cannel shale, measuring 1 foot 3 inches, 8 feet 3 inches and 1 foot 2 inches, while between the last two the dip is about 8 degrees compared with about one degree elsewhere. A noteworthy feature is that while the ash in the cannel is from 21 to 25 per cent. and that in the pure coal below is only 1.6 per cent., yet the ratio of volatile matter to fixed carbon is practically the same throughout.

Lesley felt convinced that the petty basins, in which cannel was deposited, were waterways or pools and that more of them existed at once in certain horizons than in others. They were not due to erosion for the underlying coal bed is not cut out, it is merely depressed. There is no evidence of currents, for the mud is fine, the lamination perfect and the roof soft. The pools were almost stagnant. How could a depression come about to give, as here, a dip

---

[57] J. P. Lesley, Second Geol. Survey of Pennsylvania, Indiana County, 1878, pp. xiv–xviii; Lawrence County, pp. xix–xx.

of 5 to 10 degrees to an almost dead level bituminous coal bed? There is no room for suggestion of crustal movement as the area is too small; equally the cavern theory is excluded for no limestone underlies the horizon except at vast depth. He can see no explanation for most of the localities except in the subsidence of a floating bog, such as Lesquereux has described. On this the fine muds accumulated and the pool was filled.

He was led in this connection to consider the sequence of coal beds. If the Carboniferous plain consisted of a low area with shallow ponds, the coal forming vegetation would conform to the dimpled surface and there would be but one coal bed, intersected by river channels. This plain, if continuous, would be not less than 1,000 miles long by 300 miles wide [this refers to the Appalachian basin]. It is very difficult to account for the submergence of this continental plain to a depth of 50 feet below sealevel in order to give opportunity for formation of a second bed. Yet this "slow depression theory" may not be rejected easily, for without it, one cannot conceive how 20,000 to 40,000 feet of palaeozoic sediments could have been deposited; the more so, since many of the strata give every evidence of deposition in very shallow water. As a partial alternative, he suggests that the relative sea level may have been changed by the filling of basins. The effect of deposits by great rivers and that of glaciation are discussed but no conclusion is reached.

In the preface to the Lawrence report, he attempts to explain the origin of underclays. A peat bog and even a lake invaded by sphagnous growth must have some water circulation due to percolation from the surrounding land and to evaporation from its own surface—but the movement would be very feeble and it could transfer only the finest mud, though in course of time the result would be important. Dry grounds are largely fine gravel with rounded quartz and feldspar grains; the feldspar is soluble, it follows the indraught and settles beneath the evaporating surface with its floating peat. If the peat area be surrounded by clayey land, the percolation would be at a minimum; the water supply would be from the surface and less muddy, so that the underclay would be less in quantity. It would appear, then, that when the margin was a tight clay, deposits of calcareous type show that limestone must have been exposed within the drainage area.

The thickest underclays should belong to beds next or near above the great sandrocks and it is a fact that our great clay beds are near the base of the Lower Productive Coal Measures [Allegheny] and that the few important clay deposits high in the series have coarse grained sandrocks not far below them. A logical consequence of such conditions is that sandrocks geologically close to such great underclays should be purer, more open sands and gravels than others which had not been robbed of so large quantity of interstitial clay. If the surrounding land contained iron in its gravel, there should be ball ore in the fireclay—as is seen in the New England ponds surrounded by drift.

Davis[58] described a cannel deposit in Yorkshire, somewhat resembling that discussed by Lesley. The bed is thickest in the center and thins away in each direction, meantime becoming less pure and passing into bituminous shale at the circumference. The condition is due to in-floating of plant remains, which sank to the bottom of the pond. The marked interlamination of shales and their marked increase toward the border resulted from more rapid subsidence of the muds. In some places the pond was filled up; there the underclay has abundance of *Stigmaria* and the plants growing in such places were converted into ordinary coal. Afterwards the whole mass was submerged and covered with black mud. The cannel is fine, close-grained, homogeneous, with conchoidal fracture, without planes of deposition and everywhere yields beautiful specimens of fishes.

Reinsch[59] undertook the microscopic study of coal. He prepared a great number of sections, subjected them to close examination and published his results in an elaborate volume with 95 plates. These exhibited the structure of the coal as well as numerous forms which seemed to be organized. Reinsch maintained that the coal

---

[58] J. W. Davis, "On the Fish Remains found in the Cannel Coal of the Middle Coal Measures of the West Riding of Yorkshire," *Q. J. G. S.*, Vol. XXXVI., 1880, p. 56.

[59] P. F. Reinsch, "Neue Untersuchungen uber die Mikrostructur der Steinkohle des Carbon, der Dyas und Trias," Leipzig, 1881.

substance originated, mainly, from marine plants of such peculiar form that they cannot be assigned to any group of known types. He created a new group for their reception, *Protophytæ,* of which he made seven divisions. Remains of land plants are of very rare occurrence. This hypothesis differs from that of Mohr in that the plants are microscopic.

Petzholdt[60] at once made a fierce critique of Reinsch himself, his methods and his results. Of the seven divisions of *Protophytæ* two are decomposition products, three are certainly inorganic, one consists of fragments of land plants and one is based on minute fragments of coal. The decomposition products, mistaken for organic bodies, are termed bitumen by Petzholdt, who thinks them the same with those discovered fifty years before by Hutton in his study of the Newcastle coals.

Fischer and Rust,[61] following Reinsch's method, found not only yellow and reddish resin-like bodies in black coal, such as make up the great part of the Scotch boghead, but also small grains, showing wood structure, in anthracite. In the black coal, they observed spindle-shaped or serpent-shaped bodies, whose relations they could not determine. The English cannel from Lancashire is very rich in little resinous cylinders and, as far as richness in resinous matter is concerned, is intermediate between the Bogheads and the ordinary coals. These studies have an important bearing on investigations which have attracted much attention in more recent years.

Green[62] says that it is not easy to see how light material, such as dead wood, could be spread out evenly over tracts of hundreds of square miles, so evenly that the deposit shows comparatively little variation in thickness; and it is equally difficult to understand how, in case the coal be composed of drifted materials, it could be so pure as we often find it. The water bringing the vegetable matter

---

[60] A. Petzholdt, "Beitrag zur Kenntniss der Steinkohlenbildung," Leipzig, 1882, pp. 23 et seq.

[61] H. Fischer and D. Rust, "Ueber d. mikroskopische Verhalten verschiedener Kohlenwasserstoffe, Harze und Kohlen," *Groth Zeitschrift f. Kryst.,* Vol. VII., pp. 209–243. This has not been seen by the writer. Cited by Petzholdt and v. Gümbel.

[62] A. H. Green, "Geology," Part I., Physical Geology, London, 1882, pp. 257–262.

would certainly carry also mineral matter. The coal and its ash may, both of them, be of vegetable origin. Logan's discovery of the underclay or Seatstone under nearly every coal bed was the first great step in the right direction toward solving the problem. Binney's study of an erect stump discovered by Hawkshaw near Manchester was the next, for there a *Sigillaria* with *Stigmaria* roots was rooted in a seat clay, while the stem was surrounded by rock. Many similar cases were discovered. The underclay was the old soil supporting plants which produced a layer of nearly pure vegetable matter. When the surface was lowered beneath the water, sand and clay were laid on top and the band of dead plants was converted by pressure and chemical change into a seam of coal.

When sinking ceased, the shallow water was filled up and a swampy plain was made. Vegetation spread out from the land and a second coal bed began to accumulate. This process repeated many times over gave a succession of sandstone and shale with coal beds at intervals. The great swampy expanses in the delta of the Ganges and Brahmapootra must bear close resemblance to the marshy flats in which the coal was formed. The nearest approach, however, is in the accumulations on the coast of Patagonia, described by Lady Brassey in "A Voyage in the Sunbeam"; "To penetrate far inland was not easy owing to the denseness of the vegetation. Large trees had fallen and, rotting where they lay, had become the birthplace of thousands of other trees, shrubs, plants, mosses and lichens. In fact in some places, we might almost be said to be walking on tops of the trees, and first one and then another of the party found his feet slipping through into unknown depths."

There are, however, deposits of subaqueous coal, derived from driftwood carried down and buried amid mechanical deposits, but they are irregular and are apt to be impure. It is probable that the patches of cannel coal mark sites of pools or lakes in which vegetable matter lay until it was macerated into a pulp. This passes gradually by increase of earthy admixture into well-stratified carbonaceous shale.

Green had already presented the same suggestions, though briefly, in his work on the Yorkshire coal-field published in 1878.

Grand' Eury,[63] in the first section of his notable memoir, gives the grounds on which his theory of transport is based.

When one makes minute examination of coal, he discovers that the plants have been broken up and the parts scattered; fruits and leaves are apart from the stems; the layers of the bark are separated and dispersed; the interior parts of the stems have disappeared and the flattened cortex alone remains. The woody portions of the stems have been dispersed as fusain [mineral charcoal]. Stems are split and torn, *Cordaites* leaves are imperfect, everything, bark or leaf, is broken up. He thinks that a great part of the tissues was transformed into a kind of vegetable pulp, which makes up most of certain coal beds. That this was not wholly fluid or homogeneous is evident, for one may distinguish some traces of organization with the microscope or even with a magnifying glass.

The disintegration of the plant organs occurred after death and its character puts aside all suggestion of violent action. All the evidence contradicts the supposition that the forests were ravaged by inundations; everything points to quiet, peaceable flow of water. Most of the material was decomposed in place and carried away piecemeal. The vegetable matter was not deposited in deltas within either the north or the center of France.

The preservation of stems reduced to their bark is not surprising, for there was little wood in trees of the Carboniferous; but the mineral charcoal is not so easily accounted for. It seems to be fossilized buried wood, dried in the air and not changed into coal. It did not originate through maceration, though after formation it may have been subjected to moisture, as is indicated by lack of sharpness in outline.

The vegetable disaggregation was rapid, mostly in air, and was completed in swamps before removal. The conversion into detritus and the quasi-dissolution were sometimes pushed very far at the base of damp forests and at the bottom of swamps. The Carboniferous forests were marshy and aquatic. The plants grew quickly, reached maturity and soon died. Growth had to be energetic in order to carbonize the bark so as to make the contraction

---

[63] G. Grand' Eury, "Memoire sur la formation de la houille," *Ann. des Mines.*, Ser. 8, T. i., Paris, 1882, pp. 101–122.

small in coalification. That the air was damp and warm is proved by the aerial roots of *Psaronius* and *Calamodendron;* and the heat of the climate appears from the dense resinous bark, which often dominated the wood. Strong light, great heat, excessive humidity, great marshes in which plants grew quickly and died, explain conditions not easily explained by conditions of the present time. The residues falling into the marshy bottom of the forest, underwent aqueous rotting; they were then transported to the areas of deposit, which preserved them from complete destruction.

Grand' Eury published much relating to this subject and in 1900[64] he summarized all the results of his long studies in a memoir presented to the geological congress.

He describes fossil forests *in situ,* which show that the Carboniferous plants, though arborescent, were forms of marsh-habit like those of the Dismal Swamp, the foot and adventive roots in the water, but the stocks and rhizomas creeping on the bottom. The forests were very local. Growing in stagnant water and fixed by few roots to the ground, they were destroyed by slight causes and the roots alone remained. This would give a "soil of vegetation" as described by Dawson—a feature as familiar at Saint-Etienne as in Canada.

Coal is stratified, evidently deposited under water. There is no evidence that roots ever traversed the parallel laminæ of which it is composed. The stocks and roots, descending in the roof, spread out on the coal but never penetrated it. This condition is constant and is due to the circumstance that slowly deposited vegetable matter, undergoing fermentation, is opposed to the introduction of roots, which, being unable to live in it, instinctively refuse to pierce it. Similarly there is no relation between stocks and overlying coal. Their roots are often enclosed in coarse twisted coal composed of overturned stems, with leaves, branches, which, however, is continuous with overlying laminated coal. The elements are the same in both and they are identical with those in the adjacent shales, so that transportation from a distance is impossible. There is then in some coal beds evidence of formation in place or almost in place.

---

[64] C. Grand' Eury, "Du bassin de la Loire," *Compt. Rendus VIII^{me} Congres Geol. Intern.,* Paris, 1901, pp. 521–538.

But most of the material forming the beds was transported; yet all coals resemble that found almost in place and the parts, certainly transported, are identical with similar parts of the rooted stems. The materials were derived from marshy forests on borders of the basin, which doubtless succeeded those temporarily installed in the basin of the deposit which afterwards became a lake. At the foot of this forest was elaborated, as in peat bogs, the humus or fundamental material of the coal. The basin of deposit was much like the bottom of a morass, for the mud of coal beds often resembles the clay underlying peat bogs. The debris of plants falling into water on the borders of the marsh became stratified in its depths. Grand' Eury was convinced that by this hypothesis he had reconciled the opposing theories, for he has shown that certain coal beds were formed by concurrence of both processes, as in the subaquatic parts of some swamps.

The permanent swamps, where primitive peat was elaborated, were not exposed to deposit of mineral sediments, they remained uncovered and disappeared; so that very little of the coal formed in place remains. The researches of Renault and C. E. Bertrand on cannel and the fundamental matter of coal show that coal was not always deposited on lake bottoms under moving waters, but that it may have been formed in stagnant or quiet waters of swamps.

The coal was deposited slowly, not continuously and there may have been long periods of arrested growth. The concentration of fossil forests and soils of vegetation in and near coal beds proves for the thick beds a very long period. Additional evidence in this direction is found in the advanced decomposition of the rocks forming the roof, their new chemical combinations, their impregnation with carbon, showing that they had been long in contact with the swamp before being transported and deposited on the coal bed.

The basin of the Loire was subjected to orogenic movements. The fossil forests have irregular distribution both vertically and horizontally; great sterile deposits break up the continuity. The basin was deepening throughout the period of formation, but each important coal bed corresponds to an interval of stability. That the mineral materials were brought in by streams is shown by their distribution. The granitic rocks of the northern portion thin toward the south and their rooted stems lean toward the south and southeast; but the micaceous rocks of the southern portion thin toward the north and the rooted stems lean in the same direction, sometimes strongly. These mineral deposits interlock as wedges. But the coal beds pass from one type of rock to the other, preserving well their distance and parallelism. Grand' Eury finds no evidence to support the delta-theory of accumulation in deep basins; every feature leads to the belief that the mass of rocks could accumulate only by means of a subsidence, equal and progressive from the clay bottom.

In a still later paper,[65] Grand' Eury shows that coals of all kinds are practically alike in origin.

Coal beds are deposits of allochthonous peats formed by an exuberant vegetation, loving water, whose detritus was carried from shores to interior of immense marshy lagoons, where barks, cuticles and the rest were stratified with ulmic substances under the water. Stipites or dry coals of the Secondary in France are clearly the same in origin with the coals. Mineral charcoal is so abundant in one of the Upper Cretaceous coals as to give a finely-stratified structure to the bed. The brown coals of the Tertiary resemble coal completely in mode of occurrence; they are composed of marsh plants, leaves of dry land plants being in small proportion. Lignite is wood-like in appearance though formed of red humus from plants; they show much variation, but the mass of the material is derived from marsh forms. The peats of lowland areas or marshy plains are allochthonous—they resemble almost all deposits of mineral coal.

Gruner[66] notes the ancient forest in the quarry of Treuil, which had been described by Alex. Brongniart many years before. At 100 meters lower and almost directly under the quarry, Gruner found in the Treuil mine twelve great trunks in a space of less than 10 meters square; their roots spread out over the coal but did not penetrate into it.

He cannot accept the doctrine that coal consists of transported material. The continuity and uniformity of coal beds make a serious

---

[65] C. Grand' Eury, "Sur la formation des couches de houille de stipite, de brownkohle et de lignite," Autun, 1902, pp. 123–132.

[66] L. Gruner, "Bassin houiller de la Loire," Paris, 1882, pp. 160–170.

objection. In the little basins of Saint-Etienne, beds can be followed 5 to 10 kilometers in one direction and 2 to 4 in another with little change. He thinks that a current capable of uprooting trees would tear away the soil and pebbles also, so as to give a mingling of trees and detrital matter.

As large streams carry much mineral material there should be an alternation of vegetable elements and mud—and this is found in coal beds where shale appears in thin layers between benches of coal. These shales or the nerfs of fine sandstone could be produced only by water-currents, by inundations of brief duration covering the debris on the surface or invading shallow basins in which leaves, etc., were deposited slowly. The two modes of accumulation went on simultaneously in the coal period as they do now in peat bogs. He does not assert that coal was the peat of palaeozoic times; the flora and the climate were different; but the mode of formation was the same. The plants of the coal epoch grew where their remains are found. He cannot accept Grand' Eury's theory, which opposes the doctrine of *in situ* accumulation because stumps and trees are wanting in the coal beds themselves. Grand' Eury maintains that the vegetable matter was transferred from the place of growth to the basin where the coal is found, but the distance was small.

Gruner maintains that the current would have brought more than leaves and stems and that it would have distributed its load unequally; he thinks it preferable to conceive of a marshland extensive enough to admit of a thick cover of vegetable débris over an area of several thousands of square kilometers—as one finds in the Nord basin. Grand' Eury emphasizes the absence of stumps and roots passing from coal beds to the mur. But at Saint-Etienne itself, Lyell and Gruner saw rootlets passing from the coal into the underclay and Gruner saw the same condition in the Batardes coal bed, where *Stigmaria* abounds in the mur. The absence of stumps in the coal is to be expected, because the soft tissues would be crushed quickly under pressure and all traces would be effaced; moreover, in the nature of the case, stumps would be only a small portion of the mass. A negative result of study does not prove that the plants did not grow *sur place.* Since the rapid current, which piled sand around the forests of Treuil, did not uproot the trees, one finds difficulty in understanding how the waters so slightly agitated as to be able to draw off only leaves and twigs did not leave in place the stumps whose roots are seen to-day in the underclays.

The preservation of the underclay proves that the stumps were not torn out before deposit of the plant debris forming the coal bed. The clay shows no signs of erosive action such as are seen so often in the roof. The deposit of the clay is itself a proof that then had begun the long period of tranquillity, which continued during formation of the coal. He is convinced that it must be admitted as almost proved that the coal beds have come from a vigorous local vegetation, whose debris accumulated at the bottom of shallow stagnant water and probably, quite as often, on a damp but not flooded surface.

The intervening rocks are, in character, wholly similar to partings in the coal beds, but they were formed not by petty inundations but by strong currents of prolonged duration. The existence of these is proved by erosions as well as by the sands which covered the coal forests. The surface subsided at intervals, as shown by phenomena connected with the faults in the Loire basin. But the flora was not destroyed, for one finds forests or isolated trees in place, in sandstones at all horizons, their bark preserved as coal. The sands are evidence that the agitated water prevented quiet deposition of vegetable debris. That was destroyed or scattered afar.

Meanwhile, the sunken surface was leveled up and the depression was filled. A second marsh was formed above the first, now buried under a thick bed of sand or mud. If the deposit of sand, etc., did not exceed 30 meters, the conditions under which the new bed was formed might not differ from those of the earlier bed. But when the sterile interval attains great thickness, 100 to 800 meters, the period of depression was very long and before its close the flora had undergone modification. Thus it is that one finds successive appearance of varied types, so that classification of the Coal Measures by their flora becomes possible. Subsidence of the type here conceived has been observed in rocks of all epochs. Lament and

Degousie, in sinking artesian wells at Venice, found beds of lignite and carbonaceous clays at 40, 60, 100 and 120 meters from the surface.

Von Gümbel,[67] perplexed by the contradictory results presented in memoirs, undertook a series of systematic studies, covering all phases of the subject. His study did not concern itself with chemical or technical matters and had little reference to botanical relations. At the outset, it deals only with questions relating to the constitution of coals; it begins with examination of peat-like substances and advances, step by step, to anthracite and graphite; it ends with a discussion of the mode in which coal beds accumulated. In breadth of scope, this study excelled that by any predecessor; in compactness and precision of statement the memoir has rarely been excelled. Much of the earlier portions bear directly on questions respecting the transformation of vegetable matter into coal, a subject to be considered in a later part of this work; but some of his observations are so closely connected with the final part of his discussion that they cannot be neglected.

The method of investigation by means of thin sections did not commend itself to v. Gümbel, who preferred the method proposed by Franz Schultze. The broken coal was treated first with potassium chlorate and strong nitric acid, and afterward with ammonia, in order to separate the particles and to make the transparent portions more readily available. Absolute alcohol completed the preparation by removing coloring matters. He gives specific directions as to the use of the reagents and warns against the possibilities of error in the study.

This investigation led him to recognize that the whole series from peat to anthracite is continuous and of similar origin. All of the members are made up of combustible materials. "Stone coal consists, apart from the earthy admixtures, of parts of plants, which, changed into a coaly substance, have taken up into their empty spaces, as well as into the intervals between the plant débris, a humin-like or ulmin-like substance (carbohumin) which was origi-

---

[67] C. W. v. Gumbel, "Beitrage zur Kenntniss der Texturverhaltnisse der Mineralkohlen," *Sitzungs. Berichten der k. bayer. Akad. d. Wissenschaften. Math.-Phys. Klasse,* 1883, pp. 113 et seq. The citations are from pp. 190–212.

nally soluble, but became insoluble, so that the whole is amorphous and apparently structureless." The taking up of this material is the Inkohlungsprozess.

Adjacent rocks, containing plant remains, may have contributed to this coalification by means of circulating waters. It is self-evident that this soluble material might be deposited by itself apart from any remains of plants, not merely as layers of a coal bed but also in cracks and fissures; but such layers of structureless coal could have contributed in only subordinate manner to the formation of coal beds.

The several types of coal, Glanz-, Matt-, Faser-, Cannelkohle and the rest cannot have originated under similar conditions. In considering these he takes the most complicated condition—where several varieties occur in the same bed. Three modes of explanation are suggested by the investigations: (1) Original differences in kinds and parts of plants; (2) differing conditions, chemical and mechanical, in which the plants came to contribute toward making the coal; (3) heterogeneous external conditions under which the transformation was completed.

Difference in material in the several types of coal appeared constantly during the study; bark, and woody parts along with leaves in Glanzkohle; abundance of leaf organs, especially of the epidermis layers and less abundance of hard parts in Mattkohle; constant recurrence of little balls, membranes, the spores of authors, in astonishing abundance with algae-like clumps in cannel-like layers; all proving a certain dependence of constitution on the character of the plant remains. It is clear that the condition under which the plant material was accumulated was of great importance. This is evident from the great amount of Faserkohle [fusain, mineral charcoal]. If this material result from decay in free air, as would occur in the occasional drying of the surface in peat bogs, one must concede that this process was of vast extent during the coal-making time. It is unnecessary to suppose that the great supply was swept in; it could have been produced as readily on the bog surface. Similarly the dismembered parts of plants, clods or flocks, and the rest belong to a stadium anterior to formation of the coal. The presence of plant remains in soil, in every peat bog, justifies us in tracing back in some degree, certain relations of coal formation to similar origin. Accumulation of cannel-like coaly substances cannot be explained otherwise. The tertiary gas coal of Falkenau, pyropissite and Lebertorf all consist of a similar wholly broken up mass of plant parts. External relations had much to do with the conditions. If inflowing water bring much mineral matter into a bog, the borders are impure while the main portion is pure. So a coal may be impure on the borders and pure in deeper portions of the basin. Even the character of the overlying rock may be important.

Passing from the composition of the coals, he considers the mode of accumulation; first of all, rejecting absolutely as without foundation, the doctrine that coal could have been formed in the open sea and from seaweeds.

Coal beds consist of alternating, mostly very thin layers, like beds of sedimentary matter; this, with the fact that they are associated in series with undoubted sediments, seems to afford proof for the opinion that coal beds originate as do other sedimentary strata, in contradiction of the so-called peat theory, which accepts the idea of an origin in place after the manner of peat bogs. If one confine his attention solely to this layer-like accumulation and make no further inquiry, the conditions appear so completely explained by the former doctrine that facts favoring the latter have no value. V. Gümbel thinks that the presence of upright stems is of comparatively little importance as a proof of autochthonous origin, since their presence is exceptional and it can be explained in several ways—by drifting, by advance of waters into swamp forests or by plant growths floating on the water.

A careful examination of the query as to whether or not the lamination of coal can be explained by anything except deposit of suspended matter, leads to surprising results, when extended to the newer coal accumulations. The Quaternary brown coal offers an instructive illustration of the mode in which the lamination originated. These have absolutely the same structure as that of stone coal beds. It is known positively that they owe their origin to peat-like swamps and that the clayey, sandy partings, which accompany them, proceeded from occasional overflows. Coming down a step farther to the coal making of our own time and ignoring for the present the various local modifications of peat, one can recognize two distinct modifications; Autochthonous, that forming or originating in place, and Allochthonous, the sedimentary, due to deposit of plant detritus in pent up waters. The latter shows, of course, evidence of sedimentary origin, is more or less dense and homogeneous, contains much earthy matter and the plant remains are notably advanced in change. Often it shows lamination only on drying.

All kinds of peat have the lamination. In Moortorf there are often alternating layers, differing in color, density and composition; in Specktorf the structure is especially distinct. Peat then is not an unstratified mass and one cannot say that the lamination of coal places it out of comparison with peat. Close investigation shows so many similarities between the peat layers and those of some coals, that this kind of structure favors rather than opposes comparison of coal-making with peat-making. This lamination appears in the autochthonous peat, in the diluvial brown coal originating in peat and in the whole range of the brown coal formation. But one must remember that the coals were not all formed on the same model; that comparison with peat is only tentative, as modern peat is made from moss and swamp grasses, while in the coal time the deposits came from a wholly different moor and swamp vegetation.

The stone coal formation for the most part is to be regarded as an inland formation, originating in widespread leveling and subsiding of the land, in many cases on swampy lowland along the seacoast, over which floods distributed materials, such as shale and sandstone. On the extensive but not high land of the Carboniferous time, waters were penned in great areas and became converted into morasses, where a luxuriant vegetation flourished. It is very probable that in occasional drying of the swamp followed by renewal of the flooding, one may find explanation of the alternating bright and dull coal. This does not exclude influx of broken and shattered plant stuff from the higher surrounding region; that might even have predominated in some localities and have been the basis for cannel and boghead. Even from the swamp vegetation itself, decaying material might float away to deep water within the swamp, so as to be heaped into peculiar massive layers like cannel. Flooding of the plain and deposit of mineral matter checked formation of coal; but the swamp would be re-established and a second formation be made; or possibly for a long period only rock material might be deposited.

How far variation in the water niveau may affect the question is considered only so far by v. Gümbel as to let him warn against the conception that basins, now filled by a thick series of coal bearing deposits, were filled with water in like manner at the beginning. These bowls were filled very gradually; they must be thought of as filled temporarily by a relatively shallow pond of water, which little by little reached a higher level.

At times, marine remains occur in strata between the coal beds, a condition which seems opposed to the explanation offered. But this occurrence is due to the fact that the low swamp land was spread out near the sea and was exposed to invasions, so that remains of marine animals might be enclosed in materials originating on the land. Marine or brackish water forms might be enclosed in the coal deposit itself, if it were formed alongside an arm of the sea.

In general, coal beds are an autochthonous product of dead, broken and disintegrated plant fragments with only local and petty contribution of transported material of the same character.

Wethered[68] called attention to the fact that coal seams are not single beds, but are separated by partings into benches which may differ in quality as well as structure. Sometimes *Stigmaria* are present in the partings.

The Cannock Chase or Shallow seam, near Edinburgh, has in its upper bench, 1 foot 10 inches thick, the brownish layers composed of macrospores and microspores, while the bright layers, containing some woody tissue, are composed mostly of a structureless material which he terms "hydrocarbon" in preference to "bitumen." Whence this comes he does not know, but wood tissue may contribute to it. The middle division of the bed is very different, consisting almost wholly of "hydrocarbon" with very few spores.

[68] E. Wethered, "On the Structure and Formation of Coal," *Q. J. G. S.*, Vol. XL, 1884, *Proceed.*, pp. 59, 60.

It is possible that spores may have been there and that they may have been decomposed, but spores are much more resistant than is woody material. The main division has a great accumulation of spores but also a fair proportion of the "hydrocarbon." He concludes that some coals are made up practically of spores, others are not; the differences in benches of a coal bed are of this character. Harker, reasoning from the ornamentation of the spores, suggested that they may have come from a plant related somewhat to *Isoetus.*

In the discussion of this paper, Carruthers took exception to conclusions based on markings seen on spores. He knew of no reason for referring those spores to *Isoetus* or any other form of submeged vegetation. Spores in coal were discovered first by Morris; they are associated with *Sigillaria* and *Lepidodendron;* the coal was the soil for the vegetation, penetrated by *Stigmaria* roots of the plants. A *Sigillaria* stem, at the Leeds museum, filled with white sand, penetrated far into the coal in which it grew. Coal seams are remains of forests which grew on swampy ground. The macrospores were not composed originally of brown substance, they are merely filled with it.

E. T. Newton stated that some coals are certainly made up of macrospores and microspores. Dull coal contains spotted tissue; intermediate coal contains both forms of spores; bright coal is a brown substance, usually structureless, but in one case, known to him, it consists wholly of spores.

Dawkins had never found sporangia in coal though both macrospores and microspores are abundant. Coal consists of carbon and resin, the latter giving the property of blazing, which Huxley would attribute chiefly to the spores. With this conclusion, Dawkins agrees only in part. The carbon comes from decomposition of woody portions, but the resin from cell concretions in the living plant. Carboniferous forests grew on level alluvial tracts but little above the water level.

Dawkins,[69] discussing the geographical conditions in Great Britain during Carboniferous time described the mode in which the coal beds accumulated.

[69] W. B. Dawkins, "On the Geography of Britain in the Carboniferous Period," *Trans. Manchester Geol. Soc.,* Vol XIX., 1887, pp. 45–47.

Oscillations of level still continued as the north, but the land constantly encroached on the shallowing sea, the mud encroaching on the Carboniferous limestone and the sandbanks following the mud closely. Meanwhile "the terrestrial vegetation was spreading from the old Lower Carboniferous land areas over the new Upper Carboniferous marsh lands, from the mountains of Wales and from the other Lower Carboniferous islands, now uplands. These forests contributed in their decay, through many generations, the accumulation which now, compacted by pressure and subjected to earth heat, is familiar to us as a coal seam. Each coal seam represents a land surface, just as the sandbanks and mudbanks (sandstones and shales) above it point to submergence. The fact too that the coal seams in a given section are parallel to each other or nearly so, implies that the forests grew on horizontal tracts of land, just as the associated sandbanks and mudbanks, with marine or freshwater shells, prove that these horizontal tracts were near the sea level or within reach of the waters of a mighty river. We may learn also from the study of the isolated coal fields that this great horizontal tract of forest clad alluvia occupied nearly the whole area of the British isles in the Upper Carboniferous age, from the Scotch Highlands southward, the dead flat being broken only by the higher lands, the old islands of the Lower Carboniferous sea, which I have already described. It was indeed the delta of a mighty river, analogous in every particular to that of the Mississippi—a delta in which from time to time the forest growths became depressed beneath the water until the whole thickness (7,200 feet in Lancashire) was accumulated of coal seams and associated sandstones and shales. After each depression the forest spread again over the bare expanse of sand and mud piled up in the depression."

The great northern and western land, termed by Dawkins, Archaia, whence came this mass of mineral deposits, occupied the North Atlantic sea, stretching from the west coast of Ireland and the Scottish Highlands to the American continent. To this great land may be traced the pebbles and groups of pebbles found in the Lancashire coal seams, mostly quartzites, which probably were brought down in flood time in roots of trees from the shingle beach.

Williamson,[70] in discussing the characteristics of the great fossil in the Owens college museum, remarked that that specimen had removed finally all doubts respecting the relations of *Stigmaria* by showing that plant to be the root of *Sigillaria.* The roots divide only once and after division extend indefinitely. The stigmata are lacking near the stem because the roots increased by exogenous growth and the superficial portion with its rootlets was thrown off. The trees grew in swampy ground as the swamp cypress does in American swamps. The gymnospermous plants grew on drier ground. The particular tree under consideration must have been at least 100 feet high. When it died, decay continued downward to the point shown and then was checked probably because the lower portion was buried in sediment and protected from air. Thence decay proceeded very slowly until the woody tissue of even the root disappeared. Meanwhile, the surrounding rock had hardened and had taken a cast of the stem and roots. The surface sank beneath the water and soft sand filled the cavity; thus the roots have their original form.

Fayol, after spending many years in study of the basin of Commentry, published his results in a remarkable work, which is unexcelled as a record of detailed observation. This work presented the grounds on which, several years before, its author had based his theory respecting the formation of coal beds. The positive position taken in favor of the transport theory and the clearness, with which the observations were offered, caused a notable reaction in favor of the doctrine that coal beds are formed of transported vegetable matter. A year after publication of the work, Fayol gave a summary of the delta theory, as he termed it, at the summer meeting of the Geological Society, when several members of the society commented on the theory. This resume, being the later presentation, is the basis of the present synopsis.[71]

The theory is based on the laws of sedimentation, as observed in

---

[70] W. C. Williamson, "On the Fossil Trees of the Coal Measures," *Trans. Manchester Geol. Soc.*, Vol. XIX., 1888, pp. 381–387.

[71] H. Fayol, "Études sur le terrain houille de Commentry," I^{re}. partie. "Lithologie et stratigraphie." *Bull. Soc. Min. Ind. St-Etienne,* 2^{me} Ser., XV., Liv., III., IV., 1887; "Résumé de la theorie des deltas et histoire du bassin de Commentry," *Bull. Geol. Soc. France,* 3^{me} Ser., XVI., pp. 968–978.

deltas. Mingled detritus brought in by streams forms a stratified deposit in the basin, where the beds may be composed of a single substance or of several. Those beds are inclined, irregular and of small extent in tranquil waters but less inclined and of wider extent in agitated water. The inclination may vary from 0 to 45 degrees; different portions of a bed may vary much in age, while beds at different levels may be contemporaneous. The total thickness of a deposit has no necessary relation to the sum of thicknesses of the beds which compose it, for a basin, 100 meters deep, may be filled with inclined beds which may have a total thickness of 1,000 meters; he gives illustrations of these conditions.

The little basin of Commentry is one of several isolated areas in a synclinal which is about 60 kilometers long. These are separated by granite and gneiss and the evidence shows that they were always separate. That of Commentry, 9 by 3 kilometers, contains only Carboniferous rocks, except at the northwest, where some Permian remains. The rocks are not disposed at hazard, but there are definite zones or areas, each with its own type of rock, and these areas, as it were, interlock laterally. Each contains detritus derived from a single locality, though there is a greater or less intermingling where the deposits interlock as overlapping wedges. The history of the basin is thus interpreted by Fayol.

A lake, 9 by 3 kilometers in area and 800 meters deep, was surrounded by steep mountains. Rainwater ate away the surface, digged valleys, carried to the lake pebbles, sands, clay and plant materials, by which at length the lake was filled. This was one of numerous lakes, depressions and alpine elevations on the central plateau of France. Sediment brought in by the streams was heaped up at mouths and formed deltas. The main stream at the northwest, the Bourrus, cut through the mica schist and reached the granite, the latter being found in the upper part of the delta. This delta has the steep slope, with pebbles, blocks, sand, clay and plant debris, all disposed in accord with the laws of delta deposit. A somewhat smaller stream, the Colombier, at the east, flowing over anthracitiferous beds and afterwards cutting back to crystalline rocks, formed another delta of similar type; while petty streams from the north formed small intermediate deltas. Apparently nothing came from the south, where the waters found their outlet. As the deltas increased in size and approached each other, their elements intermingled.

The lighter materials, clay and plant, floated into a bay in the southeast corner, where they formed some beds of shale and coal, while in less degree, similar materials floated off on the other side of the Bourrus delta into the bay at the west, where, in like manner, deposits of shale and coal accumulated. Eventually the Bourrus delta divided the lake into two small ponds and in the larger were formed thin irregular lenticular beds of impure coal. At length the lake was filled up and streams began to destroy the coal formation. Disturbances set in afterward but they were not serious, for the Permian deposits are almost horizontal.

The facts to support this explanation of the origin of the beds, both mineral and vegetable, are presented abundantly in the great excavations. The walls show local faultings, thinning of faisceaux of beds, pebbles of coal are seen in several strata, a great lenticular parting, in part very coarsely conglomerate, occurs in the Grande Couche. This remarkable coal bed is only a few centimeters thick at the southeast outcrop, but it swells thence to 10 to 12 meters and retains that thickness along the outcrop for about 2 kilometers and a half, beyond which it becomes thinner and at length disappears. Followed down the dip, it decreases in thickness and disappears toward the depth of 350 meters. The outcrop resembles an open C and the interval from the outcrop to the old rock is 500 to 800 meters. Before disappearing at the west, the bed breaks up into six diverging branches. Two other beds, the Gres noirs and the Pourrats, are in contact with the great bed at the southeast but they diverge westward. Some lenticular deposits of anthracite occur at the base of the series in both bays.

Fayol made careful calculation of the quantity of vegetation which could be produced on the whole drainage area of the lake and asserted that enough be produced to give ten times the coal present—and this within the period of 17,000 years. This period is a maximum, corresponding to a very slow filling and to the minimum transportation of vegetable material. On the hypothesis of formation *in* *situ* after the manner of swamps, he thinks a period of 800,000 years would be required.

Fayol's delta theory, then, is that the deep lake was filled gradually with material carried down by the streams; that this material was deposited according to its gravity, fine clay and vegetable matter being regarded as equivalents; the arrangement being that observed in deltas. It differs from the theory offered by Jukes by adding the suggestion of great original depth of the basin, a conception against which v. Gumbel had argued a number of years before.

The record of the summer meeting of the Geological Society was issued as a separate[72] and it contains the discussions by several members. The doctrine as enunciated by Fayol was regarded by Busquet as applicable to the basin of Decize, by Nougarede as supported by much observed in the basin of Epinac, and by Bergeron as explaining the conditions observed at Grassesac and Decazeville.

Renevier[73] was not prepared to give assent to the doctrine and he suggested some grounds for hesitation. Vegetable materials in suspension are equivalent to fine mineral débris. If the coal beds were formed, as Fayol thinks, by the sweeping off of vegetable débris from the land and its deposition on the surface of the delta, that débris should accumulate on the border of the dejection cone, in the more tranquil waters, so that the deposit should have only a gentle original slope. But the great bed of Commentry has an extreme dip of 50 degrees, the same with that of the beds which accompany it. He regards these dips as impossible in a cone of dejection and suggests other modes of accounting for them. He maintained that the phenomena indicate, in part at least, the agency of marshy or semi-aquatic vegetation. Even the great thickness of the Grande Couche seems to him an argument in favor of vegetation in place, receiving increment brought in from the neighboring forests.

Delafond[74] was inclined to question the applicability of the doctrine without modification to the basins of the Saone-et-Loire (those of Autun, Blanzy and Creusot). Fayol conceived the existence, before the coal deposition, of a deep depression transformed

---

[72] "Réunion extraordinaire dans l'Allier," *Bull. Soc. Geol. de France*, 3^{me} Ser., XVI., 1890.

[73] E. Renevier, "Réunion, etc.," pp. 77, 78.

[74] F. Delafond, "Réunion, etc.," pp. 73–78.

into a lake, in which would be deposited, in form of a delta, the various elements which constitute the Coal Measures; the plants, giving the coal beds, would have been furnished principally by the luxuriant forests which grew on the alluvial plains of the deltas. During and after the formation of the Coal Measures, the movements of the crust were so unimportant as to leave no apparent trace, so that to-day one can easily find all the circumstances accompanying the formation of the deposit. But these were not the conditions in either the basin of Autun or in that of Blanzy and Creusot. There were important movements of the crust during and after the Carboniferous and the Permian.

In Autun the successive stages overlap in such fashion as to be explained only by admitting, during the process of deposition, the existence of crustal movements which modified profoundly the shape of the basin. Further, it would be difficult to explain by this doctrine why in Autun the important coal beds are in only the lowest part of the formation, at the time when the alluvial plains of the deltas were small; whereas, in the later part of the formation when those plains should have acquired great extent and could support immense forests, there were formed only some insignificant deposits in the Upper Coal Measures. Similarly in the other basins of the Saone-et-Loire, there were movements during the formation of the Coal Measures and of the Permian, which caused the overlapping of deposits.

Delafond recognizes that the process of delta formation explains the manner of deposit, the separation of the various materials, coal, shale, sandstone; but the intervention of movements of the crust is indispensable.

De Launay[75] remarked that it would not be incompatible with the theory of deltas to believe that movements of the crust occurred during the period of the Coal Measures and that they had given progressively the great depth observed to-day.

Almost at once after the appearance of Fayol's first publication, de Lapparent[76] gave his adhesion to the new doctrine. His first

---

[75] L. De Launay, "Réunion, etc.," p. 102, footnote.

[76] A. de Lapparent, "L'Origine de la houille," Assoc. Franc. Avanc. Science. Conferences de Paris, 1892. The same in *Rev. des quest. scientifiques,* Juillet, 1892.

publication was in 1887; in 1892 he presented his views in vigorous fashion. The statements are made with that clearness and precision which characterized his writings, so that it is well to give the synopsis in detail.

The early observers regarded coal as due to transported vegetable materials but the fascination of actual conditions, as exposed by Lyell, led men to abandon that explanation and to see in the vast peat bogs of this day the modern representative of coal beds. De Lapparent gives a synoptical statement of the peat bog theory. He thinks this doctrine deserving of a double reproach—it draws no argument from the nature of the coal itself[77] and it does not consider sufficiently the topographical conditions of each bed.

De Lapparent says that coal, especially in the great maritime basins, has wholly mineral aspect, laminated, with conchoidal fracture and showing no sign of organization; even thin sections show only amorphous material with rare indications of cellular structure. In most cases, chemical and microscopical examination must be combined, but sometimes the former is unnecessary. Fayol discovered at Commentry, in 1883, lenticular brilliant zones which proved to be flattened stems. Grand' Eury, in 1876, asserted that the coal of the Loire basin was formed of vegetable remains laid flat in a position uniform enough to suggest a liquid in repose. Several beds at Saint-Etienne consist wholly of *Cordaites* bark and the Grande Couche at Decazeville is composed of bark of *Calamodendron*. This determination, first made by Grand' Eury, is interesting as showing that the leaves, barks, etc., play in the coal the same part that vegetable imprints do in the shale. The ulmic matter, resulting from maceration of vegetable detritus, formed the sediment in which the recognizable remains were buried.

To explain the origin of this amorphous material, he quotes Saporta, who relates graphically the conditions existing in the dense forests of the hot, humid Carboniferous time. The rapidly accumulating mass of leaves, loose internal material from tree trunks, was

---

[77] It is well to remark in passing that de Lapparent's statement was made 54 years after Link's investigations, 33 years after Dawson's publications in the *Q. J. G. S.* and 9 years after publication of v. Gümbel's elaborate researches.

converted into ulmic material, the lower part of the deposit becoming a blackish paste. Detached heaps of leaves, peripheral sheaths of ferns, cortex of *Sigillaria, Cordaites,* etc., obstructed places at foot of slopes and awaited only the passage of waters in order to abandon to them the great mass of material in various stages of decomposition. This vegetable pulp is the amorphous gangue in which one finds the barks and leaves. But it is no longer in place. It shows evidence of having been suspended in water; the condition of the fragments shows that they have been subjected to frequent and energetic friction. By what mechanism was this transport effected?

Grand' Eury thought that the waters of great rains sweeping down the slopes drew the vegetable detritus into lagoons—such waters were limpid. At other times the streams carried muddy water with sand and clay giving sandstone and shale. Thus was explained the alternation of coal with other rocks. But de Lapparent cannot understand this selective process—the conditions are unlike those of the present day. The delta theory of Fayol is preferable and it applies perfectly to the lacustrian basins of central France. It is no mere hypothesis, but the result of long, painstaking observation in the great open quarries of Commentry. More, Fayol made experiments which proved that the conditions were such as must be due to delta formation.

The cause was gained and it remained only to answer objections offered by adherents to the old theory. The presence of vertical trunks was shown to be not only not inconsistent but rather consistent with the theory. And this was the most important objection. The presence of *Stigmaria* in the underclay is no objection. Those are rhizomas capable of giving origin to *Sigillaria;* when swept by torrential currents, they were drawn into the deltas, where being heavier they would pass to the bottom of the mass which was to become coal. The delta theory is full of important consequences. There is no further need of numerous and complicated movements of the crust. The beds have been deposited one on the other as sediments on the surface of a submerged dejection cone. If complete stability of the surface be one of the conditions of the phenomenon, there is at least no *a priori* reason to put it in doubt; as the beds had to be deposited with a certain inclination, there is no need of calling in, for lake basins, dislocations to explain phenomena which may very well be primordial. The time required for the deposits is vastly shortened. Not only a complete coal bed, whatever its thickness, but also a portion of the underlying clay and sandstone, becomes before our eyes the product of a single flood. Fayol has shown also the rapidity with which vegetable matter is transformed into coal. The coal of pebbles in the rocks is coal, so that when a portion of the delta was exposed by a change in equilibrium of the surface, its coal suffered erosion as did the other rocks. De Lapparent finds in the study of Commentry some important matters bearing on the origin of the coal itself, which will be considered in another connection.

The coal of the maritime basins of France is a vegetable alluvium deposited in a delta; but the material has been brought from a greater distance and by the action of the waves it has been spread out over a greater area. In the central plateau the vegetable paquets descended violently from the neighboring steep slopes to be deposited *en bloc* with pebbles of the torrent, thus producing some thick but very localized masses of coal. In the Nord area, there must have been, far above the mouth, wide river sheets in time of flood, many kilometers broad, like the Amazon and Orinoco, on whose surface the vegetable matter was spread. In subsiding, the ulmic materials, which formed the chief mass, separated themselves from the fine clays. This explains the constancy of the floor, while the roof may consist of any material. As the unmacerated vegetable matters, fronds and barks, had to float on the surface of the ulmic materials, one can understand why they are so abundant in the roof. The mouth of rivers changed their position, which explains the invasion of brackish waters. Thus is understood easily the filling of the old arm of the sea.

Why is it that a theory, so luminous, has not gained the adhesion of any but Frenchmen? De Lapparent thinks the hesitation due to lack of confidence in anything novel which comes from outside, and tends to overthrow notions so long accepted that they seem to be part of a national patrimony. Foreign doctrines are subjected to quarantine as foreign goods at a custom house. It is possible that the hesitation is due to imperfect exposition of the doctrine at the outset, when Fayol declined to accept crustal movements as having had any influence; but that error was corrected afterward by Fayol. De Lapparent considers that to deny all influence of orogenic movements upon even the lacustrian areas would be excessive. Coal basins are depressions, feeble lines of the earth's crust, are landmarks of fractures whose equilibrium has been disturbed frequently.

Malherbe[78] notes that, though the explicit statement is not made, Fayol evidently regarded his doctrine as of universal application. But Malherbe asserts that, while it may suffice for Commentry, it cannot suffice for other basins. He utilizes the Liege basin as testing ground. That basin has an area of 40 by 15 kilometers, with 50 coal beds and numerous petty seams. The northerly border is but slightly disturbed; away from that the disturbances become serious and some of the faults extend through the formation, which is 1,200 to 1,500 meters thick. This is very different from Commentry, which is small in surface and depth, enclosing an insignificant number of beds. If the Commentry strata are in the original position, those of the Liege basin must be the same; but everything proves the contrary—the enormous displacements of the beds, the presence of *Cardium* in horizontal and inclined beds alike; all show original horizontal deposit. The waters from the Liege basin carry salt and Roget-Laloy has proved the same for the coal formation of the north of France, concluding therefrom that that is the sea water of the coal time imprisoned in the rocks. The deposit is not lacustrian but fluvio-marine.

Fayol's capital objection to theories other than his own is the apparent impossibility of periodicity in deluges due to terrestrial oscillations. Malherbe thinks it equally difficult to explain by Fayol's hypothesis the transport of a mineral formation, 1,500 meters thick and enclosing 50 coal beds from 0.45 meter upwards on an area comparable with that of modern seas—for the elevations breaking the area into basins came after the coal time. Oscillations are known in the present time, they are probable for other times. If one recognize that subsidences necessary for formation of beds

---

[78] R. Malherbe, "Géologie de la houille," *Ann. Soc. Geol. de Belgique*, T. XVII., 1890, Memoirs, pp. 25–40.

occurred only during accumulation of the great beds and that the overflows, bringing about the deposition of sterile rocks, led to transportation of vegetable matter intercalated in the intervals as veinettes, the number of overflows would be greatly reduced. Malherbe discusses Fayol's doctrine in detail and at the close expresses much doubt respecting its competence to explain even the phenomena of Commentry.

Renault[79] says that coal beds are intercalated among beds of sandstone and shale and, like those, they have all the features of deposits made in water. In sandstone, the fragments are inorganic and preserve the chemical as well as the mineralogical characters of the rocks whence they came; in coal, they are derived from plants and conserve the anatomical, at times, also the chemical characters of the plant organs. The fragmentary condition of these organs, the small proportion which they form of the mass, consisting chiefly of a blackish vegetable powder as gangue, show that the plants had been subjected to repeated energetic friction before their burial. So one cannot admit that coal beds were formed solely by accumulation, *sur place,* of debris from an exceptional vegetation, spreading over marshes, lowlands, lagoons, etc., near lakes or the sea; that the surface, subject to elevation and depression, saw, checked and again restored, that great vegetation of which innumerable generations would be represented by successive coal beds.

The fragments of wood and bark are very small. If the vegetable materials had been changed into coal and buried where their debris is found, it is certain that, in place of these reduced fragments, there would be entire trunks, branches and complete leaves as principal constituents of the mass. More, taking into consideration the diminution of volume, which vegetable tissues experienced in becoming coal, it is evident that numerous forests of high trees growing successively on the same place, would form hardly a few centimeters of compact coal—even though one suppose that, at the foot of the trees, there grew a mass of herbaceous plants. Further, the thick coal beds are separated by great deposits of sandstone or shale; as those deposits were formed slowly after the

---

[79] B. Renault, "Études sur le terrain houiller de Commentry," Livr. 2^{me} Flore fossile, Saint-Etienne, 1890, pp. 704–712.

manner of sediments, one must assign, if he admit this succession, an extraordinary duration to the coal epoch.

Renault accepts the explanation offered by Fayol and commends especially the shortness of the time which it requires. During the Carboniferous time, the air held more moisture than now, as no ice cap covered the polar regions; the rains were frequent and abundant; depressions occupied by lakes were filled rapidly. If one consider the strength of the torrents, greater than now, and the vigorous growth of vegetation, surpassing that of the present tropical regions, he will recognize that the formation in the Basin of Commentary could have been deposited in even less time than is required by the Fayol hypothesis. The selection, so distinct in deposition in inorganic materials, would take place with equal readiness in the plant materials. Coarse fragments, such as trunks, branches, would be dropped with the sand and clays, while the lighter, finer materials would be carried beyond into deeper parts of the basin.

Erect stems have little bearing upon the question at issue. Many of them are merely in-floated fragments, while those, which are *in situ,* do not penetrate the coal beds and have no relation to them.

Spring[80] undertook investigation along a new line. His study, though bearing largely on the question of transformation, finds place here because the results have an important bearing on the manner of accumulation. The homogeneity, the structure and composition of coal beds all seem to favor the doctrine of transport; but the stratification within coal beds does not exclude the doctrine of *in situ* origin, for with rare exceptions modern peat bogs show a structure resembling that of coal. It is clear that a definite conclusion respecting mode of formation cannot be reached by study of the coal bed alone; he determined to investigate the shales of mur and toit.

The mur of a bed formed by transport would be impregnated with vegetable matter to some distance below the coal while the toit should contain little. In the Belgian terrane, the shales of the toit,

---

[80] W. Spring, "Détermination du carbone et de l'hydrogène dans les schistes houillers," *Ann. Soc. Geol. de Belgique,* XIV., 1888, "Memoires," pp. 131–154.

when broken up by atmospheric agencies, yield a hard rather plastic material, resisting plant growth, yet they are as black as those of the mur. The theory of origin from peat would require that, in the mur, the quantity of carbon increase as it approaches the coal, as it must contain roots of plants; while in the toit the carbon should decrease gradually as one recedes from the coal. There is no abrupt change from coal to shale in the roof, so that the latter should be richer in carbon than the mur.

It is necessary to see how transformation of vegetable matter into coal is explained by each theory. This necessity is felt by defenders of the transport theory, because the flowing water furnishes only a mass of wood, bark, leaves whereas according to the theory of peat bog origin, the change of vegetable matter into peat is associated with the deposition.

In passing from vegetable matter to coal, there is great loss in hydrogen and great enrichment in carbon. Either the plant materials were changed into peat, lignite and the rest successively, or the organic matter was converted at once into its present state without passing through the intermediate stages. The latter explanation rests chiefly on Fremy's experiments, which showed that vegetable matter, subjected to high pressure and a temperature of 200° to 300° C. for a long time, becomes converted into a material very closely resembling bituminous coal. A fundamental objection to this theory is that no evidence exists suggesting that any such temperature prevailed, and nothing is less established than the conception that time could compensate for deficiency in heat.

However this may be, it is evident that, according to the doctrine of transport, the change going on in materials between the shales requires that specimens of shale collected at equal distances in receding from the coal, should show the carbon and hydrogen varying in a determinate manner; in proportion as one recedes from the coal the shale should have less of carbon and more of hydrogen as the more volatile hydrocarbons would go farther. But the doctrine of peatbog origin leads to a contrary condition.

A determination of the carbon and hydrogen in shales near coal beds may aid in answering the question as to whether the hydrocarbons are impregnations from the forming coal or are due, as in the coal itself, to transformation in place of vegetable debris, imprisoned when the shales were deposited. These determinations would tell us if one should prefer the doctrine of transport to that of formation *in situ,* and whether the transformation of vegetable matter into coal has been accomplished by a kind of distillation or has been caused by a special kind of fermentation.

In the course of his studies, Spring discovered an unexpected condition—that the shales, containing organic matter, were the seat of slow oxidation, depriving them of hydrogen. The shales not only protected the coal from erosion but also from oxygen, as gas or in solution, the action of the oxygen being exhausted in the shales. As the encasing rocks are not the same everywhere, the character of the coal should differ in the same bed and in different beds. Usually, meager coals are on the peripheral parts of a basin while fat coals prevail in the middle portions. May this be because the latter have been better protected against the action of oxygen?

The shale samples studied were from the Saint-Gilles mine near Liege, eight of them, with one from the coal bed. Five were taken from the toit and three from the mur, each representing a vertical space of a half meter. They are marked "a," "b," "c," "d" and "e" for the toit and 1, 2 and 3 for the mur. The material was dried and analyzed with these results;

	Coal.	"a"	"b"	"c"	"d"	"e"	1	2	3
Carbon	86.61	7.54	3.35	2.21	1.20	0.70	0.99	0.93	0.80
Hydrogen	4.65	0.79	0.62	0.54	0.56	0.59	0.84	0.53	0.58
Ash	1.84	98.33	92.05	93.86	92.00	94.08	95.16	93.50	93.20
Oxygen, sulphur by difference	4.80	3.34	3.98	4.10	6.24	4.63	3.01	5.04	5.42

The carbon varies greatly but regularly, decreasing as one recedes from the coal. No conclusions can be drawn from conditions in the mur as the quantity is very small, but the variation in the toit is a logarithmic curve, the cause producing the variation is in inverse relation to distance from the coal. This seems to show that Fremy's conclusions are right and that the shales were impregnated with carbonaceous materials at expense of the coal, the compounds less rich in carbon going farther. But the relations lead to a chemical impossibility; "a" gives C_8H_{10}, while the coal gives practically $C_{16}H_{10}$.

The reason is that not all of the water of hydration goes off at 120°. To escape this error, Spring employed hydrofluoric acid and continued the solution until the ash was about 10 per cent., the same with that of many coals. Analysis of the residues gave these ratios;

	"a"	"b"	"c"	"d"	"e"	1	2	3
C:H	24.80	30.45	36	?	?	19.80	?	?

The results for "d" and "e" are uncertain as are also those for 2 and 3, the hydrogen being present in such small quantity. Determining the absolute relation of hydrogen he has

	Coal	"a"	"b"	"c"	"d"	"e"	1	2	3
Carbon	88.61	7.54	3.35	2.21	1.20	0.70	0.99	0.93	0.80
Hydrogen	4.65	0.30	0.11	0.06	?	?	0.05	?	?
C:H	19.09	24.28	30.45	36.00	?	?	19.80	?	?

The relation of carbon and hydrogen in the mur is very nearly the same as in the coal; it contains particles of coal little altered. But the toit results are remarkable; the hydrogen diminishes in relation to the carbon and in "d" and "e" it is no longer in appreciable quantity. Evidently the roof shales are not impregnated by volatile materials coming from the coal, as required by Fremy's theory. The transformation of the vegetable matter is rather by ulmic fermentation. Within the primitive marshy mass the plant substances have yielded ulmic materials while becoming richer in carbon. These have impregnated the whole and have been modified by external agencies.

The doctrine of transport seems to be out of harmony with the results as by it one would have difficulty in explaining the richness in carbon characterizing the toit. The alluvium, because of its physical nature, could not support a sufficient vegetation. If one suggest that the alluvium at its origin was mingled with much vegetable debris, it may not be superfluous to ask if the plants could remain on slopes, denuded and torn up by the flood which had swept away the most thoroughly rooted plants. Everything speaks of origin *in situ*. But returning to the analyses.

If the alluvium covering the peat bogs came gradually it would be mingled with a greater or less quantity of vegetables, which had to undergo the same changes as the underlying mass in order to become coal. One ought to find in the alluvium the same proportion of carbon and hydrogen as in the coal itself, or at least nearly so. If this relation do not exist, evidently some external influence has been exerted. And the relation does not exist; the variation increases as one recedes from the coal; this irregularity must be due to some slow action becoming appreciable through lapse of time. Everything seems to indicate that slow oxidation went on in the shales, acting chiefly on the hydrogen, for which oxygen has the greater affinity, so that it has converted the vegetable matter into anthracite in the more distant part of the shales.

According to this conception, coal with abundant gas could have been formed only when the material was protected against atmospheric agencies. The many varieties of coal owe their origin rather to unequal degrees of protection; the fattest coals give off the most abundant grisou—evidence that the enclosing rocks are impermeable.

Wild[81] in describing the Lancashire coal-field, referred to the "bullions" which are characteristic of the Mountain-Four-foot coal bed. These, embedded in the coal, are ferro-calcareous "concretions" more or less pyritous, frequently enclosing mineralized wood, "showing the woody and cellular structure of the plants which have produced the seams of coal from which the concretions are extracted." Shells are absent, the nodules being for the most part fossil wood in varying degrees of preservation. The coal bed is persistent and its roof shale contains concretions, known as "baum-pots," which at times are embedded partly in the coal. These are ironstone or calcareous, sometimes weigh 40 pounds and contain marine shells but rarely any wood.

After a review of all the coal beds he considered the question of their formation. The generally accepted theory that coal comes from growth *in situ* seems to be a natural conclusion, for the roots in the underclay pass through several layers. It is true that under-

---

[81] G. Wild, "Lower Coal Measures of Lancashire," *Trans. Manchester Geol. Soc.*, Vol. XXI., 1892, pp. 364 et seq.

clay is not essential for vegetable growth, but more than three fourths of the coal beds have it. The "bullions," composed of fossil wood, occasionally show rootlets working their way through the decaying wood, separating the fibers which now surround them. The fossil wood is often parallel to the bedding of the coal, a condition familiar in prostrate forests and in peat accumulations. Erect trunks and stems are unusual both in coal and peat. The underclay was the land surface which supported vegetation like the forests of swamps where warmth and moisture prevail.

If coal is to be considered as derived from drifted material, he is puzzled to discover what has become of the shells and fishes, which must have abounded in the tracts of water in which the deposits were laid down. To float some of the large trees either vertically or horizontally, with their outspread roots having a radius of 15 to 20 feet, would certainly require enough water to accommodate fishes and mollusks. Remains of fishes are not necessarily destroyed by embedding them in coal-forming material, and shells are as capable of resisting destruction as fish spines are. Shells and fish remains occur often in impure cannel. The "bullions" have yielded no shells, and fish remains are very rare in pure coal. That the trees were forest growth is proved by the splendid specimens in the Manchester and other museums.

Estuarial swamps with intermittent subsidence, permitting deposition of sand and mud, would explain alternations of coal and other strata, whichever theory of coal accumulation be accepted. Marine conditions frequently followed directly upon formation of a coal bed; fishes of shark-like types are in shales directly overlying coal at many horizons. But shells and fish are unknown in the underclay.

Orton,[82] in his description of the coal-fields of Ohio, considers the various theories of formation; some of them appear to be based on merely local conditions, others are extravagant and only a very small proportion of the explanations seems to have been the result of careful observation in extensive areas.

In a coal-field, one finds a system which can be explained only by subsidence. Limestone is found above and below coal beds and

---

[82] E. Orton, Geol. Survey of Ohio, Vol. VII., Antioch, 1893, pp. 256–262.

is accompanied by iron ore. The coal beds, though variable, are wonderfully persistent and are always associated with fireclay. There is no haphazard mode of occurrence. Coal is product of land life; limestone is of marine origin; the ore depends on life for concentration; sandstone, occupying the intervals between other rocks, is due to inorganic forces and it may be about equivalent to the others. Orton's conclusions based on more than twenty years of study in much of the Appalachian basin, are:

(1) The Ohio coal-field, at the beginning of the Carboniferous, was an arm of the sea with the Cincinnati arch as the western boundary. (2) Marginal swamps of varying width became the earliest coal seams by long continued growth and subsequent fossilization. (3) While the swamps were submerged, in succession, and covered by shale, sandstone or limestone, in turn covered by other swamps, the continental nucleus grew slowly at the south and the Cincinnati arch united with it by like advance eastward, expelling the waters of the gulf and converting the earlier formed portions of the coal formation into dry land. (4) Every coal swamp had a narrower area than its predecessor. (5) As all coal seams were formed at sea level, so all were raised by continental growth to an approximate equality, which their outermost outliers still retain. (6) To look for the earlier formed seams in the center of the basin would be to look for the living among the dead. (7) In the formation of one seam, in particular, the floor of the gulf, around which the swamps were growing, seems to have been raised nearly to sea level at many points, and coal appears to have been formed in island-like masses over much wider areas than any single marginal swamp would account for.

Bolton[83] describes a peculiar deposit of coal in Ireland. The Jarrow coal bed appears to be a great cake, attaining a maximum thickness of 16 feet and thinning in all directions except toward the west, in which direction no tests have been made. Underclay is absent at almost all localities. The lower part of the deposit is a smutty anthracite with slaty structure and containing abundance of

---

[83] H. Bolton, "Notes on the Plant and Fish remains from the Jarrow Colliery, Co. Kilkenny," *Trans. Manchester Geol. Soc.*, Vol. XXII., 1894.

Lepidodendron stems. The upper part is a pure typical anthracite. Fish remains, *Gyranthus, Megalichthys*, etc., occur throughout. The plant remains are *Halonia*, in the form of crushed cylinders of wood. This condition and the mingling of fish remains led Bolton to conceive that the deposit was due to the bursting of a lagoon-like swamp and to the discharge of vegetable debris, consisting of bottom accumulations as well as of the twigs, etc., on the surface. He refers, for illustration, to the bursting of Solway moss in 1771, which spread over a square mile of ground, giving a mass of vegetable matter, 30 to 40 feet deep, demolishing houses, overturning trees and so contaminating the Esk that no salmon ventured into the river during that year.

Kuntze[84] took up the discussion from a botanist's standpoint and advanced a wholly new theory. He antagonized v. Gümbel's conclusions which he maintains are wholly at variance with that observer's facts. His own studies from 1879 to 1883 had shown that the Carboniferous flora was sylvo-marine, a floating vegetation. The objection that marine forms are wanting does not hold good: the forms, described by v. Gümbel as resembling algae, are chitinous bryozoans related to *Aulopora*. These, as stated by v. Gümbel, occur abundantly in cannel and make up a great part of the boghead coals. Carboniferous coals contain much sodium chloride, one fourth to one half kilogram per ton; Tertiary coals contain none. It is certain that the Carboniferous coals are not allochthonous; the flora must have been marine.

He contends that students have failed to interpret *Stigmaria* rightly, for the appendices, regarded as rootlets, are water leaves. The *Stigmaria*, with intertwining rhizomas and hollow stems rising above the water, formed floating islands. When overloaded, they sank to the bottom and through the mud until checked by some harder rock. He agrees with Potonié's conclusion that they are not allochthonous but he cannot concede that the underclay or clay shale is a petrified humus, for the clay is no more a soil than are the granite and other silicious rocks with which coal beds are often in

---

[84] O. Kuntze, "Geogenetische Beitrage." Leipzig, 1895, pp. 42–77. Sind Carbonkohlen autochthon, allochthon oder pelagochthon?

contact. The thickness and extent of some coal deposits are serious objections to growth *in situ*. Richthofen describes a bed in China, 20 to 30 feet thick and having an area of 600 German square miles. This would require at least 400 feet of plant remains. The bottom three feet might have been a soil in which *Stigmaria* rhizomas could have grown, but the sturdiest defender of autochthony would be at loss to find a soil for the remaining 397 feet. Such a deposit could have been made only by a matt of sylvo-marine vegetation.

All allochthonous and land basin theories are untenable because transportation yields no undisturbed sedimentation; there is no transportation of organic detritus without contemporaneous transportation of inorganic material—the transportation of purely plant detritus is a superstition; subsiding land basins giving 7,000 meters of Carboniferous rocks, while neighboring basins subside at different rates, would be a marvel, for in order to account for the thick mineral beds the process of coal making would have to be intermitted a hundred times; there are no basins so great as those of coal sedimentation. The four great deltas do not equal the Pennsylvania coal-field alone; Richthofen's southeast Shansi field would require a basin sixteen times as large as the Caspian sea. The great basins must have been sea basins and a sylvo-marine forest alone explains the intermittent deposit of coal, the clays being due to influence of streams.

Kuntze classifies the theories as Autochthony, the irregular deposit of the coal-producing substance directly on the place of vegetation; Allochthony, the irregular deposit of coarse coal-producing substance on a distant place; only the powdery substance is deposited after the manner of sediments.

Pelagochthony, the sedimentary deposit of coarse substance in water of the sea directly under the vegetation; a secondary product is the powdery detritus sometimes floated away from the coal magma and deposited elsewhere as anthracite.

Autochthonous types are found in tropical or subtropical brown coal from wood-covered bogs, without sphagnum; newer peats in cooler regions with sphagnum; shore swamps and some others.

Allochthonous types are drift woods; sedimentary peats; sea peat; paper peat, which is a bituminous clay with infusoria; Blatterkohle, a marly clay with a little sedimentary peat.

Pelagochthonous types are: (1) Normal Carboniferous coal fields. The coal beds have originated from floating forests and remains of rooted trees occur in very limited localities. Naumann's paralic coal-fields belong here; they are found in America, China, etc. (2) Sea basin deposits, consisting of limited but often very thick beds, the coal frequently thinning seaward; these contain, besides sylvo-marine remains, abundant remains of trees rooted in clay. Best seen in France. Here, in part, Naumann's limnic basins. (3) Amorphous anthracite, consisting of the finest detritus and forming irregular deposits; does not include Faser-, Staub- or Koksanthracite coal.

Penhallow[85] has given the results obtained by study of cannel-like coal from the lower Mesozoic of British Columbia. All the samples are composed of rod-like bodies more or less closely compressed, which resemble dark amber and are embedded in a cementing material. The rods show tubules within, many of them branching, which are very suggestive of *Mycelium;* granulations are common and often form zones around hyaloid areas. The features revealed by the microscope are:

(1) Absence of structure, (2) tubular ramuli of diverse dimensions, (3) rounded cavities, (4) large proportion of material in angular fragments and resembling that of the rods, (5) an amorphous substance, associated with (4), occurring as distinct flakes or as cement to unite the rods.

Appearance of structure was observed in only one rod and in that case it is evidently due to shrinkage; he thinks the spore-like aggregations are of chemical rather than of organic origin. The general character of the ramuli at once suggest *Mycelium,* but the intimate features and the arrangement forbid reference to vegetable structure. They rather resemble effects of internal shrinkage, following hardening of the outer layer, such as one sees in amber and other resins. The material occupying spaces between the rods and

---

[85] D. P. Penhallow, "A Preliminary Examination of So-called Cannel Coal from the Kootanie of British Columbia," *Amer. Geologist,* X., 1892, pp. 331–339.

apparently cementing them "consists of an amorphous and irregular mass full of rounded holes, thereby giving it a spongy character." It contains fragments of perhaps broken rods, the material in both being the same. The source of the amorphous material is not certain.

Penhallow offers no positive hypothesis respecting the origin of these coals, though he is inclined to think that it must be "sought elsewhere than in modified vegetable structure." At the same time, he feels that the evidence is not sufficient to justify the assertion that they did not originate in vegetable structure.

In 1892 and 1893 there appeared papers by Bertrand and Renault describing Bogheads and related types. Afterwards those observers published their results independently. The later studies of Renault concern the matter in hand only indirectly and they will receive consideration in another portion of this work. It is necessary, however, to make detailed reference to Bertrand's contributions, for, though they consider similar topics, the conclusions have a notable bearing on the formation of coal beds; and in this connection, the stratigraphical relations of the several types must be given. Without that one cannot appreciate the full bearing of the studies. The joint study by Bertrand and Renault[86] was of boghead obtained from Permian beds at Autun, France. This deposit occupies an area of 7 kilometers by 150 to 450 meters. The chief constituent is a thallophyte, *Pila bibractensis,* which makes up about three fourths of the mass; the remaining fourth being the "fundamental material" with some clay. Vegetable débris is wanting, but pollen of *Cordaites* and remains of fishes are present.

These observers recognized the bodies of yellow, red and other tints, which had been mentioned by earlier students, but their study proved that "certain resin-like bodies represent the organic gelose and even entire organisms. A great proportion of the yellow and red bodies enclosed in coals are in this category and M. P. F. Reinsch has the great merit of making this known." The inferior gelatinous plants have been preserved in this way when buried in

---

[86] C. Eg. Bertrand et B. Renault, "Pila bibractensis et le boghead d'Autun," *Bull. Soc. d'Hist. Nat. d'Autun,* V., 1892, Separate, pp. 95, pl. 2.

ulmic materials. The Autun boghead, 24 to 25 cm. thick, is not an accumulation of resinous pellets due to injection of hydrocarbons into plant débris, but it consists of 1,600 to 1,800 beds of algæ, which sank to the bottom along with grains of pollen and the fundamental material as well as the detritus. The fundamental material is brown, rather flocculent and feebly colored. It is a precipitated brown substance analogous to the ulmic matters which color the Amazon and certain of its affluents. It contains particles of a darker material, thelotite, an infiltration which penetrates the thalli.

The Pilas were algæ of very low type. Their isolation in the fundamental material, their accumulation in beds, with traces of pressure on the under surfaces, suggest that they were floating algæ like the *fleurs d'eau*. The pollen grains, usually reduced to their coats, were a powder resting on the water with the *fleurs d'eau*. The accumulation, which may have been very rapid, was only an incident in the formation of bituminous shale. It was made in quiet waters, with little or no current, and so rapidly that putrefaction could not begin in the mass. The deposit was laid down probably in shallow brown waters, like those of the Amazon region, whose acidity is unfavorable to development of many bacteria. Nearby, were forests of *Cordaites*, which furnished the pollen.

The second paper by the same authors[87] gives results of study of the so-called kerosene shale of New South Wales, which had been utilized as a source of gas and illuminating oil. This shale, known as Hartley mineral, Wollogongite and, in some reports as Torbanite, is of uncertain occurrence. Mackenzie[88] says that the deposits are very irregular, there being no guide to discovery except the presence of fragments at or below the outcrop. Toward the border of a mass, the rich mineral becomes deteriorated and gradually passes into indurated clay, bituminous or non-bituminous shale, coal or ironstone. It occurs at two horizons in the Permo-Carboniferous of New South Wales, the most notable deposits being in the Upper Coal Measures, including the well-known areas of Hart-

---

[87] C. Eg. Bertrand et B. Renault, "Reinschia australis et premières remarques sur le kerosene shale de la Nouvelle-Galles du Sud," *Bull. Soc. Hist. Nat. d'Autun*, VI., 1893. Separate, pp. 105, pl. 7.

[88] J. Mackenzie, Ann. Rep. Dept. of Mines for 1896, p. 100.

ley, Joadja creek and Wollongong at the south and Murrurundi (Doughboy hollow) at the north. The only important deposit in the Lower Coal Measures is at Greta near Newcastle in northeast port of the province.

Long ago, Clarke[89] recognized the close resemblance of this mineral to the boghead or Torbanite of Scotland. He thought it due to local decomposition of some resinous wood and believed that the lens-form of the deposits and their passage laterally into shale could be explained easily by supposing the mineral to be due to drifted resinous trees, undergoing changes in shallow pools surrounded by material changing into ordinary coal. The quartzose constituents are merely sand carried by wind into the pool. The thickness of the deposit depended only on the supply of drift timber.

Wilkinson[90] says that the kerosene shale occurs in irregular lenses, sometimes in actual contact with layers of coal as at Joadja creek, sometimes wholly unassociated with layers of coal, as at Hartley, or even as forming part of a great coal bed, as at Greta. At the last locality, the boghead is a great lens in the coal, but there are many petty lenses of the same material scattered through the coal benches. At Joadja, one finds small irregular patches of bright jet-like material, plant remains lying horizontally and numerous vertical stems of *Vertebraria,* whose lustrous bright jet substance is in contrast with the dull luster of the shale.

David[91] found the shale in one place at the bottom of a great coal bed; Mackenzie[92] found it at the top in another; while in still another David found a mass of alternating coal, clay and "shale," five beds of the boghead and four of bituminous coal. At the last locality the whole mass thinned out in one direction, the several layers disappearing in succession until the last layer of boghead passed into bituminous shale. There he saw many stems of *Vertebraria,* both vertical and prostrate; in one tunnel, some of them four

---

[89] W. B. Clarke, "Mines and Mineral Statistics of New South Wales," Sydney, 1875, pp. 179–180.

[90] C. S. Wilkinson, "Mines and Min. Stat., 1875," p. 131; Ann. Rep. Dept. Mines, 1884, pp. 149, 156; 1890, p. 208.

[91] T. W. E. David, Ann. Rep. Dept. Mines, 1888, p. 170; 1890, pp. 221–224; 1892, pp. 159–163.

[92] J. Mackenzie, Rep. 1895, p. 104.

inches in diameter were converted into coal. Mineral charcoal is abundant in a mine in Camden County, while at Murrurundi the boghead "contains numerous fragments of mother-of-coal and small fragments of what appears to be coniferous wood like *Araucaria*, together with coniferous fruit."

In the pages already cited, David gives ten analyses by Mungaye, which show that at Murrurundi the ash varies from 17 to 68 per cent. and the fuel ratio from 0.11 to 0.24; while at Ketoomba eight analyses show ash from 10.7 to 78.1 and the fuel ratio from 0.13 to 1.10. A specimen from Joadja Creek had 77 per cent. of silica in the ash.

The material studied by Bertrand and Renault consisted of two great blocks, one in Paris and the other in Brussels, each more than one meter thick, apparently the full thickness of the deposit. Like the Autun mineral, the kerosene shale consists of a fundamental brown, flocculent material, holding algæ and remains of dead plant tissues. The algae are assigned to the genus *Reinschia*, now extinct, but belonging to a group which was spread widely during Permo-Carboniferous times. The algæ are all separate, though, at times, owing to paucity of the fundamental matter, they are in contact, they are still independent. They were free, floating on the surface of absolutely tranquil brown water, and they rained down upon the bottom, while at the same time, under the influence of calcareous waters, an ulmic jelly was precipitated to form the fundamental material. The great specimen in the Paris Museum shows 36,000 beds of these algæ, but the proportion of algae varies in the several layers from 0.019 to 0.900 of the whole mass. At Joadja creek the mineral is often beautiful, with a satin-like homogeneous surface, and it consists almost wholly of the algæ.

Infiltrations are here as at Autun. The most important is red-brown, in strings or sheets, and shows fluidal structure; it is harder than the fundamental material; it often impregnates leaves and wood; some plants have the property of absorbing this to a notable extent. Its mode of occurrence and its tendency to penetrate the substance of plant remains suggest great resemblance to the thelotite of Autun. The authors make no attempt to decide respecting the source of this infiltration; they are convinced that it penetrated the deposit, if not contemporaneously, at least very soon after its formation and they suggest that it may be a kind of asphaltum, like that of lake Brea in Trinidad. The kerosene shale contains no animals except at Murrurundi, where some coprolites have been discovered. It is a charbon produced by unaltered gelosic organisms.

Bertrand's[93] later studies were published in a series of papers, his conclusions being summed up in a memoir presented to the Geological Congress at Paris in 1900.

The bogheads, typified by deposits at Autun of France, the Torbanite of Scotland and the kerosene shale of New South Wales are charbons gelosiques of Bertrand, accumulations of fresh water algae in a humic jelly,.their fossilization being in the presence of bitumen. The basal material of all is a clear brown fundamental jelly, the dull part of the bogheads and the same as the basal material of v. Gümbel's Mattkohle. Spores and pollen have undergone maceration, but they did not liquefy. They gave two kinds of yellow bodies and they condensed bitumen strongly. When they abound, the coal, though dull, is brighter than mattkohle. Débris of vegetable matter, also a contribution by the wind, is distributed irregularly. The hardened tissues are usually brilliant, prismatic like v. Gümbel's Glanzkohle. Wood and barks can be found as brilliant coal, but this depends less on their organic nature than on the extent of alteration and their capacity to imbibe bitumen. Vegetation along river banks yielded tree-trunks, which, after imbibing bitumen, were converted into bright coal.

The algæ were *fleurs d'eau*. They consisted of gelose and a little protoplasm, which, when humefied, would condense bitumen. They descended in sheets with other accidental bodies; in times of low water, the descent would be very slow, being impeded by the

---

[93] C. Eg. Bertrand, 1, "Nouvelles remarques sur le kerosene shale de Nouv, Galles du Sud.," *Bull. Soc. d'Hist. Nat. d'Autun,* IX., 1896; 2, 3, "Conférences sur les charbons de terre," *Bull. Soc. Belge de Géol.,* etc., VII., 1894; XI., 1898; (4) Caractéristiques du kerosene shale." *Assoc. Franc. pour l'avancem. des Sci.,* 1897; (5) "Les charbons humiques et les charbons de purins," *Trav. et Mem. de l'Univ. de Lille,* VI., 1898; (6) *C. R. du Congrés Int. de Géol.,* Paris, 1900, pp. 458–497.

fundamental jelly. Each ball of gelose yielded a little mass of glassy, transparent gold-yellow hydrocarbon.

The bituminous matter found in all is wholly different from the fundamental material. There is proof of its intervention, for it follows clefts made by contraction of the fundamental material, which it does not color. The coalified stems of *Vertebraria* on Joadja creek are humefied vegetable material charged with bitumen. There is no evidence that this bituminous enrichment was due to condensation of resinous matter held in suspension by the fundamental material; nor is there any evidence that the fundamental material originated from alteration of the enclosed bodies.

The accumulation could be made with remarkable rapidity. A few good days with low water would suffice. All the accidental bodies, enveloped in a humic coagulum, make a raft on the absolutely tranquil water. A very slight cause, colder weather, more water, would hinder formation of gelose and cause descent. The precipitation of brown matter was continuous but formation of gelosic matter was fortuitous; with check of algic growth, the deposit passes over to a humic coal or organic shale. The vegeto-humic deposit was fixed at once and remained unaltered. The fossilization was in the presence of bitumen, which became altered so as to be insoluble in the ordinary solvents of asphaltum.[94]

Bertrand's charbons humiques differ from the charbons gelosiques in that the fundamental matter is not diluted with foreign bodies. They are typified by the Broxburn shales of Scotland, containing, according to Cadell, about 75 per cent. of ash. Accidental bodies, such as algæ, spores, pollen, vegetable débris are in small proportion. Bitumen penetrated through the fundamental jelly and enriched the shale. Bertrand finds no evidence that this bitumen is a leakage or exudation from a fermenting vegetable mass; he believes that it was in the water and that it penetrated the accidental bodies only with difficulty.

---

[94] After the memoir was read in the Paris congress, de Lapparent asked what is to be understood by the term "bitumen." Bertrand replied that "the term bitumen implied for him the idea of a substance charged with carbon and hydrogen, intervening wholly formed in the rock."

Gresley[95] called attention to the persistence of slate partings in the Pittsburgh coal bed as having an important bearing on the origin of coal beds. Two of them, one fourth to one half inch thick and separated by 3 to 4 inches of coal, are present in an area of 15,000 square miles. Under the lower one is a coal bench somewhat more than 2 feet thick, while above the upper one is a bench varying from 3 to 5 feet. The clay of the thin binders or slate partings is extremely fine grained, mottled, non-plastic, contains macrospores and indefinite plant remains, but no *Stigmaria*.

Accepting in full the doctrine of transport, he assumes that, at the close of deposition of the lowest bench, that mass of vegetable matter lay practically level on the bottom of a vast lake or inland sea. Such being the condition he finds difficulty in explaining the overlying shale as due to fine material brought in by currents; the shale is uniform in thickness and composition over a great area, so that the supply of material must have been uniform throughout; there could have been no changes in currents or offshore conditions during the period of deposition. The quantity is not less than 100 tons per acre. He finds equal difficulty in the suggestions that the shale consists of wind-blown dust, that it is a precipitate from solution, that it is concretionary. The supposition that these shales are substitution or replacement formations or that there was a segregation of inorganic substances during solidification or the process of coal-forming involves serious difficulties. "To suppose that such shale bands were originally thin films of chalky mud, since chemically converted into silica, alumina, iron, etc., would, I think, be exceedingly unsafe." At the same time, he suggests that the globigerina ooze, widespread "over the bottom of the Atlantic, where deepest and farthest from land would seem to furnish us with about the only way (as to physical conditions) in which our shale binders in the 'Pittsburg' coal bed can be imagined to have accumulated."

If the lower slate binder was really deposited as silt by aqueous transportation, the interesting query presents itself, How could the succeeding 4 inches of coal be formed *in situ?*

---

[95] W. S. Gresley, "The Slate Binders of the Pittsburg Coal Bed," *Amer. Geologist,* XIV., 1894, pp. 356–395.

The Pittsburgh coal bed thickens toward the southeast and the slate partings, as well, thicken in that direction. The evidence favors the assumption that the organic as well as the inorganic materials came from the land surface in that direction. The absence of *Stigmaria* casts reasonable doubt upon the hypothesis of formation *in situ*, and this doubt is increased by the discovery of an aquatic fauna in the underclay of the bed, which Gresley has found to be a calcareous shale.

The extraordinary uniformity of the Pittsburgh coal bed in purity and structure, the evenness and geographical extent of its several divisions make it the most remarkable known. In explanation of its phenomena, about all that can be said safely is "that, everything being horizontally stratified, every part of it was most likely accumulated under water. I have therefore come to the conclusion that this coal is the accumulated remains on the bottom of a lake or sea of vegetable growth of *aquatic forms* (though much of it did not necessarily grow *in* the water) living afloat and dying and decaying, falling through the water." All the familiar phenomena can only be explained by an aqueous origin for the coal.

The problem of coal accumulation attracted Potonié's attention in 1886 but he published no results of direct study until 1895.[96] In that year he had opportunity to study a core obtained in the Upper Silesian coal field. This core, 750 meters long, one to 2 decimeters in diameter, begins in Saarbruck beds and ends in the Upper Ostrau deposits. As submitted to Potonié, it was complete and it was studied by him in company with C. Gaebler of Breslau. The core shows not less than 27 coal beds, each of which is in direct contact with a *Stigmaria* underclay; in most of them, remains of *Sigillaria* are present and some contain *Lepidodendron*—particularly in the accompanying carboniferous shale.

Ochsenius, who urged the allochthonous origin of coal beds, explained cases, such as are present in the core, as due to local subsidences and thought them of rare occurrence. But Potonié, as an outgrowth of broad observation, asserts that these cases are

---

[96] H. Potonie, "Ueber Autochthonie von Carbonkohlen-Flötzen und des Senftenberger Braunkohlen-Flötzes, *Jahrb. d. k. preuss. geolog. Landesanstalt für 1895*, pp. 31, pl. 2.

merely illustrations of the ordinary conditions. "The allochthonous formation of fossil humus beds is not the normal, as Ochsenius maintains, but autochthony is the normal, exactly as in the corresponding beds of the present day." But this does not exclude contributions from other localities. He cites the abandoned ox-bows of the Mississippi, into which drift wood is thrown at high water, but which are filled eventually with autochonous peat in which the driftwood is enclosed. The existence of *Stigmaria* in intervening beds is a normal thing and to be expected, as appears from conditions in cypress swamps of North America. Its existence in the coal itself is explained by autochthony, for, on that hypothesis, the old decaying vegetation becomes soil for the new. Indeed, the only difference between deposits of the several geological periods is in character of the vegetation, there is none in the mode of accumulation.

He finds a fossil swamp of the American type in the Miocene deposits of brown coal at Gr. Raschen near Senftenberg, which contains, among other plants, *Taxodium distichum.* The brown coal is 10 meters thick and shows several generations of forests, one above the other, the stumps remaining rooted in the brown coal. Every feature of recent swamps is reproduced there except that the humus has become brown coal. Many of the stems are hollow, containing more or less of Schweelkohle. It is worthy of note that an old peat bog exists on the clay overlying the brown coal, and that, in the humose sand covering the peat, there are trunks of *Pinus silvestris:* the conditions favoring accumulation of humus continued there until diluvial time. The Schweelkohle is due to resinous exudations from broken parts of the tree—the familiar process of closing wounds.

Absence of stumps in no wise proves allochthonous formation. If the fossil moor had borne only non-resinous dicotyledons, the Gr. Raschen condition could not have come about. The fact that *Stigmariæ* are often filled with sand is no evidence of allochthony, for hollow alder stumps in West Prussia swamps, exposed to high water, are filled with sand even to the roots, so that they must be cleaned out before the axe is applied.

In a later paper,[97] Potonié says that having supported the cause of autochthony, he must describe a deposit of allochthonous type. The distinctions are simple; in plants of autochthonous origin, the more tender parts are preserved but they are practically wanting in those of allochthonous origin. In connection with coal beds one has to do chiefly with autochthonous plants; but in Culm localities he has to do with "Haecksel," shreds of plants, which are characteristic of allochthony. These fragments are at time large enough to show by their arrangement the direction of the transporting current.

Allochthonous deposits of carbonaceous material have few botanically recognizable plants; many stems and branches, often coal coated but with surface sculpture so obscured that determination is impossible; stems of the *Knorria* type are of frequent occurrence; while *Stigmaria* is almost wholly absent, those which do occur being imperfect. Sub-surface organs can be carried away only after having been washed out from their place: other portions of plants must be the essential material of a transported mass.

He presents the following contrasts.

Autochthony.	*Allochthony.*
1. Coal beds common.	1. Coal beds are.
2. Haecksel deposits absent or insignificant.	2. Plant remains prevailingly Haecksel.
3. Determinable plants numerous, especially in roof.	3. Few determinable plants; if coal bed, Haecksel in the roof.
4. Few indeterminable casts.	4. Indeterminate casts abundant.
5. *Knorria* rare.	5. *Knorria* abundant.
6. Abundant *Stigmaria* in the liegend. With their appendices.	6. *Stigmaria* absent or rare; they are without appendices.
7. Excellent preservation of ferns.	

Potonié presented a brief systematic discussion of the whole

---

[97] H. Potonié, "Die Merkmale allochthoner palaeozoischer Pflanzen-Ablagerungen," *Naturwiss. Wochenschrift*, XIV., 1899, pp. 81, 82.

subject in 1905;[98] since that time, in successive editions, he has widened the scope of his inquiries until, in the fifth, the presentation covers every phase with abundant illustration from German areas and references to those of other lands. Only certain portions of the work can be referred to in this place but, farther on, many citations will be made. He approaches the subject from the double standpoint of stratigraphy and palaeobotany.

The coals and allied substances are termed Kaustobiolithe, because they are combustible rocks of organic origin. He groups them into—

Sapropel deposits, originally "stinking muds" composed of aquatic animals and plants,
Humus deposits, derived from land plants.

The former include the cannels, the oil shales and, as a derived product, petroleum; the latter include the ordinary brown and stone coals. The difference in origin of the two groups is evident from the physical composition shown by the microscope as well as by the chemical composition, the Sapropels yielding compounds of the paraffine group while humus deposits yield compounds of the benzol group. The Sapropels are formed in quiet, almost or wholly stagnant water and are of limited extent; whereas the humus deposits were formed as are the moors of to-day and are of vast extent. He illustrates the modes of origin by description of a great bog in northern Germany, which exhibits the passage from sapropel muds at its shore, to the Flachmoor, well wooded; thence by the Zwischenmoor, with changing type of trees, to the Hochmoor, hour-glass in form, which is treeless except alongside of rivulets. He compares the conditions with those existing in sapropel and humus deposits of the older periods. The existence of both autochthonous and allochthonous deposits is recognized, but he asserts that the former have been the prevailing type throughout and that, in every age, the latter have played an insignificant part.

Potonié finds a strong argument for autochthony in the surprising resemblances, chemical and physical, existing between beds of

---

[98] H. Potonié, "Die Enstehung der Steinkohle," *Naturwiss. Wochenschrift*, IV., 1905, pp. 1–12; the latest edition is "Die Enstehung der Steinkohle und der Kaustobiolithe überhaupt," funfste Aufl., Berlin, 1910, pp. 225.

brown and black coal on one side and the modern Flachmoor on the other. The laminated structure is frequently present in peat. The vast extent of some beds of comparatively pure coal cannot be paralleled in recent autochthonous deposits, but the latter are of great extent in some regions, whereas no extensive areas of allochthonous carbon deposits are known to exist anywhere. He lays great stress upon the occurrence of sub-surface parts of fossil plants in the soils where they grew, the so-called petrified humus-soils. He emphasizes especially the mode in which the *Stigmaria* rhizomas and their appendices penetrate the underclay of coal beds, spreading out and interlacing in such a manner that transport is inconceivable. They must be in place. Equally conclusive are the modes in which roots of *Calamariaceæ* rhizomas occur in the clays. This almost universal underclay was the soil in which were rooted trees introducing the moor-formation.

The occurrence of forest beds in stone- and brown-coal formation is not infrequent. He notes that at White Inch near Glasgow, Scotland, and that near Senftenberg. Sometimes the profile is shown in the roof; sometimes there are successive forests embedded as at Senftenberg, where erect stumps are associated with prostrate trunks. These are conditions familiar to students of modern swamps. The mode in which the *Stigmariæ* have developed indicates, in some localities, even the prevailing direction of the wind at the time the trees grew. The growth of reeds in banks and the parallel arrangement of their roots are the same in Mesozoic, Cenozoic and recent deposits.

Potonié carefully distinguishes the features of autochthonous deposits as contrasted with those of allochthonous origin, elaborating the discussion given in the paper just cited. He states that *Stigmaria* is not rare in the Commentry basin and that his search there for that plant was rewarded abundantly. He discovered a fine autochthonous stump, with spreading stigmarian rhizomas, still retaining the delicate appendices, the whole occupying a space of 6 meters diameter. He found there also a fern tree, almost completely preserved and with a frond attached to the stem. He concludes that the condition must have been that of great quiet to permit so nearly complete preservation.

Potonié's description of secondary-allochthonous formations, due to erosion and transport of materials from beds already existing, will find place in another connection, as will also his arguments drawn from the testimony of the fossil plants, respecting which his authority is unquestioned.

Ochsenius[99] published many noteworthy papers but that of 1896 is especially important in this connection. The author recognizes the force of the objection to allochthony—that, as running water carries organic and inorganic materials together, the deposit should be an indiscriminate mass of both kinds but his recent study of coal beds in the Lahn country has convinced him that phenomena observed in the Frische Haff present a true explanation and destroy the force of the objection. The history of the Frische Haff is complete since 1510.[100]

The Vistula, a stream laden with everything that can be drawn from a rich lowland province, gives off an arm at Peickel, the Nogat, which flows northeast to the long narrow Frische Haff, separated from the Gulf of Dantzig by the Frisch Nehrung or lowland, and communicating with the gulf by the Pillauer Tiefs at its northern end. For convenience of discussion, he confines his attention to the Nogat, ignoring the old Vistula and the rivers which enter from the east.

Under the supposed conditions, the sea having control and the Haff being filled with salt water, a marine bed is deposited on the floor. Such beds occur locally at the bottom and higher up in the series of coal deposits. Phase 1 of coal formation is brought about through sanding up of Pillauer Tiefs by wave action, and the consequent conversion of the Haff into a fresh-water basin by influx from the Nogat. The débris brought down by that river, an indiscriminate mass of organic and inorganic material, will be deposited on the bottom. If now the sea cut a shallow passage through the lowland, floating stems and twigs would form a "rake" at the head of the

---

[99] C. Ochsenius, "Die Bildung der Kohlenflötze," Verhandlungen, II., Erste Halfte, pp. 224–230.

[100] The Frische Haff is a great sound on the border of the Gulf of Dantzig, about 60 miles long by 5 to 7 miles wide. It may be compared as to superficial area and position to Lake Ponchartrain on the Mississippi delta.

passage. If the water-surface of inflowing stream be lowered, a "barricade" of wood would accumulate in curves and narrows of the Nogat, to become compacted in time—a familiar phenomenon in this day. This "barricade" would prevent passage of large wood and only fine material, "Spulgut" would go over to be deposited as a layer in the coal basin, *i. e.*, the Haff. Brushwood would be caught by the "rake" beyond. Thus a bituminous shale with plant impressions and paper-like laminæ of bright coal would accumulate.

Phase 2 comes with moderate height of the water. Now there goes with the "Spulgut" also the "Sperrgut," stems, rooted stumps, branches and the rest, which the Vistula pushes over into the Nogat; but the "rake" does not permit its escape to the sea, it circles round in the basin, finally sinks and forms pure coal. So much of the mud as does not pass through the "rake" will accumulate on the borders or be mingled with the coal magma, as clay is in the globigerina ooze; or it may form bands in coal beds. Repeated sinkings of waterlevel in the feeding stream, the Nogat in this case, would give a clay shale like the floor as roof, the roof of the coal. No sand or gravel could pass the "barricade" but it would be heaped up there. Phase 3 comes with a high flood, which overthrows the "barricade" and pushes all into the coal basin. The sand and gravel form sandstones and conglomerates as roof of coal beds and formation of coal ceases. The woody portions become at most only isolated stems buried in the "Rollgut"; by repeated pressure they may perhaps be pushed into an oblique position. If the "rake" be torn away, the seawater again enters the basin and lays down a marine bed.

This is the characteristic succession in coal bed formation. All depends on the condition of the water-level. Changes in that cause alternation of clay, shale, coal and psammite, and effect the sharp mechanical separation of those substances by the easily explained formation of "Rakes" and "Barricades." The elevation of important mountain ranges in Carboniferous and Tertiary times afforded abundant material for widespread lowlands, approximating sea-level. These advanced seaward and their luxuriant forest growth yielded material for the stone-and brown coals. Networks of rivers must have cut through the lowlands and must have deposited their loads in huge depressions. It is clear that many channels fed the coal basin, but all worked after the same fashion. The process throughout was that which Ochsenius terms "Barrenwirkungen" or barricade action.

The memoir discusses many details, rock fragments in coal, stumps filled with sandstone, the occurrence of gypsum, the presence of land shells, all of which are explained very readily by the theory. The conditions at Senftenberg, described by Potonié, are clearly due to this barricade-action.

The numerous coal beds of the Carboniferous were deposited quietly, but they are rarely more than 15 meters thick; whereas the brown coal beds are comparatively few in number, show irregular deposit and at times attain a thickness of 50 meters. The explanation is simple. The soft plants of the Carboniferous had, at most, a diameter of one meter and a height of 40 meters, so that they floated easily in a few meters of water over the "barricade"; whereas the Tertiary and Quaternary giant trees had a diameter of 10 meters and a height of 170 meters, so that they needed a depth of, say, 15 meters to float them over the "barricade." Clearly a depth of one meter would sink more quickly to some centimeters so as to permit only "Spulgut" to pass than would a depth of 15 meters—whence the more frequent interruption of coal deposit in the Carboniferous and the great constancy of formation in Neozoic time.

Almost all our mighty coal deposits are freshwater formations, which came into existence through the factor of "Barrenwirkungen." Autochthony holds in their formation an exceedingly limited place in comparison with that of allochthony.

Schmitz[101] has contributed a series of important papers to the literature of the subject.

In 1894, he regarded the *in situ* doctrine as merely a hypothesis. The presence of transported pebbles in the coal itself rather favors the doctrine that the coal is composed of transported materials.

---

[101] G. Schmitz, "A propos des cailloux roulés du houiller," *Ann. Soc. Geol. de Belgique,* XXI., 1894, pp. lxxi–lxxv; "La signification géogénique des Stigmaria au mur des couches d'houille," *Ann. Soc. Sient. de Bruxelles,* XXI., 1897, 6 pp.; "Formation sur place de la houille," *Rev. des. Quest. Scientifiques,* Avril, 1906, 35 pp., 9 pl.

These pebbles, he had discovered, are much more numerous than had been supposed. They are covered with a carbonaceous patine and are found mostly in the lower portion of the beds; he never saw any in the upper portions. The patine suggests that the pebbles may have made a long journey in fermenting pulp, and he thinks that their presence with this coating is confirmatory of Renault's opinions respecting the conditions of deposition of materials composing the coal. At the same time, the "French theory" of the origin of coal, though probable for the ensemble of the coal formation, does not explain the underclay. As for Belgium, the special, the constant facies of the mur is evidence of formation in place. The convincing fact is the presence of *Stigmaria* in the mur with interlacing of the rootlets. *Stigmaria* remains in the roof are fragmentary.

In 1897, Schmitz reviewed Potonié's paper on Autochthonie; he recognizes that the mur is autochthonous but is not satisfied that that necessarily involves the conclusion that the coal itself is autochthonous also. A mur without coal is evidence of erosion, that its vegetable cover has been washed away. If there be coal without mur, it is allochthonous. A thick bed may be autochthonous below and allochthonous above. While recognizing the valency of many of the arguments presented by Potonié, he is not convinced that they are final.

In 1906, he reviewed the whole subject. His own position in 1896 was that of uncertainty between the old doctrine of autochthony and the new forms of allochthony presented by Fayol and Grand' Eury. Many phenomena observed in the Belgian basins seemed to support Fayol's hypothesis, but the mur, with *Stigmaria,* clearly *in loco natali,* is a fact which cannot be ignored. Autochthony found its chief support in conditions observed in recent swamps, but the knowledge of those was too imperfect to make the argument wholly satisfactory; so that Schmitz, at that time, was inclined to hold an intermediate position and to think that both doctrines might be true.

But Potonié's later publication,[102] based on the study of swamps in a great area, goes far toward removing objections. Schmitz summarizes the processes described as occurring in the formation of

---

[102] "Die Enstehung der Steinkohle."

Sapropel; the gradations from peat to coal; and asserts that all point toward autochthony. He antagonizes conclusions drawn from the presence of vegetable matter in material obtained by deep-sea dredging in the Gulf of Mexico, for that is mingled with ooze and proves nothing for transport. He maintains that vegetable pulp cannot be transported far without notable loss and he urges that black waters from swamps soon lose their color through oxidation, as appears from conditions in the Congo, Rio Negro and other rivers. De Lapparent has protested against the "fascination of present causes" and Schmitz admits willingly that it is an error to seek in the present an absolute representative of the past; but he asserts that it is equally an error to disregard the present in the study of the past.

Schmitz presents an elaborate argument. He traces the formation of Sapropel in an arm of the sea, the encroachment of vegetation, the formation of a bog covered by trees—the *tourbière boisée,* the loss of moisture and the destruction of the forest, the formation of the moss bog with *Sphagnum, Scheuchzeria,* etc.—the *tourbière bombée* or hochmoor, which may continue to rise until it reach the heath stage—that of final decrepitude. He shows how this normal development is often interrupted, that a newer stage may return to an older stage or may originate without existence of previous stages.

The wooded bogs are modern representatives of the Carboniferous type. They show conditions observed in the coal beds; peaty maceration disintegrates the most resistant plants so that one rarely recognizes the parts. The mode of growth in bog plants resembles that of the coal plants; the root is radial not tap. He describes an extensive bog in Hanover, in which the peat had been burned, leaving exposed great tree-trunks, the luxurious crown existing when the bog was wooded; if that bog had been covered with sediment during the life of those trees, there would have been a legion of autochthonous tree-trunks.

The immensity of the great coal areas, to be compared with the immensity of modern bogs, must not be disregarded. One cannot think of the great Westphalian-Belgian-English basin as a mere lagoon to be filled by rivers; and Schmitz asks how vast must have been the low country to yield humic material for the coal beds of that basin. He thinks that to accept the land conditions necessary would require too great draft on one's credulity. But the case is wholly different with the peat bog theory.

Schmitz concludes that the coal systems consist of allochthonous rocks and autochthonous coal beds. The underclay is not a special sediment; it is a sediment modified by the establishment of vegetation. There must have been some allochthonous deposits of carbonaceous matter, but they were merely local. The accumulation as a whole was autochthonous, after the manner of the forested swamps.

Sterzel[103] thinks that very probably no theory of formation is of universal application, the conditions being unlike in different regions, even in different parts of the same region. In studying the Zwickau region area, he became convinced that plants embedded in shales accompanying the coal are not in their original place, for they are broken, they are in different stages of decomposition, their remains are mostly parallel to the stratification, and they show distinct evidence of sorting due to currents of water. Plants *in situ* occur only locally.

Some features favor belief in the autochthony of coal; the narrow variations in thickness of important beds within great areas; the small proportion of ash in many beds; the localization of *Stigmaria* in the Liegenden; the occurrence of erect stems in the Hangenden. But there are others equally favoring allochthony; the distinct lamination of the coal; the mineral matter, often forming a considerable part of the bed, is mostly clay, the same with that of the roof and floor, and it tells of quiet deposition; *Stigmaria* occurs abundantly in the roof of coal beds; erect stems are of exceptional occurrence.

The greater number of phenomena favor allochthonous origin of the Zwickau coal beds. They were deposited in a lake basin surrounded by forested swamps. The gently inflowing waters carried little mineral matter and the plant material accumulated long time on the bottom, where it was converted slowly into coal. When the

---

[103] T. Sterzel, "Palaeontologische Character der Steinkohlenformation und des Rothliegenden von Zwickau in den Erlauterung zur geologischen Specialkarte," Section Zwickau, 1891, pp. 87–142; "Mittheil. aus d. Naturw. Sammlung d. Stadt-Chemnitz," 1903, 22 pp.

water-courses swelled, a great quantity of material, inorganic detritus, was brought down to form the intervening bed, on which, when quiet was restored, the plant material was deposited anew. Periodical changes, slight crustal movements, variation in fall of rivers, lead to deposit of a great mass of rock over the coal bed; the thickness of this intervening rock depending on the extent and continuance of those changes. When quiet returns, the forested swamp again expands. Many localities with particular species of plants had been destroyed wholly and those forms do not reappear in later beds—an explanation of the irregular occurrence of plant-forms in the series.

The lake was comparatively deep, for the Zwickau measures are about 400 meters thick. By accepting this hypothesis of a lake, one finds explanation also of the origin of the great salt-content characterizing the Zwickau deposits—in 1854, 400,000 kilos of sodium chloride and 15,000 kilos of calcium chloride were obtained from mine waters of the Tufen Planitzer beds.

In 1903, Sterzel qualified a statement made on p. 90 of the preceding paper, which refers to the value of erect stems as evidence. The only stems of that sort, observed by him, were "Sargdeckel," the "coal-pipes" of English miners. One *Sigillaria* stump, examined by him, was completely cut off at the base, with no trace of *Stigmaria.* It had been torn from its place by running water, robbed of basal branches and then deposited in the roof of the bed, where its softened bottom was flattened under pressure. He notes that the overlying rock is sharply defined, that there is no passage of plants from the coal, such as would be the case if the place of plant-growth were flooded by masses of rock material.

Lemiere[104] presented a memoir to the Geological Congress of 1900, which discussed the conversion of vegetable matter into coal. In 1904, he returned to the subject and considered in addition the manner in which coal beds accumulated. The discussion is based largely on the assumption and conclusions of Fayol that the coal

---

[104] L. Lemiere, "Sur la transformation des végétaux en combustible fossiles," *C. R. Congrés Géol. Intern.*, Paris, 1901, pp. 500–520; "Formation et recherches comparies des divers combustibles fossiles," *Bull. Soc. de l'Ind. Min.*, 4^{me}. ser., IV., V. Published separately, 1905. Citations from pp. 70–142.

beds were formed of transported vegetable matter deposited in basins of deep water. In this later memoir, he discusses the laws governing deposition of inorganic materials of varying density and shape, on lake bottoms in tranquil water, on beds of streams and on shores exposed to the action of waves. This completed, he applies the ascertained principles to explain the formation of coal deposits.

The basins in which those deposits were laid down were ordinarily gaping faults, very long except where divided transversely by uplifted granite, and, in many cases, the fault is still apparent. Streams began to flow into the basins at once. Where the fault valley was divided transversely by uplifted granite, lake basins were formed like Commentry, Montvicq, etc., in which the beds are irregular. At other times the fracture valley retained its length and was wide enough to be a strait or estuary, common to several rivers and bordering on seas extensive enough to be affected by tides and waves. Respecting the latter he makes the frank remark: "It is hardly possible to admit that the areas of coal deposit were in direct communication with the high sea, because high-level floods are little compatible with free access of this [the ocean]; now, the floods are a condition, *sine qua non,* of vegetable contributions; it is necessary, then, to admit that the areas of deposition were lagoons, sheltered from the ordinary tides, fronted by vast low plains, themselves above the tides and furnishing few coarse elements to the river load."

Other basins retaining their length, were less affected by marine conditions, possibly because of the narrowness or because of variations in level. Of such is the great syncline extending from Moulins to Decazeville. The deposits are lacustrian. The form of the depression affects the speed of currents and therefore the type of deposits; if broad, the rivers from different points form deltas, but if narrow, the speed along the middle is such as to sweep away such deposits. The contrasting conditions are shown by the Saint-Etienne and Rive-de-Gier divisions of the Loire coal basin.

The vegetable matter, to form coal beds, was brought in mostly during floods; some of it remained afloat; some was held in suspension; while some, which had undergone thorough maceration, sank immediately. But all alike were deposited at last on the soaked talus of the delta. The lake basin, in which the deposition was made, is conceived to have been quite deep, for Lemière's diagram shows curves to a depth of 350 meters and the last is still at considerable distance from the bottom; it is supposed also to be large in comparison with the breadth of the tributary streams. The important source of plant material is the space along the streams between the average low water line and that reached by high floods; but the still higher portions of the drainage area, being exposed to rain and wind, would contribute.

During a long period of low water, little aside from inorganic matter would be carried to the basin; but when that was followed by a period of heavy rains, the forested area was invaded, the vegetable contributions were increased, while inorganic contributions were decreased. The forest soil was covered with humus, which had been accumulating without cessation. The soil, thus covered, became increasingly unfavorable to vegetation, whose roots as Grand' Eury says, hate to penetrate it deeply. Lemière thinks this a "peremptory argument against formation *sur place* of coal beds formed by aerial plants very different from those which have formed peat bogs. That the forest might continue and might renew itself after destruction, it was necessary that the soil be cleared away at intervals by winds, rains and especially by floods."

The humus, already macerated and denser than living plants, was swept off first; afterwards, the living plants would be uprooted and broken. The macerated humus, being denser, was deposited on the convex surfaces of the delta, while the living plants had to become watersoaked before sinking, so that they were superimposed upon the other plant material. They would come to rest more abundantly in the bays between deltas, so that one should find more of volatile matters in coal laid down within the bays than in that deposited on the delta slopes, along the axes of the currents. The volatile should increase as one departs from those axes but it should decrease with the depth at which the vegetable matter was deposited.

Floating islands are possible, since a flood might tear off bodily part of a forest, which, carried down, might float for a while and then sink to give the appearance of growth *in situ.* If the storm continue long enough, it would wash off the soil itself, which would become an intercalation in the bed. If the flood return, attaining a higher stage than before, another area of forest region would be torn off to form a new bench of coal, possibly directly on the other. When the flood subsides, the superficial currents would find only inorganic materials on which to act, and the first deposit would be mud to form the roof of the coal bed, after which would follow some sandstone and conglomerate. Between floods the vegetation is restored and the area is increased by encroachment on the lake. During this long interval, the flora might be changed.

Lemière is convinced that, by his hypothesis, he has succeeded in explaining converging beds, parallel formations and floating islets. All are allochthonous; aerial plants have formed no autochthonous beds, for no erect stem has been found in the coal; in fact, the plants could not thrive in a humus not nitrefied. Peat cannot become coal, as its tannic acid checks the process of conversion. He applies his doctrine with great ingenuity to several basins in France and finds it confirmed in all.

Lemière[105] has published several papers in more recent years and he presented a résumé of his opinions in 1910. In that he expresses surprise that in recent congresses the dominant opinion was that coal beds are ancient wooded-bogs buried by successive subsidences, because this opinion involves the supposition that the coal beds were not formed in the same way as the sterile beds which enclose and, at times, penetrate them. This opinion is based upon palaeobotanical evidence, which is often untrustworthy, providing two-edged weapons, available equally for defenders of each theory. It is necessary to discover some criterion which will be conclusive. In an earlier paper, he had demonstrated finally in geometric form that the peat bog theory leads to arrangement of beds unknown in nature. In this he proposes to restudy the conditions after the same method, avoiding palæontological discoveries, and availing himself of discoveries which have the character of certitude. He describes three types of structure observed in areas of the coal formation.

---

[105] L. Lemiere, "Résumé des théories sur la formation de la houille," *Bull. C. R. mensuels. Soc. Ind. Min.*, Sept., 1910, separate, 19 pp.

The first type is that of the Hainaut coal basin in Belgium, a small area, 15 kilometers wide and separated from the Campine basin at the northwest by 60 kilometers of older rocks, while on the southeast it is bounded by a fault. The fossils show that, at times, this basin communicated with the sea. The deposits are thin at the north, where the beds have remained unaffected by subsequent disturbance; but they thicken to 3 kilometers toward the southerly border of the basin, where the disturbance increases as the fault is approached, the downthrow having caused close folding. The hinge of movement was near the southeast bounding fault. If the peat bogs were formed at the unvarying sea-level, the first of them should have had, when the basin was filled, an inclination of 25 cm. per meter and the last should be almost at sea-level, while the intermediary beds should converge toward the shore line at the northwest. The conditions being absent, it is evident from this mathematical demonstration that the coal beds are not buried peat bogs. The warning against the dangers of dependence on palaeontology is repeated, and the necessity for the warning is proved by the discovery of the Bernissart iguanodons in rocks other than those to which the animals belonged, as well as by the possibility that some day remains of fossil man may be discovered under a landslide from a chalk cliff.

The second illustration is that of an area, increasing in extent as it deepens. There, convergence of the beds toward the hinge of movement would not be a criterion. The upper beds should be of greater extent than the lower. This is to explain conditions existing in the Appalachian basin, where one thick coal bed, the Pittsburgh, has an area equivalent to not less than 400 kilometers square. It is difficult to understand how materials from the anticlinal borders could reach the central parts of such a synclinal to give parallel beds there. In the central parts of the basin are great masses of red shale and beds of limestone and the coal beds are not rigorously parallel. He is inclined to think that the materials within the central parts are due to precipitation (from solution) without mechanical transportation from the borders. One cannot assert positively that in this area peat bogs are excluded from consideration.[106]

The third illustration is from the basin of Vendee, which is an isoclinal formation in an isoclinal valley, bounded on one side by a fault. The reference to this area is brief. Lemière states that the phenomena of the faisceaux at the north and the dips in the basin suggest, *a priori,* that here one has a case of peat bog formation. But he plots the conditions in a diagram and states that, as shown thus, they are evidently due to influence of the fault.

He concludes that the French coals as well as those of the Franco-Belgian basin are not old peat bogs but are of alluvial origin and that the same conclusion is probable for the coal beds of North America. These conclusions do not proscribe the theory of peat bogs; on the contrary they appropriate those conditions and their results. All that is insisted on is that, at present, we can find no trace of successive deepenings of feeble amplitude and repeated for each bed; but there are evidences of many subsidences, important or at distant intervals, corresponding to the faisceaux of beds.

Lemière, feeling himself no longer in danger of being paralyzed by the question, Is coal formed *in situ* or as alluvium?, proceeds to show wherein his doctrine differs from other forms of the transport theory. As the distinction depends in great measure on his conception of the mode in which vegetable matter was converted into coal, the details have no place here.

This extended reference to Lemière's publications is justified by the fact that he has presented the characteristic of the transport theory more fully than most of his predecessors and has attempted to explain all the conditions as far as they are known to him.

Stainier,[107] whose numerous contributions will find consideration in another connection, believes that formation of coal beds is essentially a geological problem and he maintains that geologists have been negligent in that they have left the discussion too long to the palæobotanists. Fayol and Grand' Eury, by studying the matter

---

[106] The diagram, illustrating the structure in this second case, shows a bounding fault on one side, such as limits the little basins in France.

[107] X. Stainier, "De la formation des gisements houillers," *Bull. Soc. Belge de Géol.,* XX., 1906, p. V., pp. 112–114.

geologically, have succeeded in solving the problem for the basins of central France. He hopes by following their methods to solve the problem in the great basins of northwestern Europe.

If one study not the coal beds alone but also the whole series of deposits in those coal basins, he finds that their strata differ in no wise from those of terranes, whose marine origin is recognized by all. No feature of coal beds suggests a different origin for them. On the contrary, when one endeavors to explain the formation of coal beds by the *in situ* doctrine, he find himself, at each step, contradicting the best established laws of geology. These contradictions, naturally not apparent to the botanists, ought long ago to have spurred geologists to make investigations for themselves. They have led Stainier to believe that coal beds, like the encasing rocks, are of purely sedimentary origin.

For him, the coal plants grew on continents, bordering great depressions, into which meteoric agencies carried the vegetable débris along with materials torn from the land by erosion. These materials, vegetable and inorganic, were mingled intimately while the water was in agitation; but in proportion as the condition of calm was re-established, they were thrown down to the bottom in a well defined order, determined by density of the materials. In cases where the succession is complete, there was formed, first, a bed of sand, ultimately becoming a bed of sandstone; then a peculiar, irregular rock, which constitutes the mur and contains the denser parts of the vegetables, *i. e.,* the sub-surface organs; then the remaining portion of the vegetable débris was deposited to form a coal bed; and finally, the impalpable elements, fine clays, reached the bottom, giving tender fine shales, the roof of the coal bed.

The reasoning on which the conclusions are based is to be given in a memoir not yet published.

Ashley[108] has offered suggestions which are not without interest here. Adopting the doctrine of autochthony, he ignores in his calculations the cannels as well as other merely local deposits, which are allochthonous and therefore outside of the discussion. He finds

---

[108] G. H. Ashley, "Maximum Deposition of Coal in the Appalachian Coal Field," *Econ. Geology,* I., 1906, pp. 788–793; II., pp. 34–47; "Significant Time Breaks in Coal Deposition," *Science,* N. S., XXX., 1909, p. 129.

that under exceedingly favorable conditions a peat bog has gained one foot of thickness in five years but that in one case this increase appeared to be only one foot in two hundred years. With the conditions normal, the rate of increase seems to be not far from one foot in ten years. Reasoning from the approximately ascertained ratio of volume of peat and the resulting coal, he conceives that 300 years would be required for the formation of one foot of coal, thus giving a period of about 4,000 years for accumulation of the Pittsburgh coal bed in western Maryland. The minimum period to be assigned for formation of the 300 feet of coal in the Appalachian basin is not far from 100,000 years.

In his later paper, seeking to ascertain whether or not a coal bed may be utilized as a time measure, he indicates some complexities of the problem, one of which is important. A coal bed, 18 inches thick at one locality may be 15 feet at another, the latter thickness requiring for accumulation 4,000 years more than the other. As the rocks accompanying the thinner bed show no compensating differences, the 18 inches is all that was formed while the 15 feet was accumulating elsewhere. There was either slow growth or a time-break, that is a period of no deposition, before or after deposition of the thin bed.

"Smooth-partings" are evidences of time-breaks and represent locally nonconformity between the under- and the overlying beds: a "smooth-parting" at one place may be equivalent to 40 feet of shale at another; an inch or two of cannel may have similar equivalence. Slow growth and temporary cessation of deposition are important elements of the problem.

Dannenberg[109] finds strong arguments in favor of autochthonous formation in the vast extent of some coal areas, the presence of the tenderest plant-parts in coal inclusions, the abundant occurrence of roots directly under the coal, and the identity of coal-forming plant species with those found in the enclosing shale rocks. Not all localities show these features with equal clearness, for in some cases there are variations along dip and strike like those in delta deposits.

---

[109] A. Dannenberg, "Geologie der Steinkohlenlager, Berlin, 1909: Erster Teil, 197 pp. The citations are from pp. 18–27.

such as appear in the basins of central France, which Fayol has proved to be allochthonous.

The deposits must have been made in shallow water; Grand' Eury has shown that the autochthonous flora of the Loire basin could not have grown in water more than 10 to 15 meters deep. There must have been a special combination of circumstances, since the deposits, in spite of the shallowness of the water, have in some basins a thickness of some thousands of meters. This can be understood if one accept a constant though variable subsidence throughout the period of deposition. A certain instability of coast line in paralic basins is proved by repeated inroads of the sea. If the sediments be laid down less rapidly than the surface sinks, marine conditions prevail. Periods of rest, possibly of some elevation, would be favorable to development of swamp vegetation, which, when subsidence began again, would be buried under muddy and sandy deposits, until a new swampy area was produced, on which vegetation began *de novo*. These movements can be followed with great clearness in the Saarbruck and Loire basins.

Similar movements in the period of man can be recognized along many coasts. Dannenberg regards the Tertiary and Quaternary history of the Netherlands as especially instructive. This he gives in detail, showing that there have been successive advances and retreats of the shore line, so that the section of Tertiary and Quaternary beds consists of sandstones, conglomerates, shales, marine beds and peat deposits, wholly similar to the succession observed in the Coal Measures. The filled river valleys observed in the Coal Measures, have their counterparts in these newer deposits. And it must not be forgotten that, in the Carboniferous time, great orogenic movements occurred, so that there was abundant material for filling the basins.

Stevenson,[110] after studying the area, found himself unable to accept Fayol's conclusions respecting the mode in which the coal beds were formed in the basin of Commentry. He agreed fully with Fayol as to the process by which the inorganic deposits were laid

---

[110] J. J. Stevenson, "The Coal Basin of Commentry in Central France," *Ann. N. Y. Acad. Sci.*, XIX., 1910, pp. 161–204, 6 pl.; "The Coal Basin of Decazeville, France," the same, XX., 1911, pp. 243–294, 2 pl.

down, seeing there the conditions of delta formation as long recognized by geologists in American coal fields; but he could discover no reason for supposing that the coal beds were formed of plant materials washed in from the drainage area. That hypothesis, as presented for this region, seems to be self-contradictory. The supposed surface conditions at the beginning of the history were such that dense vegetable cover seems in the last degree improbable; but the vegetation required by the hypothesis was so dense, that it would have been its own protection against any but a long-continued series of the most terrific cloud-bursts; in case of such a débâcle, only a small part of the vegetable matter could be deposited as a coal bed, for the trees, supposed to have composed one half of the whole vegetation, would be loaded by material around their roots, would be snags in the mass of detritus and would be buried in the sands; even the twigs and underbrush would be entangled in the mass, for there could be no sorting action in the short course of the little torrent and all would be dropped when the flood's velocity was checked on the comparatively broad delta surface, supposed to exist when formation of the Grande Couche began. Only the finest material, mineral, or vegetable, could find its way to the bottom of the basin—yet it is certain that trees make up a very considerable part of the Grande Couche. The objections presented by this writer will be considered in another connection. He thinks that the structure of the Grande Couche shows that its vegetation accumulated *in situ* and that there is no evidence to favor the suggestion that Lake Commentry was a deep water basin at the time when coal accumulation began.

Study of the Decazeville basin led him to similar conclusions respecting that area. The conditions there are very different from those in the Commentry basin, so different that any doctrine of transport formulated to account for the conditions at Commentry could not be applicable at Decazeville.

Study of investigations by v. Gümbel and Potonié led Gothan[111] to study the coal area near Fünfkirchen. The economic importance of the Liassic coals within that area had been known for more than

---

[111] W. Gothan, "Untersuchungen über die Entstehung der Lias-Steinkohlenflötze bei Fünfkirchen (Pecs, Ungarn)," *Sitzungsber. d. k. preus. Akad.*, VIII., 1910, pp. 129–143.

100 years and the relations of the beds had been described by several geologists; but nothing was known which showed the mode in which the coals had accumulated. The section contains about 100 coal beds, of which fully 25 attain workable thickness in much of the area. Gothan had already discovered underclays with roots associated with Mesozoic coal beds on the Yorkshire coast of England, and it seemed probable that search for similar clays at Fünfkirchen would be successful.

He was not disappointed, though he found the difficulties in the way of study greater than anticipated.

Under the coal bed, no. 7, there is a well-marked underclay with irregular branching coaly markings, varying in diameter and in every respect resembling roots; and, at one locality, a rhizoma with its rootlets was complete, enabling him to determine the relations of the other forms. "Through such horizontal rhizomas, the analogy of this Mesozoic underclay with the Carboniferous *Stigmaria*-beds and the recent or sub-recent reed-beds is the more marked." A four-inch layer of carbonaceous shale lies between the underclay and the coal, but one cannot trace the roots in it; they cannot be distinguished in the dark material, which is so crossed by cleavage planes that none but irregular angular fragments can be obtained. The planes do not coincide with the direction of the rootlets.

Roots are seldom observed in the freshly exposed rock within the mines, but they are distinct enough where the rock is somewhat weathered. Gothan exposed the outcrop for several meters at different horizons and in the course of a day's excursion, he found well-marked underclays, with roots, associated with 8 coal beds. The analogy with Tertiary and Quaternary underclays is complete. His conclusions are that the underclay, associated in more than a dozen instances, with the Fünfkirchen coal beds, shows that these are, for the most part, of autochthonous origin, as are, predominantly, the younger and older humus deposits of the present time as well as those of the Tertiary and Palæzoic. The failure to secure proof of this origin for all the Fünfkirchen beds is due merely to the unfavorable conditions to which reference has been made. In a footnote he notes his discovery of typical underclay, with roots, just below a Wealden coal bed in a neighboring district.

THE TRANSPIRATION OF AIR THROUGH A PARTITION OF WATER.

By C. BARUS.

(*Read April 21, 1911.*)

1. *Molecular Transpiration of a Gas.*—Ever since 1895 I have observed that the Cartesian diver, used in my lectures, grew regularly heavier from year to year. The possibility of such an occurrence is at hand: for the imprisoned air is under a slight pressure-excess as compared with the external atmospheric air. But this pressure gradient is apparently so insignificant as compared with the long column of water through which the flow must take place, that opportunities of obtaining quantitative evidence in favor of such transpiration seem remote. If, however, this evidence is here actually forthcoming, then the experiment is of unusual interest, as it will probably indicate the nature of the passage of a gas, molecularly, through the intermolecular pores of a liquid. It should be possible for instance to obtain comparisons between the dimensions of the molecules transferred and the channels of transfer involved.

2. *Apparatus.*—Hence on February 27, 1890, I made a series of definite experiments[1] sufficiently sensitive that in the lapse of years one might expect to obtain an issue. The swimmer was a small light balloon-shaped glass vessel, *vd*, Fig. 1, unfortunately with a very narrow mouth, 2 mm. in diameter, at *d*, in the long column of water *A*. The small opening however gave assurance that the air would not be accidentally spilled in the intervening years. For this reason it was temporarily retained, the purpose being that of getting a safe estimate of the conditions under which flow takes place.

In Fig. 1 *ab* is a rubber hose filled with water, terminating in the receiver *R*. Here the lower level of water may be read off. Moreover *R* is provided with an open hose *C*, through which pressure or suction may be applied by the mouth, for the purpose of raising or

---

[1] *Am. Journ. of Sci.*, IX., 1900, pp. 397–400.

lowering the swimmer, *vd*, in the column *A*. In this way constancy of temperature is secured throughout the column.

3. *Barometer.*—The apparatus is obviously useful for ordinary barometric purposes, and provided the temperature, *t*, of the air at *v*, is known to .025° C., the barometric height should be determinable as far as .1 mm. Apart from this the sensitiveness of the apparatus is surprising. Care must be taken to avoid adiabatic changes of temperature, so that slow manipulation is essential. These and other precautions were pointed out in the original paper (*l. c.*)

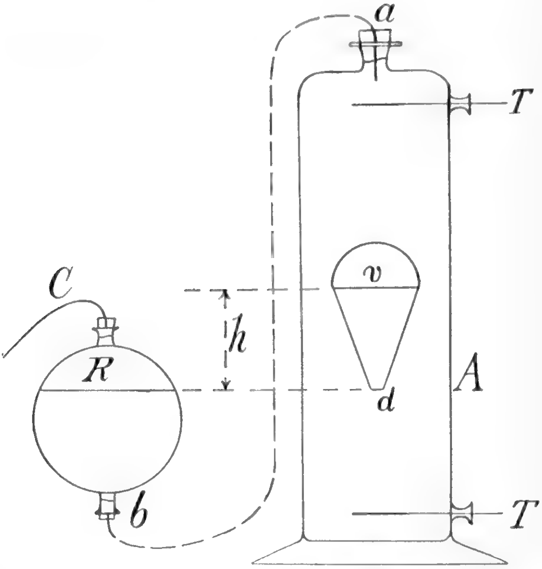


FIG. 1. Swimmer and appurtenances.

4. *Equations. Manipulation.*—Let *h* be the difference of level of the imprisoned water and the free surface in the reservoir *R*. Then it follows easily that

$$h + H\frac{\rho_m}{\rho_w} = \frac{Rm}{gM}\,\frac{\tau}{(1 + m/M) - \rho_w/\rho_g}, \qquad (1)$$

where *H* is the corrected height of the barometer (from which the mercury head equivalent to the vapor pressure of water is to be deducted), ρ_m, ρ_w, ρ_g, the densities of mercury (0° C.), water (t° C.), and glass, respectively, m the mass of the imprisoned air at v, R its gas constant, and $\tau = t + 273°$ its absolute temperature. M is the mass of the glass of the swimmer and g the acceleration of gravity.

The equilibrium position of the swimmer is unstable. To find it, R may be raised and lowered for a fixed level of the swimmer; or R may be clamped and the proper level of the swimmer determined by suction and release at C. The dropping of the swimmer throughout the column of water may occasion adiabatic change of temperature of .23°. It was my practice to use the latter method and to indicate the equilibrium position of the swimmer by an elastic steel ring, encircling A. In this way the correct level may be found to about 1 mm., and afterwards read off on the cathetometer.

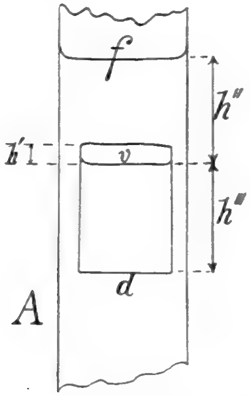


FIG. 2. Cylindrical Swimmer.

After making the observations, the hose ab is to be separated at a, so that the swimmer falls to a support some distance above the bottom, admitting of free passage for diffusion. Clearly this diffusion is due to the difference of level, h'', between the water level in v and at the free surface of the liquid, f (see Fig. 2). Increase of barometric pressure has no differential effect. A large head h'' however means a longer column for diffusion.

5. *Data.*—In the following summary a few of the data made in 1900 are inserted, chosen at random.

In the intermediate time, I did not return to the measurements until quite recently (January, 1911), when a second series of observations was made. As much as one fourth of the air contained in 1900 had now, however, escaped, in consequence of which the above method had to be modified and all heads measured in terms of mercury. Hence if H denotes the height of the barometer diminished by the head equivalent to the vapor pressure of water, and if m/M be neglected in comparison with 1 (about .06 per cent.) the equation becomes

$$m = \frac{Mg\rho_m}{R} \frac{H(1/\rho_m - 1/\rho_g)}{\tau} \qquad (2)$$

in which the first factor of the right-hand member is constant. If the observations are made at the instant the swimmer sinks from the free surface in A, Fig. 2, H must be increased by the mercury equivalent of the height h' of v. The table contains all the data reduced to mercury heads. $A = Mg\rho_m/R$. Consequently $1,842 \times 10^{-6}$ grams of the imprisoned air escaped in the intervening 10.92 years; *i. e.*, .265 of the original mass of air. In other words 168.7×10^{-6} grams per year, $.462 \times 10^{-6}$ grams per day, or 5.35×10^{-12} grams of dry air per second.

6. *Conditions of Flow.*—It is now necessary to analyze the above experiment preparatory to the computation of constants. The mouth of the swimmer had an area of but .0314 cm.^{2} When sunk the head of water above the surface v was $h'' = 24$ cm. The column of water between v and d was $h''' = 8$ cm. Hence the length of column within which transpiration took place was $24 + 2 \times 8 = 40$ cm. The right section of this column is taken as .0314 cm.^{2} throughout. Naturally such an assumption, accepted in the absence of a better one, is somewhat precarious; but it may be admitted, inasmuch as the pressure of the gas sinks in the same proportion in which the breadth of the channel enlarges. Thus there must be at least an approximate compensation. In more definite experiments a cylindrical swimmer whose internal area is the same as the annular area without will obviate this difficulty (see Fig. 2).

The pressure difference urging the flow of air from v is

$$\Delta p = 24 \times .997 \times 981 = 23470 \text{ dynes/cm.}^2$$

Hence per dyne/cm.^{2} per sec.

$$\frac{10^{-12} \times 5.346}{10 \times 2.347} = 10^{-16} \times 2.28$$

grams of air escape from the swimmer.

A few comparisons with a case of viscous flow may here be interesting. Using Poiseuille's law in the form given by O. E. Meyer and Schumann's data for the viscosity of air, it would follow that but $.194 \times 10^{-6}$ cm.^{2} of the .0314 cm.^{2} of right section at d is open to intermolecular transpiration. The assumption of capillary transpiration is of course unwarrantable and the comparison is made merely to show that relatively enormous resistances are in question.

Again the coefficient of viscosity

$$\frac{\eta}{1 + 4\xi/r} = \frac{t}{m}\,\frac{\pi}{16}\,\frac{r^4}{lR\tau}(P^2 - p^2)$$

may be determined directly. In this equation m is the number of grams of air transpiring in t seconds through the section πr^2 and in virtue of the pressure gradient $(P - p)/l$, when η is the viscosity and ξ the slip of the gas. Hence the value $\eta/(1 + 4\xi/r) = 4.8 \times 10^6$ would have to obtain, a resistance, which would still be enormously large relative to the viscosity of air ($\eta = 180 \times 10^{-6}$), even if the part of the section of the channel which is open to capillary transpiration is a very small fraction.

7. *The Coefficients of Transpiration.*—To compute the constants under which flow takes place the concentration gradient dc/dl may be replaced either by a density gradient $d\rho/dl$ or a pressure gradient dp/dl. If the coefficients in question be k_ρ and k_p respectively

$$k_p = \frac{k_\rho}{R\tau} = \frac{\dot{m}}{a\,dp/dl} \tag{3}$$

where a is the section taken equal to the area of the mouth of the swimmer, R is the absolute gas constant, τ the absolute temperature of the gas, and $\dot{m}$ the loss of imprisoned air in grams per second. If $\dot{v} = \dot{m}R\tau/p$ is the corresponding loss of volume at τ and p

$$k_p = \frac{k_\rho}{R\tau} = \frac{p\dot{v}}{aR\tau\, dp/dl}. \tag{3'}$$

If in equation (3) the full value of m is inserted and t denotes current time, or $\dot{m} = m/t$; if

$$\frac{dp}{dl} = \frac{h''\rho_w g}{h'' + 2h'''}$$

where ρ_w is the density of water, h'' and h''' the difference of level (see Fig. 2) of the surface in v below the free surface in A and above the mouth at d, the relations are

$$k_p = \frac{M\rho_m}{Rt}\,\frac{H}{\tau}\,\frac{1 + 2h'''/h''}{a\rho_w}(1/\rho_w - 1/\rho_g), \tag{4}$$

$$k_\rho = k_p R\tau. \tag{5}$$

The acceleration of gravity, g, has dropped from both equations; k_ρ is independent of $R\tau$. The coefficient k_p, however, is more perspicuous.

If h''' is made very small in comparison with h'' (care being taken to avoid loss of air during manipulation) h'' will also vanish; or for $h'' = 0$

$$k_p = \frac{M\rho_m}{tRa\rho_w}\,\frac{H}{\tau}(1/\rho_w - 1/\rho_g), \tag{6}$$

and similarly for $h'' = 0$

$$\dot{m} = k_p a\rho_w g\, \frac{1}{1 + 2h'''/h''}$$

reduces to

$$\dot{m} = k_v a\rho_w g.$$

Thus the apparatus is most sensitive if a is as large as possible and h'''/h'' as small as possible and the length of the column in A is eventually without influence on the result. Hence if for a cylindrical swimmer the internal right section is equal to the area of the annular space between the outer wall of the swimmer and the inner wall of the vessel A, if the column of water above the swimmer is removed during the prolonged intervals of time between observations, the section *a* through which capillary transpiration takes place is definitely given. It is obvious that the swimmer must be suspended, for instance by fine cross wires, above the bottom of the tank *A*.

Reference is finally to be made to convection and to temperature. The manipulation during observation necessarily stirs up the water and distorts the regular pressure gradient. Hence observations are to be made rarely. Again to obviate convection in general the vessel must be kept in a room of nearly constant temperature.

8. *Values of the Coefficients.*—If the data of the above summary be inserted in the equations for k_p and k_ρ,

$$k_\rho = \frac{mR\tau}{a\,dp/dl} = \frac{5.35 \times 10^{-12} \times 2.87 \times 10^{6} \times 298}{10314 \times 23470/40} = 250 \times 10^{-6},$$

$$k_p = k_\rho/R\tau = .29 \times 10^{-12}.$$

Hence for a gradient of 1 dyne per cm., 2.9×10^{-13} grams of air flow between opposed faces of a cu. cm. of water per second. This may be put roughly as about 2.4×10^{-10} cu. cm. of air per second. The speed of migration of individual air molecules intermolecularly through a wall of water is thus 2.4×10^{-10} cm./sec. for a dyne/cm. gradient.

Since the gradient is the energy expended when the cu. cm. is transferred 1 cm. along the channel and if the number of air molecules per cu. cm. be taken as $N = 60 \times 10^{18}$, the force acting per molecule to give it the velocity just specified is $1/(60 \times 10^{18})$ dynes. Hence the force or drag per molecule if its speed is to be 1 cm. per sec. is

$$f = \frac{1}{2.4 \times 10^{-10}}\,\frac{1}{60 \times 10^{18}} = \frac{1}{144 \times 10^{8}}\ \text{dynes}$$

$$f = 6.9 \times 10^{-11}\ \text{dynes, if } v = \text{cm./sec.}$$

This may be compared with the force necessary to move a small sphere through a very viscous liquid of viscosity η. This force is

$$f = 6\pi\eta r v.$$

If $v = 1$ cm./sec., $2r = 10^{-8} \times 2$ cm. the diameter of the sphere of influence of a molecule, and $f = 6.9 \times 10^{-11}$ dynes the value just found,

$$\eta = \frac{6.9 \times 10^{-11}}{6\pi \times 10^{-8}} = 366 \times 10^{-6}.$$

In other words the molecule moves through a liquid about twice as viscous as the air itself.

9. *Conclusion.*—The above data are subject to the different hypotheses stated; but it has been shown that the results may be obtained by the method described free from ulterior assumption. It seems to me that detailed investigations of the above kind carried on with reference to both the chemical and the physical properties of the liquid, *i. e.,* with different liquids and different gases at different temperatures and pressures, cannot but lead to results of importance bearing on the molecular physics involved. Hence experiments of this kind have been begun in this laboratory and I hope to report the results from time to time. Obviously in a doubly closed water manometer (U-tube) the unequal heads of the two columns of liquid must in a way similar to the above vanish in the lapse of time. This method seems particularly well adapted to obviate convection. Finally hydrogen shows a measurable amount of molecular transpiration in the daily march of results already obtained, and with this gas a new and direct method for obtaining the molecular diameter is foreshadowed.

Brown University,
Providence, R. I.

ELLIPTIC INTERFERENCE WITH REFLECTING GRATING.

By C. BARUS.

(Read April 21, 1911.)

1. *First Method.*—There are two or three typical cases in the use of reflecting gratings for the production of interferences in the spectrum, each of which shows peculiarly interesting features. The first of these is given in Fig. 1 and corresponds closely to the method described for transmission gratings in a preceding paper. If L is the source of light and M a glass plate grating, it was shown that

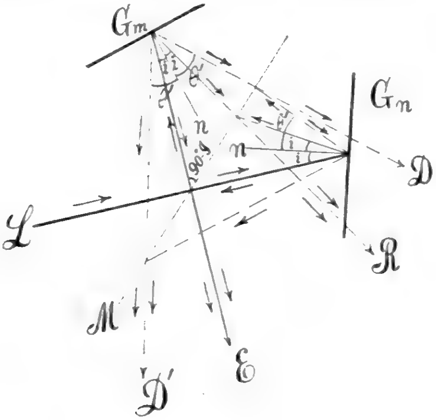


FIG. 1. Diagram, showing positions of mirror, M, and grating, G.

plane mirrors in the positions G_m and G_n, each reflecting a spectrum from M, produce elliptical interference whenever the rays returned after passing M by transmission and reflection, respectively, are made to overlap in the spectrum, under suitable conditions.

The present method is the converse of this, since the gratings and the opaque mirrors change places. Parallel rays from L strike the plate of glass M and the component rays reach identical reflecting gratings G_m and G_n, placed symmetrically with respect to M at an angle i to the E and L directions. The undeviated rays pass off eccentrically at R and are not seen in the telescope at E. They may, however, be seen in an auxiliary telescope pointed in the line R and they then facilitate the adjustments. Rays diffracted at the angle $2i$, however, are respectively transmitted and reflected by M and interfere in the telescope in the line E. Similarly rays diffracted at an angle $\theta' > i$ interfere in the line D.

To make the adjustment it is sufficient to bring the Fraunhofer lines in the two spectra seen at E into complete coincidence, horizontally and vertically. Coincidence of slit images at R (at least vertically) aids in the same result. It is also necessary that the rulings on G_m and G_n and the slit should be parallel, or that the images of slit and spectra shall lie between the same horizontals. One of the gratings, G_n, may now be moved parallel to itself by the micrometer screw until the elliptic interferences appear. If the plate M is not half silvered there are three groups of these as described in the preceding paper. Each group passes from the initial degree of extreme fineness, through maximum size, to a final degree, for a play of the screw of about 1 mm. There is the usual radial motion of the fringes, together with the drift through the spectrum as a whole. To bring out the set of solitary ellipses, the silvered surface of M should be towards the light and remote from the eye. As a rule the adjustment is difficult, as an extra condition is imposed in the parallelism of the slit and the rulings of the gratings. The ellipses are liable to be coarse with their axes oblique, clearer in some parts of the spectrum than in others, unless means are provided for placing the rulings accurately parallel. Even when well adjusted they are rather polygonal than rounded in their contours. They are about as strong with non-silvered glass M as with half-silvered glass; but in view of the multiple spectra the adjustment is much more difficult in the former case.

It has been suggested that the white slit images must appear eccentrically in the direction R. Hence if a special telescope is directed in this line, the final adjustment is reached on coincidence of the proper slit images, provided the rulings of the gratings and the slit are parallel.

For $\theta' > i$ the second series of interference spectra occurring at D, eccentrically, are broader, but only on perfect adjustment do they occur simultaneously with the other set. In fact, since for the preceding case $i = \theta$, or

$$2 \sin i = \lambda/D$$

and in the present case,

$$\sin \theta' - \sin i = \lambda/D,$$

therefore

$$\sin \theta' = 3 \sin i = 3 \sin \theta.$$

There is also an available set in the second order to the left of E. In the gratings used above D lies in front of G_n, being nearer the E than the L direction.

2. *Inversion of the Method.*—The occurrence of the undeviated ray R suggests another method. For if the white ray R is *reversed, i. e.,* comes from an eccentric collimator, slit images will be seen in telescopes at L and E, whereas overlapping spectra will appear in the direction D' eccentrically and in the lines R and R'. One of the latter may be lost in the collimator. The former occurs for the same angle θ' so that

$$\sin \theta' = 3 \sin i.$$

Moreover, if $I = 45°$ is the angle of incidence of L upon M when sodium light is taken, so that $\theta' = 26° \ 14'$, $i = 8° \ 28'$, the R, D, D' rays make angles $2i$, $\theta' + i$, $\theta' - i$, respectively, with the E direction; or the sum of the angles at D and D' with the E line is $2\theta'$, their difference $2i$, and the rays D, R, D' intersect at a common centre on G_m. Hence if we place the plane of G_m at the centre of the spherometer and arrange M and G_n eccentrically, the angles may be measured as before.

3. *Resolution of the Slit Image.*—If the sharp white images of the slit in a Michelson apparatus for the case in which the incident light consists of parallel white rays from a collimator, be accurately superimposed and the opaque mirrors be set at the proper distances from the semi-transparent mirror by the micrometer, the slit image may itself be viewed through a grating and will then show elliptic interferences in all the spectra. The apparatus is here eccentric,

while the grating (either transmitting or reflecting) must be at the center of the spectrometer, if angles are to be measured. The same is true for any of the other superimposed white slit images in the above or the earlier experiments and may even be repeated with successive transmitting gratings. It is interesting to note that the position of the center of ellipses is at the same wave length in all the spectra though the form of ellipses may differ enormously. The same phenomenon may thus be seen by a number of observers at the same time, each looking through his own telescope.

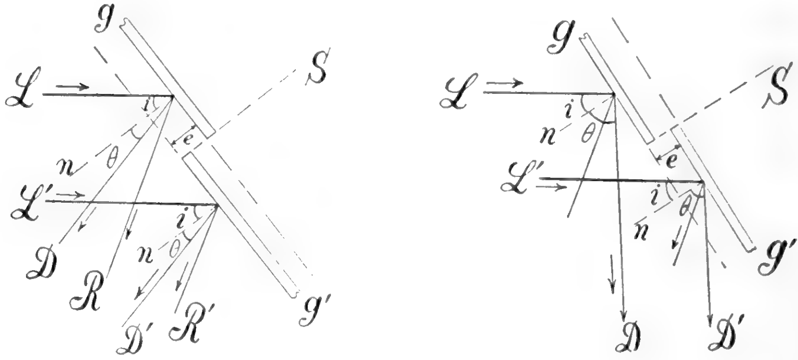


FIG. 2. FIG. 3.

Diagrams showing position of gratings, *g*, *g'*.

4. *Third Method. Parallel Gratings.*—In this case the two halves of the grating are treated displaced parallel to themselves, from their original coplanar position in the grating, from which they are cut. Their mounting is thus something like the case of the two black plates of Fresnel's mirror apparatus, one of the plates being adapted for displacement parallel to itself.

In Fig. 2 g and g' show the two halves of the grating cut along the plane S, normal to the plates and parallel to the rulings. The half g' is provided with a micrometer screw, so that it may be successively moved from the position g' in Fig. 2 to the position g' in Fig. 3, through all intermediate positions, while the half g remains stationary. Each of the halves g and g' is controlled by three adjustment screws (horizontal and vertical axes of rotation), to secure complete parallelism of the faces of the grating. Each, moreover, may be rotated around a horizontal axis to place the lines parallel to the slit of the collimator. The duplex grating is mounted on a spectrometer as is usual for reflection. Finally each half may be raised and lowered and moved horizontally to and fro, parallel to itself, so that the half gratings when coplanar may approximately reproduce the original grating.

After each of the spectra are clear as to Fraunhofer lines, the interferences here in question are produced by bringing these lines (the D lines for instance) into perfect coincidence, horizontally and vertically. Under these circumstances if the distance apart, e, is suitably chosen, the interference fringes will appear throughout the spectrum. These consist of an approximately equidistant series of lines parallel to the slit, *i. e.*, vertical lines, which are finer, *cæt. par.*, as the breadth of the crack at S between the gratings is larger. They may be increased from the extreme fineness as they enter the range of visibility to a maximum coarseness (in the above experiments) of about three to five minutes per fringe, after which they vanish. They cannot, in practice, be passed through infinite size; neither can they be produced symmetrically on the two sides of the adjustment for infinite size. They cannot in other words be changed from the positive to the negative condition of appearance.

The occurrences are in fact as follows: if as in Fig 2, $i > \theta$, (parallel white rays coming from L and L', R and R' being reflected, D and D' diffracted rays for the normal n), the grating g' must be in advance or forward of g. If now the airspace e is reduced micrometrically, g' retreating, the lines travel in a given direction (from left to right) through the spectrum, while at the same time they grow continually larger until for a minimum value of e still positive, they vanish as a whole. The period of indistinctness before evanescence is not marked.

On the other hand if $\theta' > i$ as in Fig. 3, the grating g' must be to the rear of g and the air space e is throughout negative. If this is now decreased numerically the lines travel through the spectrum in the opposite direction to the preceding case, while at the same time they coarsen until they vanish as a whole as before. The grating g' is still behind g when this occurs.

Finally if for any suitable value of e the grating g' is moved in its own plane without rotation away from g, so as to widen the crack at S between them, the fringes grow continually finer until they pass beyond visibility, and vice versa; *i. e.*, as the crack at S is made smaller the lines continually coarsen.

5. *Nature of the Evanescence.*—The fact that the lines vanish as a whole and almost suddenly after reaching their maximum distance apart is very peculiar, as is also the fact that they cannot be passed through infinite size or appear symmetrically on both sides of this adjustment. To investigate this case I provided both the collimator and the telescope with slits so that the parts of the grating g and g', from which the interfering pencils come, might be investigated.

If a single vertical slit about 1 mm. wide is passed from right to left toward the objective of the telescope, a black line passes across the field of the spectrum, which line is merely the image of the crack at S. In the diagram Fig. 4, the G rays, for instance, come from the edge of both gratings g and g', whereas the R rays and the V rays come from but a single grating. Now when the space e

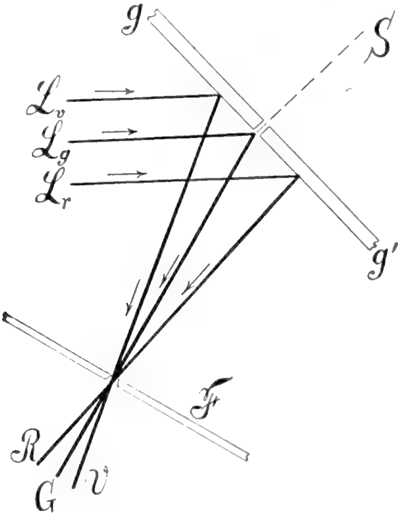


FIG. 4. Diagram.

is diminished, the black band at *G* gradually vanishes and in its place appear the coarsest fringes producible. When the slit *F* is removed these coarse fringes disappear. The fringes visible through the slit have however both an inferior and superior limit of angular size. When *e* is diminished to zero they vanish and when *e* is sufficiently increased they again vanish, though they now appear when the slit is either removed or widened. From this it follows that the coarsest fringes come from the edges of the crack *S* of the gratings, and that the remainder of the grating will not produce coarse fringes. By moving the slit the fringes may be made to appear in any other part of the spectrum.

The same fact may be proved by putting the vertical slit *F* over the lens of the collimator and allowing the white light *L* to fall on the edges of the grating at *S*. Coarse fringes limited as to range and size are then seen throughout the spectrum at *g*.

Whenever the slit or vertical stop is used, the fringes are exceptionally sharp and easily controlled for micrometry. It is not even necessary to adjust the two spectra horizontally with the same care as when no slit is used, but the vertical coincidence of spectrum lines must be sharp. Naturally the use of the slit has one drawback, as the resolving power of the grating is decreased and the spectrum lines are only just visible. The adjustment, however, may be made before the slit is added. A few examples may be given. For a slit 1 mm. wide over the telescope or collimator, only the immediate edges at the crack *S*, about .5 mm. each in breadth, are active. A narrow range of large fringes are seen in the field easily controlled by the micrometer screw. With a slit 3 mm. in width the lower limit is much increased the upper diminished, to a size of about 3 inches per fringe. In the absence of the slit the field is free from fringes. With a slit 6 mm. wide, the upper limit is again decreased the lower much increased; nevertheless the finest fringes appear only after the slit is removed. Using double slits over the collimator, each 1 mm. wide and 3 mm. apart, fringes of medium size limited at both ends appear; 3 mm. slits 6 mm. apart show only the very fine fringes. but both sizes are still limited. Finally when all but about .5 mm. of the edge of the crack of the grating *g'* is screened off, whereas the whole grating *g* (about one half inch square) is without a screen, all the fringes from the maximum size to complete evanescence beyond the range of visibility are producible. Naturally if the edge of *g'* is quite dark everything vanishes.

It follows therefore that pairs of corresponding rays are always in question. These corresponding rays are at a definite *ND*, apart where *D* is the grating space and *N* the number of lines per cm. of the grating in question. This distance *ND* is greater as the fringes are smaller and may be of the order of a cm. when the fringes pass beyond the range of visibility. Again *ND* is equal to the width of the crack when the largest fringes vanish. Finally when *ND* is zero, as in the original unbroken grating. the size of the fringes is infinite.

It has been stated that the use of the slit or a laterally limited objective is advantageous because all the lines are much sharper. Inert or harmful illumination is cut off. If the slit is over the objective of the telescope only a small part of the field of view shows the lines; if placed over the objective of the collimator. the fringes are of extreme clearness throughout the spectrum. It may be ultimately of advantage to use the edge near the crack *g'* only, together with the whole of *g*. For if a small strip of *g'* at the crack *S* is used with the whole of *g*, the smaller fringes are weakened or wiped out. Thus the inner edge of the nearer grating with successive parts of the further grating is chiefly effective in the production of these interferences.

To bring the two edges quite together was not possible in my work, as they were rough and the apparatus improvised.

7. *Data.*—Some measurements were attempted, with the view only of checking the equations presently to be deduced. The adjustment on an ordinary spectrometer is not firm enough and the fringes being very fine (a few minutes of arc) are difficult to follow unless quite stationary.

Table I., however, gives both the values of de/dn, displacement per fringe, for different angles of incidence i and of diffraction θ, and $d\theta/dn$, the angular deviation per fringe at the *D* line. In measuring the latter it was necessary to count the fringes between the C and D lines and divide their angular distance apart by these numbers. As e cannot be measured, its successive increments Δe from the first position are given. These are presently to be associated with the corresponding increments of $dn/d\theta$.

TABLE I.

VALUES OF $d\theta/dn$, ETC. $i = 53° 15'$. $D = 200 \times 10^{-6}$ cm.

No. of Fringes.	Observed.					Computed.			Region.
	θ and θ'	$d\theta/dn$	$dn/d\theta$	$\Delta dn/d\theta$	Δe	At θ $\Delta dn/d\theta$	At θ' $\Delta dn/d\theta$	Mean $\Delta dn/d\theta$	
120	30° 27′	1′ 17″	3080	1130	.025	1260	1028	1140	Between C and D lines
75	28° 14′	1′ 46″	1950						
	Diff.								
	2° 13′								
90	29° 09′								
71	28° 14′	46″	4438		.025	1116	1027	1072	Near C line
55	Diff.	1′ 0″	3438	1000	.050				
36	55′	1′ 32″	2250	1188	.075				
24	30° 27′	1′ 50″	1875	1328	.025	1259	1196	1228	Near D line
41	29° 43′	1′ 4″	3203						
	Diff.								
	44′								

8. *Equations.*—In Fig. 5, L and L' represent a pair of corresponding white rays, reflected into R and R' and diffracted into D and D' at angles i and θ, respectively. The half gratings g and g' are separated along the crack S, and g' is movable parallel to itself by a micrometer screw normal to g'. Let the normal distance apart of the gratings be e. The incident rays L, L' strike the originally coplanar grating at points N rulings apart, or ND cm. apart, if D is the grating space. In the separated grating let these points be at a distance c apart. Let d be the incident wave front and h the corresponding diffracted wave front and call the angle between c and d, γ.

When there is reinforcement the path difference of the rays L and L' from the incident (d) to the diffracted (h) wave front, may be written

$$n\lambda = b - a,$$

where b and a are the distances of h and d from the points of incidence of L and L' on the grating g and g' respectively. If finally f

is the length of the prolongation of L' between the gratings we may write in succession

(1) $$d = ND \cos i,$$

(2) $$f = e \sec i,$$

(3) $$a = ND \sin i - e \sec i,$$

(4) $$\tan \gamma = a/d,$$

(5) $$C = ND \cos i \sec \gamma,$$

(6) $$b = c \sin (i + \theta - \gamma).$$

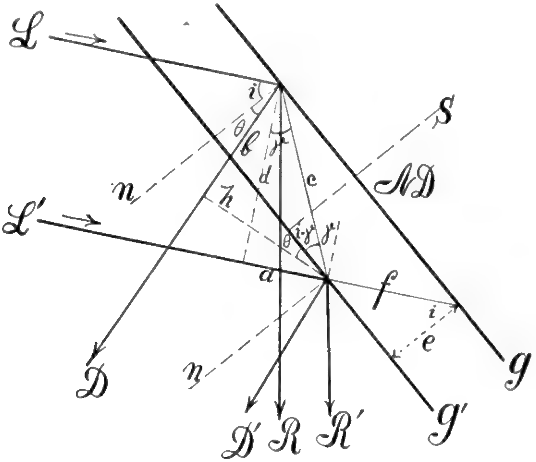


FIG. 5. Diagram.

To these should be added

(7) $$dN/de = \tan i/D.$$

Hence after removing γ and arranging

$$n\lambda = ND\{\cos i \sin (i + \theta) - \sin i \cos (i + \theta) - \sin i\} + e \sec i(1 + \cos (i + \theta)),$$

which reduces to

$$n\lambda = ND(\sin \theta - \sin i) + e \sec i(1 + \cos (i + \theta)),$$

or since

$$\sin i - \sin \theta = \lambda/D,$$

finally

$$(8)\qquad (n+N)\lambda = e\frac{1+\cos(i+\theta)}{\cos i} = \frac{2e\cos^2(i+\theta)/2}{\cos i}.$$

This must therefore be regarded as the fundamental equation of the phenomenon. Equation (7), however, leads on integration to

$$(9)\qquad N = e\tan i/D + N_0,$$

where N_0D is the width of the crack.

If the value of N from (9) is put into (8) together with the equivalent of λ/D, it appears after reduction that

$$(n+N_0)\lambda = e(\cos i + \cos\theta) = 2e\cos\frac{i+\theta}{2}\cos\frac{i-\theta}{2}.$$

The case of $N=0$, $e>0$ would correspond to the equation

$$(10)\qquad n\lambda = e[1+\cos(i+\theta)]\Big/\cos i = 2e\cos^2\frac{i+\theta}{2}\Big/\cos i,$$

which is only a part of the complete equation (8). For $i>\theta$, one active half, *kh*, is necessarily partly behind the other half, *k'h'*, and therefore not adapted to bring out the phenomenon as explained, unless $e=0$.

9. *Differential Equations. Displacement per Fringe, de/dn.*—To test equation (8) or (10) increments must be compared. The latter gives at once since N is constant relative to e like i, θ, and λ,

$$(11)\qquad \frac{de}{dn} = \frac{\lambda}{\cos i + \cos\theta} = \frac{\lambda}{2\cos\frac{i+\theta}{2}\cos\frac{i-\theta}{2}}$$

which is the interferometer equation when the fringes pass a given spectrum line, like either D line, which is sharp and stationary in the field. Equations (7) and (11), moreover, give after reduction

$$(12)\qquad dN/dn = \tan i \tan\frac{i-\theta}{2}.$$

Table I. contains values of de/dn computed from (11), made under widely different conditions ($i>\theta$, $i<\theta$, first and second order). The agreement is as good as the small fringes and the difficulty of getting the grating normal to the micrometer screw in my improvised apparatus admit. If this adjustment is not perfect N_0 changes with e. From equation (12), moreover,

$$(12') \qquad \frac{dN}{dn}=\frac{dN}{d\theta}\frac{d\theta}{dn}=\frac{dN_0}{d\theta}\frac{d\theta}{dn}=\frac{dN_0}{dn},$$

since N_0 is constant only relative to e when θ varies.

10. *Deviation per Fringe, etc., $d\theta/dn$, $d\theta/de$.*—These measurements are still more difficult in the absence of special apparatus, since e is not determinable and the counting of fine flickering fringes is unsatisfactory; but the order of results may be corroborated by observing the number of fringes between two Fraunhofer lines, like the C, D and other lines used. Differentiating equations (8) and (10) for variable n, λ, θ, and N (since $dN/d\theta$ is equal to $dN_0/d\theta$, equation (12′)) and inserting $-D\cos\theta\cdot d\theta/dn=d\lambda/dn$, it follows after arranging that

$$(13) \qquad \frac{d\theta}{dn}=\frac{\lambda^2}{eD}\frac{1+dN/dn}{1+\cos(i+\theta)}=\frac{\lambda^2}{eD}\frac{1}{\cos i(\cos i+\cos\theta)}$$

or

$$\frac{d\theta}{dn}=\frac{\lambda}{e\cos i}\tan\frac{i-\theta}{2}.$$

Combining this with (11)

$$(14) \qquad \frac{d\theta}{dn}=\frac{\lambda}{eD\cos i}=\frac{\sin i-\sin\theta}{e\cos i}.$$

Since, in equation (13), e is not determinable it is necessary to compare increments $\Delta dn/d\theta$ in terms of the corresponding increments Δe, whence

$$(15) \qquad \Delta(dn/d\theta)=\left(\cos i/\lambda\tan\frac{i-\theta}{2}\right)\Delta e.$$

Table I. also contains data of this kind computed separately for the Fraunhofer D, C, etc., employed and their mean values. To find the mean width of fringes between these lines, their angular deviations were divided by the number of fringes counted between them at different values of e. The results agree as closely as the difficulty of the observations warrants. One may note that without removing N, the corresponding coefficients would be $\Delta d(n+N)/d\theta$, and these are much more in error, here and in the preceding cases. If from $d\theta/dn$, e is eliminated in terms of $(n+N)$ the equation is

$$(16) \qquad \frac{d\theta}{dn}=\frac{\lambda}{D}\frac{1}{(n+N_0)\cos i},$$

so that for a given value of i, θ, N_0, they decrease in size with n. If $n=0$ they reach the limiting size

$$\frac{d\theta}{dn}=\frac{\lambda}{DN_0\cos i}.$$

If the crack N_0D should be made infinitely small, they would be infinitely large. To pass through infinity, N_0 must be negative, which has no meaning for $i>\theta$ or would place one effective edge of the crack S behind the other. These inferences agree with the observations as above detailed. If, however, $i<\theta$, a negative value of N_0 restores equation (16) for $n=0$ to equation (17), as was actually observed (Figs. 2 and 3).

Finally equation (14) might be used for observation in the incremented form

$$(17) \qquad \Delta(de/d\theta)=\frac{D\cos i}{\lambda}\Delta e;$$

but I did not succeed with it. One loses track of the run of a fringe with de.

11. *Colored Slit Images and Disc Colors of Coronas.*—In the above experiment the fringes were but a few minutes apart. It is obvious, however, that if N_0 is sufficiently small the fringes will grow with decreasing n, in angular magnitude, until there are but a few black bands in the spectrum. Under these circumstances the undeviated image of the superimposed slits must appear *colored*, particularly so if an effect equivalent to N_0 is present throughout the grating. This phenomenon of colored slits is apparently of interest in its bearing on the theory of coronas, where there is also an interference phenomenon superimposed upon a diffraction phenomenon, as is evidenced by the brilliant disc colors. For instance suppose

a corona were produced by a sufficient number of fog particles distributed throughout a plane normal to the undeviated rays. Now let the alternate particles be moved *in the same way* slightly to the rear of their original position and let the distance between the two planes be small relatively to the wave length of light. In such a case there should be two identical coronas, superimposed in all their parts and they should therefore interfere. Inasmuch, however, as even small fog particles are of the order of size of .0001 cm. and their mean distance apart fifty times larger, *i. e.*, .005 cm., it remains to be proved whether such an effect can be looked to as an explanation of the disc colors of coronas.

Brown University,
Providence, R. I.

ON THE TOTALITY OF THE SUBSTITUTIONS ON *n* LETTERS WHICH ARE COMMUTATIVE WITH EVERY SUBSTITUTION OF A GIVEN GROUP ON THE SAME LETTERS.

BY G. A. MILLER.

(*Read April 20, 1911.*)

§ 1. INTRODUCTION.

The problem to determine all the substitutions on n letters which are commutative with every substitution of a regular group on the same letters was first solved explicitly by Jordan in his thesis. It was found that with every regular group there is associated a group which is conjugate with this regular group, such that each is composed of all the substitutions which are commutative with every substitution of the other.[1] These two regular groups were called ***conjoints*** by Jordan and it is evident that they have a common holomorph and that their group of isomorphisms is the quotient group of this holomorph with respect to either of these two regular groups.

The more general problem to determine all the substitutions on n letters which are commutative with every substitution of any transitive group on the same letters seems to have been solved for the first time by Kuhn in his thesis.[2] He found that with each transitive group G of degree n there is associated a group K on the same n letters which is composed of regular substitutions on these n letters, in addition to the identity. The order of K is α, the degree of the subgroup composed of all the substitutions of G which omit a given letter being $n - \alpha$. Hence a necessary and sufficient condition that K be transitive is that G be regular, and the number of the systems of intransitivity of K is always equal to n/α. When $\alpha < n$ K is formed by establishing a simple isomorphism between n/α

---

[1] Jordan, thesis, Paris, 1860, p. 39.

[2] Kuhn, *American Journal of Mathematics*, Vol. 26, 1904, p. 67.

regular groups, each of these regular constituent groups being transformed into every other under G. In particular, the degrees of these separate regular groups are systems of imprimitivity of G.

While K is composed of all the substitutions on these letters which are commutative with every substitution of G it is not generally true that G is also composed of all the substitutions which are commutative with every substitution of K and involve only the letters of K. It is evident that a necessary and sufficient condition that such reciprocal relations should exist between G and K is that G involves as an invariant subgroup the direct product of n/α regular groups, and that the remaining substitutions of G permute these regular groups according to the symmetric group of degree n/α. The order of G must therefore be

$$\alpha^k \cdot k!, \quad \text{where} \quad k = n/\alpha.$$

Hence the theorem: *A necessary and sufficient condition that a transitive group G of degree n involve all the substitutions on these n letters which are commutative with every substitution of the group K composed of all the substitutions on these n letters which are commutative with every substitution of G, is that the order of G be $\alpha^k \cdot k!$, where the degree of the subgroup of G which is composed of all its substitutions which omit a given letter is $n - \alpha$ and $k = n/\alpha$.*

When G does not include all the substitutions which are commutative with every substitution of K it is clearly a subgroup of the group formed by such substitutions. Hence we have the theorem: *If a transitive group of degree n is such that a subgroup composed of all its substitutions which omit a given letter is of degree $n - \alpha$ the order of this transitive group must divide $\alpha^k \cdot k!$, where $k = n/\alpha$.* To illustrate this theorem as well as the theorem of the preceding paragraph we may use for G the group of the square represented as a substitution group on four letters. In this case $\alpha = 2$, $k = 2$, and the order of G is exactly $\alpha^k \cdot k!$ Moreover, K is of order 2, and of degree 4, and G includes all the substitutions on these four letters which are commutative with every substitution of K, so that G and K are so related that each is composed of all the substitutions on these letters which are commutative with every substitution of the other. A necessary and sufficient condition that K be a subgroup of G, when G and K are so related that each is composed of all the substitutions on these letters which are commutative with every substitution of the other, is that K be abelian. When G and K are both abelian they must be regular and identical.

It may be of interest to consider several of the special cases of the general theorems expressed above. When $\alpha = 1$, K is the identity. That is, if the subgroup, composed of all the substitutions which omit a given letter of a transitive group of degree n, is of degree $n - 1$ the identity is the only substitution on these n letters which is commutative with every substitution of this transitive group, and the order of this group divides $n!$ In the other extreme case, when $\alpha = n$, the given theorems include the main known results as regards the substitutions which are commutative with every substitution of a regular group. As the term conjoints has an established meaning as regards regular groups it seems undesirable to use this term with the more general meaning that each of two substitutions groups of degree n is composed of all the substitutions on these n letters which are commutative with every substitution of the other. We shall therefore call such groups *amicable,* using a term of Greek number theory. Hence we may say that a necessary and sufficient condition that a transitive group of degree n is one of a pair of amicable groups is that its order be $\alpha^k \cdot k!$, $n - \alpha$ being the degree of one of its subgroups composed of all its substitutions which omit a given letter, and $k = n/\alpha$. This proves also incidentally that n is always divisible by α.

From the preceding results it is easy to deduce a theorem as regards the total number of the transitive groups of degree n which belong to pairs of amicable groups. In fact, since K is composed of simply isomorphic regular groups the number of the distinct possible groups K is equal to the number of the different abstract groups of order α, two substitution groups being regarded as distinct only when it is not possible to transform one into the other. As G is completely determined by K there results the following theorem: *The number of the distinct transitive groups of degree n which* *belong to pairs of amicable groups is equal to the sum of the numbers of the abstract groups whose orders are divisors of n, including n and unity among these divisors.*

§ 2. AMICABLE INTRANSITIVE GROUPS.

In the preceding section it was observed that a necessary and sufficient condition that each of two amicable groups be transitive is that they be regular, and that if a non-regular transitive group belongs to a pair of amicable groups the second group of the pair is intransitive. It remains to consider the case when each one of a pair of amicable groups is intransitive. An infinite system of such groups may be constructed by establishing a simple isomorphism between n symmetric groups of degree n, $n > 2$, and determining the totality of the substitutions which are commutative with every substitution of the intransitive group G thus formed. It is evident that this totality of substitutions constitutes a group K which is similar to G. That is, G and K are two conjugate intransitive substitution groups each being composed of all the substitutions on these n^2 letters which are commutative with every substitution of the other.

The existence of the two amicable intransitive groups G and K of the preceding paragraph may also be established as follows: Consider the n^2 m-sets[1] of the symmetric group of degree n as regards the symmetric group of degree $n - 1$. On multiplying these n^2 m-sets on the right by all the substitutions of this symmetric group the n^2 m-sets are permuted according to a group G' similar to G, and by multiplying them on the left they are permuted according to a similar group K'. From the fact that multiplication is associative it results that every substitution of G' is commutative with every substitution of K'. Moreover as every substitution on these n^2 letters which is commutative with every substitution of G' must permute some of its systems, it is evident that K' is composed of all the substitutions on these letters which are commutative with every substitution of G', and vice versa; that is, G' and K' are in fact two amicable intransitive groups for every value of n. The group

---

[1] If H is any subgroup of a group G, the total number of distinct sets of operators of the form $S_\alpha H S_\beta$, where S_α and S_β are operators of G, are known as the m sets of G as regards H.

generated by G' and K' is clearly imprimitive and of order $(n!)^2$.

The existence of amicable intransitive groups which are not included in the preceding infinite system can be easily proved by the following examples: Let G be the dihedral group of order 8 and H any one of its non-invariant subgroups of order 2. With respect to H there are 8 m-sets of G since H is transformed into itself by 4 of the operators of G. Hence these eight m-sets are permuted according to a group which is simply isomorphic with G and has two transitive constituents both by right and also by left multiplication. Each of the two substitution groups obtained in this way is clearly composed of all the substitutions on these eight letters which are commutative with every substitution of the other and hence these are two amicable intransitive groups whose transitive constituents are not symmetric.

The substitutions which are commutative with every substitution of an intransitive group G either interchange systems of intransitivity, or they are composed of constituents which are separately commutative with the various transitive constituents of G. The latter have been considered in the preceding section. Hence we shall, for the present, confine our attention to those substitutions which are commutative with every substitution of G and interchange its systems of intransitivity. It is evident that these systems of intransitivity are transformed by all the substitutions which are commutative with every substitution of G according to a substitution group, and that those transitive constituents of G which are transformed transitively among themselves must be simply isomorphic in G. These constituents are clearly transformed according to a symmetric group by all the substitutions which are commutative with every substitution of G. Hence the theorem: *If an intransitive group G is one of a pair of amicable intransitive groups, and if the transitive constituents of G are such that no substitution on the letters of the separate constituents is commutative with every substitution of the constituent, then must the consituents of G be symmetric groups.*

It is clear that G may have more than one set of transitive constituents such that all those of a set are conjugate under the totality of the substitutions K which are commutative with every substitution of G. In other words, the substitution group according to which the transitive constituents of G are transformed may be intransitive. When this condition is satisfied K is the direct product of two or more symmetric groups. This suggests a more general infinite system of pairs of amicable intransitive groups than the one mentioned above: viz., Let G be the direct product of the ρ groups formed by establishing simple isomorphisms between n_1 symmetric groups of degree n_1, n_2 symmetric groups of degree n_2, $\cdots$, n_ρ symmetric groups of degree n_ρ ($n_1, n_2, \cdots, n_\rho$ being distinct numbers greater than 2), it is clear from what was proved above that K is similar to G and hence G and K are amicable intransitive groups. It should be observed that G and K are *always amicable whenever they are similar* but that the converse of this theorem is not always true. This more general system of amicable intransitive groups may clearly be constructed by forming the direct product of the ρ symmetric groups of degrees $n_1, n_2, \cdots, n_\rho$ respectively and forming the m-sets as regards the subgroups H obtained by forming the direct product of ρ symmetric groups of degrees $n_1 - 1, n_2 - 1, \cdots, n_\rho - 1$ respectively, one being taken from each of the given symmetric groups, in order. If the m-sets thus obtained are multiplied on the right and on the left by all the operators of these sets there clearly results the two systems of amicable intransitive groups in question.

To obtain a still more general infinite system of amicable intransitive groups it should be first observed that the intransitive group formed by establishing a simple isomorphism between m_1 symmetric groups of degree n_1, written on m_1 distinct sets of letters, is amicable with the one obtained by establishing a simple isomorphism between n_1 symmetric groups of degree m_1, written on n_1 distinct sets of letters, where $n_1, m_1 > 2$. Hence it results that the direct product formed by multiplying ρ intransitive groups of degrees $n_1m_1, n_2m_2, \cdots, n_\rho m_\rho$ respectively, each being formed in the former of the two ways mentioned above, is amicable with the direct product formed by multiplying the ρ groups of the same degrees respectively, but constructed by establishing a simple isomorphism between n_1 symmetric groups of degree m_1, n_2 of degree m_2, $\cdots$, n_ρ of degree m_ρ respectively. Moreover, it results from the given theorem that these direct products include all the possible sets of amicable groups in which each of the two groups is intransitive and each of the transitive constituents is not commutative with any substitution besides the identity on the letters of the constituent.

The above therefore completes the determination of amicable groups when both groups are intransitive, and the transitive constituents are such as to involve subgroups whose degrees are just one less than the degrees of the respective constituents. The cases in which at least one of the two amicable groups is transitive were considered in the introduction. It may be observed that whenever an intransitive group is formed by establishing a simple isomorphism between more than two symmetric groups it is one of a pair of amicable groups. The second group is transitive when each of these symmetric groups is of degree 2, when this condition is not satisfied the second group is also a simple isomorphism between symmetric groups. The group obtained by establishing a simple isomorphism between two symmetric groups is evidently never one of a pair of amicable groups unless the two symmetric groups are of order 2. We may express this result in the form of a theorem as follows: *The intransitive group G formed by establishing a simple isomorphism between three or more symmetric groups, written on distinct sets of letters, is one of a pair of amicable groups, the second group K being also such an intransitive group whenever the degree of the given symmetric groups exceeds 2. The intransitive group formed by establishing a simple isomorphism between two symmetric groups is one of two amicable groups only in the special case when these symmetric groups are of degree 2.*

By means of the given results it is not difficult to complete the determination of all possible pairs of amicable intransitive groups. Suppose that G is constructed by establishing a simple isomorphism between any number of conjugate transitive groups written on distinct letters, each constituent being one of a pair of amicable groups. If these constituents are not symmetric and not regular it is clear that G is one of a pair of amicable groups and that the number of the transitive constituents of K is equal to the number of transitive constituents in the amicable group corresponding to a transitive constituent of G. Moreover, G is evidently not one of a pair of amicable groups when its constituents do not have this property. Hence there results the theorem: *Two necessary and sufficient conditions that a given intransitive group be one of a pair of amicable groups are:* 1) *that it be the direct product of transitive constituents which belong to pairs of amicable groups, or of sets of simply isomorphic transitive constituents of this kind, or* 2) *that the number of simply isomorphic constituents be greater than two whenever they are symmetric but not regular.* From the Introduction it results that the second group of this pair is also intransitive except in the case when the intransitive group is composed of simply isomorphic regular groups. It reduces to the identity whenever the given intransitive group is the direct product of symmetric groups whose degrees exceed 2. The pair of amicable groups are conjugate whenever one is the direct product of regular groups, of sets of m simply isomorphic non-regular symmetric groups of degree n if the m's and n's may be put into (1, 1) correspondence such that the corresponding pairs are equal, or of sets of m simply isomorphic non-symmetric transitive groups of degree n ($n - \alpha$ being the degree of a subgroup composed of all the substitutions of the constituent which omit a letter) if the α's, m's and n/α's may be put into (1, 1) correspondence such that the corresponding triplets may be α, n/α, αm for every set of values α, m, n.

UNIVERSITY OF ILLINOIS.

PROCEEDINGS

OF THE

AMERICAN PHILOSOPHICAL SOCIETY

HELD AT PHILADELPHIA

FOR PROMOTING USEFUL KNOWLEDGE

VOL. L MAY–AUGUST, 1911 No. 199

NOTES ON CANNON—FOURTEENTH AND FIFTEENTH CENTURIES.

By CHARLES E. DANA.

(Read April 20, 1911.)

There can be seen to-day in the fair city of Florence, on the Arno, an old yellow parchment, upon which is transcribed an edict dated February 11, 1326. This, expressed in the monkish Latin of the day, gives authority to the Gonfalonier, the Priors, and twelve "good men," to superintend the manufacture of "palloctas ferras et canones de metallo," balls of iron and cannon of metal, which may possibly, in this case mean *brass*. What these cannon for the defence of Florence were like, or what they did, we shall never know, but with them the real history of ordnance begins; these little pop-guns are the ancestors of the 14- and 15-inch B. L. R. (breech-loading rifle) of today; the fathers threw a wee projectile a hundred or two yards; the degenerate offspring throw a shell weighing about a ton, fifteen or twenty miles. That the Florentine guns were the very first no one would assert, but with our present information, only legend lies back of them.

Of course the credit for the invention is given to the Chinese. There is not time here to do more than state that the *Institutes of Timur,* about the middle of the fourteenth century, although they

Cannon of 1390–1400.

One of the earliest representations of a Fire-arm. (From German Codex. Royal Library, Munich.)

give full details of the equipment of his troops, do not mention either cannon or gunpowder. The *"Wuh-li-Siao,"* published 1630, says "gunpowder came from the outer barbarians."

The mention of an explosive in the *Sukranita,* a Hindu work said to ante-date everything Chinese, is admitted by experts, I understand, to be a modern interpolation.

The "Liber Ignium a Marco Graeco Descriptus," dating back of the eleventh century, gives some 22 to 35 recipes for the so-called "Greek-Fire" etc. No Greek or Moslem writer ever uses the term "Greek-Fire." Col. Hime, an authority on this subject[1] concludes that the earlier recipes in the "Liber Ignium," were translated from the Arabic by a Spaniard. The first four recipes are for the compounding of "sea-fire," or, as there described, mixtures which will ignite "when rain falls on them." Quicklime was the cause of ignition; to it was added (C. 1300) sulfur, oil, gum Arabic; (C. 1350) sulfur and turpentine; (C. 1405) sulfur, petroleum, wax. None of these were true explosives.

Berthold Schwartz, of Freiburg, in Breisgau, the favorite German discoverer of gunpowder, made his discovery about 1320 to 1330, at the time the Florentines were popping off their "canones de metallo." Schwartz is said to have preceded the Florentines in the making of cannon but this claim has not as yet been established.

Lieut. Col. Hime undertakes to translate the "Epistola de secretis," of the liberal minded Friar Bacon (1214?–1294). This letter is probably earlier than 1249. It is written according to some cryptic method, a bad habit both famous Bacons indulged in, and if the secret of the over-cautious Friar has been guessed with even partial success, we have a right to suppose that while the good Friar was "experimenting with some incendiary compositions . . . the mixture exploded and shattered all the chemical apparatus near it" (Hime. 161). After this smash-up, Bacon could not fail to be convinced that saltpeter, sulfur and charcoal, when mixed in right proportions, had a distinctly explosive tendency—but he never seems to have advanced the next step and discovered the projectile force of the compound.

---

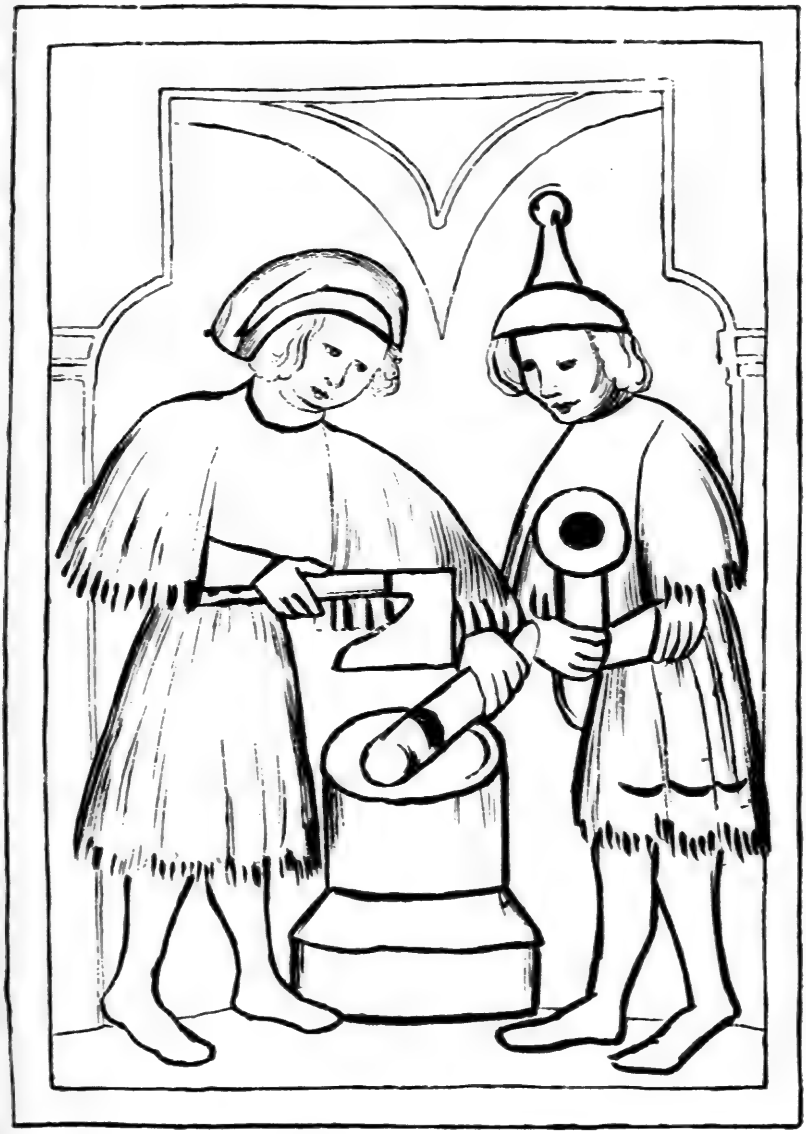
[1] Lieut.-Col. Henry W. L. Hime, "Gunpowder and Ammunition," London, 1904.

A few more words on gunpowder. In early days saltpeter was most difficult to procure; it was collected from cellars and caves; later, depots were established for its reception, while strict laws were passed to ensure its purification and baking. Costing much, saltpeter was very sparingly used, much to the detriment of the gunpowder of course. The proportions differ greatly according to the kinds of powder—whether, for cannon, priming, hand gun, etc., from equal parts of each; to, saltpeter, 3, sulfur, 1 ½, charcoal, 1 ½ to 4: 1: 1. and 6: 2: 1. The formula of today being about 6: 1: 1.

The price of gunpowder in the fourteenth century seems to have been almost prohibitive. Assuming that my figures are correct, which is more than doubtful, for there is no real standard of value, the price was, in money of to-day, rarely as low as twenty-five dollars, and quite possibly, occasionally, as high as fifty dollars a pound; now it costs a quarter of a dollar or less a pound. These prices rapidly decreased with the systematic collecting of saltpeter.

In a campaign the ingredients for making powder were carried separately, and mixed only when need came. Here is a note or two from an authority of about 1465. Keep the three ingredients separate, as the niter and sulfur if mixed soon spoil. Better carry the willow wood unburned, as charcoal absorbs the damp. A secret process for the preservation of powder: Take clear and very strong vinegar, make the powder into a paste; form cakes of four to eight livres (*livre,* about a pound), dry in the shade, sun, or even in an oven. We are getting close to granulated powder. As the usual powder was in the form of a very fine dust, the ignition must have been slow, and much of it was, in all probability, blown out at the muzzle.

The next mention of cannon is in an "indenture" of 1338, between John Starylyng, former keeper of the "King's vessels" (Edward III.) and Hemyng Leget. "Ij [ij] canons de ferr sanz estuff," presumably, without ammunition. Also "un canon de ferr ove ii chambres, un autre de bras ove une chambre." The cannon with two chambers was the form of breech-loader often used even for large bombards until the early part of the next century, and for smaller iron and brass cannon until the art of casting iron guns was well understood (in England not until c. 1545), and even into the



Loading Cannon of 1390–1400.

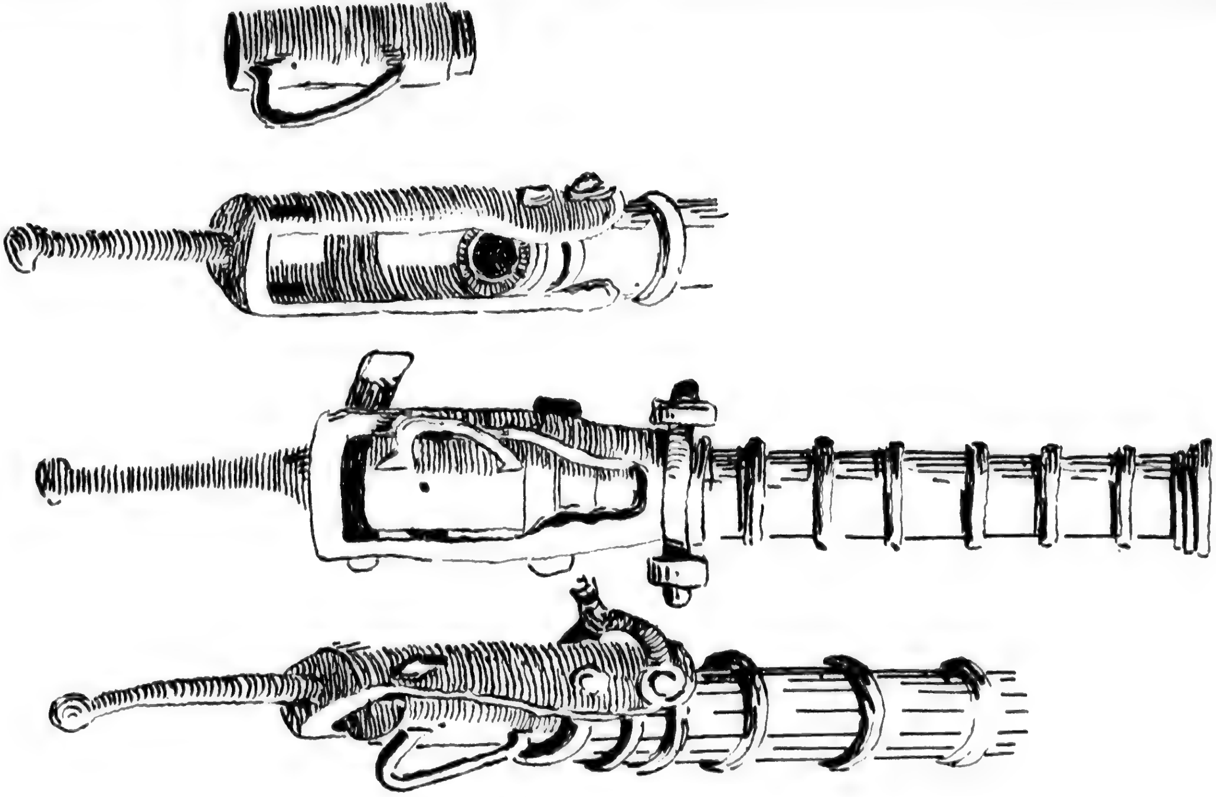
Cutting off wooden Plug for Wad. (From German Codex. Royal Library, Munich.)

seventeenth century, especially for guns used in China. An iron tube was fastened by bands of iron to a strong stock, with a space hollowed out at the breech to hold an iron box, the "chamber," sometimes called "a pot." Later this hollow became part of the gun, a sort of basket, or cradle. The chamber contained the powder charge, upon which a round section of wood was tightly driven as a wad. The projectile was placed at the breech end of the tube, with a straw, felt or rag wad in front to hold it; the chamber was wedged against it, then primed, and touched off with a heated iron rod. Needless to say that a goodly portion of gas escaped between chamber and tube. These were the earliest quick-firing guns, and in the sixteenth century were used on the upper works of the ships, very much as we use quicker firing guns today; the ancient ones, when there were four chambers, say, could be discharged about every two minutes. Later they will be called "murtherers"; and well they earned the name when the projectiles consisted of rusty nails, bullets and scraps.

The chambers, or "canones," for the huge bombards, which we shall meet with later, were held in place by heavy timbers. By or before 1400 the heavy, wrought-iron powder chamber was welded or screwed onto the chase of the bombard.

In the year 1338 appeared, in the Arsenal of Rouen, a terrible engine of destruction, called by its proud keepers, a "pot de fer à traire garros," an iron pot for throwing arrows. These arrows, much like cross-bow bolts, were tipped with iron and winged with brass, the latter metal obtained from kitchen utensils, cut up and melted for the purpose. The projectile was wound with leather to make it fit snug in the barrel. The powder charge for this dread engine of war was about seven tenths of an ounce of the ill-proportioned powder of that day. When all was prepared, and fire was applied, the bolt of destruction no doubt emerged, but certainly with considerable reluctance.

A recipe of a few years later enables us to approximately figure out the cost of cannon of that day. Five cannon of wrought-iron weighing 25 lbs. each, and five "canon de metal," presumably brass, cost three hundred dollars of to-day, say $30 each. All of which is submitted with considerable hesitation.



Chamber-Piece, 1338–c. 1700.

Chamber or "Pot," to hold powder charge. Cradle and Breech of Chase. Tail for pointing. Chamber wedged in place; part of Chase removed to show Projectile. Side-view showing means of horizontal and vertical motion.

The first mention of cannon by Froissart, who is as "faithful as an eye witness," is in the year 1340 at the siege of Quesnoy, on the northeast border of France, not very far from Valenciennes. "Those of Quesnoy let them hear their cannons and bombards, which flung large iron bolts in such a manner as made the French afraid of their horses."[2]

The earliest English use of this word *bombard* given by Dr. Murray, is in a quotation from John Lydgate, 1430. The noun has left us, but the verb, *to bombard* still lingers.

It is usually asserted that the first field-guns were used at the battle of Crécy, August 26, 1346. The Florentine chronicler, Giovanni Villani, remarks, in the somewhat florid manner of the time, "the bombards of the English made balls of iron to leap with fire, to frighten and drive off the horses of the French. . . . That the roar of the bombards made such a trembling of the earth, such a noise, that it seemed as if God thundered, with great slaughter of men and beating down of horses."

This terrible slaughter must have been produced by three small toys somewhat like blunderbusses, the charge for each of which was an ounce, more or less, of very bad powder. Cause and effect do seem disproportionate.

The "Grandes Chroniques de St. Denis" assert that it was the three cannons of the English that spread panic amongst the Genoese cross-bowmen and made them indulge in the singular antics by which they sought to frighten the English archers. In only one known copy of Froissart is there any mention of cannon at Crécy; this happens to be that in the library of the city of Amiens, not far from the battlefield; there is some reason to believe that the words in question are an interpolation; when one remembers that from Falkirk (1298) to Flodden (1513)—Bannockburn excepted—the English archer, firing ten or more armor-piercing projectiles a minute, with an effective range of 250 yards, was always victorious, it does appear possible that French writers, with more patriotism than truth, introduced these terrible cannon into their accounts of the battle as an excuse for the crushing disaster to their arms.

Edward III. took with him several cannon when he entered

---

[2] Chap. IV., Book I., p. 40.

France, July, 1346, the month before Crécy. We have too the King's Privy Wardrobe Accounts, as they were termed, giving lists of guns, ammunition, gunners and other details of the ordnance sent from the Tower of London to be used at the siege of Calais, which followed the battle of Crécy.

At this siege of Calais only leaden projectiles are mentioned, and from the very moderate amount of ammunition required for their propulsion, the guns although called "great" must have been exceeding small. The main reliance of besiegers and besieged continued to be in the huge engines for hurling masses of rock and other unpleasantnesses.

The derivation of the word *gun* is not without interest. Consulting both Murray and Skeat, we find that *Gunnhildr* was an Icelandic, female, proper name, once applied to war engines. As *Gunn* (Icel. *Gunnr*) signified *war,* and *hildr* a *battle,* it was certainly appropriate. An account of the munitions in Windsor Castle, 1300, 01, mentions a large ballista named "Domina Gunilda." As there does not seem to have been any great lady, famous or infamous, so called in the fifteenth century, this is quite probably a survival of the old Scandinavian name. The M. E. word *gunne,* is, of course, but a shortened pet name for the fearsome lady.

Here is one of the early tragedies connected with cannon. In 1346, the year of Crécy, Peter of Bruges had established a high reputation for the making of "connoiles." The word may come from "tonnoiles," which in its turn, may have come from "tuyaux de tonnoire," or tubes of thunder. In September of that year the consuls of the city of Tournay hearing that connoiles were useful to be let off in a good town when besieged, desired the aforesaid Peter to make them one as a sample, and if it proved satisfactory they would give him an order for more. Peter, the thrifty burgher, did make one and then proceeded to show the worthy consuls what it would do. The connoile was placed with great care, outside the gate "Noire aux Champs." Peter states in his own account that he loaded the connoile with a quarrel, meaning in this case a heavy bolt, not an altercation. To the quarrel Peter affixed two pounds of lead. From the subsequent happenings there is reason to suppose that he did not omit powder. Peter "laid" the connoile so that it pointed against a door and wall. The spectators heard a "cruel noise," but the antics of the connoile remain a mystery.

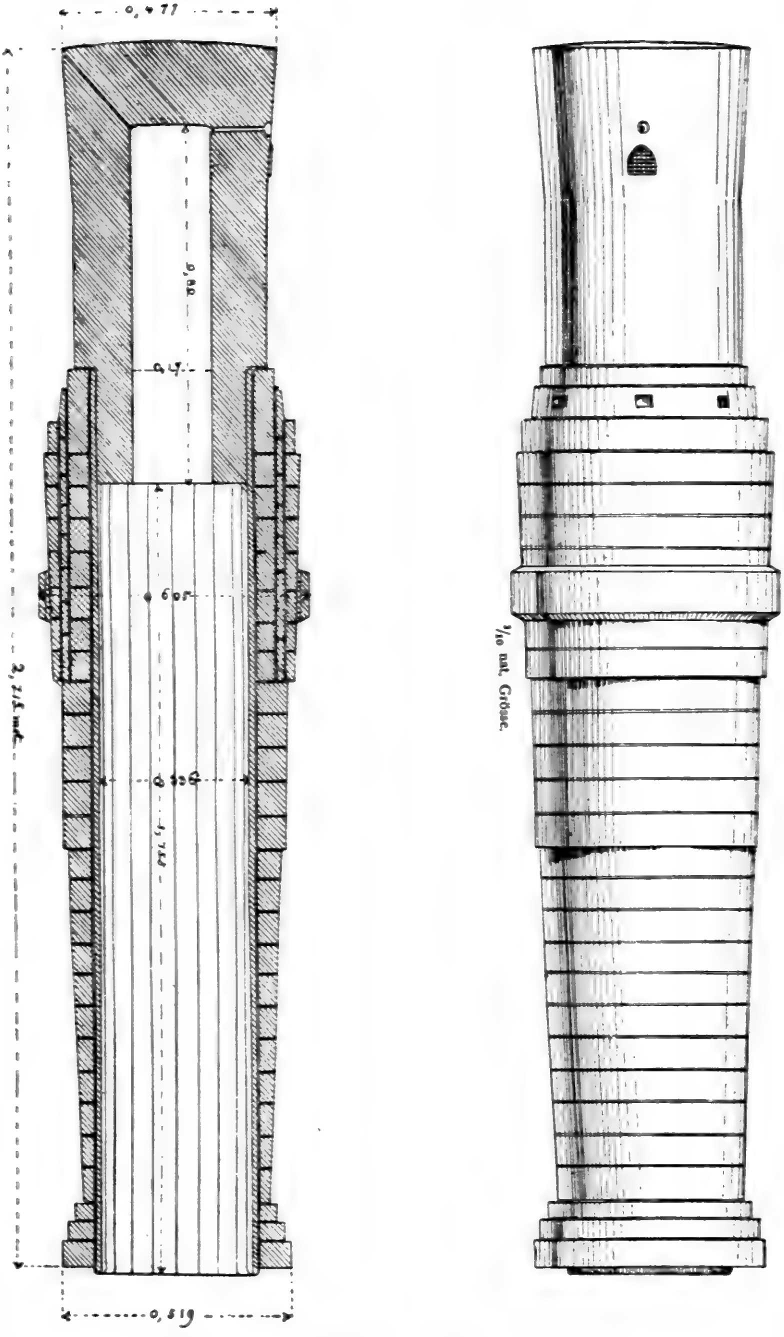
In quite another part of the city of Tournay, an industrious fuller was busily at work; when lo, along came the erratic quarrel, with its two pounds of lead,—and the guild of Fullers gave their deceased brother one of those picturesque funerals for which the good town is so celebrated. When Peter of Bruges heard of this mishap, he fled into sanctuary and gave himself up for lost. Then followed a solemn session of the consuls. Contributory negligence could not be charged against the Fuller, for if ever bolt came "from the blue" it was this one. After a long discussion the conclusion arrived at was: Peter of Bruges fired the connoile at the order of the consuls; he was not known to have harbored any ill feeling against the fuller;—they might have added that neither ill feeling nor skill in aiming would have enabled Peter to hit the far-off fuller. The consuls thereupon held Peter blameless, merely remarking that the event was a misfortune and a sad pity.

A curious point is brought out by the list, dated 1347, of artillery, in its broader sense, for the defense of the castle of Brioul in France. At the fag end of the list we are told that one man managed two cannons, and that the efficiency of their projectiles, and of stones thrown from the towers *by hand,* was considered about equal.

Before glancing at the great bombard of Caen, 1375, which marks a considerable step in advance, let me say that during the fifty years we have glanced at, there have been cannon of wrought iron, occasionally of brass. The largest of the former did not weigh over 120 lbs. Breech-loaders were common, and the projectiles were bolts, or balls of lead—iron balls are referred to, but never stone.

March 20, 1375, an order was received at Caen, in Normandy, from Jehan Le Mercier, one of the King of France's councillors, for the building of "a great cannon of iron." March 21 work began by erecting three forges in the market place, and surrounding them with a wooden paling to keep the curious at a proper distance.

March 22, the four smiths with their eight helpers began to draw wages. Fifteen men worked for six weeks, sometimes at night. April 3, Jehan Nicolle, a master smith, said to have been the best in Normandy, arrived from "Sap." 2,110 pounds of wrought iron,



Built-Up Wrought-Iron Bombard, 1420–1430.
Length 8 ft. 6 in. Caliber 13¼ in. Basel Arsenal.

and 200 pounds of steel were used. The inner tube was formed by longitudinal bars; encircling these were tight-fitting rings of iron, driven on, one touching the other, till they formed an unbroken surface. 400 pounds of the iron was Spanish, presumably a better quality. The "cuve" for which it was used, may have been that part of the breech which enclosed the powder chamber. 200 pounds of steel were needed; could the chamber have been of that metal? The chamber seems to have formed a permanent part of the bombard, as the vent is specially mentioned with its large projecting apron of iron.

After the metal part was finished ninety pounds of rope was wound about the gun, for what purpose we are not told. Over this was sewn a cover of hide to prevent the rope rotting or the metal rusting if exposed to rain.

The manner of attaching the monster to its heavy wooden bed and braces, is fully and confusedly described. General Favé thinks its carriage was a kind of cage, somewhat like that used by blacksmiths in France for shoeing unwilling animals. Four stone balls, size not given, were provided, at a cost of two sous six deniers each ($1.50? today). Two of these were used in the proof rounds.

After this date (1377) the size of cannon rapidly increased. Froissart mentions 140 cannon used at Odruik or Outherwyck, by the Duke of Burgundy, in 1377, which threw balls of 200 pounds. A work (name not given) professing to quote contemporaneous authority, mentions a cannon of the Duke of Burgundy, 1377, throwing a shot of 450 pounds, which would require a calibre of say, 21 inches.

1382, at the siege of Oudenarde by Philip van Arteveld, the Flemings made use of a "marvellously great bombard," so they said, at least. They added, that when this bombard was fired, by day it could easily be heard a distance of five leagues, and by night ten. It made such a terrible din (French "noise") that to those who listened, it seemed as if all the devils in hell were rushing on. The rather imaginative old chronicler says that this monster had "53 pouces de bec" (mouth). Englished, a trifle over 58 inches. Either we must credit him with having measured the circumference, —rather an unusual manner of classifying artillery, making the real caliber only about 18 inches, or else,—but the alternative is too painful.

The accounts of the fighting about Chioggia, 1380, between the Genoese under Pietro Doria, and the Venetians under their beloved Vittore Pisano, are well authenticated, and give a vivid picture of the power of these old bombards. January 22, the great bombard, a two-hundred pounder, was fired by the Venetians at the campanile of Brondolo; it knocked out a large piece of wall, and some of the flying stones struck and killed Pietro Doria, the Genoese commander, together with his nephew. The next day the same bombard brought down a still greater piece of the same campanile, killing 22 men; so that as an implement of slaughter, the clumsy thing was a success and endeared itself proportionately to the Venetians.

Before leaving the fourteenth century a few short notes might be added.

The castle of Tannenberg, in Germany, was captured 1399. A huge bombard belonging to the city of Frankfort a/M., was loaned to the besiegers. Tremendous difficulties were met and overcome in getting the gun into position, very close to the castle. The first projectile stuck in the wall; the second passed through, and soon the defences were in ruins. These were never rebuilt. Excavations were made in 1849 and many stone balls were found. They varied in diameter from three inches to 31½ inches, the latter weighing 825 pounds, and unquestionably one of the shot for the "Frankfurter Buechse."[3]

Napoleon gives an inventory of the Artillery of Bologna, 1381/97, in which stone balls of 1,000 pounds for bombards and mortars, together with iron balls of 1, 2, 3 and 6 pounds are mentioned.

A word about *field-guns.* Froissart,[4] speaking of the capture of the castle of *la Roche sur Yon* (1369) by the Black Prince, mentions "several cannons and springalls with which the army was provided, and from long custom had always carried with them."

In the year 1382 the bumptious burghers of Bruges were engaged in one of their usual wars with their equally bumptious neighbors

---

[3] "Die Burg Tannenberg und ihre Ausgrabung." Hefner und Wolf, Frankfurt, a/M., 1850.

[4] Chap. 268, Vol. 1.

of Ghent, who took the field 5,000 strong with 200 "ribaudequins." The latter were heavy built push-carts—Napoleon calls them "wheel-barrows," bearing in front two or three, sometimes more, of the small cannon of the day, with an ugly fringe of bristling lances projecting beyond. These disagreeable field-pieces were trundled along in front of the line of battle. The effect of two lines of "ribaudequins" meeting and neutralizing each other must have given rise to some curious tactics in battle. In this case the 5,000 of Ghent formed themselves into a dense mass and with "ribaudequins" in front, drove off 40,000 men of Bruges.

At the battle of Roosebeke, November 27, 1382, where the Flemings were cut to pieces by the French and their leader Philip van Arteveld killed, Froissart states that the battle began by "a cannonade with bars of iron and quarrels headed with brass."

This battle did not end the war, and a curious picture of the ineffectiveness of the smaller cannon of the day is given by Lieut. Gen. Sir Henry Brackenbury, in his account of the siege of Ypres by the English and Flemings. The siege lasted from the eighth of June, 1383, to the eighth of August. During that time a steady cannonade was maintained, but apart from interfering with the sleep of the good burghers of Ypres, not a soul was one whit the worse. Two guns were advantageously posted in front of one of the gates, and kept up a steady fire, in all 450 shots. When the siege was raised those of Ypres were forced to admit that the gate in question was in need of immediate repairs. Much danger to the inhabitants was avoided by a thoughtful device; the besiegers considerately heralded by a trumpet blast each discharge; this enabled promenaders to step aside and avoid any possible annoyance from intruding cannon balls.

Another curious picture of by-gone days is given us in the "Issue Roll of the Exchequer for 1384," in which the amount of payments for the hire of cannon and cannoniers is given, making it plain that private individuals often owned one or more cannons which they hired out like cabs.

Viollet le Duc mentions this same custom on the continent; he says that during the middle ages the engines of war were made by non-military workmen, and the same rule prevailed after the introduction of cannon. Not only did ordinary mechanics make the new artillery, they also served it; letting their cannon for hire as one lets carts and drivers; and it was not until the death of Charles VII, 1461, that they formed companies of bombardiers and culveriniers, heavy and light artillery, like the companies of cross-bowmen and archers, gave to them military organization, and placed them under the command of the grand master of artillery.

The fifteenth century was one of development, very important but less startling than its predecessor.

The most marked advance was in cast bronze and iron guns. Pretty much any date after 1400 may be taken as the beginning of that phase of the smelter's art. Erfurt claims 1377 as her beginning; it seems needlessly early, but no one can say her nay. There are two cast-iron guns in the Leipzig Museum, one between 1400 and 1420; another, less archaic, 1420 to 1430.

Francis Grose says:

> It seems extremely strange, that none of our workmen attempted to cast them, [cannon] till the reign of King Henry VIII. when in 1521, according to Stowe, or 1535 [Camden says], great brass ordnance, as canon (sic) and culverins, were first cast in England, by one John Owen, they formerly having been made in other countries; . . . 1543. . . [Stowe] . . . the King minding wars with France, made great preparations and provisions, as well of amunitions and artillery as also of brass ordnance; amongst which at that time, one Peter Bawd, a Frenchman born, a gun-founder, or maker of great ordnance, and one other alien, called Peter Van Collen, a gun-smith, both the King's freedmen, conferred together, devised and caused to be made, certain mortar pieces, being at the mouth, from eleven inches up to nineteen inches wide. . . . and after the King's return from Bullen [Boulogne], the said Peter Bawd by himself in the first year of Edward VI. [1547] . . . did also make certain ordnance of cast yron of diverse sorts and forms, as fawconets, falcons, minions, sakers, and other pieces. Chamber'd pieces for throwing stones, called cannon-perriers, port-pieces, stock-fowlers, sling-pieces, portingale-bases, and murtherers, were about this time much used in small forts and on shipboard.[5]

Of course all these guns were cast hollow; that is a core covered with clay, was suspended in the center of the mould while the metal was poured in. Despite all precautions it was very nearly impossible with the imperfect means then in use, to keep this core in place and true; cavities formed in the metal about it, and the scoria did not

---

[5] Francis Grose, "Military Antiquities," London, 1788, II., p. 383.

rise freely; certainly too much cannot be said in praise of the founders who could cast such a gun as the serpentine of Charles the Bold (say 1476), in the arsenal at Neuveville, near Bern; a cast-iron field gun some fifty-two inches long, and 2-inch bore.

Machinery for boring cannon is said to have been invented by Lew, in Switzerland. It was introduced into France 1740/44, by Jean Maritz, born in Bern (1711–1790), who, after accepting office under the French was naturalized. Maritz seems to have been the first who thought of placing the gun horizontal and making it, not the drill, revolve.

The Great Bombard, the characteristic gun of the latter half of the fourteenth century and the greater part of the fifteenth, was often, in its early days but a huge tube—"tuyeau de tonnerre." It is possible that after the frequent burstings, the occasional survivor noticed that these annoying accidents usually had their origin just in front of the chamber, about where the great stone ball was placed. The gun-maker would naturally strengthen this portion with much thicker bands, and doubtless he would soon deduce the fact that the strain decreased from the bursting point to the muzzle, then he would shape his gun to suit. The early gunners suffered terribly from the bursting of their guns. James II., King of Scotland, was killed at the siege of Roxborough Castle, 1460, in this manner; 1470, a bombard near Paris burst, killing 14 men and wounding as many more.

It was long before the early gunner discovered (the figures are for a 4.25 inch caliber) that the proportional pressure on the bore increased alarmingly with the weight of the ball; 3.6 per square inch for stone; 10 for iron; 10.9 for bronze; 14.5 for lead. For the same caliber; the cost for one round; 4-inch ball, charge 1–9 wt. of ball:—In money of to-day: with a stone ball, $1.25; iron, $4.75; lead, $6.25; bronze, $9.00.

Stone balls had two bad defects—they were apt to shatter to pieces when used for breaching purposes against heavy masonry; and their rough surface greatly damaged the interior of the bombard; it was sought to correct these defects; the first by bands of iron about the ball; the second by enclosing the ball in an envelop of soft lead.

The difficulties in the construction of these big bombards were greatly lessened by the system of forging the very heavy breech piece so that it could be screwed to the chase—and unscrewed, when desired; the square holes for the levers, that worked like capstan bars on board ship, are conspicuous in such guns, usually in the rear ring of the chase, and at the rear end of the breech. In some bombards there were three divisions, greatly adding to convenience in transportation.

Here are the dimensions of the largest bombard that has come down to us, the one on the Place du Marché at Ghent. The lady is called "Dulle Grete," which they tell me can be translated "Mad Meg." Her caliber is 26″; interior of chase 10′ 4″, or five calibers. Chamber caliber 10.23″, length 4′–6.16″; five to six calibers. The exterior length 16′ 6″. The gun is built up of 32 longitudinal iron bars, 2.17″ wide, 1.2″ thick; these are soldered together. Over them are 41 iron rings, welded together and diminishing in thickness from the junction with the breech to the muzzle, except the three which form the muzzle moulding or swell. In addition, there are 20 bands, called "rondelles," in two of which, the one at the extreme end of the breech and the one at the end of the chase, are holes for the levers used in unscrewing breech from the chase. Curiously enough, the breech is not exactly in line with the chase, inclining slightly to the left,—might possibly be a trifle trying for the right-hand side of the chase after a few shots. Meg's weight is 36,080 pounds, but painters of that day represent Flemish women of her class as distinctly heavy. The ball weighed 748 lbs., and the powder charge was 88 lbs., between 1/8 and 1/9 the weight of the projectile. The range was about 3,000 yards, at least Meg claimed that, though her effective range could not have been more than three hundred yards. But, it is only fair to remember that in Nelson's day six hundred yards was long fighting range.

The date of this huge, but rather useless engine of construction —destruction, I fear, would be gross flattery—is rather uncertain. The Flemings took it to the siege of Oudenarde, in 1452; a coat-of arms I found near the vent is that of the father of Charles the Bold, called "Philip the Good," because he was bad. He warred from 1422 until 1467.

At the siege of Caen, in 1450—this is all quoted from an account in very bad Latin—the town was ringed about with twenty-four bombards, horrible to behold, for they were of such immense size that a man could sit in any one of them without bending his head! Possibly this old chronicler's account was intended to fall into the the hands of the besieged—though of course, cannon of that size would make very comfortable quarters for at least 48 men.

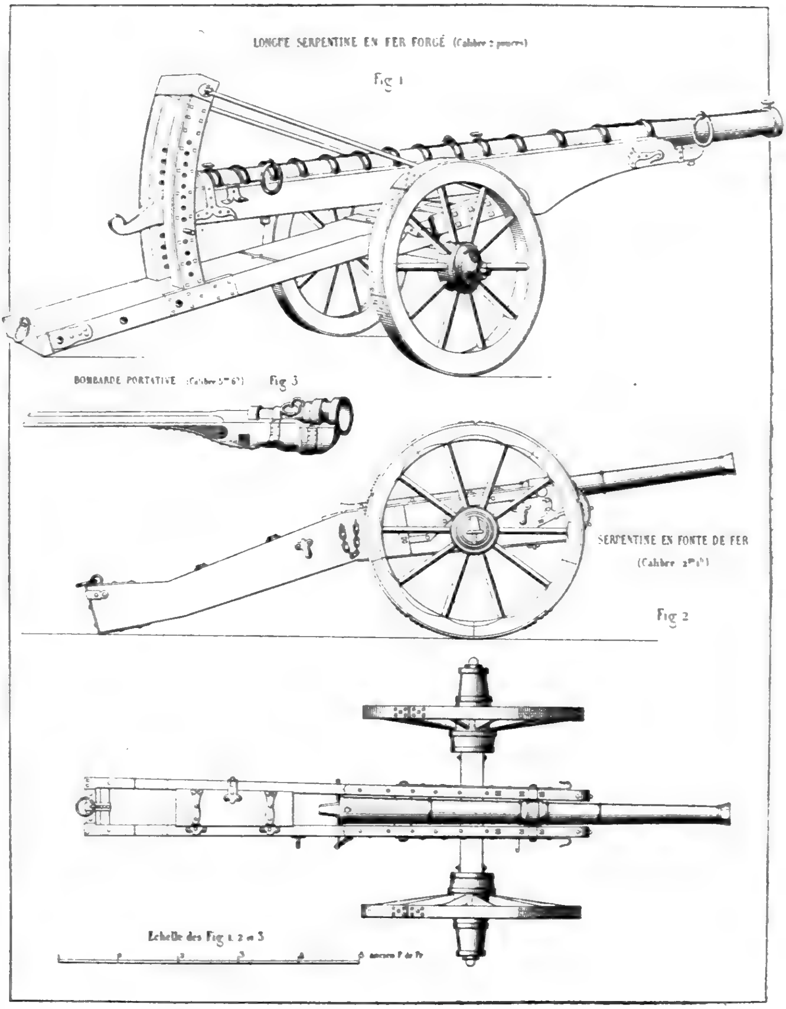
The preceding is but a dip into the doings of bombards; we have not touched on that most interesting one, "Mons Meg," at Edinborough Castle; nor the "Michelettes," at Mont St. Michel, which are of unique value; the "Faule Mette," was a cast bombard, a resident of Brunswick, but alas she has disappeared.

Wooden guns are of great interest, not only on account of the frequent tendency to burst which must have been theirs, but also on account of the very unreliable descriptions of them that we possess.

About 1450 trunnions appear (not the first, by any means) on some of the Burgundian guns, adding, of course, greatly to their efficiency, both in permitting more exact aiming and as a help to resist the recoil. Omitting all other technical details it may be of interest to take a look at the Burgundian, and afterwards at the French artillery.

The town of Neuss, near the Rhine, and not far from Duesseldorf, was unsuccessfully besieged by Charles the Bold, 1474/5. The Burgundian artillery, then the best in Europe, was well represented there, and more or less careful accounts of it have come down to us. The following list is taken from Napoleon's "Etudes"; unfortunately the calibers are omitted.

Nine large bombards. Eight bronze bombards, 8 to 11 ft. long; these had lions' heads at the muzzle. Ten courtaux, 4 feet long, on wheels. These were a little like the carronade of just before 1800, to forty or fifty years after; there are accounts of courtaux which carried 60-lb. balls and were used as siege pieces. 115 Serpentines, one of which was 13 feet long. Six serpentines of bronze, with dragon heads at the muzzle, one of these guns was 8 feet long. Sixty-six serpentines 6 to 9 feet long. Fifteen others of the same caliber weighing 4,000 pounds.



Field-Guns of Charles the Bold, c. 1476.

FIG. 1. More ancient build; wrought-iron bars, banded. FIG. 2. Cast-iron; modern looking gun and carriage. FIG. 3. "Portable bombard"; throws incendiary bomb or stone ball.

Like many other weapons, artillery is not of much service unless you know how to use it, and do not hesitate to use it. Charles the Bold was the last of the knights-errant, unless we include the chivalric Don Quixote. Cannon had changed all that and Charles was a failure, though a magnificent one.

March 2, 1476, was fought the battle of Granson; Charles of Burgundy had 20,000 men and his splendid train of field-artillery; both these he proceeded to post as badly as he conveniently could. The Swiss always attacked in solid squares, impervious to cavalry but just the food for cannon to devour. Nine thousand men, and absolute silence, save the word of command; instant death to whoever faltered. A few shots took effect on that solid human mass, as it moved slowly towards the guns, each ball mowing down ten or a dozen men; then a dip in the ground protected them, and the balls passed over their heads. Now was the time for Charles to have concentrated his artillery fire on the square and rent it to pieces, for his cavalry to drive off the field. Instead, time and again he launched his magnificent gendarmerie against that bristling wall of steel, those 16-foot spears held by sturdy mountaineers who knew not fear. Every attack failed, panic followed, and that splendid Burgundian artillery now adds interest to a score of Swiss museums.

Napoleon III. and General Favé consider the artillery of Charles VIII. the beginning of that arm of the French service. Of course guns of earlier days still lingered on, but the newer ones took on almost the form they were to retain for three hundred years.

Guns changed but little from 1500 until the astounding development of today. Drake fought the Spaniard with almost the same guns that Nelson used at Trafalgar.

A better organization, and an improvement in tactics was made by Charles of France, before his great Italian campaign of 1495. On the other hand he was opposed by very different foes from the heroes who defeated Charles of Burgundy at Granson, Morat and Nancy. One may safely say that France easily, almost pityingly scattered before her powerful guns the very worst troops the world contained at that time. Burgundy, on the contrary, had faced the bravest and best fighters history tells of. Swiss tactics, the old phalanx of Greece, steadily adhered to, soon became obsolete, and the system of rushing the guns with such unwieldy squares, received its death blow on the days of Marignano, 1515; when, cannon to the right of them, cannon to the left of them, cannon in front of them, volleyed and thundered. Two days of carnage failed to shake the Swiss; but when Francis I., massed his artillery, and the

Swiss attack was exposed to a cross fire that tore their squares to shreds,—just what Charles of Burgundy should have done at Granson, they sullenly fell back and the rule of the cannon began; alas, that its end is not yet in sight.

Ten years later this same Francis was routed and captured at Pavia; one reason for it was that he stupidly masked his own guns by advancing his troops in front of them; another, that many of the Swiss of Marignano were then fighting on his side; but those days of Marignano and the slaughter were not forgiven; so when the crisis came, the Swiss, despite the despair and entreaties of their officers, threw down their arms and pretended to be cowards,—for a Swiss it *could* only be *pretence.*

AUTHORITIES.

"Ancient Cannon in Europe" (fourteenth century), Lt. Henry Brackenbury (Later Lt.-Genl.), *Proceedings of the Royal Artillery Institution,* 1865, Woolwich, Eng.
"Etudes sur l'Artillerie," Prince Louis Napoleon, Paris, 1846.
"Etudes sur l'Artillerie," General Favé, Paris, 1862.
"Quellen sur Geschichte der Feurwaffen," Leipzig, 1877.
"Military Antiquities Respecting a History of the English Army," Francis Grose, London, 1812.
"Principles and Practice of Modern Artillery," Lt.-Col. C. H. Owen, London, 1873.
"Gunpowder and Ammunition." Lt.-Col. H. C. L. Hime, London, 1904.
"Naval Gunnery," Capt. H. Garbett, London, 1897.
"Catalog of the Musée d'Artillerie," Paris.
"Encyclopedia Britannica."
"Encyclopedie Larousse."
"Dict. du Mobilier Français," Viollet le Duc.
"Biographie Nouvelle."
Author's notes, etc.

MOREAU DE SAINT MERY AND HIS FRENCH FRIENDS IN THE AMERICAN PHILOSOPHICAL SOCIETY.

BY JOSEPH G. ROSENGARTEN.

(*Read April 20, 1911.*)

Born at Fort Royal, Island of Martinique in 1750, dying at Paris in 1819, Moreau de St. Mery had a career characteristic of the stormy period through which he passed. Of a good family of Poitou, his father's early death left him with little means. At nineteen he came to Paris, became a King's gendarme, studied law, letters and mathematics. Returning to Martinique he became a lawyer at Cap Français, and in 1780 a member of the Upper Council of Saint Domingo. He classified the laws of the French Colonies of the Antilles; discovered and restored the tomb of Columbus, and sent many scientific papers and many curious archeological articles to the American Philosophical Society, and was elected a member in 1789.

Returning to Paris as a member of the Constituent Assembly from Martinique, he was warmly welcomed by the scientific world in recognition of his frequent contributions to scientific societies.

When the French Revolution broke out, he was elected President of the Electors of Paris, twice addressed Louis XVI. on their behalf, and was fond of boasting that for three days he had been King of Paris, and helped to secure for Lafayette the command of the National Guard.

Elected Deputy from Martinique in 1790, he brought many colonial matters before the Constituent Assembly, and in 1791 became a member of the Judicial Council.

Wounded in an attack by a maddened crowd, he took refuge in a country village in Normandy, escaped the guillotine and came to the United States. After a short stay in New York, he settled in Philadelphia in 1793, opened a book store at Front and Walnut Streets, and became active in the Philosophical Society, attended its meetings regularly, contributing papers, making gifts to its collections, introducing many of his fellow exiles, some of them soon elected to the Society. Returning to France in 1799 and making use of his distant relationship to Josephine, wife of Bonaparte, he was employed by Bonaparte in the preparation of a Maritime Code. Appointed to the Council of State in 1800, he was sent in 1801 to Parma as Administrator of the Duchy of Parma, fulfilling his duties with moderation, but showing a lack of firmness and energy that cost him his position, and the enmity of Napoleon, who sent Junot to replace him, and to end a threatened revolution by fire and sword.

When he lost his place in the Council of State, he told Napoleon that his honesty need not be feared, for it was not contagious in that body. The Empress Josephine helped him, and afterwards he became historiographer of the Marine Department.

He sold to the French government, for a pension from Louis XVIII., his large collection of historical papers, documents, maps, etc., often mentioned by recent historians. One unkind critic, who worked at making a calendar of his papers, says he sold to the government not only the copies he had made, but many originals which he had taken from the files in his care. His printed works include one in six volumes, on "The Laws and Constitutions of the French Colonies in the West Indies from 1550 to 1785." Louis XVI. ordered a copy to be placed in each French colony in America.

His "History of Saint Domingo" was translated by William Cobbett, then living in Philadelphia, and his list of subscribers included many notable Americans then in office and a large number of French exiles in the United States.

He translated and published a pamphlet on "The Prisons of Philadelphia," by Rochefoucauld Liancourt, reprinted in Paris and in Holland, and in one of Rochefoucauld Liancourt's bulky six volumes of his "Travels in the United States." He had the honor of an eloge by Fournier Pescay printed in Paris in 1819 and the biographical dictionaries give the dates of his various publications, of the offices he held and make mention of his best service: the collection and preservation of an immense number of papers, maps, etc., relating to the French colonies in America, from their origin down to the French Revolution. Calendars of parts of them have been printed by the Canadian Archive office and by the Wisconsin Historical Society and in France.

His shop at Front and Walnut was the rendezvous of all the notable French exiles then in Philadelphia, and he entertained them very modestly,—cooking his own simple meals in his rear office, and sharing his good wine with them. He figures in the "Memoirs" of Talleyrand and in the "Travels" of Rochefoucauld and in the books on the United States by Brissot and Volney and other French writers.

He translated and published two big quarto volumes on China by Van Braam, who had resided in that country as a member of a Dutch embassy. The book was dedicated to Washington. Van Braam became a merchant in Charleston in 1783 and was naturalized in 1784, then made his voyage to China, returned to Philadelphia in 1796, bringing with him several Chinese servants, and a large collection of paintings, drawings, maps and curios, which he exhibited in Philadelphia for several months, then kept in his house near Bristol, "China Hall" on the Delaware. In the appendix to the second volume of his book, there is a detailed account of his collection, filling many pages. He too was elected a member of the Philosophical Society in 1797.

Moreau de St. Mery printed a catalogue of the contents of his book store, of 72 pages, including many books in English, French, Italian, Spanish, Latin, German, Dutch, maps, music, and advertised "a general business of stationers, booksellers and dealers in engravings, a printing office and book bindery, to fill orders for books from Europe, deal in every kind of business on commission, and will not spare any care in studying to accomplish their enterprise intended to propagate and diffuse knowledge," and at the end of the catalogue of books, etc., offered for sale, "particular goods out of the booksellers' station, everything belonging to the Fleecy hosiery manufacture of New York, as foot and ankle socks, goutty mittens and stockings, shirts with and without sleeves, drawers, muffs, etc., elastic garters and gallices of different sizes." Perhaps his field was too large, and the public not appreciative, for he failed for $5,000, and Philadelphia lost the advantage of such a bookseller, printer and publisher, as well as philosopher, author and translator.

No doubt the same industry and energy led him to make the large collection known by his name, now in Paris, of original documents, copies, maps, etc., filling 287 volumes, bought by the French government, and now in its great archives for the use of students of colonial French history.

That St. Mery was well thought of in Philadelphia, during his residence here is attested by the long list of subscribers to his book on Saint Domingo, including Vice-President John Adams, Adet, the French minister, Benjamin Franklin Bache, William Bingham, Thomas Bradford, Samuel Breck, Rev. Dr. Collin, Alexander James Dallas, P. S. Duponceau, Dupont, of Wilmington, Rufus King, Dr. Logan, Noailles, Timothy Pickering, Rochambeau, Talleyrand, John Vaughan, Volney, and many notable French exiles both in Philadelphia and elsewhere in the United States. Many of them were elected members of the American Philosophical Society, and its minutes show that its meetings were frequently attended by Talleyrand, Rochefoucauld, Volney, Van Braam, and its library has many books, the gifts of St. Mery and his fellow exiles.

In a recent biography of Talleyrand we are told that when he landed here in 1794, it was the finest city in the United States, full of life, everywhere new buildings and work on them going on, the streets full of elegant equipages, crowded with men of business, workmen and sailors.

Chateaubriand speaks of the beauty of the Quakeresses. Every stranger from Europe was welcomed by the wealthy merchants,—life was very expensive, board $8 to $12 a week, without fire, light or wine; a negro servant cost $10 to $12 a month even with food and washing. Emigrés of all political creeds found a Noah's ark of refuge in Philadelphia. Talleyrand's arrival was quite an event; he found old friends, old soldiers of Lafayette, fellow members of the constituent assembly, among them Blacon, who had been deputy from Dauphine and one of the intermediaries between Mirabeau and the King. Hamilton gave him a warm welcome, but Fauchet, the French Minister, prevented Washington from receiving him, and Washington wrote to Lord Lansdowne, explaining why his letter of introduction did not enable him to meet Talleyrand. However, he did not busy himself with politics, but at once began speculating in land, then the great money-making business. The Scioto Company was then all the vogue in Paris. The Holland Land Company was buying right and left. LaForest, the French Consul General, had bought an estate in Virginia in 1792. Noailles and Omer Talon in association with Robert Morris had bought large tracts of land on the Susquehanna for a colony of French royalist exiles, offering land, which had cost them 15 sous an acre for 6 francs, as a refuge from France.

Talleyrand urged Mme. deStael and his friends in Europe to send money for investment, and he proposed buying land in Maine from General Knox. He told Moreau de St. Mery that he had a plan for settling in Louisiana, and was a frequent visitor at St. Mery's book store, meeting there his old friends and fellow exiles,—Fayettists, Girondists, Constituents, Jacobins, Royalists, one of them, Count de Moré, says "wandering like ghosts, full of regrets, lost hopes and disappointment over their shattered political careers."

Moreau de St. Mery often spoke of the three days in 1789 when as president of the Electoral College he was King of Paris. But while the others were bewailing their hard fate, Moreau was busy with his shop and his books, and Talleyrand wrote to Paris of schemes for revictualling Paris, starved by the Reign of Terror, crying for bread, by ships loaded with rice, grain and fish, named the best merchants to deal with, and on the strength of his services, secured the long-sought permission to return to France, and there began that career of success which carried him safely through the Republic, the Directory, the Empire, the Bourbon restoration and into the reign of Louis Philippe.

Other Frenchmen had planned a great French colony,—twenty-four men, mostly young noblemen, had joined in forwarding Joel Barlow's scheme of a great settlement on the Ohio,—the Scioto Company was organized, to buy 24,000 acres,—d'Epresmenil, their leader, lost his life on the guillotine; Marnesia, after a tour through America, returned to France, and with Lally Tollendal, Mounier and Malouet, lost touch with their colony in the midst of the great events in their own country.

One of Moreau de St. Mery's friends and visitors, Rochefoucauld Liancourt, wrote an account of the prisons of Philadelphia, which was printed by Moreau in French and in English in Philadelphia, (he was the translator), and later it was published in Paris, and in Dutch in Holland, and later still was made part of one of his six volumes describing his travels in the United States.

Rochefoucauld spent four years in the United States and describes in great detail his experiences in the northwest and north, in Canada, in Maine, in the south, and in New York, New Jersey and Pennsylvania.

Talleyrand from Philadelphia wrote to Mme. de Genlis, "Rochefoucauld is here, making notes, asking information, writing, and more a questioner than Sterne's curious traveller; he wants to see and know everything," in his eager search for the truth. He met Knox, Sullivan, Jefferson, John Adams, Priestley, Livingston and Kosciusko. He appealed to Washington to intercede for the release of Lafayette from Olmutz. His inquiries included politics, constitutions, judicial organizations, army, agriculture, industries, statistics, charities, education. In Georgia he studied cotton and indigo plantations; he condemned slavery and argued for the education of the negroes to prepare them for freedom; in Niagara and the great forests he foresaw the sources of future industries. He established in France on his return societies like the Pennsylvania Prison Society, and took home much that he had learned in the United States, which he introduced in France, useful reforms that made him a real philanthropist.

Another French settler in or near Philadelphia, Pierre Legaux, was elected a member of the American Philosophical Society in 1787. A Counsellor of Parliament, a member of the Academy of Arts and Sciences and of several foreign academies, employed in the French West Indies, he came to Philadelphia about 1786 and made his mark as a representative of French culture and scientific ability and by his charm of manner. He bought land on the Schuylkill near Conshohocken and planted vineyards. Washington and Mifflin and other notable men visited them and approved his enterprise. Jefferson, Genet, Brissot, Audubon, Wistar, were among those whose visits and encouragement he recorded in his diary. He tried to get Jefferson to recommend to Congress protection for his infant industry. In 1791 he offered his country house to Washington as a home during the session of Congress and "hoped the country which owes its liberty to your wisdom and military talent will owe her wine to your generosity."

In 1793 the Legislature of Pennsylvania chartered a company to promote the cultivation of vines, with a capital of $20,000 in $2 shares; in 1800 the stock was fixed by a law passed by the Legislature at $1 a share down, and the balance of the $20 in easy instalments. Later he advertised that apprentices, black or white, would be received, with terms of payment, and the promise of a gift of vines that they could take home and start the industry wherever they lived. In 1802 the company received its charter and organized. Among the stockholders were Thomas McKean, Robert Morris, Genet, Duponceau, Stephen Girard, Alexander Hamilton, Aaron Burr, Jared Ingersoll, Muhlenberg, Bartram and other notable people of the 385 subscribers to the stock of the Pennsylvania Vine Co. Legaux was elected superintendent at a salary of $600 a year with residence and living at the farm. Expenses soon outrân receipts, the managers quarreled with Legaux, litigation brought ruin, and he, harassed, worried, disappointed, became a mere servant where he had once been a genial host, finally succumbed and broken in spirit died in 1827, and was buried at Barren Hill. Thus sadly closed another one of the frequent failures of French enterprises in the United States.[1]

Moreau de St. Mery kept a journal, cited by Pichot in his "Souvenirs intimes de Talleyrand," in which he speaks of Talleyrand's frequent visits to his book store, meeting there Noailles, Rochefoucauld, Omer Talon, Volney and others less famous.

While the host dined meagerly on rice and milk cooked in his store, Talleyrand enjoyed drinking his own old Madeira, and was the life of the party. When Blacon called him monseigneur all the company burst into a hearty laugh. Talleyrand urged Napoleon to erect a statue of Washington in Paris and to give France the

---

[1] *Philadelphia Press,* September 9, 1899, article by Samuel Gordon Smythe.

same perfect religious freedom that he saw practiced in the United States and he also advised the sale of Louisiana to the United States as a method of strengthening the ties between the two countries.

One would like to see the journal kept by Moreau de St. Mery during his residence in Philadelphia. Did he in his palmy days as a member of the Council of State under the Empire or in the time of his modest clerkship in the Marine Department, meet his old visitors at his book store in Philadelphia, Louis Philippe, Talleyrand and Rochefoucauld and Volney and the other exiles now restored to their old prosperity, and did they recall the meetings of the American Philosophical Society and their attendance and share in them? His large collection of historical papers, now rescued from oblivion by calendars by and for the American students of history, perpetuates his name and memory and services, more than do the volumes he wrote and printed and published at his book store at Front and Walnut Streets.

The latest historian of the French Revolution, Aulard, frequently mentions Moreau de St. Mery and his share in it, and refers to the collection of historical documents. His name does not figure in Dr. Mitchell's capital novel, "The Red City," with its picturesque account of the French exiles living here in the closing years of the eighteenth century, nor in Kipling's picturesque story of Philadelphia at that time. All the more reason therefore for an attempt to recall the memory of the French exiles who were members of the American Philosophical Society and especially of that one who figures most often and most usefully in its records of that time, Moreau de St. Mery.

Of the other French exiles during their residence in Philadelphia, there is occasional mention, as for instance in Talleyrand's "Memoirs." His two papers on the United States and the relations between France and this country, read before the French Institute, were no doubt largely inspired by what he heard at the meetings of the American Philosophical Society, and his share in the sale of Louisiana to the United States helped to secure that vast territory for the future growth of the young republic and its ultimate great development.

In the report of M. E. Richard on the Moreau de St. Mery collection, printed in the supplement to Dr. Brymner's Report on Canadian Archives for 1899 (Ottawa, 1901), he says it was stored in the archives of the Marine at Versailles up to 1887, then removed to the Ministere des Colonies, and stored in the attic of the Louvre. They were then fearful of the great risk of fire, but were considering the removal to other quarters.

In the reports of 1883–85 and 1887, mention is made of 287 volumes in the collection of Moreau de St. Mery, some forty of which relate to Canada, others to Louisiana and the French islands of America. These belonged formerly to the Colonial Archives of the Marine; of the collection headed Moreau de St. Mery seventeen volumes contain description, etc., of the colonies, including a series of memorials on Canada, 3 volumes are on the religious missions of Canada, 12 volumes on Newfoundland, 12 volumes containing royal instructions to governors, and decrees relating to Canada, 119 registers on Canada, Acadia, etc., 6 volumes on civil status of Canada, 34 volumes on Louisbourg; an analysis was made of 17 volumes of the Moreau de St. Mery collection for the Canadian Archives.

It is open to the objection that "there is no strict order followed in the compilation; it contains but a limited number of documents, or even extracts from documents. It is difficult to understand the dominant idea of this collection."

This collection is, nevertheless, most valuable, for it contains a considerable number of important papers, both transcripts and originals, not to be found elsewhere.

On p. 5 of Richard's Report, in a footnote, it is said Moreau de St. Mery, born in Martinique in 1750, studied law in Paris and practiced in St. Domingo, where he became a member of the Superior Council of the Island. Entrusted by Louis XVI. with the compiling of a colonial code, he published in Paris "Les Lois et Constitutions des Colonies Françaises de l'Amerique sous le Vent." Representing Martinique in the Constituent Assembly, he drafted the report of the Committee on the Colonies. Forced by political events to leave France, he fled to Philadelphia, where he remained from 1793 to

1798, employing himself as a bookseller and publisher. He there published his "Description de la partie Espagnole de St. Domingue," which he signed "Moreau de St. Mery, member of the Philosophical Society of Phila." He also translated or edited foreign works, and among them VanBraam's "Voyage to China." Having returned to France on the 18 Brumaire, he was, through his relationship with Josephine de Beauharnais, appointed in 1800 to the position of Historiographer of the Marine. Napoleon appointed him to the Council of State, in view of his knowledge of colonial affairs. In 1802 he was administrator of Parma and Guastalla, but lost favor and was removed in 1806. He died poor and in receipt of a pension from Louis XVIII.

While entrusted with a mission in St. Domingo, as publisher in Philadelphia and historiographer in Paris, we find him everywhere an observer and a worker, taking notes on everything. His collection of manuscripts comprises 287 large volumes, and was purchased by the state after his death, that is to say the government had to pay not only for the transcripts he had caused to be made, but even for the originals he had appropriated.

Persons who take a special interest in the social and religious condition of the country, the disputes and conflicts between the authorities will find in the Moreau de St. Mery collection far more than they could find in any other series.

That Moreau de St. Mery did a good work in preserving and making his collection is shown by the statement (in Richard's Report, p. 8, etc.), that the Archives of the Ministry of Marine were so utterly neglected that the precious papers were used during five weeks of the winter in 1793, as fuel to feed the stoves of the post of the Garde Nationale in the building where the archives were kept, and in 1830 an employee gave up the archives to pillage and sold, by weight for his own profit, whole piles of documents, bought by autograph collectors.

Thanks to the suggestion of Prof. Cleveland Abbe, I found in the *Monthly Weather Review* for February, 1906 (Washington, Weather Bureau, 1907), at pp. 64, etc., in a notice by C. Fitzhugh Talman of the U. S. Weather Bureau, the following: "Foremost among the early writers upon the island of Santo Domingo, was Mederic Louis Elie Moreau de St. Mery, who produced three voluminous works upon the French possessions in the West Indies. Born at Fort Royal, Martinique, in 1750, he passed his early manhood in Haiti, and settled at the then capitol of the colony, Cap Français (now Cap Haitien). He held an important office in the administration of the colony, and also, under a commission from Louis 16th, travelled extensively through the French West Indies, collecting material for a work published in 1785, under the title "Lois et Constitutions des Colonies Françaises de l'Amerique sous le vent, de 1550 à 1785." Returning to France he took an active part in the French Revolution, until obliged to flee from his political enemies to the United States. It was during a period of exile in the latter country that he published two works descriptive of the island of Santo Domingo, one devoted to the Spanish part of the island, the other to the French part. Published by himself in Philadelphia in 1797, it was republished in Paris in 1875 by Morgand in 2 vols. 8vo. It is to this day regarded by the Haitians as the highest authority upon the physical geography of their country and is quoted at length in the latest Haitian gazeteer (Ronzier Dic. geog. et admin. d. Haiti, Paris, 1899). Mr. Talman reproduces St. Mery's chart of the Island, and a full abstract of his description of its meteorology.

Moreau de St. Mery was active in the Philadelphia Society of Cap Français, and in the Library of the American Philosophical Society there is the 1st vol. of its Proceedings,—no 2nd or later volume is preserved,—it shows that Moreau de St. Mery was the leading spirit in its activities. That his meteorological observations of San Domingo during his residence there in the eighteenth century, should be found of value today, is but another proof of his useful activity. His chief monument however is his collection, bearing his name, of original documents on the French in America, and by it he is now made known to students in the pages of Aulard, Brymner, Thwaites and other historians.

THE NEW HISTORY.

By JAMES HARVEY ROBINSON.

(*Read April 22, 1911.*)

I propose to discuss in this paper the value of historical study. The question has long haunted me and certainly merits a more careful consideration than it has, so far as I can discover, hitherto received. It will be impossible to do more here than to analyze the problem and briefly state the general conclusions which that analysis suggests.

The older traditional type of historical writing was narrative in character. Its chief aim was to tell a tale or story by setting forth a succession of events and introducing the prominent actors who participated in them. It was a branch of polite literature, competing with the drama and fiction, from which, indeed, it differed often only in the limitations which the writer was supposed to place upon his fancy. As Professor McMaster has recently said: "It was by no mere accident that Motley began his literary career with a novel called "Merry-Mount," and Parkman his with "Vassall Morton." These bespoke their type of mind. The things that would interest them in history would be, not the great masses of toiling men, not the silent revolutions by which nations pass from barbarism to civilization, from ignorance to knowledge, from poverty to wealth, from feebleness to power, but the striking figures of history, great kings and queens, the leaders of armies, men renowned for statescraft, and the dramatic incidents in the life of nations. Each must have his hero and his villain, his plots, conspiracies and bloody wars. Just as Froude had his Henry VIII.; just as Macaulay had his William III., Carlyle his Robespierre and Cromwell, and Thiers his Napoleon, so Motley had his William of Orange and Philip of Spain; Prescott his Cortez, Pizarro, Ferdinand and Isabella; and Parkman his Pontiac, Frontenac and La Salle. History as viewed by writers of this

PROC. AMER. PHIL. SOC., L, 199 L, PRINTED JUNE 27, 1911.

school is a series of dramas in each of which a few great men perform the leading parts and use the rest of mankind as their instruments."[1] The commonly accepted definition of history was long, "a record of past events" and these, naturally, the most startling and romantic and the best adapted for effective literary presentation. Doubtless there was some serious effort to describe conditions and institutions, since they formed the necessary setting for the events and anecdotes; sometimes they would even be assigned a place on their own intrinsic merits; but what may be called the epic ideal of history prevailed until perhaps fifty or sixty years ago when, owing to the influence of the modern scientific spirit, a very fundamental revolution became apparent.

Now let us review, by way of preliminary, what were deemed the advantages of the study of history of this older type. Lord Bolingbroke in his "Letters on the Study of History," written about 1737, says: "An application to any study that tends neither to make us better men and better citizens, is at best but a specious and ingenious sort of idleness; . . . and the knowledge we acquire by it is a creditable kind of ignorance, nothing more. This creditable kind of ignorance is, in my opinion, the whole benefit which the generality of men, even the most learned, reap from the study of history: and yet the study of history seems to me of all others the most proper to train us up to private and public virtue." History, he quite properly says, is read by most people as a form of amusement, as they might play at cards. Some devote themselves to history in order to adorn their conversation with historical allusions,—and the argument is still current that one should know enough of the past to understand literary references to noteworthy events and persons. The less imaginative scholar, Bolingbroke complains, satisfies himself with making fair copies of foul manuscripts and explaining hard words for the benefit of others, or with constructing more or less fantastic chronologies based upon very insecure data. Over against these Bolingbroke places those who have perceived that history is after all only "philosophy teaching by example." For "the exam-

---

[1] "The Present State of Historical Writing in America," reprinted from the *Proceedings of the American Antiquarian Society* for October, 1910; Worcester, 1910, p. 18.

ples which we find in history, improved by the lively descriptions and the just explanations or censures of historians," will, he believes, have a much better and more permanent effect than declamation, or the "dry ethics of mere philosophy." Moreover, to summarize his argument, we can by the study of history enjoy in a short time a wide range of experience at the expense of other men and without risk to ourselves. History enables us "to live with the men who lived before us, and we inhabit countries that we never saw. Place is enlarged, and time prolonged in this manner: so that the man who applies himself early to the study of history may acquire in a few years, and before he sets foot in the world, not only a more extended knowledge of mankind but the experience of more centuries than any of the patriarchs saw." Our own personal experience is doubly defective; we are born too late to see the beginning, and we die too soon to see the end of many things. History supplies in a large measure these defects.

There is of course little originality in Bolingbroke's plea for history's usefulness in making wiser and better men and citizens. Polybios had seen in history a guide for statesmen and military commanders; and the hope that the conspicuous moral victories and defeats of the past would serve to arouse virtue and discourage vice has been urged by innumerable chroniclers as the main justification of their enterprises. To-day, however, one would rarely find a historical student who would venture to recommend statesmen, warriors and moralists to place any confidence whatsoever in historical analogies and warnings, for the supposed analogies usually prove illusive on inspection and the warnings, impertinent. Whether or no Napoleon was ever able to make any practical use in his own campaigns of the accounts he had read of those of Alexander and Cæsar, it is quite certain that Admiral Togo would have derived no useful hints from Nelson's tactics at Alexandria or Trafalgar. Our situation is so novel that it would seem as if political and military precedents of even a century ago could have no possible value. As for our present "anxious morality," as Maeterlinck calls it, it seems equally clear that the sinful extravagances of Sardanapalus and Nero, and the conspicuous public virtue of Aristides and the Horatii, are alike impotent to promote it.

In addition to the supposed uses of history mentioned by Bolingbroke there was the possibility of tracing the ways of God to man. Augustine had furnished the first great example of this type of narrative in his "City of God" and thereafter history had very commonly been summoned to the support of Christian theology. Bossuet, writing for the Dauphin in the latter part of the seventeenth century, says: "Mais souvenez-vous, Monseignèur, que ce long enchaînement des causes particulières qui font et défont les empires dépend des ordres secrets de la Providence. Dieu tient du plus haut des cieux les rênes de tous les royaumes; il a tous les coeurs en sa main; tantôt il retient les passions, tantôt il leur lâche la bride, et par là il remue tout le genre humain. Veut-il faire des conquérants; il fait marcher l'épouvante devant eux, et il inspire à eux et à leurs soldats une hardiesse invincible. Veut-il faire des législateurs; il leur envoie son esprit de sagesse et de prévoyance; il leur fait prévenir les maux qui menacent les états, et poser les fondements de la tranquillité publique. Il connoît la sagesse humaine, toujours courte par quelque endroit; il l'éclaire, il étend ses vues, et puis l'abandonne à ses ignorances; il l'aveugle, il la précipite, il la confond par elle-même; elle s'enveloppe, elle s'embarrasse dans ses propres subtilités, et ses précautions lui sont un piége. Dieu exerce par ce moyen ses redoutables jugements, selon les régles de sa justice toujours infallible."[2] It was assumed by such writers as Bossuet that in spite of the confessedly secret and mysterious character of God's dispensations it was nevertheless quite possible for the skilled theologian to trace them with edifying confidence and interpret them as divine sanctions and disapprovals, blessings and punishments, trials and encouragements. For various reasons, which it is unnecessary to review here, this particular method of dealing with the past and deriving useful lessons from it finds few educated defenders at the present day.

In the eighteenth century a considerable number of "philosophies of history" appeared and enjoyed great popularity. They were the outcome of a desire to seize and explain the general trend of man's past. Of course this had been the purpose of Augustine and Bossuet

---

[2] "Discours sur l'histoire universelle," concluding chapter.

but Voltaire devoted his "Philosophie de l'histoire" (1765) mainly to discrediting religion as commonly accepted; and instead of offering any particular theory of the past he satisfied himself with picking out what he calls *les vérités utiles.* He addresses Madame du Châtelet in the opening of his "Essai sur les Moeurs et l'esprit des nations" as follows: Vous ne cherchez dans cette immensité que ce qui mérite d'être connu de vous; l'esprit, les moeurs, les usages des nations principales, appuyés des faits qu'il n'est pas permis d'ignorer. Le but de ce travail n'est pas de savoir en quelle année un prince indigne d'être connu succéda a un prince barbare chez une nation grossière. Si l'on pouvait avoir le malheur de mettre dans sa tête la suite chronologique de toutes les dynasties, on ne saurait que des mots. Autant il faut connaître les grandes actions des souverains qui ont rendu leurs peuples meilleurs et plus heureux, autant on peut ignorer le vulgaire des rois, qui ne pourrait que charger la mémoire. . . . Dans tous ces recueils immenses qu'on ne peut embrasser, il faut se borner et choisir. C'est un vaste magazin où vous prendrez ce qui est à votre usage.[3] Voltaire's reactions on the past were naturally just what might have been expected from his attitude toward his own times. He drew from "le vaste magazin" those things that he needed for his great campaign, and in this he did well, however uncritical his criticism may at times seem to a modern historical student.

Herder in his little work, "Auch eine Philosophie der Geschichte zur Bildung der Menschheit. Beitrag zur vielen Beitragen des Jahrhunderts" (1774), condemns the general lightheartedness and superficiality of Voltaire and other contemporary writers who were, he thought, vainly attempting to squeeze the story of the universe and man into their puny philosophic categories. Ten years later he wrote his larger work, "Ideen zur Geschichte der Menschheit," in which he strove to give some ideal unity and order to the vast historic process, beginning with a consideration of the place of the earth among the other heavenly bodies, and of man's relations to the vegetable and animal kingdoms. "If," he says, "there be a god in nature, there is in history too; for man is himself a part of creation, and in his wildest extravagances and passions must obey laws not

[3] "Avant propos."

less excellent and beautiful than those by which all the celestial bodies move. Now as I am persuaded that man is capable of knowing, and destined to attain the knowledge of, everything that he ought to know, I step freely and confidently from the tumultuous scenes through which we have been wandering to inspect the beautiful and sublime laws of nature by which they have been governed." Humanity is the end of human nature, he held, and the human race is destined to proceed through various degrees of civilization in various mutations; but the permanency of its welfare is founded solely and essentially on reason and justice. But it is a natural law that "if a being or system of beings be forced out of the permanent position of its truth, goodness and beauty it will again approach it by its internal powers, either in vibrations or in an asymptote, as out of this state it finds no stability."[4] Herder formulates from time to time a considerable number of other "laws" which he believes emerge from the confusion of the past. Whatever we may think of these "laws" he constantly astonishes the modern reader not only by his penetrating criticism of the prevailing philosophy of his time but by flashes of deep historical insight. He is clearly enough the forerunner of the "Romantic" tendency that culminated in Hegel's celebrated "Philosophy of History" in which the successive migrations and national incarnations of the *Weltgeist* are traced to its final and highest medium of expression, the German people.

These genial speculations of the philosophers of history rested usually upon no very careful study of historical sources and their conclusions seem to us now very hazardous, even if we grant the correctness of the data upon which they relied. It was inevitable that the historical students who, about the middle of the nineteenth century, commenced to feel the influence of the general scientific spirit of the period, should begin to look very sourly upon the earlier attempts to bring order and beauty out of a mass of historic assertions which were so commonly either erroneous or unproved, and to establish laws for events which one could not be sure had ever happened. The reaction against the dreams of the philosophers of history was, and is still, very clear. What may be called, for convenience, the "scientific" modern school of historians believe that history,

---

[4] Opening sections of Book XV.

like all other forms of scientific research, should be pursued first and foremost for its own sake. The facts must be verified and classified by the expert, without regard to any possible bearing which his discoveries may have upon our attitude toward life and the proper way of conducting it. Attempts to draw lessons from the past have, it is plausibly maintained, produced so reckless a disregard of scientific accuracy and criticism, that the prudent historian will confine himself to determining "how it really was"—an absorbing and delicate task which will tax his best powers.

Along with more exacting criticism and the repudiation of supernatural considerations and explanations came a revulsion against the older epic or dramatic interest in the past. The essential interest and importance of the normal and homely elements in human life became apparent. The scientific historian no longer dwells by preference on the heroic, spectacular, and romantic episodes, but strives to reconstruct past *conditions*. This last point is of such importance that we must stop over it a moment. History is not infrequently still defined as a record of past *events* and the public still expect from the historian a *story* of the past. But the conscientious historian has come to realize that he cannot aspire to be a good story teller for the simple reason that if he tells no more than he has good reasons for believing to be true his story is usually very fragmentary and uncertain. Fiction and drama are perfectly free to conceive and adjust detail so as to meet the demands of art, but the historian should always be conscious of the rigid limitations placed upon him. If he confines himself to an honest and critical statement of a series of events as described in his sources it is usually too deficient in vivid authentic detail to make a presentable story. The historian is coming to see that his task is essentially different from that of the man of letters. His place is among the scientists. He is at liberty to use only his scientific imagination, which is surely different from a literary imagination. It is his business to make those contributions to our general understanding of mankind in the past which his training in the investigation of the records of past human events especially fit him to make. He esteems the events he finds recorded not for their dramatic interest but for the light that they cast on the normal and prevalent conditions which gave rise to them. It makes no difference how dry a chronicle may be if the occurrences that it reports can be brought into some assignable relation with the more or less permanent habits and environment of a particular people or person. If it be the chief function of history to show how things come about—and something will be said of this matter later—then events become for the historian first and foremost evidence of general conditions and changes affecting considerable numbers of people. In this respect history is only following the example set by the older natural sciences—zoology dwells on general principles not on exceptional and startling creatures or on the lessons which their habits suggest for man. Mathematics no longer lingers over the mystic qualities of numbers, nor does the astronomer seek to read our personal fate in the positions of the planets. Scientific truth has shown itself able to compete with fiction, and there appears to be endless fascination for the mind in the contemplation of what former ages would have regarded as the most vulgar and tiresome commonplace.

In addition to the characteristics of modern history just enumerated two great historical discoveries of the latter half of the nineteenth century have served still further to revolutionize our attitude towards the past of mankind. Curiously enough neither of these discoveries are due to historians. I refer to the well substantiated fact that man is sprung from the lower animals, and secondly, that he has in all probability been sojourning on the globe for several hundreds of thousands of years. These discoveries have gravely influenced all speculations in regard to the earlier history of our race and have placed the so-called "historical period" in a new setting. The historian no longer believes that he knows anything about man from the very first but realizes that what is commonly called history comprises only a very recent and very brief period in man's development. All history is modern history from the standpoint of prehistoric anthropology. Lastly, a group of anthropological, psychological and social sciences have made their appearance during the past fifty years which are furnishing the historian with many new notions about man and are disabusing his mind of many old misapprehensions in regard to races, religion, social organization, and the psychology of progress. The older historians used such words as race, human nature, culture, religion, church, people, Renaissance, Reformation, Revolution, almost as if they were the names of animistic forces. These terms must be analyzed and reinterpreted in the light of the newer sciences of man.

The kind of history, accordingly, the practical value of which we shall attempt roughly to estimate, and which for convenience sake we may call the "new" history, is scientific in its methods, exacting in regard to the inferences it makes from its material; it rejects supernatural explanations and an anthropocentric conception of the universe; it studies by preference the normal and long enduring rather than the transient and exceptional; it accepts the descent of man from the lower animals, many of whose psychological traits he shares; it recognizes that man has lived on the earth for not merely five thousand but perhaps for five hundred thousand years; it avails itself, when fully abreast of the time, of all the suggestions and criticisms that are constantly being contributed by the newly developed sciences of anthropology, comparative, social and functional psychology, comparative religion, etc.[5] So much for the attitude of mind of the modern historian who realizes the changes which have overtaken his subject during the past fifty or sixty years.

But if "history" be re-defined as no longer a record of past events but the attempt to describe with all possible scientific precision what we know of the nature and conditions of human institutions, conduct and thought in the past, does not the term become hopelessly vague—as vague at least as the term natural science? Does not the historian sacrifice his only obvious clue to the past when he gives up tracing a succession of conspicuous events, for only these lend themselves to an obvious and orderly selection and arrangement? Every human interest and achievement has its history, every accomplished, and every vain dream. It would seem as if every attempt to deal with the past must necessarily imply an arbitrary selection dictated by the investigator's particular humor and tastes. This situation is still disguised by the continued popularity of a *standard* variety of history, mainly political, dynastic and military, transmitted to us from the past and taught in our

---

[5] See "The Relation of History to the Newer Sciences of Man" in *The Journal for Philosophy, Psychology and Scientific Methods*, Vol. VIII., No. 6, March, 1911, where I have elaborated this point.

schools and colleges and presented to the adult public in many well known older and newer treatises.

In order to appreciate the arbitrary nature of the selection of historic facts offered in these standard text books and treatises, let us suppose that a half dozen alert and well trained minds had never happened to be biased by the study of any outline of history and had by some happy and incredible fortune never perused a "standard" historical work. Let us suppose that they had nevertheless learned a good deal about the past of mankind directly from the vast range of sources that we now possess, both literary and archæological. Lastly, let us assume that they were all called upon to prepare independently a so-called general history, suitable for use in the higher schools. They would speedily discover that there was no single obvious rule for determining what should be included in their review of the past. Having no tradition to guide them, each would select what he deemed most important for the young to know of the past. Writing in the twentieth century, they would all be deeply influenced by the interests and problems of the day. Battles and sieges and the courts of kings would scarcely appeal to them. Probably it would occur to none of them to mention the battle of Issus, the Samnite wars, the siege of Numantia by the Romans, the advent of Hadrian, the Italian enterprises of Otto I., the six wives of Henry VIII. or the invasion of Holland by Louis XIV. It is tolerably safe to assume that none of these events, which are recorded in practically all of our manuals to-day, would be considered by any one of our writers as he thought over all that man had done, and thought, and suffered, and dreamed, through thousands of years. All of them would agree that what men had known of the world in which they lived, or had thought to be their duty, or what they made with their hands, or the nature and style of their buildings, public and private, would any of them be far more valuable to rehearse than the names of their rulers and the conflicts in which they engaged. Each writer would accordingly go his own way. He would look back on the past for explanations of what he found most interesting in the present and would endeavor to place his readers in a position to participate intelligently in the life of their own time. The six manuals when completed would not only differ greatly from one another but would have little resemblance to the *fable convenue* which is currently accepted as embodying the elements of history.

History in its broadest sense, is, in short, nothing less than the experiences of our race, so far as we can determine or surmise them And what uses are we to make of the experiences of the race? The same kind of use that we make of our own individual history. We may question it as we question our memory of our personal acts, situations and past ideals. But those things that we recall from the superabundant fund of our own experiences vary continually with our moods and preoccupations. We instinctively adjust our recollections to our immediate needs and aspirations and ask from the past light on the particular problems that face us. Just as our individual history is thus not immutable but owes its value to its adaptability, so with the history of mankind. As Maeterlinck has beautifully said, with increased insight, "historic facts which seem to be graven forever on the stone and bronze of the past will assume an entirely different aspect, will return to life and leap into movement, bringing vaster and more courageous counsels." History is then not fixed and reducible to outlines and formulas but it is ever alive and ever changing, and it will, if we will but permit it, illuminate and explain our lives as nothing else can do. For our lives, are made up almost altogether of the past and each age should be free to select from the annals of the past those matters which have a bearing on the matters it has specially at heart.

If we test our personal knowledge of history by its usefulness to us, in giving us a better grasp on the present and a clearer notion of our place in the development of mankind, we shall perceive forthwith that a great part of what we have learned from historical works has entirely escaped our memory, for the simple reason that we have never had the least excuse for recollecting it. The career of Ethelred the Unready, the battle of Poitiers, and the negotiations leading up to the treaty of Nimwegen are for most of us forgotten formulæ, no more helpful, except in a remote contingency, than the logarithm of the number 57. The ideal history for each of us would be those facts of past human experience to which we should have recourse oftenest to our endeavors to understand ourselves and our fellows. No one account would meet the needs of all, but all would agree that much of what now passes for the elements of history meet the needs of none.

It would take too long to attempt an analysis of the value of a genetic treatment of the elements in our social life. It is perhaps the greatest single discovery of modern times that we understand a situation best through its history, and this discovery has revolutionized every branch of organic and social science. Indeed we ordinarily first get a fairly comprehensive notion of a given phenomenon by tracing its origin and development, whether it be the human backbone, the order of St. Benedict, the stock exchange, the Wagnerian opera, or the doctrine of *stare decisis.* In many cases the knowledge of the history of an institution not uncommonly gravely affects our attitude toward it. The United States Senate looks different to one familiar with the history of the bicameral system and to one who is not. The Puritan sabbath could never have sustained a critical historical examination. One's views of democracy, or of the present laws of property, or of the prevailing economic organization, can readily be deeply affected by a study of the earlier conditions which lie back of present conditions. History has a disintegrating effect on current prejudices which is as yet scarcely appreciated. It makes both for understanding and for intellectual emancipation as nothing else can.

Obviously history must be rewritten, or rather, innumerable current issues must be given their neglected historic background. Our present so-called histories do not ordinarily answer the questions we would naturally and insistently put to them. When we contemplate the strong demand that women are making for the right to vote, we ask ourselves how did the men win the vote? The historians we consult have scarcely asked themselves that question and so do not answer it. We ask how did our courts come to control legislation in the exceptional and extraordinary manner they do? We look in vain in most histories for a reply. No one questions the inalienable right of the historian to interest himself in any phase of the past that he chooses. It is only to be wished that a greater number of historians had greater skill in hitting upon those phases of the past which serve us best in understanding the most vital problems of the present.

Columbia University.

THE ATOMIC WEIGHT OF VANADIUM DETERMINED FROM THE LABORATORY WORK OF EIGHTY YEARS.

By DR. GUSTAVUS D. HINRICHS.

(*Read April 21, 1911.*)

Vanadium can no longer be considered a rare element. Ferrovanadium is produced on a large scale for the manufacture of special vanadium steels. Strangely enough, it was in a kind of natural vanadium iron that Sefström detected this element eighty years ago.

In 1830, while technical director of the famous iron works at Taberg in Smaland, Sweden, Sefström thought it might be interesting to submit his high quality malleable iron to the Rieman Test for cold-short iron, notwithstanding the apparent absurdity of such an undertaking. Accordingly he took one of his bars. On a part of its bright metallic surface he drew the little circular ridge of tallow and poured dilute sulphuric acid into the shallow dish thus formed, expecting, of course, to see no change whatever of the bright metallic bottom of this improvised dish. But he was amazed to see that bright bottom instantly turn black while the shallow dish rapidly filled up with a black powder, exactly as it does when the iron tested is badly cold-short.

The distinguished disciple of the great Berzelius instantly realized that this striking contradiction between test and fact was a positive indication of the presence of a hitherto unknown chemical element. Accordingly he set about isolating this new element. Working up quite a number of pounds of his iron, Sefström obtained less than a decigramme of the substance from which the new element was to be separated. Hence he turned hopefully from the iron to its fresh slag and found it to yield a much larger per cent. of the black powder. He now soon succeeded in isolating the new element which, as a good Scandinavian, he named vanadin after Vanadiis, a designation of Freya, the greatest Goddess in Valhalla.

Sefström had promptly informed his teacher of the discovery and soon after brought his entire stock of the new element to Berzelius, requesting him to continue the research for which his own industrial work and the professorial duties at the Fahlun Montan-School left him neither the leisure nor the facilities. For a short time Sefström worked with Berzelius on the new element in that famous "Kitchen Laboratory" where Berzelius alone completed the splendid work of which he published a summary on pp. 99–110 of the "Annual Report" which he presented to the Swedish Academy of Sciences on March 31, 1831—exactly eighty years ago.

For almost forty years the element vanadin of Sefström and Berzelius remained undecomposed, but the striking isomorphism of the mineral vanadinite with the remarkable isomorphic group of apatite and pyromorphite presented the anomalous condition of the isomorphism of the element vanadin of Berzelius with the group PO of apatite and pyromorphite. This anomaly invited further attempts of the reduction of vanadin in which Roscoe was successful, 1867, proving vanadin to be really the oxide VaO, in which Va is the symbol of the present element vanadium of the atomic weight 51. This fully explains the isomorphism of vanadinite containing the oxide VaO, with pyromorphite, containing the corresponding oxide PO.

In this first research of Berzelius on vanadium, the old master already determined the atomic weight of the new element; for his value 67 for what we now know to have been VaO gives Va 51. He devised and used five distinct chemical methods for this atomic weight determination to which not one new method has been added in the eighty years elapsed since that work was done by the great chemist in his kitchen laboratory. It is a well-authenticated historic fact, Berzelius not only made atomic weight determinations for vanadium, but they were as accurate as those made forty years later by Roscoe, while some were as precise as corresponding determinations made eighty years later by Prandtl; besides, not only Roscoe and Prandtl, but all chemists have done this work by means of the methods devised by Berzelius which he practiced in his laboratory in 1831.

It is therefore with great astonishment that I read in the first edition of the "Recalculation" of F. W. Clarke: "Roscoe's determination of the atomic weight of vanadium was the first to have any scientific value. The results obtained by Berzelius . . . were unquestionably too high, the error being probably due to the presence of phosphoric acid in the vanadic acid employed."

The same erroneous statement is repeated identically at the opening of the chapter on vanadium in the succeeding two editions of the work as may be seen by comparing: p. 183, edition 1882; p. 211, edition 1897, and p. 305, edition 1910.

The only new method, quite recently applied to the determination of the atomic weight of vanadium, is that of Edgar F. Smith.[1] This admirable method strictly conforms to the Berzelian advice "to chose such chemical methods for atomic weight determinations that the final result shall depend as little as possible on the operator's skill in manipulation." In my summary of the work of one hundred years on the determination of the atomic weight of hydrogen[2] I have given this great rule of Berzelius, in his own handwriting, from his "Sjelfbiografiska Anteckningar," published by the Kgl. Svenska Vetenskapsakademien, 1901, p. 41.

This rule requires to select such chemical reactions in which the physical and chemical characters of the substances weighed are so definitely fixed that the unavoidable errors of man and his instruments become negligible quantities. Such is the reaction no. 311 above referred to. Hence the work done by McAdam in the laboratory and under the direction of Edgar F. Smith has furnished the highest direct chemical approximation obtainable to the absolute scientific truth that Va is 51 exactly. This will appear, we think, from a careful examination of all the results actually obtained during the eighty years from 1831 to 1911 as plotted in our two diagrams no. 730 and no. 731 published with this paper.

The above reference to the presence of phosphoric acid in the

---

[1] See *Journal Amer. Chem. Society,* 1910. p. 1603. in the December number.

[2] In the *Révue Generale de Chimie,* 1910, Nos. 22 and 24.

vanadic acid used by Berzelius reminds us of the homely but sound scriptural advice habitually given by Berzelius to his disciples: "do not strain at a gnat while swallowing camels." The phosphoric acid in the vanadic acid used by Berzelius was detected by Roscoe in the sample which Berzelius had presented to Faraday; but the molybdic reagent necessary for the detection was not known to chemistry in the year 1831 when Berzelius did his work on vanadium.

As a matter of fact, Berzelius did not see this gnat; but his work shows that he did avoid some of the camels that stalk about the laboratories and which were deglutinated unconsciously forty and eighty years after Berzelius failed to strain that gnat. The error-shares due to the oxygen are the fattest and most numerous of these camels, up to the present day.

OUR METHOD OF REDUCTION.

In order to solve the riddle of the conflicting experimental data obtained in the chemical laboratories of the world during an entire century of painstaking work, we have, especially in the last quarter century, carried on special researches on the proper mathematical reduction of this kind of laboratory work.

The final results of this extended research are briefly summarized in five tables of which two only have thus far been published. Our work itself has been published in the following books and special papers:

"The True Atomic Weights," St. Louis, 1894, xvi + 256 pp., 8vo, with 7 plates and many illustrations. Dedicated to Berthelot.

"The Absolute Atomic Weights," St. Louis, 1901, xvi + 304 pp., 8vo, with portrait of Berzelius and three plates.

"The Proximate Constituents of the Chemical Elements," St. Louis, 1904, with 7 portraits, many plates, 112 pp. text, 8vo. This is an inductive treatise of the subject.

The "Cinquantenaire," 1910, gives some historical data, copies of older papers, letters in fac-simile and "Fragments inédits" with fine diagrams; 66 pp., 4to, with plates and portraits.

"Notes" published in the *Comptes Rendus* of the Academy of Sciences of Paris from 1873 to the present, almost sixty in number, forming a volume of over 200 pp. 4to. The first, and in fact the greater number of the "Notes," were presented by Berthelot; others were presented by Messrs. Gautier, Lemoine, Haller, Gernez, and other academicians.

In the *Moniteur Scientifique,* from 1906 to 1909 more than a dozen longer articles have appeared with many diagrams. The first two tables above referred to are found in the November number for 1901, with discussions, pp. 731–744.

The papers were originally written in four languages: Danish, German, English and French. To these papers the reader may be referred by the Cinquantenaire and the list in the Prox. Constit. The results obtained, being in conflict with the dominant chemical school, have not been widely circulated except as adopted children.

For these reasons it is necessary here to give enough of the details of the finally worked out practical method of reduction to enable the reader to repeat all the calculations required, so that he can verify the results given.

It will then be seen that the final method is quite simple; the difficulty was to get this method.

Let α represent *the absolute atomic weight* of any chemical element, that is the whole or round number ($\frac{1}{2}$, or even $\frac{1}{4}$) which the experiments indicate to be near the *true atomic weight A,* which exactly to determine is the object of the reduction. The *unit* adopted is exactly $\frac{1}{12}$ of carbon-diamond which is practically identical with $\frac{1}{16}$ of that of oxygen.[3]

The *departure* of the true atomic weight from the absolute atomic weight we designate by the Greek letter epsilon (ϵ); that is: $A = \alpha + \epsilon$. This departure, as a matter of fact, is found to be a small fraction of the unit; we invariably express it in thousandths of that unit.

This departure—in units of the third decimal—is really our new variable, the quantity to be determined. This apparently insignificant matter of form is really of the greatest importance. For this new variable all products and powers become negligible quantities

[3] *Comptes Rendus,* 117, p. 1075, 1893.

in our necessary calculations, because the departures are small quantities; hence, *all calculations,* even involving the most complex mathematical functions, are reduced to the simple rule of three and *carried out by proportional parts.* The importance will soon be recognized by the practice of the method.

The actual *laboratory work* consists essentially in the determination of *two weights* which we denote by p and q and which represent chemically pure compounds of the formula P and Q respectively. The necessary condition is that the weight p has been completely changed into q according to the exact formulæ P and Q by means of a suitable *chemical reaction.* Of such reactions we have tabulated and examined over three hundred that have been actually used for atomic weight determinations. We designate each such reaction by a number for ready reference. This number is simply marking their place in our table above referred to; it is arbitrary but a practical necessity. We have already above referred to the remarkable chemical reaction, recently applied in the Harrison Laboratory of the University of Pennsylvania as reaction no. 311.

Substituting the absolute atomic weights α for the chemical symbols in the formulæ of the two compounds P and Q, we can readily calculate the value of the quotient P/Q which we call the *atomic ratio* R and calculate the same to five decimals, the limit of precision today. On the following pages, giving the data for the chemical reactions that have been used for the determination of the atomic weight of vanadium there will be found examples of these and of all other processes, to which we request the reader to turn as new operations are defined.

On the other hand, the weights actually taken in the laboratory and designated by the letters p and q will give the *analytical ratio* r which we calculate also to five decimal places. The analytical ratios determined by the different experiments with the same two compounds P and Q will give hardly any identical values of r; we notice their *extreme values,* that is the maximum and the minimum in any given series of determinations made in the same manner with the identical material. The differance between the greatest and the least value of the analytical ratios of a series is the range of that series. This characterizes the *concordance* of the different determinations of any series without introducing any false theoretical notion, as is done by the calculation of the so-called probable error of the mean. The actual *mean value* we do calculate and use.

While the individual analytical ratios vary for the different individual determinations in a series and even the means for the different series, it is found, as a matter of fact, that they bear a close relation to the atomic ratio. We call the excess of the analytical ratio over the atomic ratio, the *analytical excess* and designate it by the symbol e. That is: $r = R + e$. The value of e is also expressed in units of the fifth decimal.

THE EQUATION OF CONDITION AND THE SOLUTION EX-ÆQUO.

In the true atomic weights of 1894 (p. 139 to p. 169, esp. p. 158) the solution of the great problem is already shown to require an application of the method of the variation of constants.

In the absolute atomic weights of 1901, the change or variation Δ of the atomic ratio for an increase of 0.1 in the atomic weight is determined for each reaction and applied for several important objects throughout the entire work. On pages 144–147 of that work the final solution is really given but implicit only, and lacking the equal distribution of the analytical excess among the elements present in the reaction.

The actual equation of condition was established in 1907 through long and difficult work, both analytical and geometrical. The general analytical deduction by means of Taylor's formula was in the hands of eminent men abroad in the form shown in fac-simile (reduced to ⅓) as printed p. 61 of my "Cinquantenaire," 1910. The most general construction, which permits the establishment of a criterion for the absolute atomic weight, is printed on p. 60 of the same "Cinquantenaire."

Here we will present the final practical solution of the resulting "insoluble" indeterminate or diophantic equation in the simplest and most direct manner, suitable for common, current, practical application.

The *true atomic weight, A,* is the quantity sought, in the unit for which carbon-diamond is 12 exactly.

The *absolute atomic weight* α is indicated by the laboratory work; in case of doubt, the criterion just referred to has to be made use of.

The *departure* ϵ is expressed in units of the third decimal (thousandths) of the unit of atomic weights. Its exact determination is the main object of this paper.

The *atomic ratio R* is a function of the absolute atomic weights, expressed by the quotient P/Q above given.

If now the absolute atomic weight for any one given element in this ratio be increased by 0.1, that ratio will change or vary by an amount readily calculated from the formula of R as given; we use throughout seven place logarithms which give the precise value sought with the least trouble. This change or *variation* we denote by the Greek *capital delta* Δ for the particular element of which the atomic weight was increased by 0.1 in the atomic ratio. In 1901 we made this calculation only for one element in the ratio; now it has to be made for every element in the ratio.

In the tables here following this matter will become quite readily understood by simply repeating some of the calculations thus indicated. For the reaction no. 98 this work is quite simple, for only two elements are present, namely Va and O. In reaction 270, the work required is about double in amount, because four elements are in reaction, namely: Va, O, Cl and Ag.

The *analytical ratio r* has to be calculated for each single determination made; it is considerably simplified if the weighings are given by the chemist to the hundredth of the milligram, are rounded off to the tenth of the milligram, which is as far as the weighings can be trusted; see, for example, my demonstration of this fact for the weighings of Richards made at Harvard-Berlin.[4]

The *analytical excess e* is now obtained as it is $r-R$; it is also expressed in units of the fifth place.

Now we have in hand all the quantities required for obtaining *the departure* ϵ sought, by solving the equation of condition. While this indeterminate or diophantic equation is, of course, insoluble in general, we have nevertheless obtained two practical solutions of the same[5] of which the one properly named *ex-æquo* is the most

---

[4] *Moniteur Scientifique,* Juin, 1909, especially pp. 384–385.

[5] *Comptes Rendus,* T. 149, p. 1074, 1909, with a most instructive figure.

serviceable and by far the most readily understood and easiest applied.

Our general deduction (really as indicated 1894 already: a method of the variation of the constants) leads to the simple form of the *equation of condition*

$$100\ e = \Sigma\Delta\epsilon,$$

where the constant 100 presupposes that the analytical excess e and the variation Δ are expressed in units of the fifth place while the departure ϵ is expressed in units of the third place or thousandths of the unit of atomic weights.

It may not be amiss here to insist on the fact that since in every chemical reaction there are at least two elements present, the above equation contains at least two unknown departures ϵ and is therefore really an indeterminate or a diophantic equation.

Our practical solution ex æquo of this equation is as follows: Let m be the number of elements involved in the chemical reaction used, then the number of terms $\Delta\epsilon$ in the above sum Σ is m.

Ascribing to all elements an equal influence on the error or excess e, the part thereof due to each element will be $e' = e/m$.

Hence the actual departure ϵ for each element in the reaction will be determined by the simple relation

$$\epsilon = \frac{100\ e'}{\Delta}.$$

If the value of Δ be above a certain limit, this determination will be sharp; the corresponding reaction therefore may also be called ***sharp***.

But if the value of the variation Δ for any element is small, the *reaction* for that element *will be dull* and the determination of the atomic weight will be impossible with any high degree of precision, as we have shown in *Comptes Rendus*, T. 148, p. 484, 1909, in the attempted determination of the atomic weight of Tellurium by a reaction quite dull for that element.

This one attempt strikingly shows the real condition of the work of the dominant school to be irrational.

After having briefly explained the manner in which we have tried to solve the great problem of the deduction of the true atomic weights from the experimental work done in the laboratories, we may proceed to the full statement of the facts obtained for the element vanadium during the past eighty years and the final results of our discussion of the same.

We shall present the facts in the most compact form of tables and finally exhibit them to the eye in the form of accurately drawn graphics, from which we shall be able to read the final result the most readily and clearly.

THE ACTUAL DETERMINATION OF THE TRUE ATOMIC WEIGHT OF VANADIUM.

I.—Absolute Atomic Data.

Fundamental Constants, Calculated from the Absolute Atomic Weights.

Only seven[5a] chemical reactions have been used for the determination of the atomic weight of vanadium, thus far; they are the following:

No. 98: Pentoxide reduced by hydrogen.
No. 269: Oxychloride to silver.
No. 270: Oxychloride to silver chloride.
No. 311: Vanadate to chloride.
(*a*)—Oxychloride to pentoxide.
(*b*)—Sulphate to barium sulphate.
(*c*)—Sulphate to pentoxide.

The last three preliminary methods of Berzelius have been used by him, each once only, and by no other chemist, except that Roscoe made four determinations according to method (*a*). No. 311 has but just been introduced by Edgar F. Smith, December, 1910. All the chemical reactions used for the determination of the atomic weight of vanadium, up to that date, were devised and first used by Berzelius in 1831, eighty years ago. It seems that his work has some scientific value, after all.

In the following Table I. we have given the most important fundamental constants required by our method of reduction. They have all been calculated from the well-known absolute atomic weights: Va, 51; T, 16; Cl, 35½; Ag, 108; Na, 23; S, 32; Ba,

---

[5a] If we count 269 and 270 as distinct reactions.

137½; H, 1.008 instead of the exact value 1.00781 determined atomechanically by us (*Rèvue gén. de Chimie,* 1910, p. 386).

TABLE I.

Fundamental Constants for Vanadium.

No.	Formula.	Atomic Ratio, R.		Variation Δ for			
		Fraction.	Decimal.[6]	Va.	O.	Cl.	Metal.
98	$\frac{O_2}{Va_2O_5}$	$\frac{32}{182}$	0.17 582	—19	62	—	—
269	$\frac{VaOCl_3}{3Ag}$	$\frac{173.5}{324.0}$	0.53 549	31	31	93	—49(Ag)
270	$\frac{VaOCl_3}{3AgCl}$	$\frac{173.5}{430.5}$	0.40 302	23	23	42	—28(Ag)
311	$\frac{NaCl}{NaVaO_3}$	$\frac{58.5}{122.0}$	0.47 951	—39	—118	304	43(Na)
a	$\frac{Va_2O_5}{2VaOCl_3}$	$\frac{182}{347}$	0.52 450	27	113	— 91	—
b	$\frac{Va_2O_5}{2BaSO_4}$	$\frac{182}{467}$	0.38 972	43	40	— 17(S)	—17 (Ba)
c	$\frac{Va_2O_5}{\text{Va sulphate}^7}$	$\frac{182.00}{398.06}$	0.45 722	27	—35	— 23(S)	—140(H)

II.—General Summary of the Experimental Work Done.

In the common reviews of the experimental work done for atomic weight determinations, the amount of substance taken in each experiment is not made the subject of special consideration. This neglect is due to the erroneous estimation in which the so-called "*probable error*" of the mean is held.

This probable error has caused the most serious errors in all branches of physical science where it has been applied—in the unfortunately common way, without proper understanding. We have treated of this repeatedly, especially in our "absolute atomic weights, 1901, on the first hundred pages, to which we must refer.

In the language of Berzelius already quoted we might say the above probable error is the gnat strained at which hides from sight the camel-like systematic and constant errors which are swallowed. We have, at last, seen one admission of the fact we have always

---

[6] Between the second and third decimal of the five, we always leave a space to make the constancy of the first two conspicuous.

[7] The crystallized sulphate is $[VaO]_2S_2O_8 + 4H_2O$.

accentuated, that large constant and systematic errors may exist though the value found for the probable error of the mean is insignificant. In Clarke's third edition (1910, pp. 93–98) the probable error of the mean amounts to only one unit in the fifth decimal of the analytical ratio while the constant error of that ratio amounts to 120 such units, according to the famous analyses of Stas and Baxter.

To detect the constant and systematic errors we have always plotted the results of the individual experimental determinations as ordinates to the weight taken as abscissæ. In these diagrams the scale selected for the atomic weights or the ratios must be very great while that for the weight taken has to be small. In my diagram representing in this manner all the atomic weight determinations of hydrogen made in a century (*Rèvue gén. de Chimie,* 1910, p. 380) the unit of atomic weights is 30 meters (about 100 feet) while a decagram of water produced is represented by three centimeters (or a little over one inch).

To permit this *search for the really important constant and systematic errors,* we give the weight taken (to the decigram) in all our tables. For a series of determinations, we give the total weight taken for all the determinations of the series, and the mean weight taken for each determination—which is obtained from the total by dividing this latter by the number of determinations made.

Table II. thus shows that 50 determinations have actually been made for the determination of the atomic weight of vanadium on 4 grams each of the substance taken, not counting the seven preliminary determinations on 1 gram of matter each.

It is also seen at a glance that by reaction 98 the work of Roscoe ought to be the most reliable, while for 270 the work of Prandtl should be the best and that the work done by one chemist for 311 has been carried out under equally as favorable condition in regard to the weight operated upon.

By means of the reference letter specified in the last column the corresponding line on the diagrams can be instantly identified. We may here already remark, that the length of this line, extending to the right or to the left from the vertical in the middle, marks the magnitude of the departures for the elements as indicated by the chemical symbol added.

Thus the least deviation or departure has resulted from the use of the Method 311 recently introduced by Edgar F. Smith. The preliminary work of Berzelius, done eighty years ago, according to methods *a* and *b* as represented by lines *D* and *T* on the diagram, showed departures for sulphur and barium extending beyond the limit of our diagram: 470 to the left (negative) in line D and 776 to the right (positive) in line *T*; the former is almost half a unit, the latter three quarters of a unit of atomic weight.

TABLE II.

Summary of the Experimental Determination.

Reaction.	Number of Determ.	Weight Taken, Grammes.		Chemist.	Letter on Diagram.
		Mean.	Total.		
98	3	1.6	4.7	Berzelius	B
	1	0.6	0.6	Berzelius	B*
	5	6.0	30.0	Roscoe	F
	4	2.5	10.0	Prandtl	C
	13	3.4	45.3		
269	9	2.7	24.3	Roscoe	N(M, R)
270	1	1.6	1.6	Berzelius	G
	6	1.2	7.4	Roscoe (A)	H } I.
	2	2.4	4.7	Roscoe (B)	K
	5	4.7	23.5	Prandtl, I.	L
	6	4.8	28.8	" II.	P
	4	8.1	32.4	" III.	O
	24	4.1	98.4		
311	5	6.0	30.2	Smith-McAdam	Q
Total or say:	51 50	3.9 4	198.2 200		

Preliminary Reactions:

(*a*) Oxychloride to Pentoxide	1	1.6	1.6	Berzelius, 1831	A
	4	1.0	4.0	Roscoe, 1868	E
(*b*) Va Sulphate to Ba Sulphate	1	0.8	0.8	Berzelius, 1831	D
(*c*) Va Sulphate to Pentoxide	1	0.8	0.8	Berzelius, 1831	T
Mean	7	1.0	7.2		

III.—THE ANALYTICAL RESULTS.

The chemical work, beginning with the determination of the weight *p* and ending with the determination of the weight *q* (or the inverse) gives directly the atomic ratio *r*, by a simple division carried to five decimal places. A simple substraction now will give the analytical excess *e* by using the atomic ratio calculated once for all for the reaction. The results obtained in this way are given in Table III.

We will here only call attention to the following peculiarly interesting circumstances:

"Analyst B" working under Roscoe makes three determinations under reaction 269, and takes almost the same weight of the oxychloride for each one of these determinations; notwithstanding the fact that he really only repeats one and the same determination three times, his results range over 501 units in the fifth place—an enormous range under so favorable conditions.

In the language of Berzelius, this enormous range is quite a big camel which was swallowed without an effort in the laboratory of Roscoe, who strained laboriously at the tiny gnat of phosphoric acid which a test of high delicacy, that was not yet known in the days when Berzelius did his splendid pioneer work on vanadium and courteously presented to Faraday a sample of the vanadic acid he had received from his disciple who discovered the element vanadium and which acid Berzelius had purified himself as far as the science of his time permitted. These facts I gather from Becker, Smithson. Misc. Collections, 358, Washington, 1880, p. 132, quoting from *Liebig's Annalen*, 93, p. 6, 1868.

TABLE III.

THE ANALYTICAL RATIOS DETERMINED.

REACTION 98.—Atomic Ratio, $R = 0.17582$.

Berzelius, 1831.—Meyer-Seubert, "Atomgew.," 1883, p. 28.

	Sums of Weights.		*r.*	*e.*
Determ.	Pentoxide.	Oxygen.		
3	4.6995	0.8120	0.17 278	—304
1	0.6499	0.1124	294	—288

Diagram. Lines B and B^x.

Roscoe, 1868.—Jour. Chem. Soc., 6, p. 330, 1868.

No.	1.	2.	3.	4	5.	Mean
Weight Oxide	7.7	6.6	5.2	5.1	5.4	6.0
$r=0.17$	533	507	489	515	501	509
$e=$	— 49	— 75	— 93	— 67	— 81	— 73

Range 44.—Diagram, Line F.

Prandtl, 1910.—Jour. Am. Chem. Soc., 1911, pp. 266–7, from *Ztsch. anorg. Chem.*, 67, 257.

No.	1.	2.	3.	4.	Mean.
Weight Oxide	9.1	9.9	8.7	12.3	10.0
$r=0.17$	261	376	395	394	356
$e=$	—321	—206	—187	—188	—225

Range 133.—Diagram, Line C.

REACTION 269.—Atomic Ratio, $R=0.53549$.

Roscoe, 1868; Analyst A.—*Jour. Chem. Soc.*, Vol. 6.

No.	1.	2.	3.	4.	5.	6.	Mean.
Oxychlor.	2.4	4.7	4.2	4.0	0.9	1.4	2.9
$r=0.53$	425	528	533	510	530	532	510
$e=$	—124	— 21	—16	— 39	— 19	— 17	— 39

Range: 108.—Diagram: Line M.

Roscoe, 1868; Analyst B.

No.	7.	8.	9.	Mean.	Mean of All 9.
Oxychlor.	2.9	2.1	1.4	2.1	2.7
$r=0.53$	980	755	479	738	586
$e=$	431	206	— 70	189	37

Range: 501.—Diagram: Line R. Range: 555.

REACTION 270.—Atomic Ratio, $R=0.40302$.

Berzelius, 1831.—1 determ.: 1.6385 oxychlor. gave 4.0515 Ag, hence $r=0.40442$ and e 140. Meyer-Seubert, "Atomgew.," 1882, pp. 90–91.

Diagram: Line G.

Roscoe, 1868; Analyst A:

No.	1.	2.	3.	4.	5.	6.	Mean.
Oxychlor.	1.9	0.7	0.8	1.4	1.0	1.6	1.2
$r=0.40$	323	531	537	337	399	174	383
$e=$	21	229	235	35	97	— 128	81

Range: 363.—Diagram: Line H.

ANALYST B:

No.	7.	8.	Mean.	Mean of A and B.
Oxychlor.	2.2	2.5	2.4	1.5
$r=0.40$	391	333	362	378
$e=$	89	31	60	76

Range: 58.—Diagram Line K. Diagram: I.

Prandtl and Bleyer.[8] Series I., 1909.

No.	1.	2.	3.	4	5.	Mean.
Oxychlor.	5.5	5.9	3.2	5.3	3.6	4.7
$r=0.40$	393	346	365	322	367	359
$e=$	91	44	63	20	65	57

Range: 71.—Diagram: Line L.

SERIES II., 1909.

No.	1.	2.	3.	4.	5.	6.	Mean.
Oxychlor.	4.9	3.7	5.0	6.5	4.3	4.1	4.8
$r=0.40$	331	286	318	315	308	325	314
$e=$	29	— 16	16	13	6	23	12

Range: 45.—Diagram: Line P.

SERIES III., 1910.

No.	1.	2.	3.	4.	Mean.
Oxychlor.	7.8	8.4	10.7	5.5	8.1
$r=0.40$	301	311	321	333	317
$e=$	— 1	9	19	31	14

Range: 32.—Diagram: Line O.

REACTION No. 311.—Atomic Ratio, $R=0.47951$.

Edgar F. Smith and *McAdam, Jour. Am. Chem. Soc.,* 1910, p. 1614.

No.	1.	2.	3.	4.	5.	Mean.
Vanadate	4.9	5.6	4.4	5.8	9.5	6.04
$r=0.47$	931	927	941	937	921	931
$e=$	— 20	— 24	— 10	— 14	— 30	— 20

Range: 20.—Diagram: Line Q.

Strictly this series consists of 3 determinations only, two of which have been made twice, as follows:

No.	1.3.	2.4.	5.	Mean.
Vanadate	4.6	5.7	9.5	6.0
$r=0.47$	936	932	921	931
$e=$	— 15	— 19	— 30	— 20

Range: 15.

This shows how even within narrow limits of weights taken (here from 4½ to 9½ grammes) *the systematic error* becomes evident as a function of the weight taken. Within the actual range, the analytical excess approaches zero with diminishing amount operated upon.

PRELIMINARY WORK.

Line.	Reaction.			Analytical Ratio. r.	Analytical Excess. e.	
A.	a	1 det. 1.6385 oxychl. gave	0.874 oxide	0.53342	892	Berzelius.
E.		4 det. 4.0418	2.1258	0.52608	158	Roscoe.
D.	b	1 det. 0.351 pentoxide	0.913 Ba sulphate	0.38445	— 527	Berzelius.
T.	c	1 det. 0.351 pentoxide from	0.775 Va sulphate	0.45290	+ 432	Berzelius.

---

[8] Clarke, "Recalc.," 1910, p. 307 for I. and II.; *Journ. Am. Chem. Soc.,* 1911, p. 266, for III.

IV. The Analytical Excess.

The analytical excess e is only comparable in work carried out according to the same chemical reaction by different chemists. This condition has determined the form of Table IV., in which the capital letter marks the line on our final diagram representing the work, while the numbers below the letter represent: the first, the number of determinations made, the second giving the analytical excess obtained. This excess will naturally be found the greatest for all preliminary (or pioneer) work such as that done by Berzelius in his single trials of reactions (*a*), (*b*), (*c*).

This table makes it very apparent that each succeeding chemist benefited by the work and experience of his predecessor. This shows best under reaction 270 where Berzelius (1 determination) gives the excess 140, Roscoe (8 determinations) only 76 and Prandtl (15 determinations) brings it down to an average of 28 only.

For Reaction 98 this relation holds good for the work of Berzelius and Roscoe only, while that of Prandtl, done as recently as 1909, reaches almost the excess of Berzelius single first trial of eighty years ago, although Prandtl used the mean weight of 2.5 grams while Berzelius had only half a gram for his work.

TABLE IV.

The Resulting Analytical Excess.

Reaction.	98	269	270	311	*a*	*b*	*c*
Chemist:							
Berzelius, 1831	B 3 —304		G 1 140		A 1 892	I 1 —527	D 1 432
	B′ 1 —288						
Roscoe, 1868	F 5 — 73	R 3 189	H 6 81		E 4 158		
I		N 9 37	I 8 76				
		M 1 —39	K 2 60				
Prandtl, 1909	C 4 —255		L 5 57				
			O 4 14				
			P 6 12				
Smith-McAdam, 1910	—			Q 5 —20			

V. THE FINAL DEPARTURES.

In this table (IV.) we have finally given all the departures for all the elements taking part in the different reactions used for the determination of the atomic weight of vanadium during the last eighty years—from Berzelius in Stockholm to Edgar F. Smith in Philadelphia. We have fully explained the manner of calculating these departures; every reader can verify any of these values for himself by the methods stated. Since the element most concerned is vanadium, we have arranged the record of departures in the order of the magnitude of the departures of vanadium, for which the extreme values are 1062 and minus 307, giving a total range of 1369, say one and one third units of atomic weight; that is, from Va 52.06 to 50.69.

If we omit the pioneer and preliminary work done by Berzelius in trying reactions (*a*) and (*b*), the extreme departures will be 800 and — 31, a total range of 831 only. The atomic weights will run from 51.80 to 50.69, which is a remarkably fine showing for so long a series of very difficult work on the rare element.

To realize the generally excellent work of the early days of Berzelius and of Roscoe—when the element was decidedly rare and difficult to purify—we need only compare the limits of the determinations by Prandtl of today with the range of the entire series (excluding only, as we have done already, the reactions (*a*) and (*b*)); these extremes of Prandtl are 594 with reaction 98 and 13 in Series II. with reaction 270; a total range of 581 thousandths. The corresponding atomic weights of vanadium are 51.59 and 51.01 differing 58 hundredths.

We are greatly tempted to point out a number of interesting features on this table, but fear that the paper will assume undue length and trust the reader will help himself.

We only remind the reader that the letter in the first column of this table permits the ready identification of the experimental result expressed in numbers in this table with the graphical representation on our two diagrams.

TABLE V.

The Departure. Determined from Eighty Years of Work.

Line in Diagram.	Chemist.	Reaction.	No. of Determ.	Analyt. Excess. ε.	Departure, ε, in Thousandths.				True Atomic Weight	
					Va	O	Cl	Metal.	Va.	O.
A	Berzelius	*a*	1	892	1062	263	—326		52.06	16.26
B	"	98	3	—304	800	—245			51.80	15.75
B*	"	98	1	—288	784	—241			.78	.76
C	Prandtl	98	4	—225	594	—183			.59	.82
D	Berzelius	*c*	1	432	400	—310	—470[9]	— 77[10]	.40	.69
E	Roscoe	*a*	4	158	195	47	— 58		.20	16.47
F	"	98	5	— 73	192	— 59			.19	15.41
								Ag:		
G	Berzelius	270	1	140	153	153	83	—125	.15	16.15
M	Roscoe (B)	269	3	189	150	150	50	— 95	.15	.15
H	" (A)	270	6	81	87	87	47	— 71	.09	.09
I	" (A, B)	270	8	76	83	83	45	— 68	.08	.08
K	" (B)	270	2	60	65	65	36	— 54	.07	.07
L	Prandtl, I	270	5	57	62	62	34	— 51	.06	.06
N	Roscoe (M, R)	269	9	37	30	30	10	— 19	.03	.03
O	Prandtl, III	270	4	14	15	15	7	— 12	.01	.01
P	" II	270	6	12	13	13	7	— 11	.01	.01
								Na:		
Q	Smith-McAdams	311	5	— 20	13	4	— 2	— 12	51.01	16.00
								Ag:		
R	Roscoe (A)	269	6	— 39	— 31	— 31	— 10	20	50.97	15.97
T	Berzelius	*b*	1	—527	—307	—330	776[9]	776[11]	.69	15.67

[9] S. [10] H. [11] Ba.

VI. Our Graphics.

The values of all departures given in Table V. are represented to the eye in our two graphics.

Fig. 1 gives all the larger departures and as many of the smaller ones as space would permit. The scale used is 200 thousandths of the unit of atomic weights to the inch; or, what amounts to the same, the unit of the atomic weights is represented by five inches in length.

Fig. 2 gives all the departures of the central region on a scale which is five times the one used in the construction of the first figure. Hence in Fig. 2 the unit is represented by a line of twenty-five inches; or, in other words, it shows forty thousandths to the inch.

The vertical of the ordinate represents the departures of vanadium, while the departures of the elements combined with vanadium are set off on the horizontal as abscissæ.

The results for a complete analysis of any given compound are therefore set off on the horizontal line drawn through the point on the vertical determined by the departure for vanadium.

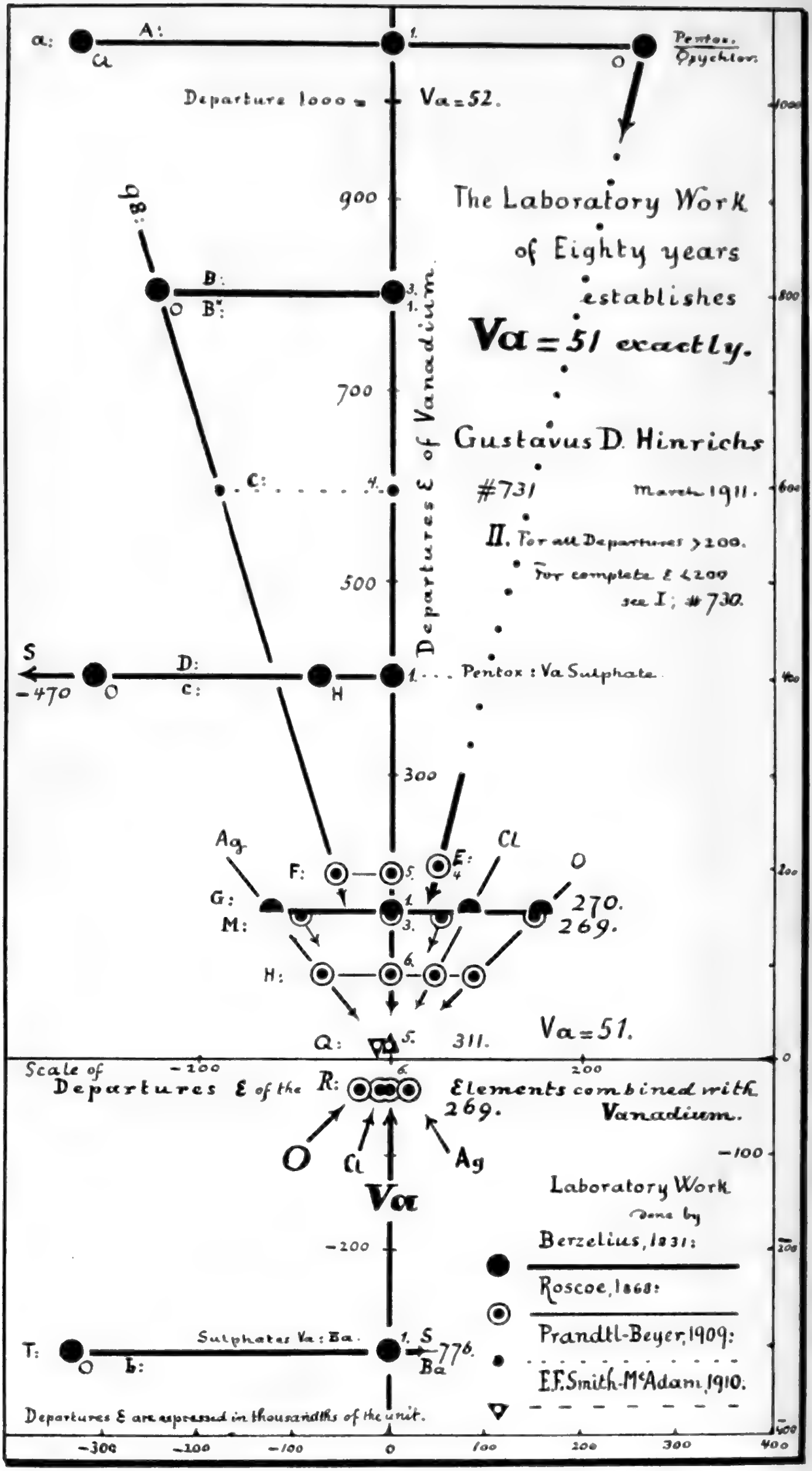


FIG. 1. Departures. Scale 200 thousandths to the inch.

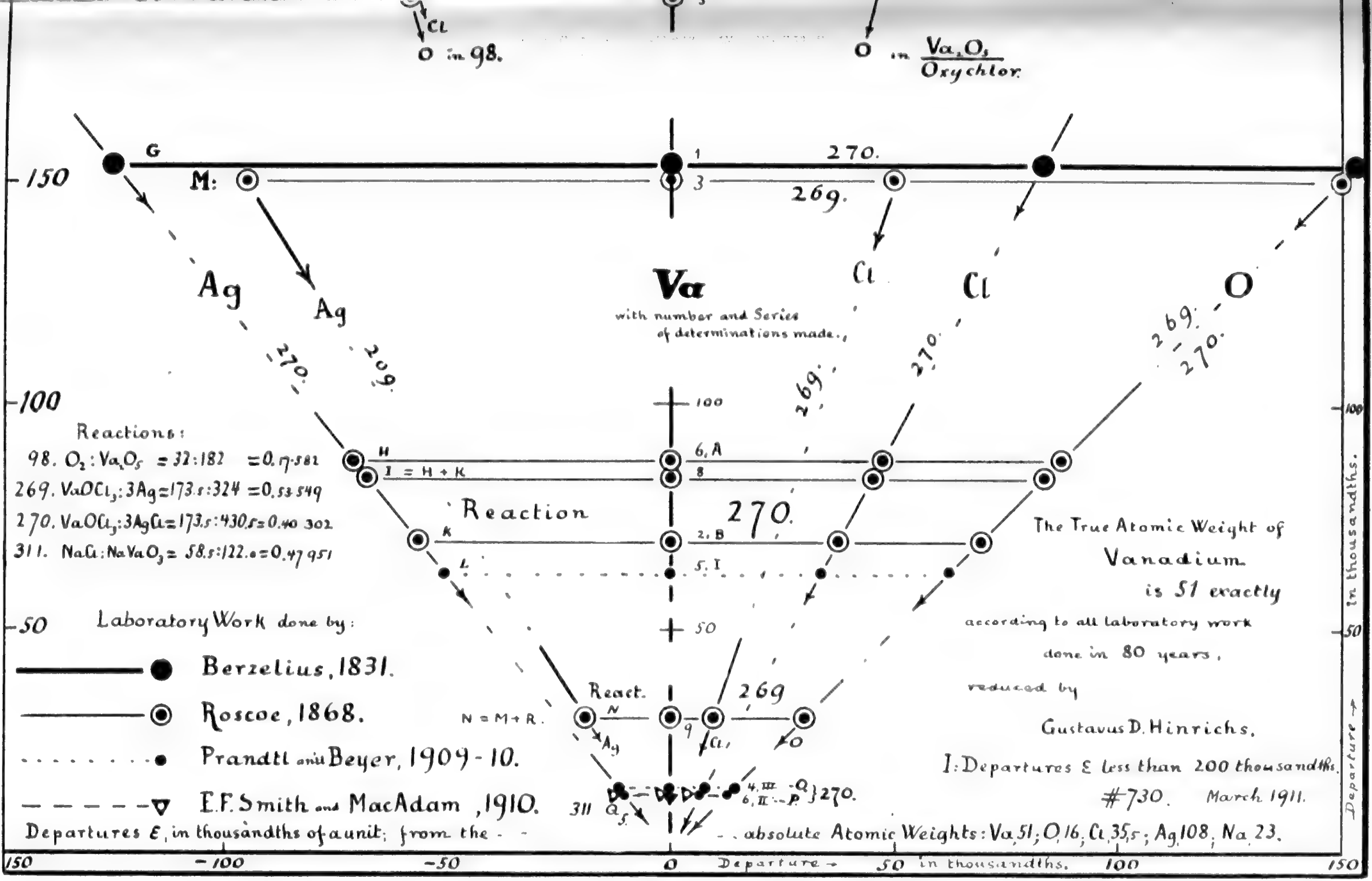


FIG. 2. Departures, E. Scale: 40-thousandths to the inch.

The chemist whose work is represented is indicated by the special mark used to designate the point, as shown in the explanation of signs on the diagram.

The small figure near the vanadium sign on the vertical indicates the number of determinations made represented in that line.

The line itself is marked by a letter, used in the tables for the purpose of ready identification.

For each reaction, the geometrical place (or locus) is a straight line passing through the center or the origin; the angle under which it cuts the axes is determined by the ratio of the variation of the element concerned and that of vanadium. These lines can therefore be drawn before any laboratory work is done, depending entirely on the chemical formulæ of the compounds taken and obtained in the reaction used.

For further particulars, some of which are very interesting as well as useful, we may refer to page 60 of our "Cinquantenaire," where also a remarkable criterion is given, permitting to detect any error in the assumed absolute atomic weight. The example there taken is copper.

Our two figures here inserted bring into clearest possible view the fundamental fact that all these departures are co-related; that the experimental error is not thrown on the vanadium for which the atomic weight is sought, but is distributed ex-æquo to all elements partaking in the reaction, as we have shown in formulæ, but which is here presented to the eye directly.

We do not recognize or find the slightest pretext for the assumption that any one element is immaculate and cannot be conceived to partake in any error of whatever cause or origin; but we have found that all elements in a chemical reaction are affected by the same cause of error according to the ties that bind them and which we have read in the chemical formula and in the mathematical relations first studied by Lagrange under the name of the Variation of arbitrary constants.[12]

We know that it is absurd to suppose that oxygen is always found to be 16, absolutely unaffected by any error, physical or chemical, in practice; that next some other atomic weight of some other element

[12] "True Atomic Weights," 1894, p. 158.

can be determined and that this value also will remain unaffected in all reactions; and so forth. That errors rapidly accumulate in such an irrational process, we have shown as far back as 1893, almost twenty years ago. That paper was presented by Berthelot to the Academy of Sciences of Paris and published in its *Comptes Rendus*.[13]

After having completed a thorough examination of all the atomic weight determinations made, we have, by a sort of crucial test, demonstrated that the present value Ag 107.88, implying a departure of 120 thousandths, is impossible; that O 16 requires Ag 108 exactly, according to all determinations made during an entire century in all the laboratories of the world.[14]

It is this same principle that is demonstrated by the diagrams here printed and this demonstration is made visible to the eye: It is not vanadium alone that causes the error affecting the laboratory work, but all elements in the reaction contribute to the error recognized in the final result of the analytical work.

Instead of the common notion that the work of the different chemists conflicts in the different values they have presented as the results of their determination of the atomic weight of vanadium our figures here inserted show to the eye that *all determinations made agree in the common result of Va 51 exactly.* While no experimental work of any kind, done by man, with instruments and by chemical reactions, all of which are but approximations to a mathematical perfection, can be expected to give perfectly exact results, we have proved that the final error cannot be ascribed to vanadium alone, as continues to be done by the dominant school, but that on the contrary, all the elements present in a reaction contribute, each one its share, to the excess or deficiency resulting. It was therefore necessary to find the laws regulating this participation of the different elements in the errors of the reactions and of the entire experimental work. Having discovered these laws, we have applied them here, to the atomic weight determinations made for vanadium and present in the two graphics (Figs. 1 and 2) the final results thus obtained.

These figures show plainly that all the departures from the abso-

---

[13] T. 116, p. 695.

[14] See paper read December 2, 1910, before the American Philosophical Society; *Proceedings*, 1910, pp. 359–363.

lute values are converging to zero along each of the lines of work pursued in the eighty years by the different chemists; there is but one insignificant exception, which we shall consider, when we take up the recent work of Prandtl.

Our Figs. 1 and 2 proclaim that the atomic weight of vanadium is exactly 51 in all these determinations, just as sure as oxygen has the atomic weight 16 exactly and silver 108 exactly, chlorine 35½ exactly, sodium 23 exactly; in fact, all the elements have as atomic weights exactly the absolute values given in our publications of the last twenty years.

Even the very first determinations made by Berzelius, with only a fraction of a gramme of material at service, and only in one single determination, by the reactions designated (*a*), (*b*) and (*c*), do confirm the value Va 51; for the deviation noted for Va affects all the other elements present as well, and therefore it would be absurd to suppose that the atomic weight of vanadium could be obtained from a reaction which fails to give an exact determination for the other elements present. Thus reaction (*c*) represented by line D in Fig. 1, gives by the single determination made by Berzelius on 8 decigrams of the rather complex hydrated vanadium sulphate, a departure of 400 thousandths from 51 for the atomic weight of vanadium; but the same determination gave the atomic weight of oxygen 310 thousandths low as marked on the figure; it also gave the atomic weight of sulphur 470 thousandths low as indicated near the edge of the diagram and by the arrowpoint: for the real circular mark falls far beyond the limit of the diagram.

Is it so hard to understand that a reaction that fails to give precise determinations for all the elements it involves cannot necessarily be expected to furnish a value of precision for vanadium? Is it not about time for each individual chemist to begin to consider these simple facts for himself, as was the practice in former days?

It would be interesting to trace the gradual approach to the center where all departures are zero, as exemplified in the actual work of the successive chemists. This will be found to hold good for all, with the single exception already mentioned. We will only point to a few special instances, expecting the reader to go over the entire ground by himself.

The preliminary analysis, represented in the line A at the top of Fig. 1, gave not only the greatest departure for Va, but also for O, in the only determination made by Berzelius. When Roscoe, forty years after, made a series of four determinations the result entered at *E* in our figure (both 1 and 2) he cut the departure from 1062 to 195 for Va and from 263 to 47 for oxygen. If this determination were repeated with the benefit of all the progress made in laboratory work, the resulting mark would undoubtedly find its place much nearer the zero departure on the line (mainly dotted) on our figure (1).

Let us also look at the results obtained by the use of reaction 270, best seen on Fig. 2, lines G, H, I, K, L, O, P. Of these lines, G is the most distant, representing the largest departures: it marks the one determination made by the old master in 1831. Then we meet, in going toward the center of perfection or zero departure, the lines H, I and K bearing the mark of Roscoe and only about half as far from the zero as the line G of 1831. The total number of determinations made by Roscoe in 1868 was 8, represented by line I; 6 of these eight were "done by Analyst A" and are represented by line H; the other two were "done by Analyst B" and are represented by line K. Finally we have three series (I., II. and III., represented by lines L, P and O, respectively) made by Prandtl quite recently; of these, the last two series come quite close to the center, the departure for Va being 14 only for the mean of the two series (see Table V.). Since on our diagram the departures for O, Cl and Ag are set off as abscissæ to that of Va taken as ordinate, *the gradual diminution of all the departures is strikingly shown in the lines for these elements converging to the point of zero departure.* At the same time we here have the positive evidence that Prandtl has produced two very concordant series (his II. and III.) with a very small departure (mean 14 for Va and O) and one series (his first, I.) represented by line L for which the departure is 62, that is more than four times as large.

Now we may consider the results obtained by the reduction test, reaction No. 98, represented on our Fig. 1 by the lines B, C and F. Here we meet that one exception before referred to; for the greatest departure (line B) of Berzelius is but slightly diminished by Prandtl's quite recent work (line C) and far surpassed by the small departures of the much older work of Roscoe (line F). It is to be hoped that Prandtl will also make one or two additional series under reaction 98, as he has done under 270; we dare say that, with due care, he may repeat the experience he has reported for reaction 270 and greatly reduce the departure, at least to that of Roscoe in 1868.

It will hardly be necessary to state that the numerical data we have quoted in the discussion of our Figs. 1 and 2 are taken from tables II. and V. especially.

CONCLUSION.

We think that the reader will have no trouble now in completing his study of the facts placed before him in our tables and in our figures which both comprise much more than their size would seem to indicate.

We therefore think that the reader will fully understand the utter fallacy of throwing all the errors of all kinds on the one element, the atomic weight of which the modern chemist tries to determine "in the chemical laboratory and by experiment exclusively."

The reader will, we believe, now fully comprehend the situation—both of the chemist and of his intended victim, the element. The victim—if it were conscious—would shiver in anticipation of being made responsible for every error and mishap that may befall any of the elements present in the reactions, the apparatus used and even the chemist at work; for all these errors and shortcomings the modern chemical school *de facto* charges up to the element the atomic weight of which it undertakes to determine. The only new step—other than what the general progress of practical laboratory work may favor him with—will be the straining out a few more innocent gnats without in the least disturbing the ever attendant herd of the old camels.

It sometimes does seem strange that in twenty years this Berzelian picture from Saint Matthew (XXIII., 24) has remained so true to Nature. It is not the fault of the individual chemists, except in so far as they have surrendered a fundamental part of their rightful domain to the International Atomic Weight Committee.

THE ORIGIN AND SIGNIFICANCE OF THE PRIMITIVE NERVOUS SYSTEM.

By G. H. PARKER.

(*Read April 21, 1911.*)

Linnæus defined a plant as an organized, living, but non-sentient body and an animal as an organized, living, and sentient body. Although no modern biologist would attempt to support the contention that animals are sentient and plants are not, the distinction drawn by Linnæus is not without a certain foundation in truth, for sentience in its full development and as Linnæus probably understood it, is the exclusive and supreme possession of the higher animals. That these animals possess intelligence as contrasted with all other natural bodies is a statement to which few naturalists will offer any serious objection. The seat of this intelligence is the nervous system and, though the integrity of the other systems of organs is essential in most cases to the well-being of the animal body, the fact that the totality of activities that makes up the mental life of human beings as well as that of other animals, is absolutely dependent upon the nervous system, is evidence sufficient of the paramount importance of these organs. It is, therefore, not without interest to inquire into the origin of this system of organs and to trace the early steps by which it passed from a position of initial obscurity to one of the highest significance.

The nervous system of the higher animals, though enormously complex in its organization, is composed of relatively simple elements, the neurones, arranged upon a comparatively uniform plan. This plan is well exemplified in the spinal cord of the vertebrates. In this organ the sensory neurones, whose cell-bodies lie in the dorsal ganglia, extend from the integument through the dorsal roots to the gray matter of the cord. Motor neurones, whose cell-bodies are situated within the gray matter of the cord, reach from this region to the muscle-fibers which they control. These two classes of neurones would seem to be sufficient for all ordinary reflex operations, but the cord contains within its limits many other neurones which serve to connect one part of its structure with another. These neurones, therefore, have been called association neurones, a term which has unfortunately proved to be somewhat misleading because of its use in psychology for quite a different range of phenomena. The so-called association neurones are interpolated between the sensory and motor elements just described and must thereby lengthen and extend the courses of the reflex impulses. Such neurones make up a large part of the substance of the cord and doubtless increase enormously its internal connections. In the brain they not only add to the nervous interrelations, but they afford in the region of the cerebral cortex the material basis for all intellectual operations.

The plan of neuronic arrangement as exemplified in the vertebrates also obtains in animals as lowly organized as the earthworm. In this form the sensory neurones, whose cell-bodies are situated in the integument instead of being gathered into special ganglia, extend, as in the vertebrates, from the skin to the central nervous organs, the brain or the ventral ganglionic chain. The motor neurones are essentially duplicates of those in the vertebrates in that their cell-bodies lie within the central organs whence their fibers extend to the appropriate musculature. Association neurones are also abundantly present in the earthworm though their function here, in contrast with that in the higher vertebrates, is pure nervous intercommunication, for it is very unlikely that the earthworm possesses what in any strict sense of the word can be called intelligence. Thus from a morphological standpoint, the nervous systems of the higher animals, even including such forms as the earthworm, have much in common, their three sets of interrelated neurones, sensory, motor, and association, being arranged upon an essentially uniform plan.

Considered from a physiological standpoint, the nervous system with its appended parts as just sketched falls in the higher animals into three well marked categories. On the exterior of these animals, are to be found sense organs or receptors such as the free-nerve terminations of the sensory neurones in the vertebrates or the sensory cells in the integument of the earthworm. These organs have for their function the reception of the external stimuli and the production of the sensory impulses. The receptors are connected by nerve-fibers with the central nervous organ or adjustor composed of the central ends of the sensory and the motor neurones and of the association neurones. Here the impulses arriving from the receptors are directed toward the appropriate groups of muscles by which the animal may respond to the stimulus and, if the animal is highly organized, impressions are made upon the adjustor which, as memories, may become more or less permanent parts of the animal's nervous equipment. Finally the adjustors are connected by nerve-fibers with the third set of elements, the effectors, which as muscles, electric organs, glands, etc., enable the animal to react on the environment. Thus three physiological categories are to be distinguished which in the order of their sequence in action are sense organs or receptors, central nervous organs or adjustors, and muscle, etc., or effectors.

It is to be noted in passing, that the physiological scheme just outlined includes a wider range of parts than is generally admitted under the head of the nervous system. The additional parts are the effectors, which, as will be shown later, form as truly a part of the whole system as do the sense organs or the central nervous organs. Since the term nervous system does not ordinarily include the effectors, it is perhaps best to designate the whole chain of related parts, receptors, adjustors, and effectors, as the neuromuscular mechanism and in dealing with the origin of the nervous system, it will be found important to keep this relation in mind, for in such an inquiry, the real question that must be confronted is the origin of the neuromuscular mechanism rather than that of the nervous system alone.

The type of neuromuscular mechanism described in the preceding paragraphs in which a group of receptors is connected with a well centralised adjustor which in turn controls a complex system of effectors, is found only in the more differentiated metazoans. Certainly in the simple metazoans, like the jellyfishes, corals, sea-anemones, etc., only the slightest evidence of this type of nervous organization can be discovered. Nevertheless these animals possess a neuromuscular mechanism but on so simple a plan that investigators have long been inclined to regard it as representing the first step in the differentiation of the neuromuscular organs. This plan of structure is well represented in the sea-anemones. Each of the two chief layers of cells that make up the living substance of the sea-anemone's body consists of three sublayers: a superficial or epithelial layer, a middle or nervous layer, and a deep or muscular layer. The epithelial layer contains, besides many other kinds of cells, large numbers of sensory cells which terminate peripherally in bristle-like receptive ends and centrally in fine nervous branches. These fine branches constitute collectively the middle or nervous layer in which occasionally large branching cells, the so-called ganglionic cells, occur. Immediately under the nervous layer is the deep layer of elongated muscle-cells. The condition thus briefly described is present over the whole of the sea-anemone's body and though the nervous layer is somewhat emphasized in the neighborhood of the mouth, it cannot be said to be really centralised in any part. Hence this type of nervous system has been designated as diffuse in contrast with the centralised type found in the higher metazoans.

Not only is the structure of the nervous system of the sea-anemone appropriately described as diffuse, but in its action this system shows those peculiarities that would be expected from the possession of so diffuse an organization. Since each part of the animal contains its own nerve and muscle, it is not surprising that after isolation many of these parts will respond to stimuli much as they did when they were a constituent of the whole organism. Tentacles, for instance, when freshly cut from the body of a sea-anemone will respond to pieces of food by encircling them, etc., in much the same way as when these organs were parts of a normal animal. Much evidence of this kind has shown conclusively that the nervous system of cœlenterates is no more centralized physiologically than it is anatomically, but is in all respects essentially diffuse.

What is really present in the neuromuscular portion of the sea-anemone's body is a large number of peripheral sensory cells whose deep branching ends connect more or less directly with the muscles, *i. e.*, without the intervention of a true central organ. This neuromuscular system, if described in the terms already used, could be said to be composed of receptors and effectors without an adjustor or at least with this member present in only a most primitive state. In my opinion this is the condition in most cœlenterates. Judging from the more recent work on the nervous organs of these animals, centralization can scarcely be said to be present at all in hydra; it is but little more pronounced in the sea-anemone; and, though most marked in the jellyfishes, it does not rise even here to a grade that entitles it to comparison with what is seen in such forms as the earthworm. The cœlenterates, then, are animals possessing receptors and effectors but without developed adjustors. Hence the adjustor or central organ is in all probability an acquisition that represents a later stage in the development of the neuromuscular mechanism than that seen in the cœlenterate.

If the cœlenterates represent a stage in the evolution of the neuromuscular mechanism in which sensory cells and muscles are the only important parts present, it is natural to ask if there is not a still more primitive state from which the cœlenterate condition has arisen. On this question several hypotheses have already been advanced. Claus and, subsequently, Chun maintained that originally the nervous system and the muscles were differentiated independently and that they became associated only secondarily. This view has deservedly received very little attention, for not only is it difficult to conceive that an animal would develop receptive ability without at the same time acquiring the power to react, but not a single example among the lower animals is known in which developed nerve and muscle are present and independent of each other.

Much more worthy of consideration than the hypothesis of the independent origin of nerve and muscle is Kleinenberg's theory of the neuromuscular cell. In 1872 Kleinenberg announced the discovery in the fresh-water hydra of what he designated as neuromuscular cells. The peripheral ends of these cells were situated on the exposed surface of the epithelium, of which they were a part and were believed to act as nervous receptors; the deep ends were drawn out into muscular processes and served as effectors to which transmission was supposed to be accomplished through the bodies of the cells. Each such cell was regarded as a complete and independent neuromuscular mechanism, and the movements of an animal provided with these cells was believed to depend upon the simultaneous stimulation of many such elements. It was Kleinenberg's opinion that these neuromuscular cells (Fig. 1, *B*) divided (*C*) and thus gave rise to the nerve-cells and muscle-cells (*D*) of the higher animals. In fact he declared that the nervous and muscular systems of these animals were thus to be traced back to the single type of cell, the neuromuscular cell, which morphologically and physiologically represented the beginnings of both. But Kleinenberg's neuromuscular cells were subsequently shown by the Hertwigs to be merely epitheliomuscular cells and no intermediate stage between them and the differentiated neuromuscular mechanism of higher forms was ever discovered. Hence this hypothesis, too, has been largely abandoned.

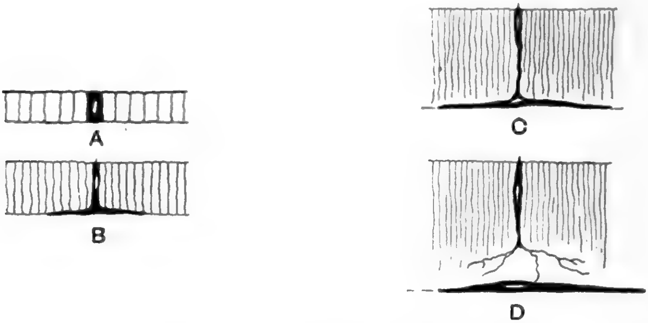


FIG. 1. Diagram to illustrate Kleinenberg's theory of the neuromuscular cell. *A*, epithelial stage; *B*, neuromuscular cell; *C*, neuromuscular cell partially divided; *D*, nerve-cell and muscle-cell of cœlenterate stage.

Some years later, in 1878, the Hertwigs published an account of the neuromuscular mechanism in cœlenterates, an account which even at the present time is accepted as authoritative by most students of the subject. In this account they described the sensory cells, the ganglionic cells, and the muscular cells of the cœlenterates, and maintained that these elements arose not by the division of single cells, as implied in Kleinenberg's hypothesis, but that each element was differentiated from a separate epithelial cell (Fig. 2) and yet in such a way that during differentiation all these elements were physiologically interdependent. This hypothesis of the simultaneous differentiation of nerve and muscle is the current opinion among biologists today.

As opposed to Hertwigs' hypothesis of the origin of nerve and muscle, I wish to present certain facts obtained from a study of sponges. As is well known, sponges are extremely primitive metazoans, more primitive even than the cœlenterates. All attempts to demonstrate in them sensory or other nervous structures have yielded negative results, so that the majority of investigators of this group have come to regard sponges as devoid of true nervous structures. Not only are sponges without parts that can be reasonably called nervous, but so far as I have been able to ascertain by an extended study of a species of *Stylotella*, they show none of those qualities of transmission and relatively quick reaction which characterize even such animals as have only primitive nervous systems. In fact in this respect sponges resemble plants rather than animals. But notwithstanding the fact that sponges show no evidence either anatomical or physiological of possessing nervous organs, they are not without powers of response. *Stylotella*, for instance, can open and close its oscula and its lateral pores, and can even contract its flesh more or less. These movements, to be sure, are carried out very slowly, but they follow certain stimuli with such regularity that they must be regarded as true responses. Thus the oscula of this sponge close regularly when the water about these openings becomes quiet and reopen after the water has been again set in motion. These movements of the sponge are carried out by contractile tissue which has the appearance of smooth muscle-fiber and which, like smooth muscle, responds with great slowness. The slowness of the response is so marked even in comparison with what is met with among the

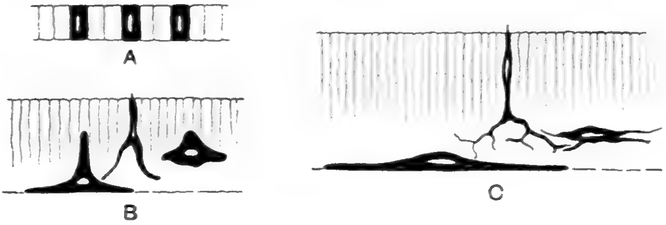


FIG. 2. Diagram to illustrate Hertwigs' theory of the origin of nerve and muscle. *A*, epithelial stage; *B*, partially differentiated muscle-, nerve- and ganglion-cell; *C*, muscle-, nerve- and ganglion-cell of cœlenterate stage.

more sluggish cœlenterates, as to suggest that the muscles in question act not through the intervention of nerves, but under direct stimulation, and since sponges have yielded no evidence anatomical or physiological of possessing nervous elements of any kind, I have concluded that their muscles normally act under direct stimulation. In other words, sponges are metazoans with effectors but without receptors; and in so far as their neuromuscular mechanism is concerned, they are metazoans one degree simpler than the majority of cœlenterates.

If this conclusion concerning the neuromuscular mechanism in sponges is correct, it follows that, of the three elements concerned, the effector or muscle is the most primitive and has developed as an organ quite independent of nerve, as seen in the sponges (Fig. 3, *A, B*). Next in sequence would appear the receptor or sense organ which, derived from the cells in the neighborhood of a developed effector (*C*), would serve as a more efficient means (*D*) of calling this organ into action than direct stimulation. This stage is represented by many cœlenterates; and their quick responses, as compared with those of sponges, are dependent, I believe, upon this advance in organization. Finally, in forms somewhat more advanced than the cœlenterates, central nervous organs or adjustors would begin to differentiate in the region between the receptors and effectors; and these would develop in the higher animals, first, as organs of transmission whereby the whole musculature of a given form could

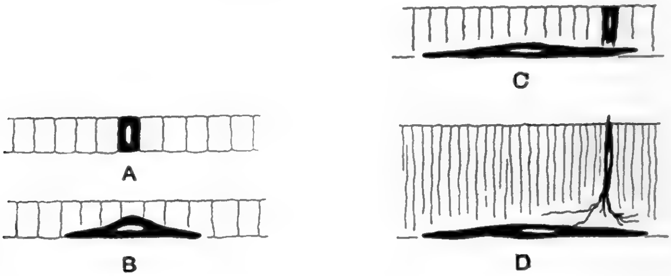


FIG. 3. Diagram to illustrate the early stages in the differentiation of the neuromuscular mechanism. *A,* epithelial stage; *B,* differentiated muscle-cell at stage of sponge; *C,* partially differentiated nerve-cell in proximity to fully differentiated muscle-cell; *D,* nerve- and muscle-cell of cœlenterate stage.

be brought into coördinated action from a single point on its surface and, secondly, as the storehouse for the nervous experience of the individual and the seat of those remarkable activities that we recognize in the conscious states of the higher animals. Thus nerve and muscle did not develop independently, as claimed by Claus and Chun, or simultaneously, as maintained by Kleinenberg and the Hertwigs, but muscle appeared first as independent effectors and nerve developed secondarily in conjunction with such muscles, first as a means of quickly setting them in action and, secondly, as a seat of intelligence.

When we survey the whole range of metazoan development, we cannot but be struck with the remarkable history of the neuromuscular mechanism. The earliest metazoans were doubtless little more than colonies of protozoan cells concerned with the common functions of feeding and reproduction and conforming more or less to Haeckel's hypothetical gastræa. To these early functions of this primitive metazoan were added colonial reactions in that a system of independent effectors, more or less such as we see in the musculature of the modern sponge, was differentiated. As a means of bringing this musculature into more effective response, nervous elements developed in close proximity to the effectors. With the growth of the musculature and the nervous system in volume and with the consequent increase of metabolism, came the development of the circulatory system and its dependencies, the respiratory and the excretory organs. Thus the relatively simple body of the primitive metazoan became gradually converted into that of the more complex type. In all these changes no system of organs has done so much to unify the metozoan body as the nervous system. If a sponge may be outlined as a metazoan whose organization concentrates on feeding and reproduction, a human being may be described as one whose organization centers around nervous action. In such an organism the nervous system is supreme; and the rest of the body may be said to do little more than afford a favorable environment for this system; and yet, if the preceding account is correct, this most important system originated somewhat late in the history of the metazoa and as a relatively insignificant organ for the discharge of muscular activity.

HARVARD UNIVERSITY,
April 20, 1911.

THE STIMULATION OF ADRENAL SECRETION BY EMOTIONAL EXCITEMENT.

By W. B. CANNON, M.D.

From the Laboratory of Physiology in the Harvard Medical School.

(*Read April 22, 1911.*)

Dreyer's demonstration that splanchnic stimulation increases the content of adrenal secretion in blood from the adrenal veins has been confirmed by several observers. Adrenal secretion therefore is under control of the sympathetic system.

Major emotional disturbances indicate the dominance of sympathetic impulses. In the cat, for example, fright causes dilatation of the pupils, inhibition of the stomach and intestines, rapid heart, and erection of the hairs of the back and tail. Do not the adrenal glands share in this widespread subjugation of the viscera to sympathetic control?

To try this suggestion the inhibition of contraction in strips of longitudinal intestinal muscle, sensitive to suprarenin 1 to 20,000,000, was used as a biologic test. From the cat when quiet, and again from the animal when excited by a barking dog, blood was obtained by introducing, through the femoral vein, into the inferior vena cava to the region of the liver, a small vaselined catheter. The blood thus obtained was defibrinated and applied to the intestinal strip at body temperature.

After an initial shortening the strip contracted rhythmically in blood from a quiet animal. In no instance did such blood produce inhibition. On the other hand, blood taken from animals after the emotional disturbance, showed more or less promptly the typical relaxing effect. As the emotional period was prolonged, the effect became prompter and more profound.

The view that inhibition of the contracting intestinal strip is due to an increased content of adrenal secretion is justified for the following reasons: (1) The effect was obtained in blood from the vena cava near the liver when that from the femoral vein taken simultaneously produced no inhibition. (2) Removal of the adrenal glands after tying the adrenal vessels resulted in a failure of excitement to produce the effect. (3) Adding varying amounts of adrenalin to inactive blood evoked all the degrees of relaxation that have been observed in excited blood. (4) Excited blood which produced prompt inhibition lost that power on standing or on being agitated by bubbling oxygen. These conditions, together with the evidence that sympathetic impulses increase the secretion of the adrenal glands, and that during such emotional excitement as was here employed signs of sympathetic discharges were observable in the animal from the eye to the tip of the tail, prove that the relaxing effect was due to adrenal secretion.

Injected adrenalin is capable of inducing an atheromatous condition of the arterial wall in rabbits, especially in elderly individuals, and is also capable of evoking hyperglycemia with glycosuria. As Ascher has shown by prolonged stimulation of the splanchnic nerves prolonged adrenal secretion with maintained high blood-pressure can be produced. In the light of the results here reported the temptation is strong to suggest that some phases of these pathologic states are associated with the strenuous and exciting character of modern life acting through the adrenal glands. Two of my students, Shohl and Wright, have recently shown that excitement of the cat results, in all cases thus far examined (more than a dozen), in glycosuria. Possibly in the wild state emotions were useful in providing material for excessive muscular exertion that might follow, and that muscular activity would utilize the sugar so that it would not appear in the urine. This suggestion, however, must be put to further test.

THE CYCLIC CHANGES IN THE MAMMALIAN OVARY.

By LEO LOEB.

(*Read April 22, 1911.*)

The observations which I wish to report to you are of interest from several points of view:

1. The process upon which the sexual cycle in mammals depend has been analyzed, and a regulatory mechanism was found to exist within the ovary.

2. A striking illustration is presented of the fact that the structure of organs is in many instances at least not a definite one, but varies in correspondence with the functional condition of the organ.

3. The accurate description of the normal cyclic changes in the mammalian ovary serves as a basis for the investigation of the pathological deviations which interfere with the natural course of the sexual functions and may lead to a temporary or lasting sterility.

4. We found in the ovary structures which must in all probability be interpreted as early stages of embryos developing spontaneously parthenogenetically within the ovary and it is probable that the development of these parthenogenetic embryos is related to certain phases of the sexual cycle.

In the ovary of the guinea-pig definite and very interesting cyclic changes exist which I made the object of my studies in the last few years.

The mammalian ovary consists of two principal constituent parts, namely: First, large and small bodies lined by granulosa cells and filled with fluid, the so-called follicles; and, secondly, the corpora lutea. Both follicles and corpora lutea have only a brief existence; they develop to a certain point and then they degenerate and gradually disappear. The follicles contain the ova. At certain periods of the sexual cycle a few follicles that have reached maturity rupture. The ova reach the Fallopian tubes and uterus and after fertilization by a spermatozoön form an embryo in the uterine wall. New follicles situated in the periphery of the ovary grow constantly to a certain size and then degeneration sets in. The lining granulosa cells disintegrate and connective tissue grows into the cavity of the follicle. The ova in these degenerating follicles undergo frequently maturation and a few more or less regular divisions and then die. While thus the majority of follicles degenerate, become atretic, before they have reached maturity, a few follicles undergo certain progressive changes and become mature. They may rupture and discharge the ovum; such a rupture is called an ovulation. The process connected with ovulation causes a degeneration of all with exception of the smallest follicles. These follicles grow and in the course of the next six days they have reached that size at which degeneration may set in. We find, therefore, degenerating follicles from the seventh day after ovulation up to the time of the following ovulation. While after the seventh day medium-sized follicles constantly degenerate, new follicles grow and take the place of the degenerating disappearing ones. It seems that it takes approximately ten days until some of the follicles reach their full size.

We may therefore distinguish two periods in the ovarian cycle: First, the period of growth extending over the first seven days following ovulation, and, secondly, the period of equilibrium in which new follicles take the place of degenerating ones. After the first large follicles have appeared, it takes a few days longer until large follicles become transformed into mature follicles that are ready to rupture. We find, therefore, the first mature follicles to appear approximately eleven to thirteen days after ovulation and it would be natural to expect that about fourteen days after the preceding a new ovulation should take place.

The sexual period—that is the period between two ovulations—should therefore have a natural duration of approximately two weeks in the guinea-pig. This is, however, not the case. The sexual period in this species actually lasts about twenty to twenty-five days. And this is due to the fact that a mechanism exists within the ovary that prolongs the sexual cycle. In order to understand this mechanism, we must follow the fate of the ruptured follicle. A follicle that has ruptured at the time of ovulation does not degenerate in a similar manner as the other follicles do after they have reached full size, but they grow in a remarkable manner and form a new gland-like organ, the corpora lutea. Now these corpora lutea also degenerate after a period of growth that lasts approximately seventeen to twenty days. In the corpora lutea resides the mechanism that prevents a new ovulation. It is necessary that they degenerate before a new rupture of follicles can take place. As long as they function they prevent ovulation. The fact that the corpora lutea degenerate when seventeen to twenty days old, explains why a new ovulation takes place approximately every three weeks. If we excise the corpora lutea at an early date after ovulation, a new ovulation occurs very soon after mature follicles have made their appearance, approximately thirteen to fifteen days after the preceding ovulation. Under these conditions, the normal sexual cycle is reëstablished.

During pregnancy the life of the corpus luteum is prolonged in consequence of the changes occurring in the uterus or developing embryo during the period of gestation and in consequence of the prolonged life of the corpus luteum, a new ovulation is prevented during the whole course of pregnancy. Toward the latter part of pregnancy, the corpora lutea again degenerate and directly after completed labor a new ovulation can take place.

Ovulation, therefore, depends upon three factors: First, upon the maturation of ovarian follicles; secondly, upon the time of degeneration of the corpora lutea; and, thirdly, upon less important, more or less accidental conditions, as for instance, the process of copulation. The third class of conditions accelerates in many (not in all) cases ovulation, but it is not necessary for its occurrence. Even without a preceding copulation, ovulation usually takes place, but in many cases at a later date. Through what mechanism does the life of the corpus luteum influence ovulation? It might be conceivable that the corpus luteum delays the maturation of follicles thus preventing a rupture. My observations have, however, shown that an inhibiting influence of the corpus luteum upon the maturation of follicles does not exist. Mature follicles appear frequently during the life of the corpus luteum, and especially during the period of pregnancy; it seems that pregnancy even favors the maturation of follicles. The corpus luteum prevents, however, the *rupture* of the mature follicles. Pregnancy as such does not prevent the rupture provided the corpus luteum has been previously removed through excision.

The structural changes in the ovaries are rhythmical and so regular that a careful histological examination of these organs enables us to decide within a certain limit of accuracy at what period of the sexual cycle the animal had been at the time of the removal of the ovaries.

Having established the normal cycle I turned more recently my attention to its pathological deviations. It occurs in a certain number of animals—and I have observed this to happen among females which showed no desire for copulation or in which notwithstanding an accomplished copulation an ovulation did not follow—that the follicles do not grow to maturity, but that they undergo involution before they reach their full size, and that all, or almost all the follicles, become sclerosed, atretic, at a very early stage of their development. Under these conditions, an ovulation is impossible and the animal, in the ovaries of which such a deviation from the normal cyclic changes exists, are at least temporarily sterile; whether such a pathological condition may ever lead to a permanent sterility, future investigations must show. It will be readily understood that here we have to deal with questions of the greatest importance to the physiology of the sexual functions.

In order to appreciate thoroughly the conditions under which such abnormalities in the sexual cycle occur, it is necessary to produce the subnormal development of the follicles experimentally. Now it is of interest to know that such a premature involution of the ovarian follicles can be produced experimentally by burning a certain relatively small part of the ovaries with the thermocautery. The remaining larger part of the ovary remains apparently perfectly well, the cells functionate but the energy of growth of certain cells is diminished and subinvolution of the follicles with resulting temporary sterility follows. A comparable condition can be produced in tumors through heating, or through the influence of certain chemicals exerted in vitro as I found a number of years ago. Under such conditions the tumors grow, but with markedly diminished energy. In both cases, in the case of the tumors as well as of the ovaries, we have to deal with a state of living matter intermediate between its full natural vigor and latent life; we may regard it a state of partial shock of cells, in which the growth takes place but with a considerable decrease in energy. Besides the changes which I have just described, additional processes of the greatest interest take place in the ovaries of a certain number of animals and it is very probable that these processes usually commence at the period following ovulation and are therefore, in a certain sense, a part of the cyclic ovarian changes. The process I refer to concerns an apparently spontaneous partial parthenogenetic development of ova in the mammalian ovary, an occurrence of which I obtained convincing proof only within the last few months.

Some years ago I described peculiar structures that are found in the ovaries of guinea-pigs, and I expressed the opinion that they originated in the ovarian follicles.[1] Very soon after I had published my observations, certain considerations suggested to me that these structures owe their origin to parthenogenetically developing ova.

In as much as at that time I had not yet seen early stages of the structures referred to, I was unable to regard this hypothesis as sufficiently founded to warrant publication. I continued, however, my investigations in this direction, and recently I succeeded in finding in two animals the desired early stages. They must be interpreted as embryos developing parthenogenetically within the ovary of the guinea-pig. We see in each case a chorionic vesicle with trophoblast, and plasmodia and syncytia penetrating into the neighboring tissues. There is present also a structure which is probably to be interpreted as a neural tube.

Aberrant blastomeres (remnants of dividing ova that failed to participate in the embryonic development) cannot be seen in the ovaries of guinea-pigs, and, inasmuch as the embryonic structures, described in my former communication, are relatively frequent, occurring in approximately ten per cent. of all guinea-pigs below the age of six months, and, furthermore, inasmuch as they are situated

---

[1] *Archiv f. mikrosk. Anatomie,* Bd. 65, 1905.

in the cortex of the ovaries at a place where follicles lie normally and are found within follicle-like cavities, they can only be derived from ova developing parthenogenetically. Fertilization through spermatozoa can be excluded, inasmuch as the history of some of these animals is known to us and precludes such an interpretation. It is very probable that the parthenogenetic development sets in soon after ovulation, the altered conditions in the ovaries at that time (variations in blood pressure, in intrafollicular pressure or changes in gas exchange) supplying the necessary stimulus. This interpretation agrees well with my former observations concerning the parallelism existing between the first segmentations taking place in non-fertilized ova within the ovary and certain stages of atresia of follicles.[2]

It is also of interest to note that frequently these changes are multiple, several ova undergoing parthenogenetic development in the same ovary.

We may, therefore, conclude that in at least ten per cent. of all guinea-pigs parthenogenetic development of the ova within the ovary starts at some period of the life of the animal. The later stages of these developing embryos bear some resemblance to chorionepitheliomata, certain tumor-like formations consisting of proliferating chorion tissue. During ovulation these structures are occasionally injured by hemorrhages and they are ultimately invaded and supplanted by the neighboring connective tissues.

These observations throw furthermore light on certain interesting tumors that are especially found in the ovaries and testicles, namely: the teratoid tumors and the chorionepitheliomata. My observations are a strong argument in favor of the view that teratoid tumors that are found in the ovaries are not derived from misplaced blastomeres, as Bonnet and Marchand believed, but that the older view is correct according to which they are derived from parthenogenetically developed ova, an opinion which I, also, expressed on previous occasions. The same statement can be made in the case of the chorionepitheliomata that occur in the ovaries and in the testicles. I believe that the observations here recorded clear up the mechanism of the sexual

---

[2] "On Progressive Changes in the Ova in Mammalian Ovaries," *Journal of Medical Research*, Vol. 1, 1901.

cycle in its essential aspects and they also make it extremely probable that in a relative large proportion of mammalian animals a spontaneous parthenogenetic development of ova takes place at some period during the life of the animal.

Department of Pathology,
Barnard Free Skin and Cancer Hospital,
St. Louis, Missouri.

THE SOLAR CONSTANT OF RADIATION.[1]

By C. G. ABBOT.

(*Read April 21, 1911.*)

If we had no eyes we should still know of the sun by the feeling of warmth. The intensity of solar rays in any part of the spectrum can be measured by delicate thermometry. Vision and photography are both restricted within comparatively narrow limits of wave-length, and each differs in its sensitiveness from wave-length to wave-length. Ultra-violet, visible and invisible red rays, however, all produce their just and proportional influences on the bolometer, or thermopile. This is not universally known, and there are still many who suppose we should distinguish between so-called actinic, visible and heat rays. Doubt has been expressed, for instance, whether bolometric measurements give true indications of the intensity of those rays which promote plant growth. Such doubts are not justified, and we may expect very valuable results in the future from the application of the spectro-bolometer to the interesting questions of radiation and plant physiology.

We use heat units to express the intensity of solar radiation. The solar constant of radiation may be defined closely enough as the number of degrees by which one gram of water at 15° centigrade would be raised, if there should be used to heat it all the solar radiation which would pass at right angles in one minute through an opening one centimeter square, located in free space, at the earth's mean solar distance. Experiments were begun about 1835 by Pouillet and by Sir John Herschel for the measurement of this great constant of nature. The investigation has been continued by Forbes, Crova, Violle, Radau, Langley, K. Ångström, Chwolson, W. A. Michelson, Rizzo, Hansky, Scheiner and others. It is an indication of the great difficulty of the research that entire uncer-

---

[1] Published by permission of the Secretary of the Smithsonian Institution.

tainty as to the value of the solar constant of radiation between the limits of Pouillet's value, 1.76 calories, and Ångström's value, 4.0 calories per square centimeter per minute, prevailed at the beginning of the twentieth century.

Professor Pringsheim has collected the following table[2] of solar-constant values, as determined by different observers:

Year.	Observer.	Calories.	Year.	Observer.	Calories.
1837	Pouillet	1.8	1889	Pernter	3.2
1860	Hagen	1.9	1896	Vallot	1.7
1872	Forbes	2.8	1897	Crover and Hansky	3.4
1875	Violle	2.6	1898	Rizzo	2.5
1878	Crova	2.3	1908	Scheiner	2.3
1884	Langley	3.1	1908	Abbot and Fowle	2.1[3]
1889	Sawelief	2.9			

He omits Ångström's 4.0, published in 1890 and withdrawn in 1900, but which is even yet sometimes quoted. He omits also Very's 3.1, published in 1901 and independently obtained in 1910. Recently published values of Kimball, Gorczynski and others, approximately 2.0, are based in part on work of Abbot and Fowle.

The determination of the solar constant involves: (1) correct measurements of the heat equivalent of the solar radiation at the earth's surface; (2) a correct estimate of the losses which the rays have suffered in the atmosphere before they reached the measuring apparatus. We shall now discuss these two branches of the work.

Pouillet invented, about 1835, his well-known instrument, the pyrheliometer, for measuring the solar rays at the earth's surface. Many criticisms have been justly made in regard to the accuracy of this pioneer instrument, and attempts have been made by many to improve on it, or to substitute a better. In our practice at the Smithsonian Astrophysical Observatory, we have substituted a silver disk for Pouillet's water chamber; inserted a cylindrical bulb thermometer, radially instead of axially, in the disk; provided a metal-lined wooden chamber to screen the instrument from the wind; and added convenient adjuncts for shading and exposing the instru-

---

[2] "Physik der Sonne," p. 417.

[3] This value was expressed in terms of a provisional scale of pyrheliometry which has since been proved too high.

ment.[4] Finally we have ceased to regard our instrument as giving more than relative measurements. It is only a secondary pyrheliometer for convenient use. We standardize its readings by comparison with an absolute pyrheliometer of another kind.

No known substance absorbs radiation perfectly at a single encounter. Kirchhoff showed, fifty years ago, that a hollow chamber must absorb perfectly, because of the opportunity for an infinite number of absorption encounters within it. W. A. Michelson, in 1894, invented a standard pyrheliometer including a hollow chamber with a narrow opening for the admission of rays. The walls of the chamber were bathed by a mixture of ice and water, and the heating effect of the solar rays was measured by the amount of ice melted, which was determined by noting the expansion in volume of the mixture of ice and water.

Nearly ten years later, being ignorant of Michelson's pyrheliometer (which was described in the Russian language), it occurred to me also to employ a hollow receiving chamber. I proposed to measure the solar heating produced in it by bathing its walls with flowing water, and determining the rate of flow and rise of temperature of the water. After experiments lasting intermittently from 1904 to 1910, I am now satisfied that this device has proved successful, and that we have truly an absolute standard pyrheliometer. With the aid of my colleagues, Mr. Aldrich and Mr. Fowle, two of these water-flow pyrheliometers were carefully tested last year.[5] Not only did they agree in measurements of solar radiation, but test quantities of heat introduced electrically within the absorbing chambers were accurately recorded by the methods ordinarily used to measure solar heating. We believe of the absolute water-flow pyrheliometer, it gives the intensity of solar radiation at the earth's surface in calories per square centimeter per minute within a probable error of 0.2 per cent. For convenience we make our daily observations with secondary silver-disk pyrheliometers, which have been standardized against the absolute water-flow pyrheliometer.

---

[4] See Abbot, "The Silver Disk Pyrheliometer," *Smithson. Misc. Coll.*, Vol. 56, No. 19, 1911.

[5] See Abbot and Aldrich, *Astrophys. Journal,* Vol. XXXIII., 125, 1911.

Having perfected the standard and secondary pyrheliometers to a satisfactory degree of accuracy and durability, the first branch of solar-constant work is accomplished by reading with the silver-disk pyrheliometer at the earth's surface, and reducing its indications to calories per square centimeter per minute. We now turn to the discussion of the second branch of the work, namely the estimation of the transmission of the atmosphere for radiation.

Lambert and Bouguer showed almost simultaneously, about 1760, that the transmission of light through a homogeneous medium may be expressed by an exponential formula, such as:

$$E = E_0 a^m.$$

Here E is the intensity transmitted, E_0 the original intensity, a the fraction transmitted by unit thickness, and m the actual thickness of the transparent medium.

Pouillet applied Bouguer's formula to the atmosphere. As the atmosphere is not homogeneous, but decreases in turbidity and density from the earth's surface upward, this would seem at first sight unjustified. But if we consider unit thickness to be the thickness of the atmosphere traversed by a vertical beam, then as the ray departs from the vertical, it still shines through every layer which it did at first, and the path in every layer increases nearly as the secant of the zenith distance of the ray. Under these circumstances it can be shown that (subject to certain limitations to be mentioned) the exponential formula given above should hold, if we consider E to be the intensity at the earth's surface, E_0 the intensity outside the atmosphere, a the transmission coefficient for a vertical beam, and m the secant of the sun's zenith distance.[6]

Owing to atmospheric refraction, the fractional increase in path of the ray, as the zenith distance waxes, tends to be greater for the outer layers of the atmosphere than for its inner ones. On the other hand, the curvature of the earth's surface produces an opposite tendency. But for zenith distances less than 70° these effects may be neglected, and they are hardly worth considering at 75°

---

[6] See *Annals Smithson. Astrophys. Obser.*, Vol. II., p. 14, 1908.

zenith distance.[7] Solar-constant determinations require no higher values of zenith distance than these to be considered.

Radau and Langley proved the necessity of confining the atmospheric use of Bouguer's formula to approximately monochromatic rays. In general, for a reason which Lord Rayleigh has shown, the transmission of the atmosphere increases gradually with increasing wave-lengths. Thus in the violet the transmission for a vertical ray to sea level may be 50 per cent., and for a deep red ray 80 per cent. But besides this gradual change there are also spectral regions of almost complete absorption by atmospheric oxygen, and by water-vapor, so that in these regions the transmission approaches zero. If we should disregard these differences, and determine the constants of the exponential formula above, by pyrheliometric measurements alone at different solar zenith distances, our result E_0 for the intensity outside the atmosphere must necessarily be too small.[8]

Langley was the first to act upon this, and to devise apparatus and methods for measuring the energy and the atmospheric transmission at all parts of the spectrum. For this purpose he invented the bolometer about 1880, and automatic registration of its indications about 1890. As we now use it the bolometer comprises two similar tapes of platinum, each about 1 cm. long, 0.01 cm. wide and 0.001 cm. thick. These are coated with lamp-black by smoking over a camphor flame. They lie parallel to the spectrum lines, and about 0.8 cm. apart. One tape may be shined upon by the rays, the other can not. Hence the heat absorbed from a narrow region of spectrum, usually about twice the extent comprised between the D lines, raises the temperature of the exposed tape with reference to the other. The two tapes and two resistance coils are combined to form a Wheatstone's bridge, and the rise of temperature produced as above stated deflects a sensitive galvanometer. The galvanometer needle reflects a tiny spot of light on a photographic plate, which moves vertically as driven by clock work. The same clock work moves the spectrum slowly over the bolometer tape. In this way may be produced in from eight to twelve minutes, according to the spectroscopic outfit employed, a bolograph, or spectrum energy

---

[7] *Loc. cit.*, p. 59.

[8] *Loc. cit.*, p. 16.

curve, extending from about wave-length 0.30μ in the ultra-violet to about wave-length 3.0μ in the infra-red. Its ordinates are deflections of the galvanometer, proportional to energy in the spectrum, and its abscissæ are proportional to differences of prismatic deviation. The Fraunhofer lines, and great oxygen and water-vapor bands, show as depressions in the curve. In order to eliminate distortions which are due to differences, for differing wave-lengths, in the reflecting power and transmission of the mirrors and prism used in the optical train, special investigations of the transmission of the apparatus are made from time to time, and the curves corrected accordingly.

In our ordinary practice, from six to eight bolographs are taken in a single forenoon, between the times when the sun's zenith distance is 75° and (say) 30°. The curves are measured at about thirty positions, uniformly spaced in the prismatic spectrum. Each group of six to eight measurements, at a single spectrum place, furnishes means of computing from Bouguer's formula the transmission of the atmosphere for that wave-length, and also the ordinate which would have been found there if the observations had been made outside the atmosphere. The sum of the ordinates measured on any bolograph is approximately proportional to the total energy of all wave-lengths observed. Similarly the sum of the ordinates computed for outside the atmosphere is proportional to the total energy there.[9]

In order to reduce the total energy, as determined bolometrically, to calories per square centimeter per minute, the pyrheliometer is read, while the spectro-bolometric work is in progress, on each day of observation. Thus a factor is obtained for deducing from the areas of the bolometric curves the true heat units corresponding.[10] A complete determination of the solar constant of radiation requires

---

[9] In the regions of great water-vapor and oxygen absorption the extra-atmospheric curve is determined by interpolation between adjacent comparatively unaffected wave-lengths on either side, for we know that there is no oxygen or water-vapor absorption of these bands produced in the sun, so that they ought not to show in the extra-atmospheric curve. Small allowances are also made for the energy of lesser and greater wave-lengths than any observed.

[10] For further details consult *Annals*, Vol. II.

about three hours of observation, under a cloudless and uniformly clear sky, and about three days of computing.

We began to make solar-constant observations in Washington at the Smithsonian Astrophysical Observatory, in October, 1902, and continued them there whenever a favorable opportunity was presented, until May, 1907. In all this time we made only 44 tolerably satisfactory determinations at Washington, for cloudless days were rare, and many days that promised fairly proved disappointing, by reason of the appearance of smoke, haze or clouds. Four important results came from the Washington observations. First, no apparently good determinations yielded solar-constant values above 2.38 of our then provisionally adopted scale of calories, or 2.25 true calories. Second, the mean value in the true calories from 44 determinations was 1.960. Third, the transmission of the atmosphere was determined on many days, and for many wave-lengths.[11] Fourth, a strong probability was raised by the results of observations of 1903 that the sun is a variable star.[12] This variation seemed to reach 10 per cent. in its extreme range, but no tendency towards a regular period was then found for it. A dependent variation in terrestrial temperatures seemed indicated.

Primarily in order to make spectro-bolometric determinations of the solar constant, suitable to test the supposed variability of the sun, an expedition under my charge went out to Mount Wilson in 1905, by invitation of Director Hale of the Mount Wilson Solar Observatory. The site proved excellent for the purpose, on account of its considerable altitude, cloudless sky and freedom from wind. Much aid and comfort was furnished by Director Hale and his staff. The expedition was repeated in 1906, 1908, 1909 and 1910. We now occupy a cement observing shelter and living quarters there, on ground leased from the Solar Observatory. Our observations have generally occupied the six months, May 15 to November 15, and in the last years we have made practically daily determinations of the solar constant of radiation during this interval.

---

[11] Astronomers have not yet very generally availed themselves of the accurate coefficients of atmospheric transmission obtained in our researches for all parts of the spectrum, and from Washington, Mount Whitney and Mount Wilson.

[12] See S. P. Langley, *Astrophysical Journal,* Vol. 19, p. 305, 1904.

It was thought doubtful by Langley, and others, if correct estimates of the atmospheric transmission can be made, even by the spectro-bolometric method of high and low sun observations. Langley, indeed, gave an argument tending to show that the values of the solar constant thus obtained fall far below the true intensity of the solar radiation outside the atmosphere. This argument, however, seems to be unsound.[13] In order to test the accuracy of the method I made spectro-bolometric measurements on Mount Whitney (4420 meters elevation) in 1909 and 1910 simultaneously with similar observations made by Messrs. Ingersoll and Fowle, respectively, on Mount Wilson (1800 meters elevation). In 1905 and 1906 solar-constant measurements were made nearly simultaneously at Mount Wilson and at Washington (10 meters elevation). It does not appear from these observations that there are any differences in the solar-constant values depending on the altitude of the observer, and not due to accidental errors of observations.[14]

In illustration of this conclusion I give the results obtained simultaneously at Mount Wilson and Mount Whitney:

Date.	1909, Sept. 3.	1910, Aug. 12.	1910, Aug. 13.	1910, Aug. 14.
Mount Wilson.........	1.943	1.943	1.924	1.904
Mount Whitney........	1.959	1.979	1.933	1.956

The very slight excess of the Mt. Whitney values is not large enough to be significant.

We conclude that the solar-constant values computed from the method of high and low sun observations do not depend on the altitude of the observing station up to altitudes of 4,420 meters, provided the sky conditions are satisfactorily clear and uniform.

Reducing values published in Vol. II. of the *Annals* to standard calories at 15° centigrade, and including the mean values obtained in later years,[15] we have:

---

[13] See *Annals*, Vol. II., pp. 119–121.

[14] As regards the Washington and Mount Wilson comparisons, see *Annals*, Vol. II., pp. 99 and 102. Note that the provisional scale of these *Annals* values is 5 per cent. too high.

[15] Many of the values of 1910 are not yet reduced.

SOLAR–CONSTANT MEAN VALUES.

Place.	Washington.	Mount Wilson.					Mount Whitney.	
Date.	1902–1907	1905	1906	1908	1909	1910	1909	1910
Times observed	44	59	62	113	95	28	1	3
Mean value	1.960	1.925	1.921	1.929	1.896	1.914	1.959	1.956

Our observations indicate as the mean value of the solar constant of radiation:

1.922 calories (15° C.) per square centimeter per minute.

The observations having been obtained mainly near the time of sun-spot maximum we think it probable that their mean is hardly high enough to represent the average condition of the sun. We incline to think this because it has been shown by Koppen, Nordmann, Newcomb, Abbot and Fowle, Bigelow, Arctowski and others that the earth's temperature is a little lower at sun-spot maximum than at sun-spot minimum. This probable correction cannot exceed one or two per cent.

There is another reason why our value of the solar constant may be too low. We have not been able to observe, even on Mount Whitney, any radiation beyond the wave-length 0.29μ in the ultra-violet spectrum. Whether the rays of less wave-length are obliterated in the earth's atmosphere or in that of the sun we cannot know, but we do know that ozone, which is perhaps formed in the upper atmosphere, exercises powerful selective absorption beyond wave-length 0.29μ. Hence it may be that we are forced to neglect some radiation not quite negligible. It is very improbable that the amount thus neglected exceeds 1 or 2 per cent.

As for the supposed variability of the sun, our determinations strongly indicate that the so-called solar constant is not really a constant, but fluctuates over a range of about 8 per cent. This result is apparently the direct outcome of our observations, but the question may well be asked if the apparent fluctuation is not due either to the inaccuracy of the observations or to incorrect estimates of the transmission of the atmosphere. If it were due merely to accidental errors of observations, a gradual march, step by step, day by day, from a low value to a high one and return would be the exception. We find it to be the rule, hence we must exclude accidental errors as the main source of the apparent variability of the sun. As for the other explanation suggested, we find no material difference in the result derived for the solar constant on a good day whether we observe at sea-level, at one mile, or at nearly three miles elevation, though the pyrheliometer readings on the ground differ by 25 per cent. between Washington and Mount Whitney. Hence we may reasonably conclude that we do, in fact, correctly estimate the loss which occurs in the atmosphere. The fluctuation in the solar-constant results therefore seems to indicate either a true variability of the sun, or else the interposition of meteoric dust, or other cosmic hindrance to the passage of radiation from the sun to the earth. These fluctuations, while not of regular periodicity, generally run their courses within five or ten days.[16]

It is now proposed to test this conclusion by conducting solar-constant measurements simultaneously at Mount Wilson and in southern Mexico. If the results of a long series of daily observations at these remote stations should agree, it would seem quite unlikely that any apparently simultaneous fluctuations of the solar constant of radiation could be attributed to terrestrial influences.

SUMMARY.

Special apparatus, including the silver-disk secondary pyrheliometer, the absolute water-flow pyrheliometer and the recording spectro-bolometer, has been employed by the writer and his colleagues at Washington and Mount Wilson and Mount Whitney, to determine the mean value of the solar constant of radiation, and its possible fluctuations.

The observations, exceeding 400 in number, have been made in all the years since 1902 to 1910, but most plentifully and accurately in 1908, 1909 and 1910. The mean value of the intensity of solar radiation outside the atmosphere, at mean solar distance, is found to be 1.922 (15°C.) calories per square centimeter per minute, but might prove 1 or 2 per cent. higher in years of less sun-spot activity. The solar-constant values do not appear to depend on the altitude of

---

[16] See Abbot and Fowle, *Astrophysical Journal,* April, 1911.

the observing station, up to the highest altitude tested, 4,420 meters. Fluctuations in the values proceeding step by step, day by day, from higher to lower values and return, within a range of about 8 per cent. usually occur in somewhat irregular intervals of from five to ten days in total period. These fluctuations are thought to indicate a true variability of the sun. It is proposed to test this conclusion by daily observations extending over several months, and to be made simultaneously in California and southern Mexico.

SELF-LUMINOUS NIGHT HAZE.

By E. E. BARNARD.

(Read April 21, 1911.)

There is one phase of the night skies which does not seem to have received much or any attention. It is the occasional presence of self-luminous haze. This matter does not seem to be similar to the luminous night clouds, "die leuchtenden Nachtwolken," which were observed by O. Jesse and others some twenty-five or thirty years ago, and which were found to be clouds at such great altitudes above the earth's surface (upwards of fifty miles high) that they received the sunlight long after or before the ordinary clouds. The observations of O. Jesse were printed in the *Astronomische Nachrichten,* Bd. 121, pp. 73, 111; Bd. 130, p. 425; Bd. 133, p. 131; Bd. 140, p. 161. In *A. N.,* Bd. 140 (No. 3347), he gives a long list of altitudes, determined by photography, which range from 81 km. to 87 km. The mean value given by the observations from 1885 to 1891 was 82 km. (52 miles). These clouds were seen in the northern hemisphere only near the time of the summer solstice. In the southern hemisphere they were seen at the opposite season. From his papers it is clear that these sunlit clouds were in no way related to the present subject, and I only mention them to forestall any suggestion that they were similar to the ones seen by me. The objects to be described here were apparently at the altitude of the ordinary higher clouds. They have been seen in all parts of the sky and at all hours of the night. In a paper on the aurora[1] I have previously called attention to the frequent luminous condition of the sky at night. This feature long ago impressed itself upon me. Indeed any one who has spent much time under the open sky hunting comets, etc., will have been forcibly impressed with this peculiarity. In most cases this illumination has been due evidently to a diffusion of the

---

[1] "*Astrophysical Journal,* 31, April, 1910.

general star light, perhaps by moisture in the air. This latter condition is present as a whitening of the sky, which gives it a "milky" appearance. At other times the sky is more or less feebly luminous, but the luminosity is different from the other condition and is evidently not due to a diffusion of star light. In reality the sky seems to be self-luminous. Sometimes the whole sky has this appearance, and at other times a large portion only. At times the illumination is so great that the face of an ordinary watch can be read with no other light than that of the sky. It is indeed seldom that the sky is rich and dark. In any determination of the total amount of the light of the sky the results must be uncertain because of the great changes that so often take place in the amount of the illumination. The self-luminous condition frequently occurs when no ordinary indications of an aurora are present. It is, nevertheless, doubtless of an auroral nature, for Professor Campbell has shown that the spectrum of the aurora is essentially always present on a clear dark night. (*Astrophysical Journal*, 2, August, 1895, p. 162.)

I have given an account[2] of the remarkable pulsating clouds of light that are seen here occasionally and which usually, but not always, have an easterly motion—generally southeast. They are mostly confined to the northern half of the heavens. There is another phenomenon that has been visible on a number of nights of last year, and also in the present year, of which I have seen no record. This consists usually of long strips of diffused luminous haze. I believe that this is really ordinary haze, which for some reason becomes self-luminous. It is not confined to any particular region of the sky nor to any hour of the night. It always has a slow drifting motion among the stars. This motion is comparable with that of the ordinary hazy streaky clouds that are often seen in the daytime. They are usually straight and diffused and as much as 50° or more in length and 3° or 4° or more in width. In some cases they are as bright, or nearly as bright, as the average portions of the Milky Way—that is, they are decidedly noticeable when one's attention is called to them. They apparently are about as transparent as ordinary haze. Sometimes, when seen near the horizon, where

---

[2] *Astrophysical Journal*, **31**, April, 1910, p. 210, etc.

they may be quite broad, they have strongly suggested the "dawn" or glow that precedes a bright moonrise. Their luminosity is uniformly steady.

The reason I speak of this matter as haze, and the reason I think it is only ordinary haze made self-luminous, is because on one occasion I watched a mass of it in the northwestern sky which was slowly drifting northerly in the region of the great "dipper" of Ursa Major as daylight came on. These hazy luminous strips had been visible all the latter part of the night—new strips coming and going slowly, sometimes several being seen at once. As daylight killed them out I noticed, when the light had increased sufficiently, that there were strips of ordinary haze exactly the same in form and motion and occupying the same region of the sky. I am sure they were the same masses that had appeared luminous on the night sky. My impression, therefore, is that these hazy luminous strips were only the ordinary haze which had for some reason become self-luminous. I am specially certain that these masses are not luminous as a result of any great altitude which might bring them within reach of the sun's light, for they were frequently seen in such positions that the sun's rays could never reach them. The sun or moon, therefore, had nothing to do with their illumination. It is also needless to say that they are not related to the pulsating auroral clouds which I have previously mentioned.

I have not noticed this luminous haze in former years, though it may have been present, and did it not seem unreasonable, one might suspect some relation between this condition of the atmosphere and the possible passage of the earth through a portion of the tail of Halley's comet on 1910, May 19.

I will give here the observations which I have obtained of these singular features. It seems to me that these objects should be observed and a record made of the times of their visibility and their motion, etc. It would be valuable to have records of them from different stations to see if their luminosity is due to some general condition of the earth's atmosphere at the time. It is not probable that this luminosity is in any way due to local conditions. In the records here given, it is possible that on one or two occasions an aurora was also present, but I have tried to confine the accounts to what I have called, and believe to be, self-luminous haze. They were not seen previous to June 7, 1910.

THE OBSERVATIONS.

1910, June 7d 13 h 0m. These diffused luminous masses were seen in different parts of the sky. They were specially noticeable near the southern horizon where the appearance was that of a definite whitish light stretching along above the horizon for a considerable distance. Long bands of this matter were parallel with the southern horizon and above Antares. In the east a long strip 3° or 4° wide stretched from α Pegasi to α Andromedæ and beyond. This moved slowly eastward. At 13h 30m another was passing through the bowl of the great "dipper" in the northwest with a slow easterly motion. A very broad one was situated about 15°–20° from the zenith to the west. They were about as bright as the Milky Way in Cygnus. I waited until near sunrise, and could then see a long mass of ordinary haze, reddish with sunlight, occupying the position of one of the strips that was seen near the bowl of the "dipper," which had been visible as a luminous mass until the dawn had killed it out. There were other strips and masses of haze at different points in the sky when the sun rose. I think it was these streaks and patches of diffused haze that were luminous during the night. They appeared as ordinary haze clouds in daylight. During the entire night there had been no ordinary trace of aurora.

June 9. Though they were looked for several times none was seen until about 10h 30m or 11h 0m. At 11h 25m a long broad hazy streak, as bright as the Milky Way in Cassiopeiæ was seen in the northwest. The lower end was in the "sickle" of Leo near the horizon. Its upper end was 15° below the polar star. From a sketch at 11h 25m the following points were taken which were involved in the hazy strip:

α 10h 5m	δ + 21°.5.
α 9 5	δ + 49.

It extended beyond this latter point for quite a distance—roughly to about

α 7h 0m δ + 67°.

The stars were visible through it where it passed over them. The motion was slowly to the northwest among the stars. Its width was 5°. At 12h 0m a similar band passed over the "dipper" parallel to the first one, evidently moving in the same direction. The first one at this time had either disappeared or was too near the horizon to be seen. At midnight I could read the time by my watch with only the illumination from the sky, which was milky and whitish or luminous.

June 10d 10h 45m. A long strip passed through Polaris and 5° below the bowl of the "dipper." Its motion was towards the north by east horizon. 11h 0m a great number of luminous masses were scattered over the western sky (and extending to the south) to nearly as high as the zenith. These were mostly parallel strips with some irregular masses. They extended from the horizon and seemed to diverge upwards.

September 29. The sky was irregularly covered everywhere with a kind of luminous haze which occurred in great areas and in strips, with a few clear spaces between which were relatively dark. They were more or less conspicuous. At 8h 25m a diffused luminous band stretched from Corona Borealis to the southwest horizon —nearly north and south. This continued northerly nearly to the pole and was diffused to the west. In the south and southeast for 20° above Fomalhaut to α Ceti was the upper edge of a luminous mass of haze covering the southeast sky to the horizon. Other diffused areas of this matter were visible at different points over the sky. The whole sky was more or less luminous, but less noticeable than the regions described above. By 8h 50m the broad luminous strip at Corona Borealis had drifted a little east among the stars, but it seemed to go westward with them. At 11h 10m a watch could be read by the light of the sky. This was one of the brightest of the luminous nights that I have seen. The matter seemed to be only ordinary haze but luminous for some reason. There was no trace of aurora. The sky on which the luminous haze was seen was, at this time, brightened with a pale uniform illumination covering the entire heavens and nearly blotting out the Milky Way. These masses had very little motion. The sky was too luminous for long exposures with a portrait lens.

September 30. At 9h 15m for 10° above the east by north horizon a broad luminous band 50° long was seen just above and involving Aldebaran. It stetched to the south of the east point and in brightness resembled the appearance produced by the moon just before it rises. The light was soft, yet conspicuous. At 10h 10m under Capella was a large soft diffused light—diffusing to the east and beyond. This light was steady with no fluctuations. Nothing of a similar nature was visible in the north or elsewhere. The sky was dull and more or less luminous. At 10h 55m the illumination extended half way up to Aldebaran and the sky near the horizon was luminous like moonrise. This extended from 25° south of east to nearly due north, rising much higher under Capella —a very soft and steady illumination. 12h 0m. The illumination was feeble and diffused. At 12h 30m it was very feeble and mostly in the northeast—scarcely noticeable. At this time dark smeary haze was visible all over the south. No evidence of an ordinary aurora was seen during the night. The sky was luminous all over, but not so much so as on the twenty-ninth.

October 1. There was a bright aurora.

October 2, 8h 0m. A pale illumination was seen in the low north and also in the low east. The effect was probably auroral.

October 6. The night was more or less luminous and misty.

October 28. There was a luminous sky at night.

October 30, 13h 0m. The night was very luminous with fully as much light as would be caused by a one quarter full moon. The Milky Way was scarcely visible. Watch easily read by the glow at 14h 0m. At 15h and 15h 30m a luminous haze covered all the low northern sky as high as half way to the pole. This was not strong and did not look like an aurora. It seemed simply to be luminous haze.

November 1, 12h 15m. The sky was remarkably luminous everywhere. In the north from the horizon to halfway to the pole the sky appeared more luminous than elsewhere. No trace of an arch. The illumination did not look like that from an aurora, but at 15h 30m a strong auroral arch had formed.

November 10, 12h 0m. There was a great amount of luminous haze in the north and northwest. At 15h 0m a large mass 10° high was visible in the northwest. Later there was a long diffused strip, 10° wide, which cut the Milky Way at right angles 20° above α Cygni. It was 40° or 50° in length and did not fluctuate. Its appearance was that of luminous haze. Below it was a region of luminous haze that extended to the north.

1911, February 28, 15h 30m. For 20° to 25° altitude all over the east and northeast the sky was luminous with a soft auroral light. There was no arch or intensification near the usual place for an aurora. This was not due to the presence of the Milky Way at that point.

March 2, 8h 10m. A long mass of luminous haze 6° or 8° broad was visible below β Leonis in the east. It diffused down to the northeast horizon. It seemed to be brighter at times, but there were no certain fluctuations of its light. It was not bright. 8h 50m. The region of luminous haze was passing over Arcturus and moving towards the east horizon. It was nearly horizontal and 30° long with the north end the lowest. 10h 45m. A long mass of luminous haze was visible one half way from Spica to the southeast horizon. It extended south as far as Corvus and inclined to the southeast horizon. It was quite bright and steady in its light. All of the southeastern sky strongly resembled the glow from an expected moonrise. 11h 35m. A strong glow from the southeast horizon extended up to 15° or 20° above Jupiter—like a strong moonrise—all along from the east to the south and diffusing upward. It was conspicuously strong. By this time the sky was increasing in luminosity. In the meantime there had been no trace of aurora during the night. These were the first of the luminous masses of haze that I had seen for a long time, except that of February 28, when it appeared near the northeast horizon.

Since the above observations I have not seen any of this luminous haze on the few clear nights that we have had in the absence of the moon.

YERKES OBSERVATORY,
April 4, 1911.

NOTE.

Since this paper was in type Mr. C. F. Talman, Librarian of the Weather Bureau at Washington, through Dr. W. J. Humphreys, has called my attention to a paper, No. 22, of the Publications of the Astronomical Laboratory at Gröningen, "On the Brightness of the Sky and the Total Amount of Starlight" by L. Yntema. Dr. Yntema calls attention to the frequent luminous condition of the sky and its effect on determinations of the amount of starlight. In section 14 of his paper, which is devoted to earthlight, he gives numerous records of this illumination. There does not appear to be any direct reference, however, to the main features of my paper—the luminous hazy strips and masses.

May 15, 1911.

SPECTROSCOPIC PROOF OF THE REPULSION BY THE SUN OF GASEOUS MOLECULES IN THE TAIL OF HALLEY'S COMET.

BY PERCIVAL LOWELL.

(*Read April 21, 1911.*)

1. The return of Halley's comet has been noteworthy chiefly for the possibility of employing upon it modern methods of instrumental research. Since its last previous apparition have been devised those two great engines of astronomic exploration, spectroscopy and celestial photography. The former has afforded us our first direct knowledge of the substances composing comets, while the latter has given us a means of easy and rapid registration of the visitant's appearance. This is especially valuable in the case of a body as vast and vague as a comet, free-hand drawing of which is peculiarly liable to distortion.

During the last return of Halley's comet that body was subjected at Flagstaff to investigation by both instruments simultaneously. One result of this was the detection that gaseous molecules—in contradistinction to minute solid particles merely—are directly repelled by a force emanating from the sun, presumably the pressure of light. Previously this had been held impossible. Schwarzschild had, as he thought, demonstrated mathematically in an able paper that molecules of gas were too small to be thus affected by the forces concerned and Arrhenius had adopted his deduction, and published it as a fact in his "Worlds in the Making." That the bodies themselves would so soon refute this would not have been deemed probable and invests the detection with the more immediate interest. Incidentally we may remark that Schwarzschild had since given up his original opinion.

2. That the tail of a comet is due to repellant force exerted by the sun is apparent from the direction the tail takes. For that direc-

tion agrees with what would be shown by particles leaving the nucleus and travelling in hyperbolic orbits away from the sun, the sun being in the full or the empty focus according to the speed of recession.

Although the general fact is thus evident, to measure the recession directly is to obtain both an observational proof of it and also something approaching an exact value of the velocity at a given time and place. Accordingly I determined to do this in the case of Halley's comet at its recent apparition. At my disposal were the two hundred photographs taken of it at the Lowell Observatory between April 18 and June 6. To obtain trustworthy results the photographs to be compared must not be separated by too long an interval, since with time a general commingling of the various particles takes place which not only renders particular decipherment of different outbursts impossible but entirely alters the actual speeds. In the case of Halley's comet this difficulty was enhanced by the unusual uniformity of the tail. Irregularities, bunches or knots were rare; the tail presenting as a rule, a remarkably orderly deportment, dishearteningly same. Among the many plates, however, I was able to select a pair taken seriatim capable of recognition and measurement. Some of these handles to investigation were in the nature of bunches of matter, some of abrupt changes in its direction looking like promontories along the general line of the tail. I chose four of the more salient excrescences and selecting identical features of them in the two negatives measured their respective distances from the nucleus on the two plates. The first plate was exposed from 9h 23m to 9h 53m and the second from 10h 0m to 10h 53m, so that the one followed directly on the other.

When the angular amounts of the changes in place of the several knots were corrected for differential refraction and then reduced to speeds, account being taken of the distance of the comet from the earth and of the inclination to the line of sight of the respective positions along the tail, the results came out as follows:

From these measurements the fact emerges unmistakably that a repulsive force directed away from the sun acted upon the particles on the tail.

Tail of Halley's Comet.

	Angular Distance from the Nucleus to the Point Measured in the Tail.	Velocity of the Point of the Tail Away from the Nucleus.
Knot 1	1° 28′	13.6 miles a second
Knot 2	3° 12′	17.2 " " "
Knot 3	4° 36′	19.7 " " "
Knot 4	6° 15′	29.7 " " "

3. While the series of direct photographs was being taken two series of spectrograms were being carried on by Dr. Slipher, one with an objective prism; the other set through a slit. The objective prism ones recorded simultaneously the spectrum of the nucleus and head, together with that of the tail out to about 11° from the nucleus. One of them was got on May 23 at the same time as the photographs measured; while others were obtained on dates before and after. Of the direct information afforded by these spectrograms of the constitution of the comet an account is given in the extensive monograph on the comet published by the Lowell Observatory.

4. But a third result was obtained by the unwitting collaboration of the spectrograms and the photographs. While the photographs were giving their pictures of the tail, the objective prism spectrograms were doing the like, with this difference that they recorded in a row pictures of it in the several colors of the spectrum, sifting out into a band those made by each separate wave-length of light. They thus made it possible to tell to what wave-lengths the visible appearances were due. For it became evident at once from the spectrograms that all wave-lengths were not equally concerned. On the contrary, there were in the spectral image several distinct tails with spectral gaps between. By an analysis of the wave-lengths yielding pictures of the tail was thus offered a diagnosis of the substances composing it. In this way it appeared that CO_2, carbon monoxide, was the chief constituent of the tail; CH_4, marsh gas, another; CN, cyanogen, a third component; and minute solid particles, giving a more or less continuous spectrum, a fourth.

That not one but a series of spectrograms was taken was important. It not only gave us a constitutional history of the tail but it showed the necessity of simultaneity in photographic and spectrographic observations for comparative purposes. For the series demonstrated that the constituents of the tail varied markedly from one period to another. Thus from April 29, 1910, to May 7 the spectrum of the tail was almost wholly emissive. On May 11 it had changed to one nearly continuous, while on May 23 it had become largely emissive again and grew more so as time went on.

By comparing the photographic with the spectrographic series of representations of the tail a striking fact came to light. To appreciate this another point must be taken into account. In order to compare properly a photograph and a spectrogram, both should be made on the same brand of plate. No plate reproduces all parts of the spectrum with equal intensity. One kind of plate will emphasize certain rays and depreciate others; the next will reverse the estimation. Great error will then be introduced unless the plates be identical.

Now the photographs measured were taken with a Brashear 5-in. doublet, an excellent lens, on a Lumiere Σ plate. The rays registered by this plate extend from 3500 in the violet to 5160 in the green where the sensitiveness ceases. Indeed the effect would have stopped sooner had it not been for the hydrocarbon emission at this point. The light, therefore, of the photograph would be exactly differentiated into its constituents by a spectrogram taken on a Lumiere Σ plate. The only difference between the two would be due to the absorption of the objective prism, an absorption relatively greater for the violet than for the blue or green. This would work as much on one kind of light as on another of the same refrangibility and as the two different kinds we are considering, the emission and the continuous spectrum, are about equally spaced in the region of the violet, the correction needed on this account is small. We may, then, directly gauge the character of the photograph's light by that of the objective prism spectrogram taken on the Σ plate.

This we now proceed to do. On the exact date of the photograph no Σ plate was used with the two objective prisms though we have objective prism spectrograms on Cramer Iso. Instantaneous on May 23, 25, 26, 28 and 29. The nearest plate to the date in question was on May 29. Of this the best estimate gives for the constituents of the light of the tail at a distance of 3° to 6° from the head:

80 per cent. of emission bands of carbon monoxide,
20 per cent. continuous spectrum,

the hydrocarbon emission being, at this distance from the head too feeble to show.

Comparing now the spectrograms taken with a Voightlander lens and a Cramer Iso. Inst. plate on May 23, 25, 26, 28 and 29 we find that the ratio of the two kinds of light varied in the direction of relatively greater emission from the former to the latter date. On May 23 itself the plates are affected by moonlight so that a direct comparison of the relative ratios is too difficult to be made a basis of direct comparison, but that of May 28 gives for the ratios in the tail 3° from the head:

70 per cent. emission of carbon monoxide,
5 per cent. emission of hydrocarbons,
25 per cent. continuous spectrum.

Putting these facts together we shall not be far out of the way in stating the ratio on May 23 of the emissive and continuous spectrum of the tail at a distance of from 3° to 6° from the head for the Σ plate as

70 per cent. emission spectrum, CO and CH_4,
30 per cent. continuous spectrum.

We have then this interesting conclusion: that the knots which showed the action of a repulsive force exerted from the sun were chiefly composed, not of solid particles, but of *molecules of gases.*

5. To clinch this deduction I next turned to comet Morehouse. Catechized in this connection it not only corroborated the fact but emphasized it. Before the time of measuring the velocities in the tail of Halley's comet I had done the like for comet Morehouse, the knotted character of its tail offering promising inducement. I was not aware that Mm. Quenisset and Baldet, in France, and Professor J. A. Miller, of Swarthmore, Pa., had measured photographs of this comet in this manner previously and detected the same accelerated motion away from the head which my own later measures showed. My measures have also revealed why certain previous observers such as Barnard at Yerkes and Campbell at the Lick had failed to find such evidence.

Of comet Morehouse this observatory possesses about sixty negatives taken by Mr. E. C. Slipher. Among them are many pairs, the one plate following the other on the same evening. From the assortment thus offered I have selected two sets for measurement, the one a pair taken on October 31, 1908, at 8h om ± to 8h 42m ± M.S.T. and from 9h 14m ± to 10h 8m ± respectively; and the other a triplet on November 16, 1908, No. 1 being taken at 6h 25m to 7h 13m; No. 2 at 7h 24m to 7h 50m; No. 3 at 8h om to 8h 32m, respectively. I chose four knots on one and five on the other with the following results:

TAIL OF COMET MOREHOUSE, OCTOBER 31.

	Plate I., Distance Knot from Head.	Plate II., Distance Knot from Head.	Difference I. and II.
Knot 1	22′.8	24′.4	1′.6
Knot 2	72′.7	76′.2	3′.5
Knot 3	95′.5	99′.4	3′.9
Knot 4	128′.4	134′.6	6′.2

TAIL OF COMET MOREHOUSE, NOVEMBER 16.

	Plate I.	Plate II.	Plate III.	Diff. I.-II.	Diff. II.-III.
Knot 1	48′.7	49′.9	51′.4	1′.2	1′.5
Knot 2	63′.4	65′.4	66′.9	2′.0	1′.5
Knot 3	79′.7	81′.6	83′.5	1′.9	1′.9
Knot 4	87′.8	89′.3	90′.9	1′.5	1′.6
Knot 5	211′.1	215′.0	217′.7	3′.9	2′.7

6. It will at once be seen that both sets of plates show accelerated velocity in the particles of the tail away from the head as the distance from the head increases. In the first set the acceleration is fairly uniform, while in the latter the velocity does not increase until the distance out has become considerable. This affords the reason why some observers have failed to detect the motion. It is at times and in certain places masked. For this the following explanation may be offered: In the neighborhood of the head the several emissions are violently contorted as a mere inspection of the photographs show, and in consequence must be subject to collision with other portions of the tail. Possibly they encountered here matter in space which speaks unspeakably of motion other than that due solely to repulsive force. If now an observer chanced to make his measures

at this inopportune moment he would naturally conclude that no repulsion existed while in truth another motion was temporarily obstructing it.

7. Lastly the spectrograms and spectroscopic observations of Frost and Parkhurst, de la Baume Pluvinel and Baldet agree in showing the light of the tail of Morehouse's comet to have been due practically wholly to emission; in other words to glowing gas. Here, then, we have not only corroboration of the fact, brought forward from study of Halley's comet, to wit: that molecules of gas are repelled by the sun, but, from the light of the tail being composed solely of gaseous molecules, any supposition that they were not the cause of the visible effect, is entirely excluded.

We reach then this interesting conclusion: that molecules of gas not only may be but demonstratedly are repelled by the action of the sun and that though we have reason to suppose that minute solid particles may be similarly impressed it is of the former not the latter that we have direct proof at present.

Lowell Observatory,
April 10, 1911.

THE NEW COSMOGONY.

By T. J. J. SEE.

(*Read April 21, 1911.*)

The results established in the writer's "Researches on the Evolution of the Stellar Systems," Vol. II., 1910, have given a new basis to our conceptions of the cosmogony. Instead of the traditional doctrine of throwing off, we now have that of capture, which means essentially that the nuclei originated in the distance and have since grown by accretion as they approached the centers about which they now revolve in greatly reduced orbits of small eccentricity. Not only have we witnessed a radical change in the point of view, but also in the method of research employed. And along with these changes has come the introduction of rigorous mathematical and dynamical criteria by which the mechanical principles involved may be extended over an almost unlimited period of time.

Not the least important of the improvements recently introduced is that resulting from a careful examination of the premises underlying our reasoning. Nothing is adopted from tradition, nor taken for granted, nor from any authority however high; but every question is examined on its merits and from the very ground up. As the subject is new it naturally follows that much still remains to be done; yet the general trend of nature's laws seems to be well established, and cosmogony begins to assume the form of a true science. Accordingly it may not be without interest to the general reader to summarize in one connected view the leading principles of the new science of cosmogony, with brief analysis of the criteria by which they are confirmed.

1. Babinet's criterion based on the mechanical principle of the conservation of areas, by which we are enabled to calculate the times of rotation of the sun and planets when expanded to fill the orbits of their attendant bodies, as imagined by Laplace. This enables us to say at once that the attendant bodies could never have

been detached by acceleration of rotation, as handed down by tradition from Laplace's original nebular hypothesis of 1796.

2. As the planets and satellites could not have been thrown off, they must have been captured and added on from without, or else have been formed from the agglomeration of fine dust right where they now revolve. This latter alternative, however, is easily shown to be impossible, owing to the feeble mutual gravitational attraction of small masses of matter under the stronger tendencies to dispersion by tidal action, which always exist near large centres of attraction. There remains therefore no possible mode of origin for the planets and satellites save that of capture, or addition to the system from without.

3. When first captured the satellites must therefore have been already of such considerable size that they were able to gather in, and consolidate with their globes, numerous smaller masses revolving in the vortices about the planets. The collisions arising in this process of the gathering in of smaller bodies by larger ones are strikingly illustrated by the craters noticed in the face of the Moon, which were formed by impact, the embedded satellites being in some cases at least twenty miles in diameter.

4. Thus while the satellites were all captured,[1] and were originally further from their planets than they are at present, they have grown larger in the course of ages as they revolved in the resisting medium about the planets, just as the earth and primary planets are still growing larger by the impact of meteorites against their surfaces, as they slowly approach the sun. The earth sweeps up daily 1,200,000,000 meteors, and the amount of this dust is calculated to to form a layer a millimeter thick in a century.

5. We know the satellites must have grown in mass since they were captured, because they have been drawn nearer and nearer their several planets, by increase of the central attraction, as in the celebrated problem of Gyldén.[1a] But if the mass of the sun has increased, by the downfall of cosmical dust, so also must the mass

---

[1] Since this was written the capture of Satellites has been independently confirmed by Professor E. W. Brown, in an important paper in the *Monthly Notices of the Royal Astronomical Society* for March, 1911, p. 453.

[1a] *A. N.*, 2593.

of the planet or satellite have been correspondingly augmented by the same cause.

6. For whilst the decrease of the major axis of the orbit of a satellite might result wholly from the growth of the mass of the planet and satellite, yet the decrease of the eccentricity of a satellite orbit can be explained only by collisions in the nebular resisting medium. This cause and no other whatsoever will explain the roundness of the orbits so characteristic of the solar system.

7. Accordingly as most of the satellites suffered collisions sufficient to reduce and well nigh destroy the eccentricities of their orbits,[2] it necessarily follows that all these bodies should have their surfaces indented by impacts with smaller masses, just as is shown by the craters on the moon.

8. For whilst Oppolzer, Gyldén and others have proved that the growth of the masses by the downfall of cosmical dust would increase the central attraction and bring the bodies close together, it is proved by the mathematical researches of Airy, Herschel, Lehmann-Filhés, and Strömgren, which I have carefully verified, that this decrease in the major axis does not decrease the eccentricity. Hence the decrease of the eccentricity is traceable to no cause whatsoever but the action of a nebular resisting medium, as held in my "Researches," Vol. II., p. 146.

9. The craters on the moon can therefore be due to no cause whatsoever other than the collisions which our satellite has suffered from other small bodies in space, and all divisions of opinion on the subject are henceforth swept away forever. For as the other satellites have had their orbits rounded up in nearing their several planets, it is necessary to suppose the same cause to have acted also on our moon, even if the eccentricity of the orbit in this case has not been rendered excessively small.

10. This solution of the problem of the roundness of the orbits—the leading problem in the cosmogony of our solar system—is what mathematicians call a *unique solution*. It reveals not only *a possible*, but also the *only possible cause of the extremely circular move-*

---

[2] In section 548 of his "General Astronomy," edition of 1904, the late Professor C. A. Young remarks that the "almost perfect circularity of the satellite orbits is not yet explained."

ment characteristic of the planets and satellites. The solution thus possesses all the rigor of a theorem in geometry, and meets the requirements of the most rigorous of the mathematical sciences.

11. The existence of planets beyond Neptune is indicated by the extreme roundness of Neptune's orbit; for this shows that the nebulosity was much too dense at that point for the system to terminate at the present known boundary. Moreover, as I have shown that the planets were originally connected with the comets, and the comets recede to their home in a spherical shell thousands of times the earth's distance from the sun, it necessarily follows that our planetary system extends on almost indefinitely. Several planets of considerable size must be assumed to revolve beyond Neptune, and they may yet be discovered by observation or photography, though at that great distance the practical difficulties will increase, owing to the feebleness of the sun's light and the slow orbital motion, which will require exposures of the photographic plate extending over many hours, and perhaps on successive days.

12. The planets have been built up out of cosmical dust, comets and satellites; so that all the matter now in the planets come originally from the heavenly spaces. This follows from the fact that the nebular development is from the outside toward the center, the formation always beginning in the distance and proceeding by accretion as the bodies gravitate towards the sun, and revolve in ever smaller and rounder orbits. This order of development is directly verified by the phenomena of the spiral and ring nebulæ; for here the movement is proved to be towards the center, where the sun develops for the domination of the system.

13. And just as our planets have been added onto the sun from without, not thrown off, as was erroneously taught for more than a century by Laplace and his successors, so also will similar planets have been formed by the same process about the other fixed stars. Thus there are undoubtedly systems of planets about the fixed stars, and they are habitable and inhabited like those revolving about the sun. Moreover, the other suns have their systems of comets, and their planets have captured systems of satellites as in our planetary system. This grand conclusion rests on an incontestable basis and is of transcendent philosophic interest.

14. The causes which have operated in the development of our solar system are thus general throughout the sidereal universe. Everywhere repulsive forces are dispersing fine dust from the stars to form the nebulæ, and the nebulæ in turn are settling down and whirling around to form stars with planetary systems about them.

15. Professor Barnard's magnificent photographs of the Milky Way show that cosmical dust everywhere pervades the heavenly spaces. And it is proved that variable stars are due chiefly to attendant bodies revolving in resisting media. When considerable bodies come into collision, as a large planet with a sun, the result is a temporary star or Nova.

16. The new cosmogony thus embraces within its scope the chief problems of the universe, and the dynamical causes assigned are deduced from simple phenomena operating according to known laws which are actually verified in the solar system. The arrangement of the nebulæ on either side of the Milky Way is the natural outcome of the operation of repulsive forces, the canopy of nebulæ congregating as far from the stratum of stars as possible. This assigns a known cause for the great order of nature first brought to light by the telescopic explorations of the elder Herschel in 1785.

Like astronomy itself it is obvious that cosmogony is at once the oldest and newest of the physical sciences. Having renewed its youth by the introduction of definite principles and exact methods, it has recently taken on such vigor that it promises to become the most majestic of the sciences. Nothing is more worthy of the attention of philosophers than the study of the great laws of the physical universe, and the marvelous processes of development by which the beauty and order of the cosmos came about. This was the great problem which gave rise to the development of the physical sciences among the Greeks, and it will always occupy a position of transcendent importance in the domain of natural philosophy.

U. S. Naval Observatory,
Mare Island, California,
April 3, 1911.

THE EXTENSION OF THE SOLAR SYSTEM BEYOND NEPTUNE, AND THE CONNECTION EXISTING BETWEEN PLANETS AND COMETS.

By T. J. J. SEE.

(*Read April 21, 1911.*)

One of the most remarkable results of the writer's recent researches on the origin of the solar system has consisted in the development of a satisfactory proof that the primordial nuclei of the planets were formed at great distances from the sun, and that their primitive orbits were highly eccentric like those now described by the comets; so that in the last analysis it is shown that the two classes of bodies are merged together, or rather that the planets have been built up by the agglomeration of cosmical dust, in the form of comets, and other fragments of matter, from our ancient nebula. The following is a brief outline of the thread of argument leading to this conclusion:

1. It is shown by the exact data supplied by Babinet's criterion that not one of our planets could have been thrown off from the sun, by acceleration of rotation, as imagined by Laplace in 1796, but that the nuclei must have started in the distance and since neared the sun, by insensible degrees, as the masses were gradually augmented by precipitations from the surrounding nebular medium.

2. When it was thus demonstrated by exact calculation that the premise handed down by Laplace is erroneous, our theory of planetary genesis was placed on a new basis by the proof that the roundness of planetary orbits is due to the secular action of a resisting medium, which has reduced the size of the planetary orbits and rendered them almost exactly circular.

3. In order to be so exactly circular, as they are now found to be, these orbits must originally have been very large, and also highly eccentric, like the orbits of comets; the orbits accordingly have been reduced in size by encounters with the other minor bodies, the

absorption of which also increased the masses of the planets enormously.

4. If one asks for ocular evidence that the planetary bodies have been in collision with smaller masses, this evidence is found in the phenomena shown in the face of the moon, which was formerly an independent planet, and is so small a globe as never to have developed water or atmosphere; so that it is a kind of hermetically sealed celestial museum, so near us in space that it serves for the illustration of the process of *absorption* and *capture* in cosmogony. The type of collisions visibly illustrated by the dents in the moon's face necessarily have occurred with all the planets; but the moon as our nearest planetary neighbor alone enables us to study the process of accretion by collisions with bodies of all sizes, from particles to satellites as large as twenty miles in diameter.

5. The obvious deposits of dust over the older lunar craters give them an aspect of great age, and in many cases the outlines of the craters are practically obliterated. In other cases newer craters are formed over the older ones; so that we can certainly infer by direct observation that the moon has been built up by accretion, dust being gathered in to be deposited over dust, and crater over crater. This is the same process which we see at work on the earth, except that the meteorites now swept up by our planet are generally small and consumed in the air before reaching the earth.

6. Since the planets were begun as independent nuclei in our nebula, and since augmented by the gathering together of an infinite number of small bodies, such as comets, the matter of planets and comets must necessarily be the same, for they are common products of our ancient nebula. The planets have been built up by the gathering in of satellites, comets and smaller particles of cosmical dust.

7. Now we have pointed out that Neptune's orbit is too round for it to be the outermost of the planets of the solar system. If the resisting medium was dense enough at that great distance to produce such extreme circularity in the motion of Neptune, there was enough of the nebulosity beyond that planet to make several more planets of comparatively large size. Thus it is certain that our system does not terminate at Neptune, but extends on almost indefinitely. It is probable that in time we may be able to discover

several trans-Neptunian planets; but the recognition of these remote bodies will be difficult, owing to their slow motion and the faintness of the sun's light at that great distance.

8. The notable expansion of our ideas of what constitutes a nebula will thus be of great practical use in the progress of astronomy. The overthrow of the theory of Laplace is only a small part of the service to science brought about by the discovery of the true laws of the development of our system. As the *comets* recede to distances amounting to thousands of times the earth's distance from the sun, so also must embryo *planets* be imagined to bridge over the gap heretofore separating the planets and comets. And we may imagine planets to extend to at least 100, perhaps 1,000 times the earth's distance from the sun. Some of the comets may go 100 times further yet, but at such great distances we can never know much about their motions in these remote regions of space.

9. When we contemplate the vast extent of our primordial nebula implied in the distances to which the comets recede, and remember the large apparent areas covered by many other nebulæ in the sky, we see that our solar nebula evidently was of the ordinary type, and that it certainly was not a gaseous mass in equilibrium under hydrostatic pressure and extending only to the orbit of Neptune. Of course all these old doctrines of Laplace are now quite abandoned, but they long deceived us, and kept cosmogony in a stationary condition for over a century.

10. The origin of the primordial nuclei in the distance is a necessary consequence of the working of planetary bodies towards the dominant center of attraction—the sun. Hence the formation of a system of planets is necessarily from without inward, just the reverse of the traditions handed down by Laplace. This harmonizes perfectly with the new theory of the spiral nebulæ, which makes the ring nebulæ particular cases of the more general spiral tendency. The formation in all cases is from the outside towards the center. Planets form in all nebulæ, and since small bodies approach the center more rapidly than large ones, under the action of a resisting medium, it follows that the planets thus capture systems of satellites such as we observe attending the planets of the solar system.

U. S. Naval Observatory,
March 7, 1911.

THE SECULAR EFFECTS OF THE INCREASE OF THE SUN'S MASS UPON THE MEAN MOTIONS, MAJOR AXES AND ECCENTRICITIES OF THE ORBITS OF THE PLANETS.

BY T. J. J. SEE.

(Read April 21, 1911.)

In the days of Newton, Lagrange and Laplace, it was assumed that the formation of the planetary system was essentially complete, and the sun's attraction rigorously constant from age to age; and it was scarcely deemed necessary to consider the secular effects of slight modifying causes such as the downfall of cosmical dust upon the bodies composing the solar system. But the progress of the past century has shown that the Newtonian hypothesis of a constant mass and a central attraction depending wholly on the distance, but not on the time, is at best a very rough approximation to the truth; for in addition to the downfall of cosmical dust upon all the bodies of our system, it has been shown by the researches of Arrhenius, Schwartzchild and others, that the sun especially is losing finely divided matter under the action of repulsive forces such as we see illustrated in the streamers of the corona and the tails of comets. In our modern studies of the orbital motions of the heavenly bodies, therefore, we have to take the central mass as variable with the time, and consider the small secular changes which will follow from a variation of the central attraction incident to a gradual change of mass.

These questions have been treated in some form by many of the successors of Newton; and even this great philosopher himself in one case supposed that the central mass might be varied by a comet falling into the sun.[1] Laplace devotes considerable attention to the secular equations for determining the effects of the decrease of the sun's mass due to loss of light, then supposed to be of corpuscular

---

[1] "Principia," Lib. III., last proposition.

character.[2] The modern discussions based on the analytical methods of Gyldén are, however, much more satisfactory than those of the age of Laplace; and I propose to give a brief account of them, chiefly with a view of summarizing the state of our knowledge, and of removing some inconsistencies which may mislead those who are unfamiliar with the literature of the subject.

For example, in the late Professor Benjamin Peirce's "Ideality in the Physical Sciences," Boston, 1881, p. 131, the following curious statement occurs:

> The constant increase of the solar mass would have an influence on the planetary orbits. It would diminish their eccentricities, according to a law of easy computation. Hence it is possible that the orbits of the planets may have been originally very eccentric, almost like those of the comets; and their present freedom from eccentricity may have resulted from the growing mass of the sun. What modification of the nebular theory may be involved in this supposition cannot easily be imagined, without the guidance of some indication from nature.

This statement is misleading and erroneous, and the only way I can explain its appearance in the writings of Peirce is by the fact that his last lectures were prepared when he was at an advanced age and in ill health; and thus it is probable that some confusion occurred. Quite recently an analogous confusion has appeared in the *Astronomische Nachrichten,* No. 4454, in a short article by Dr. R. Bryant, on the secular acceleration of the moon's mean motion.

In order to place before the reader a summary of the chief investigations bearing on the problems now under discussion we cite the following papers:

1. "The Problem of the Newtonian Attraction of two Bodies with masses Varying with the Time," H. Gyldén (*A. N.,* 2593).
2. "Ein Specialfall des Gyldén'schen Problems," J. Mestschersky (*A. N.,* 3153 and 3807).
3. "Ueber Central Bewegungen," R. Lehmann-Filhés (*A. N.,* 3479–80).
4. "Note on Gyldén's Equations of the Problem of Two Bodies with Masses Varying with the Time," E. O. Lovett (*A. N.,* 3790).
5. "Ueber die Bedeutung Kleiner Massenänderungen für die Newtonsche Central Bewegung," Dr. E. Strömgren (*A. N.,* 3897).

---

[2] Mécanique Céleste, Liv. X., § 20.

The last of these papers is the most important, since it supplements and extends the results of the earlier investigators. Professor Strömgren's method is one of great generality and appears to be the most satisfactory yet devised; and we shall base our brief discussion chiefly on this paper.

If σ be a very small quantity, and $\phi(t)$ some function of the time, the original unit of mass becomes $1 + \sigma\phi(t)$, and the differential equations of motion become

$$\left.\begin{aligned} \frac{d^2x}{dt^2} + k^2[1 + \sigma\phi(t)]\frac{x}{r^3} = 0, \\ \frac{d^2y}{dt^2} + k^2[1 + \sigma\phi(t)]\frac{y}{r^3} = 0; \end{aligned}\right\} \qquad (1)$$

where k^2 is the gravitation constant, and the mass is unity at the initial epoch $t = 0$.

The new constant of areas becomes

$$x\frac{dy}{dt} - y\frac{dx}{dt} = k\sqrt{[1 + \sigma\phi(t)]p} = \text{const.} \qquad (2)$$

Other formulæ of interest are:

$$V^2 = k^2[1 + \sigma\phi(t)]\left(\frac{2}{r} - \frac{1}{a}\right), \qquad (3)$$

$$\delta a = a_0\sigma\phi(t) - 2a_0^2\sigma\int_0^t \phi'(t)\frac{1}{r}dt, \qquad (4)$$

$$\frac{1}{r} = \frac{1}{a}[1 + 2\Sigma J_i(ie)\cos i(e + nt - \pi)] \qquad (5)$$

And finally after a careful investigation of all effects due to errors of the first order of the disturbing force, $\sigma\phi(t)$, Strömgren finds:

$$\left.\begin{aligned} \delta a &= -a\sigma\left[t + 2\frac{e}{n}(\sin E - \sin E_0)\right], \\ \delta e &= -\frac{1 - e^2}{n}\sigma(\sin E - \sin E_0), \\ \delta\pi &= \frac{\sqrt{1 - e^2}}{en}\sigma(\cos E - \cos E_0). \end{aligned}\right\} \qquad (6)$$

Here n is the mean motion and E the eccentric anomaly. It will be seen from the first of equations (6) that the semi-axis major is diminished by a secular term depending on t, and by a periodic term depending on the difference of the sines of the angles E and E_0, or the position in the orbit. Thus the mean distance is subjected to both periodic and secular variation.

In the case of the eccentricity, however, the second of the equations (6) shows that there is no secular term, and only periodic changes occur. A similar remark applies to the longitude of the perihelion as shown by the third equation of (6).

We conclude, therefore, from Strömgren's careful analysis that there is no secular decrease in the eccentricity due to a steady growth of the central mass; and that the views expressed by Peirce and Bryant are due to confusion, or to some error in the chain of reasoning.

This conclusion accords with the result reached by Professor Lehmann-Filhés, in paper No. 3.[3] cited above. For Lehmann-Filhés shows that

$$\left.\begin{aligned} e \cos \pi &= e_0 \cos \pi_0 + \text{periodic terms}, \\ e \sin \pi &= e_0 \sin \pi_0 + \text{periodic terms}; \end{aligned}\right\} \qquad (7)$$

and remarks that when the attracting mass slowly increases the orbit slowly narrows up, but yet always remains a similar conic section. He adds that this is true for any eccentricity whatever. The results of Lehmann-Filhés and Strömgren, each worked out independently of the other, and with much detail, are therefore in entire accord; and as Strömgren's development is given in full, and every step in his analysis is quite clear, we must reject the conclusions of Peirce and Bryant as not well founded.

This concllusion that the *steady increase* of the central mass will not diminish the eccentricity also confirms the results reached by Airy[4] and by Sir John Herschel.[5] For these eminent authorities show that a central attractive disturbance decreases the eccentricity as the planet moves from the perihelion to the aphelion, but increases

---

[3] Cf. *A. N.*, 3479–3480.

[4] "Gravitation," pp. 50–51.

[5] "Outlines of Astronomy," tenth edition, 1869, p. 463.

it correspondingly in going from the aphelion to the perihelion; so that only periodic changes of the elements e and π occur.

Accordingly it follows that the only possible cause which could have diminished and practically obliterated the eccentricities of the orbits of the planets and satellites is the secular action of a resisting medium, as fully set forth in Volume II. of my "Researches on the Evolution of the Stellar Systems," 1910. Increasing the central mass accelerates the mean motions, and thus becomes very sensible in the theory of the motions of the planets; but it has no effect on the shape of their orbits. The almost circular form of the planetary orbits, therefore, may be referred to the secular action of a resisting medium and to no other cause whatsoever.

This result is of no ordinary interest, since it refers the roundness of the planetary orbits to but a *single physical cause,* and gives us what mathematicians call a *unique solution* of the leading problem of cosmogony. For Babinet's criterion shows beyond doubt that the planets never were detached from the central bodies which now govern their motions; and the argument given in Volume II. of my "Researches" proves that all these bodies were formed in the distance and afterwards neared the central masses about which they now revolve. The demonstration of the true mode of formation of our solar system is therefore supported by the necessary and sufficient conditions usually required in mathematical reasoning; and we may say that the laws of the formation of the solar system have been confirmed by mathematical criteria having all the rigor required in the science of geometry. This generalization will, I think, add not a little to our interest in the geometry of the heavens; and it is equally worthy of the attention of the astronomer, the geometer and the natural philosopher, who so long struggled to unfold the wonderful process involved in the formation of the planetary system.

U. S. Naval Observatory,
Mare Island, California,
March 20, 1911.

ON THE SOLUTION OF LINEAR DIFFERENTIAL EQUATIONS OF SUCCESSIVE APPROXIMATIONS.

By PRESTON A. LAMBERT.

(Read April 20, 1911.)

The object of this paper is to apply to the solution of linear differential equations, both ordinary and partial, the method of expansion into series used in the solution of algebraic equations in the papers read by the author before the Philosophical Society in April, 1903, and in April, 1908.

Let the given differential equation be

$$(1)\qquad f\left(x, y, \frac{dy}{dx}, \frac{d^2y}{dx^2}, \cdots, \frac{d^ny}{dx^n}\right) = 0.$$

The method of solution consists of the following steps:

(*a*) Break up the left-hand member of the differential equation into two parts,

$$f_1\left(x, y, \frac{dy}{dx}, \frac{d^2y}{dx^2}, \cdots, \frac{d^ny}{dx^n}\right)$$

and

$$f_2\left(x, y, \frac{dy}{dx}, \frac{d^2y}{dx^2}, \cdots, \frac{d^ny}{dx^n}\right),$$

such that the first part equated to zero can be integrated by some known method, and multiply the second part by a parameter S, independent of x and y. Replace the given equation by

$$(2)\quad f_1\left(x, y, \frac{dy}{dx}, \frac{d^2y}{dx^2}, \cdots, \frac{d^ny}{dx^2}\right) + Sf_2\left(x, y, \frac{dy}{dx}, \frac{d^2y}{dx^2}, \cdots, \frac{d^ny}{dx^n}\right) = 0.$$

(*b*) Assume that

$$(3)\qquad y = y_0 + y_1S + y_2S^2 + y_3S^3 + y_4S^4 + \cdots$$

makes equation (2) an identity.

(*c*) In this identity arranged according to the ascending powers of S equate to zero the coefficients of the different powers of S.

(*d*) Solve the differential equations thus obtained in regular order for $y_0, y_1, y_2, y_3, y_4, \cdots$.

(*e*) Substitute these values in (3) and make S unity. The resulting value of y, if it contains a finite number of terms or if it is a uniformly convergent infinite series, is a solution of the given differential equation.[1]

The method of solution of linear differential equations as here outlined does not seem to occur in mathematical literature except as developed by the author.

The method will be exemplified by applying it to two differential equations, important in mathematical physics—Bessel's equation, a second order ordinary differential equation, and Fourier's equation for the flow of heat, a second order partial differential equation.

Bessel's equation is

$$x^2\frac{d^2y}{dx^2} + x\frac{dy}{dx} + (x^2 - n^2)y = 0.$$

Replace Bessel's equation by

$$\left(x^2\frac{d^2y}{dx^2} + x\frac{dy}{dx} - n^2y\right) + Sx^2y = 0$$

and assume that

$$y = y_0 + y_1S + y_2S^2 + y_3S^3 + y_4S^4 + \cdots$$

makes the latter equation an identity.

When arranged in ascending powers of S this identity is

$$\begin{array}{ll|ll|l}
x^2\frac{d^2y_0}{dx^2} & +x^2\frac{d^2y_1}{dx^2} & S & +x^2\frac{d^2y_2}{dx^2} & S^2 + \cdots \equiv 0. \\
+x\frac{dy_0}{dx} & +x\frac{dy_1}{dx} & & +x\frac{dy_2}{dx} & \\
-n^2y_0 & -n^2y_1 & & -n^2y_2 & \\
 & +x^2y_0 & & +x^2y_1 &
\end{array}$$

---

[1] This method gives a formal solution of non-linear differential equations, but up to the present time the author has been unable to test the resulting series for convergency.

Equating to zero the coefficients of the powers of S in this identity, there result the following differential equations for the determination of $y_0, y_1, y_2, y_3, \cdots$.

$$x^2\frac{d^2y_0}{dx^2}+x\frac{dy_0}{dx}-n^2y_0=0,$$

$$x^2\frac{d^2y_1}{dx^2}+x\frac{dy_1}{dx}-n^2y_1+x^2y_0=0,$$

$$x^2\frac{d^2y_2}{dx^2}+x\frac{dy_2}{dx}-n^2y_2+x^2y_1=0.$$

. . . . . .

The equation in y_0 is a homogeneous linear differential equation and its solution is

$$y_0=Ax^n+Bx^{-n}.$$

Substituting this value of y_0 the equation for determining y_1 becomes

$$x^2\frac{d^2y_1}{dx^2}+x\frac{dy_1}{dx}-n^2y_1=-Ax^{n+2}-Bx^{-n+2}.$$

This equation becomes exact when multiplied by x^{-n-1}. The resulting equation integrated gives a linear equation of the first order, the solution of which is

$$y_1=\frac{-Ax^{n+2}}{2^2(n+1)}+\frac{Bx^{-n+2}}{2^2(n-1)}.$$

Substituting this value of y_1 in the equation for determining y_2 and proceeding in the same manner

$$y_2=\frac{Ax^{n+4}}{2^4\cdot2\,!\,(n+1)(n+2)}+\frac{Bx^{-n+4}}{2^4\cdot2\,!\,(n-1)(n-2)}.$$

In like manner

$$y_3=\frac{-Ax^{n+6}}{2^6\cdot3\,!\,(n+1)(n+2)(n+3)}+\frac{Bx^{-n+6}}{2^6\cdot3\,!\,(n-1)(n-2)(n-3)},$$

and so on.

Substituting these values of $y_0, y_1, y_2, y_3, \cdots$ in

$$y = y_0 + y_1S + y_2S^2 + y_3S^3 + y_4S^4 + \cdots$$

and making S unity,

$$y = Ax^n\left[1 - \frac{1}{n+1}\frac{x^2}{2^2} + \frac{1}{(n+1)(n+2)}\frac{x^4}{2^4\cdot 2!} - \frac{1}{(n+1)(n+2)(n+3)}\frac{x^6}{2^6\cdot 3!} + \cdots\right]$$
$$+ Bx^{-n}\left[1 + \frac{1}{n-1}\frac{x^2}{2^2} + \frac{1}{(n-1)(n-2)}\frac{x^4}{2^4\cdot 2!} + \frac{1}{(n-1)(n-2)(n-3)}\frac{x^6}{2^6\cdot 3!} + \cdots\right].$$

When n is not an integer the terms of both series in this value of y continue indefinitely according to the law of formation which inspection makes evident, both series are uniformly convergent except when $x=0$, and both series are solutions of the given differential equation.

When n is a negative integer the law of formation of the terms of the first series changes after the (n)th term and when n is a positive integer the law of formation of the terms of the second series changes after the (n)th term. The second case will be considered.

When n is a positive integer the (n)th term of the second series is

$$y_{n-1} = \frac{Bx^{n-2}}{2^{2(n-1)}(n-1)!(n-1)!}.$$

Substituting this value of y_{n-1} in the differential equation for determining y_n,

$$x^2\frac{d^2y_n}{dx^2} + x\frac{dy_n}{dx} - n^2y_n + x^2y_{n-1} = 0,$$

and solving for y_n by the method used in solving for $y_1, y_2, y_3, \cdots$,

$$y_n = \frac{B}{2^{2n-1}n!(n-1)!}\left[x^n \log x - \frac{x^n}{2n}\right].$$

In determining $y_{n+1}, y_{n-2}, y_{n-3}, \cdots$, the second term in the bracket gives the terms of the first series in the value of y multiplied by a constant. This new series is combined with the first series in the value of y.

The first term in the bracket gives

$$y_{n+1} = \frac{-B}{2^{2n-1}n!\,(n-1)!}\left[-\frac{x^{n+2}\log x}{2^2(n+1)} + \frac{x^{n+2}}{2^2(n+1)}\left(1 + \frac{1}{n+1}\right)\right],$$

$$y_{n+2} = \frac{-B}{2^{2n-1}n!\,(n-1)!}\left[\frac{x^{n+4}\log x}{2!\,2^4(n+1)(n+2)} - \frac{x^{n+4}}{2!\,2^4(n+1)(n+2)}\left(1 + \frac{1}{2} + \frac{1}{n+1} + \frac{1}{n+2}\right)\right].$$

. . . .

The solution of Bessel's differential equation when n is a positive integer is therefore

$$\begin{aligned} y = {} & Ax^n\left[1 - \frac{1}{n+1}\frac{x^2}{2^2} + \frac{1}{(n+1)(n+2)}\frac{x^4}{2^4\cdot 2!} - \frac{1}{(n+1)(n+2)(n+3)}\frac{x^6}{2^6\cdot 3!} + \cdots\right] \\ & + Bx^{-n}\left[1 + \frac{1}{n-1}\frac{x^2}{2^2} + \frac{1}{(n-1)(n-2)}\frac{x^4}{2^4\cdot 2!} + \cdots + \frac{x^{2n-2}}{2^{2(n-1)}(n-1)!\,(n-1)!}\right] \\ & - \frac{Bx^n\log x}{2^{2n-1}n!\,(n-1)!}\left[1 - \frac{1}{n+1}\frac{x^2}{2^2} + \frac{1}{(n+1)(n+2)}\frac{x^4}{2^4\cdot 2!} - \frac{1}{(n+1)(n+2)(n+3)}\frac{x^6}{2^6\cdot 3!} + \cdots\right] \\ & - \frac{Bx^n}{2^{2n-1}n!\,(n-1)!}\left[\frac{1}{n+1}\left(1 + \frac{1}{n+1}\right)\frac{x^2}{2^2} - \frac{1}{(n+1)(n+2)}\left(1 + \frac{1}{2} + \frac{1}{n+1} + \frac{1}{n+2}\right)\frac{x^4}{2^4\cdot 2!} + \cdots\right]. \end{aligned}$$

This is also the solution of the differential equation when n is a negative integer.

Fourier's partial differential equation for the linear flow of heat is

$$\frac{\partial V}{\partial t} = K\frac{\partial^2 V}{\partial x^2}.$$

Replace Fourier's equation by

$$\frac{\partial V}{\partial t} = SK\frac{\partial^2 V}{\partial x^2}$$

and assume that

$$V = V_0 + V_1 S + V_2 S^2 + V_3 S^3 + \cdots$$

makes the latter equation an identity.

When arranged in ascending powers of S this identity is

$$\begin{array}{l|l|l|l|l} \frac{\partial V_0}{\partial t} & + \frac{\partial V_1}{\partial t} & S + \frac{\partial V_2}{\partial t} & S^2 + \frac{\partial V_3}{\partial t} & S^3 + \cdots \equiv 0. \\ & - K\frac{\partial^2 V_0}{\partial x^2} & - K\frac{\partial^2 V_1}{\partial x^2} & - K\frac{\partial^2 V_2}{\partial x^2} & \end{array}$$

Equating to zero the coefficient of the powers of S in this identity, there result the following partial differential equations for the determination of $V_0, V_1, V_2, V_3, \cdots$,

$$\frac{\partial V_0}{\partial t} = 0, \qquad \frac{\partial V_1}{\partial t} - K\frac{\partial^2 V_0}{\partial x^2} = 0,$$

$$\frac{\partial V_2}{\partial t} - K\frac{\partial^2 V_1}{\partial x^2} = 0, \qquad \frac{\partial V_3}{\partial t} - K\frac{\partial^2 V_2}{\partial x^2} = 0,$$

$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

These partial differential equations solved in regular order give

$$V_0 = \phi(x), \quad V_1 = \phi''(x)(Kt), \quad V_2 = \phi^{\mathrm{IV}}(x)\frac{(Kt)^2}{2\,!},$$

$$V_3 = \phi^{\mathrm{VI}}(x)\frac{(Kt)^3}{3\,!}, \cdots.$$

Substituting these values of $V_0, V_1, V_2, V_3, \ldots$ in the assumed value of V and finally making S unity, there results

$$(A) \quad V = \phi(x) + \phi''(x)(Kt) + \phi^{\mathrm{IV}}(x)\frac{(Kt)^2}{2\,!} + \phi^{\mathrm{VI}}(x)\frac{(Kt)^3}{3\,!} + \cdots,$$

which is a solution of Fourier's equation for all values of $\phi(x)$ for which V either contains a finite number of terms or is an infinite series uniformly convergent both in x and in t.

The following table shows several values of $\phi(x)$ and the corresponding solutions of Fourier's equation,

I	(1) $\phi(x) = A$,	$V = A$,
	(2) $\phi(x) = Ax$,	$V = Ax$,
	(3) $\phi(x) = Ax^2$,	$V = A(x^2 + 2Kt)$,
	(4) $\phi(x) = A \sin(nx)$,	$V = Ae^{-n^2Kt} \sin(nx)$,
	(5) $\phi(x) = A \cos(nx)$,	$V = Ae^{-n^2Kt} \cos(nx)$,
	(6) $\phi(x) = Ae^{nx}$,	$V = Ae^{nx+n^2Kt}$,
	(7) $\phi(x) = Ae^{-nx}$,	$V = Ae^{-nx+n^2Kt}$,
	(8) $\phi(x) = Ae^{nx} \sin(nx)$,	$V = Ae^{nx} \sin(nx + 2n^2Kt)$.

It will be noticed that in these solutions $\phi(x)$ is the value of V when $t = 0$, that is $V = \phi(x)$ is the initial heat distribution.

It will also be noticed that in all these results x may be replaced by $x + a$. This statement is true of the results in the several following tables.

If Fourier's differential equation is replaced by

$$S\frac{\partial V}{\partial t} = K\frac{\partial^2 V}{\partial x^2}$$

and the assumption made that

$$V = V_0 + V_1S + V_2S^2 + V_3S^3 + \cdots$$

makes this equation an identity, this identity arranged in ascending powers of S is

$$K\frac{\partial^2 V_0}{\partial x^2}\left| \begin{matrix} +K\dfrac{\partial^2 V_1}{\partial x^2} \\ -\dfrac{\partial V_0}{\partial t} \end{matrix} \right| S + \left. \begin{matrix} K\dfrac{\partial^2 V_2}{\partial x^2} \\ -\dfrac{\partial V_1}{\partial t} \end{matrix} \right| S^2 + \left. \begin{matrix} K\dfrac{\partial^2 V_3}{\partial x^2} \\ -\dfrac{\partial V_2}{\partial t} \end{matrix} \right| S^3 + \cdots \equiv 0.$$

Equating to zero the coefficients of the powers of S in this identity,

$$\frac{\partial^2 V_0}{\partial x^2} = 0, \quad \frac{\partial^2 V_1}{\partial x^2} - \frac{1}{K}\frac{\partial V_0}{\partial t} = 0, \quad \frac{\partial^2 V_2}{\partial x^2} - \frac{1}{K}\frac{\partial V_1}{\partial t} = 0, \ \cdots.$$

Solving these partial differential equations in regular order for $V_0, V_1, V_2, V_3, \cdots$, substituting these values in the assumed expression for V, and finally making S unity, the result

$$(B) \quad \begin{aligned} V = \phi(t)x + \frac{1}{K}\phi'(t)\frac{x^3}{3!} + \frac{1}{K^2}\phi''(t)\frac{x^5}{5!} + \cdots \\ + \theta(t) + \frac{1}{K}\theta'(t)\frac{x^2}{2!} + \frac{1}{K^2}\theta''(t)\frac{x^4}{4!} + \cdots \end{aligned}$$

is a solution of Fourier's differential equation for all values of $\phi(t)$ and $\theta(t)$ for which V either contains a finite number of terms or is an infinite series uniformly convergent both for x and for t.

Solutions of the differential equation when $\phi(t) = 0$ corresponding to several values of $\theta(t)$ are as follows—

II $\quad \phi(t) = 0$,

(1) $\theta(t) = A$, $\qquad V = A$,

(2) $\theta(t) = At$, $\qquad V = A\left(t + \frac{x^2}{2K}\right)$,

(3) $\theta(t) = At^2$, $\qquad V = A\left(t^2 + \frac{x^2 t}{K} + \frac{x^4}{3\cdot 4K^2}\right)$,

(4) $\theta(t) = At^{\frac{1}{2}}$,

$$V = At^{\frac{1}{2}}\left[1 + \frac{x^2}{2!(2Kt)} - \frac{x^4}{4!(2Kt)^2} + \frac{3x^6}{6!(2Kt)^3} - \cdots\right],$$

(5) $\theta(t) = At^{-\frac{1}{2}}$, $\qquad V = \frac{Ae^{-\frac{x^2}{4Kt}}}{Kt^{\frac{1}{2}}}$,

(6) $\theta(t) = At^{\frac{3}{2}}$,

$$V = At^{\frac{3}{2}}\left[1 + \frac{3}{2!}\frac{x^2}{2Kt} + \frac{3}{4!}\frac{x^4}{(2Kt)^2} - \frac{3}{6!}\frac{x^6}{(2Kt)^3} - \cdots\right],$$

(7) $\theta(t) = At^{-\frac{3}{2}}$,

$$V = At^{-\frac{3}{2}}\left[1 - \frac{3}{2!}\frac{x^2}{2Kt} + \frac{3\cdot 5}{4!}\frac{x^4}{(2Kt)^2} - \frac{3\cdot 5\cdot 7}{6!}\frac{x^6}{(2Kt)^3} + \cdots\right],$$

$$(8)\ \theta(t)=A\sin(nt),\quad V=A\left[\sin(nt)+\frac{n}{K}\cos nt\,\frac{x^2}{2\,!}-\frac{n^2}{K^2}\sin(nt)\,\frac{x^4}{4\,!}-\cdots\right],$$

$$(9)\ \theta(t)=A\log t,\quad V=A\left[\log t+\frac{1}{Kt}\,\frac{x^2}{2\,!}-\frac{1}{K^2t^2}\,\frac{x^4}{4\,!}+\frac{2}{K^3t^3}\,\frac{x^6}{6\,!}-\frac{2\cdot 3}{K^4t^4}\,\frac{x^8}{8\,!}+\cdots\right],$$

$$(10)\ \theta(t)=Ae^{nt},\qquad V=Ae^{nt}\left[1+\frac{n}{K}\,\frac{x^2}{2!}+\frac{n^2}{K^2}\,\frac{x^4}{4\,!}+\cdots\right].$$

It will be noticed that in these solutions $V=\theta(t)$ is the heat distribution when $x=0$.

Solutions of the differential equation when $\theta(t)=0$ corresponding to several values of $\phi(t)$ are as follows:

III $\theta(t)=0$,

$$(1)\ \phi(t)=A,\qquad V=Ax,$$

$$(2)\ \phi(t)=At,\qquad V=A\left[xt+\frac{x^3}{3\,!\,K}\right],$$

$$(3)\ \phi(t)=At^2\qquad V=A\left[xt^2+\frac{2x^3t}{3\,!\,K}+\frac{2x^5}{5\,!\,K^2}\right],$$

$$(4)\ \phi(t)=At^{\frac{1}{2}}\qquad V=At^{\frac{1}{2}}\left[x+\frac{1}{2Kt}\,\frac{x^3}{3\,!}-\frac{1}{2^2K^2t^2}\,\frac{x^5}{5\,!}+\frac{3}{2^3K^3t^3}\,\frac{x^7}{7\,!}-\cdots\right],$$

$$(5)\ \phi(t)=At^{-\frac{1}{2}},\qquad V=At^{-\frac{1}{2}}\left[x-\frac{1}{2Kt}\,\frac{x^3}{3\,!}+\frac{3}{2^2K^2t^2}\,\frac{x^5}{5\,!}-\frac{3\cdot 5}{2^3K^3t^3}\,\frac{x^7}{7\,!}+\cdots\right],$$

$$(6)\ \phi(t)=Ae^{nt},\qquad V=Ae^{nt}\left[x+\frac{n}{K}\,\frac{x^3}{3!}+\frac{n^2}{K^2}\,\frac{x^5}{5\,!}+\cdots\right],$$

$$(7)\ \phi(t)=A\sin(nt),\quad V=A\left[\sin(nt)x+\frac{n}{K}\cos(nt)\frac{x^3}{3!}-\frac{n^2}{K^2}\sin(nt)\frac{x^5}{5!}-\cdots\right],$$

$$(8)\ \phi(t) = A \log t, \qquad V = A\left[x \log t + \frac{1}{Kt}\frac{x^3}{3!} - \frac{1}{K^2t^2}\frac{x^5}{5!} + \frac{2}{K^3t^3}\frac{x^7}{7!} - \cdots\right].$$

It will be noticed that in this set of solutions $V = 0$ when $x = 0$.

Let $u_1 = f_1(x, t)$, $u_2 = f_2(y, t)$, $u_3 = f_3(z, t)$ represent solutions of the three one-dimensional Fourier's equations,

$$\frac{\partial V}{\partial t} = K\frac{\partial^2 V}{\partial x^2}, \quad \frac{\partial V}{\partial t} = K\frac{\partial^2 V}{\partial y^2}, \quad \frac{\partial V}{\partial t} = K\frac{\partial^2 V}{\partial z^2}$$

respectively. It is readily proved that

$$V = u_1u_2 \text{ and } V = u_1u_2u_3$$

are solutions respectively of the two-dimensional Fourier's equation

$$\frac{\partial V}{\partial t} = K\left(\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2}\right)$$

and the three-dimensional Fourier's equation

$$\frac{\partial V}{\partial t} = K\left(\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2}\right).$$

This shows how solutions of the two- and three-dimensional Fourier's equations can be obtained from the solutions of the one-dimensional equation.

For example, from the one-dimensional solutions

$$V = \frac{Ae^{-\frac{x^2}{4Kt}}}{Kt^{\frac{1}{2}}} \quad \text{and} \quad V = Ae^{-n^2Kt}\sin(nx)$$

the three-dimensional solutions

$$\text{IV}\ (1) \qquad V = \frac{Ae^{-\frac{r^2}{4Kt}}}{K^3t^{\frac{3}{2}}},$$

$$(2) \qquad V = Ae^{-(\alpha^2+\beta^2+\gamma^2)Kt}\sin(\alpha x)\sin(\beta y)\sin(\gamma z),$$

respectively, are obtained.

If the solution of the three-dimensional Fourier's equation

$$\frac{\partial V}{\partial t} = K\left(\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2}\right)$$

is a function of r and t only, so that

$$V = f(r, t), \text{ where } r = (x^2 + y^2 + z^2)^{\frac{1}{2}},$$

the transformation of the given equation from rectangular to polar coördinates shows that the solution is

$$V = \frac{u}{r},$$

where u is a solution of the Fourier's equation

$$\frac{\partial u}{\partial t} = K\frac{\partial^2 u}{\partial r^2}.$$

It follows that solutions of the three-dimensional equation of the form $V = f(r, t)$ are obtained by replacing x by r in any solution of the one-dimensional equation

$$\frac{\partial V}{\partial t} = K\frac{\partial^2 u}{\partial x^2},$$

and dividing the result by r.

In this manner are obtained the solutions

V (1) $$V = \frac{A}{r},$$

(2) $$V = \frac{Ae^{\frac{-r^2}{4Kt}}}{rKt^{\frac{1}{2}}},$$

(3) $$V = \frac{A}{r}e^{nr}\sin(nr + 2n^2Kt).$$

It is interesting to compare the solutions of Fourier's partial differential equation obtained in this paper with the solutions tabulated by Sir William Thomson in the mathematcal appendix of the article on "Heat" in the "Encyclopaedia Britannica," ninth edition.

Sir William Thomson obtains his results by summation, that is by integration, from the solution IV (1) above. All his results occur directly in the above tables or are combinations of two of these solutions. It is evident that there are several misprints in the results as printed in the "Britannica."

Of course there are many solutions of Fourier's equation which must be built up from elementary solutions, however found, by means of Fourier series, or which must be obtained by the methods of harmonic analysis.

The solution III (5) above is the series used by Sir William Thomson in his solution of the problem of the secular cooling of the earth.[2]

An interesting result in pure mathematics is obtained as follows: Sir William Thomson shows that for a continued point source of heat, if the rate is an arbitrary function of the time, $f(t)$, the solution of Fourier's equation when $K = 1$ is given by the definite integral

$$V = \int_0^\infty dx f(t - x) \frac{e^{\frac{-r^2}{4x}}}{8\pi^{\frac{3}{2}} x^{\frac{3}{2}}}.$$

The second part of the general solution (B) above shows that

$$V = \frac{1}{4\pi}\left[\frac{1}{r} f(t) + f'(t)\frac{r}{2\,!} + f''(t)\frac{r^3}{4\,!} + \cdots\right]$$

is also the solution of Fourier's equation for the same conditions.

It follows that

$$\int_0^\infty dx f(t - x) \frac{e^{\frac{-r^2}{4x}}}{8\pi^{\frac{3}{2}} x^{\frac{3}{2}}} = \frac{1}{4\pi}\left[\frac{1}{r} f(t) + f'(t)\frac{r}{2\,!} + f''(t)\frac{r^3}{4!} + \cdots\right]$$

is a general formula for computing the definite integral.

LEHIGH UNIVERSITY,
BETHLEHEM, PA.

---

[2] "Mathematical and Physical Papers," Vol. III.

PROBLEMS IN PETROLOGY.

By JOSEPH P. IDDINGS.

(*Read April 21, 1911.*)

The development of the science of petrology from that condition of the study of rocks, properly termed petrography, is characterized by the shifting of the emphasis from the purely observational and descriptive phases of the work to those that relate to the origin and formation of rocks, both with respect to their occurrence as integral parts of the earth, and to their composition and structure.

Not that there is less need than formerly for accurate observation and study of rocks, and for thorough description of their composition, texture and occurrence, but the introduction of greater definiteness into conceptions of their modes of formation, and the widening of the horizon of this field of research through the experimental and synthetic investigations of the geophysicist, have advanced the study of rocks from the accumulation of data and statistics, to the formation of laws and relationships, both as regards minutest details of composition and texture, and with respect to petrographical provinces, and their connection with the dynamical history of the regions of the earth in which they occur.

As a consequence of this advance new problems present themselves, and invite the coöperation of workers in several branches of inorganic science. Leaving out of consideration for the present the great problems of metamorphism, some of which are being successfully treated by Adams, or have been under investigation by Van Hise and Leith, I wish to call your attention to certain phases of the study of igneous rocks that may be grouped under three heads for present purposes, as follows: (1) The actual mineral composition of igneous rocks, (2) the mathematics of the petrology of igneous rocks, and (3) petrographical provinces.

I. ACTUAL MINERAL COMPOSITION OF IGNEOUS ROCKS.

Although the minerals constituting various rocks are their most obvious features, aside from their general color and texture, and have been the chief object of study by petrographers since the introduction of microscopical methods of investigation, they still remain among the most important problems before the petrologist.

The exact composition, crystal characters and optical properties of many of the minerals are well known. But some of the commonest, such as the micas, amphiboles and aluminous pyroxenes, are not perfectly understood chemically, and the relation between their composition and optical constants is not so definite that one may be employed to determine the other, as is the case with the lime-soda-feldspars.

Moreover, the exact amounts of the component minerals in various kinds of igneous rocks have not been determined, except in a very few instances; nor has the precise composition of those minerals that occur in mixed crystals, that is, the principal ferromagnesian minerals, been determined in the vast majority of the rocks described.

There is, therefore, a great field of research, imperfectly cultivated, capable of yielding immediate returns of the first importance for the solution of other problems connected with the mineral composition of these rocks.

Similarly, more definite and specific study and description are needed of the crystal forms and arrangements of the mineral constituents of igneous rocks than have heretofore appeared in petrography, in order that the texture of various rocks may be clearly understood, since texture is a very definite exponent of physical conditions that attended the crystallization of each igneous magma. Up to the present time petrographers have been content with very vague and incomplete descriptions of rock textures, as well as of kinds and amounts of minerals composing various igneous rocks.

The determination of the kinds and amounts of the minerals in every rock leads to the problem of the formation of the minerals in each instance, and a comparison of the mineral composition of a rock with the chemical composition of the magma from which it solidified. This involves the chemistry of solutions of inorganic compounds, chiefly silicates; the mutual interaction of the various chemical elements that appear in an analysis of the whole rock; together with the possible catalytic action of constituents, notably water gas, that may not become parts of the fixed compounds, but may escape in greater part upon the solidification of the magma.

Some of the minor problems, or factors, within this large one may be alluded to briefly as follows: The first and most obvious result of a strict correlation of the mineral composition of rocks with the chemical composition of the whole mass, representing the fixed components of the formerly liquid magma, is the recognition of the nonappearance in certain kinds of rocks of some minerals whose presence is necessary to satisfy the chemical requirements of the magma solutions. This is the case with completely crystallized but exceedingly fine-grained lavas of particular compositions, notably andesites.

Minerals that should be present to the extent of as much as 30 per cent. in some instances are not visible, are occult, and must be hidden within the substance of those minerals that are visible; that is, they must be held in solid solution within other kinds of crystals. An example will illustrate the case.

TABLE I.

	1.		2.	3.
SiO_2	59.87	quartz	13.02	18.29
Al_2O_3	15.02	orthoclase	17.24	9.46
Fe_2O_3	2.58	albite	28.56	24.63
FeO	3.40	anorthite	17.28	14.18
MgO	4.06	diopside	3.99	——
CaO	4.79	hypersthene	11.11	——
Na_2O	3.39	hornblende	——	15.39
K_2O	2.93	biotite	——	14.38
H_2O	1.86	hematite	——	1.12
TiO_2	0.72	magnetite	3.71	——
P_2O_5	0.26	ilmenite	1.37	——
F	0.02	apatite	0.50	0.50
Etc.	1.10	water	1.51	0.84
	1.00.00	Etc.	1.26	1.26
			99.51	100.05

A magma whose chemical composition is shown by analysis 1,

Table I., under favorable conditions should form the mineral compounds in the proportions shown in column 2. In this there are 13 per cent. of quartz, and 17 per cent. of orthoclase, together making 30 per cent. of the whole. And this amount of quartz is the least amount of free silica capable of separating from a solution of such a chemical composition, assuming that the minerals formed are those known to occur in igneous rocks. A magma of this chemical composition commonly crystallizes as a pyroxene-andesite composed, so far as the microscope can determine, of lime-soda-feldspar, pyroxene, and magnetite, with no visible quartz or orthoclase. And, yet, from the chemical analysis of the rock there should be 30 per cent. of these compounds.

The orthoclase molecules may be readily imagined in solid solutions within the lime-soda-feldspars, although in coarsely crystallized forms of such a magma, diorite, orthoclase crystals appear as independent individuals. It has been shown in the Geophysical Laboratory of the Carnegie Institution. that orthoclase and anorthite molecules form homogeneous mixed crystals when melted together and cooled in an open crucible. The disappearance of 17 per cent. of orthoclase in this particular andesite is, therefore, due to the conditions of solidification of the rock. The non-appearance of the quartz may be explained in part by its existence in solid solution in other minerals of which, however, we have not sufficient evidence at present; or it may occur in minute crystals mistaken for andesine feldspar, since the optical properties of the two that may be recognized in minute crystals, are almost identical. In coarser grained forms of chemically similar magmas the quartz appears, but the conditions attending crystallization in the contrasted cases may favor its disappearance through solid solution in one instance, and its separation as quartz crystals in the other.

In this connection it is to be pointed out that the apparent actual mineral composition of certain igneous rocks may not be the real mineral composition by as much as 30 per cent. of the whole. For the occult minerals in solid solution are as much a part of the rock as though visible. Moreover, the percentages assigned to the minerals that are seen must be in error by the amounts of the occult minerals in solution. The problem of the determination of the mineral composition of rocks is for this reason more complex than at first appears, and is further complicated by the difficulty of determining the amounts of colored and colorless crystals, when they appreciably overlap one another in thin section.

Another obvious result of a comparison of the actual mineral composition of igneous rocks with the chemical composition of their magmas is the notable variability in the combination of minerals that may in some instances result from the crystallization of magmas of like chemical composition. This is true both as to kinds and amounts of the resulting minerals. A striking illustration of this variability is found in the mineral composition of three rocks from the same region, the parish of Gran, Norway, which have been described by Brögger. Analyses of the three are shown in columns 1, 2 and 3, Table II. The first rock is an essexite, the second a camptonite, the third a hornblendite, and while the compositions differ slightly in percentages of silica, and to a less extent in other constituents, the chemical resemblances are striking, and the three analyses lie within the range of many well-known series of analyses of particular rocks.

TABLE II.

	1.	2.	3.	4.		5.	6.
SiO_2	43.65	40.60	37.90	42.35	orthoclase	7.2	6.1
Al_2O_3	11.48	12.55	13.17	12.29	albite	——	3.7
Fe_2O_3	6.32	5.47	8.83	3.89	anorthite	18.9	18.3
FeO	8.00	9.52	8.37	7.05	leucite	3.9	——
MgO	7.92	8.96	9.50	13.09	nephelite	11.1	10.2
CaO	14.00	10.80	10.75	12.49	diopside	26.9	30.2
Na_2O	2.28	2.54	2.35	2.74	olivine	8.0	17.9
K_2O	1.51	1.19	2.12	1.04	magnetite	11.6	5.6
H_2O	1.00	2.28	1.40	1.82	ilmenite	10.2	3.5
CO_2	tr	2.68	—— etc.	0.62	hematite	0.8	——
TiO_2	4.00	4.20	5.30	1.82	apatite	——	2.2
P_2O_5	tr	——	tr	.99	H_2O	1.4	1.8
	100.16	100.79	99.69	100.19	Etc.	——	0.3
						100.0	99.8

The first rock consists of lime-soda-feldspar and augite, with some olivine and mica, and rarely a little hornblende. The second rock consists of feldspar and hornblende in nearly equal proportions;

while the third is almost wholly hornblende, only 2 per cent. being pyroxene and nephelite. The same magma might have crystallized as nephelite-basanite, as appears from the calculated mineral composition shown in column 5, and from comparison with the analysis and mineral composition of a nephelite-basanite from Colfax County, N. M., shown in columns 4 and 6.

This is only an extreme case of variations well known to exist in most groups of rocks that may be referred to chemically similar magmas. And the magma already cited as capable of furnishing a pyroxene-andesite may also yield a quartz-mica-diorite, whose composition is shown in column 3 of the first table.

It is evident from these examples that the minerals called hornblende, or more properly amphibole, in the descriptions of these rocks differ widely in chemical composition, and often represent totally different mixed salts. Thus in the hornblendite of Gran, the hornblende contains all the components that might, under other conditions, have crystallized as pyroxene, olivine, feldspar, leucite, nephelite and magnetite.

Any attempt to correlate igneous rocks on the basis of the actual mineral composition, without taking into account the actual chemical composition of the minerals involved in each case must lead to confusion.

One of the most important problems in petrology is the elucidation of the laws controlling the production of mineral compounds from molten magmas. A consideration of the simpler chemical reactions that may be expected to take place in silicate solutions like rock magmas, and which do take place in crucibles in the laboratory, explains the formation of the feldspars, leucite, nephelite, quartz, diopside, hypersthene, olivine, magnetite and some other rock minerals.

Minerals like mica clearly involve the chemical action of water, or its components, hydrogen and hydroxyl, since hydrogen enters into its constitution. According to Penfield hydroxyl, and sometimes fluorine, enters into the composition of hornblendes, forming bivalent radicles with aluminium, and ferric iron. In pyrogenetic analcite, and in other possibly primary zeolites in igneous rocks, H_2O enters into the silicate compound. The physical conditions which control the chemical equilibrium within magma solutions that yield these mineral compounds are problems for the geophysicist, though their nature may be inferred in a general way from the mode of occurrence of the rocks containing the minerals in question.

Indications of a catalytic action of H_2O within rock magmas are furnished by the association of free silica with orthosilicates containing magnesium and iron, such as the common occurrence of quartz and biotite in granitic rocks; the frequent association of quartz and tridymite with olivine in lavas; and of quartz, tridymite and fayalite in lithophysae in certain highly siliceous lavas.

The instability of these systems under changed conditions of equilibrium is shown by the inversion of hornblende to an aggregation of pyroxene, magnetite and feldspar, in some lavas; and by the solution of quartz phenocrysts in some basalts, accompanied by the formation of shells of metasilicates surrounding them.

Already laboratory research has established the range of stability of some of the rock minerals under laboratory conditions: the inversion temperatures under atmospheric pressures of the various forms of SiO_2, quartz, tridymite, crystobalite; of the simpler compounds crystallizing as orthorhombic and monoclinic pyroxene, and the corresponding amphiboles; of a simple system involving aluminium, magnesium calcium silicates; and of other series of compounds. The value of these definite contributions to the problems of the mineral composition of igneous rocks is great. Much more is needed. And the necessity for eventually approaching nearer to the physical conditions obtaining in rock magmas is apparent, when the probable efficiency, chemical and physical, of highly heated gases under strong pressures is taken into consideration. Research under such conditions is attended with great difficulties, and some risks. Enough has been mentioned to show a wide range for future study by the geophysicist, the chemist, and the petrographer.

2. The Mathematics of the Petrology of Igneous Rocks.

The study of igneous rocks involves the consideration of groups of intricate relationships, the exact expression of which is at present beyond our competence. Abstract conceptions of some of the simpler relationships, based on partial knowledge of the factors involved, serve to point the way along which quantitative investigation may be profitably pursued.

The stoichiometric character of the chemical compounds that constitute rock minerals relates them as definite functions to the chemical constituents of the liquid magma from which they crystallized. The existence of mixed crystals, and of solid solutions, introduces the treatment of series into the problem of the expression of the relationship between the mineral composition of a rock and the chemical composition of its magma. In such an expression the fixed components alone are involved. But there are definite quantitative relationships to be expressed regarding those chemical components of a magma which may act only catalytically in producing the actual mineral combination constituting the rock. Such actions may be chemical, in the sense that compounds form that subsequently disappear, as should H_2O combine with SiO_2 to form hydrogen orthosilicate, H_4SiO_4, and subsequently resolve itself into water and quartz or tridymite. Or they may be physical, in the sense that increased molecular mobility in the magma liquid may affect the character of the crystallization by changing the freezing point and the nature of the compounds stable under the conditions obtaining at the time. In the broadest sense, then, the mineral composition of an igneous rock is a function of the chemical composition of the magma.

Since the physical conditions attending the solidification of rock magmas affect the chemical equilibrium of the constituents, as well as the physical character of the liquid, its temperature and viscosity, and also influence the chemical composition with respect to the gaseous components capable of being held in solution under pressure, the mineral composition of an igneous rock is also a function of the physical conditions attending its solidification.

To a notable extent is this also true of the texture of such rocks, their degree of crystallization, size of grain, and the shape and arrangement of the individual minerals. In the expression of these relationships the treatment of serial functions must be a pronounced feature. The gradual variations of temperature and pressure are as essential factors in the consideration of the physical conditions of rock magmas, as the variations in texture and in mineral composition are universally characteristic features of igneous rocks.

The existence of definite quantitative relations between the mineral composition and the texture of igneous rocks on the one hand, and the chemical composition of the magma and the physical conditions attending its eruption and solidification on the other, rests on the obedience of the component elements to the laws of physical chemistry. These laws are not fully established, or known, at this time, and the relationships involved may be too intricate to be completely expressed in customary mathematical terms, nevertheless, the definiteness of the quantitative relationships can not be doubted, and approximate expressions of them become problems for petrologists of the future.

In the consideration and correlation of all known igneous rocks, variability in composition and texture and the existence of continuous series are the most conspicuous general characteristics. The variability in the composition of igneous rocks indicates heterogeneity in magma solutions. This may be inherent in them, and represent a condition of existence before the initiation of eruption; or, as is more probably the case, it may result from differentiation of homogeneous magmas during periods of eruptive activity, within more or less extended regions. Differentiation results from diffusion of compounds in solid molecules, or less complex ones, either at the time of separation as crystals, or earlier, through convection currents, differences in density, or differences in solution pressure. The resulting magma solutions differ only in the quantities of various chemical compounds; the amount of some in extreme instances reaching zero. Subsequently formed compounds are not inherently different from those in other magmas except by reason of the amounts of certain chemical components, which may be concentrated in some differentiated parts; as in the concentration of the rare elements in some pegmatites; or by different combination of chemical elements through catalytic agents. There are no inherent, or inherited, characteristics of form, organism, or immaterial traits, as in living beings. The magmas are simply differently mixed solutions of inorganic compounds.

Magma solutions possess different degrees of heterogeneity as shown by the composition of various bodies of igneous rocks. In some there are slight differences in different parts, extending through large masses. In others marked differences occur within short distances in small masses. Variability in the composition of igneous rocks from place to place is a universal characteristic, resulting in series of varieties of composition within single bodies, and among different masses. The aggregate of all such series of variations in one region may form a continuous series of wide extent; or there may be gaps in the series in one region, which may be filled by the phases of composition exhibited by rocks in another region.

In one region the composition of a nearly homogeneous rock mass of considerable magnitude may assume a certain local petrographic importance, while in another region it may appear only as a facies of another rock body. There appears to be no chemicophysical reason for the production of a magma solution of one mixed composition rather than of another very nearly the same. But it is known that magmas of intermediate, or more mixed, compositions, are more abundant than those of extreme, or simpler, compositions.

The accumulated evidence of chemical analysis, microscopical study of rock sections, and observation in the field, shows the existence of wide serial variations of composition, continuous along numerous lines, owing to the number of variable components. This evidence also shows that there is no one definitely composed magma solution more abundant throughout large areas of the earth than others; none that deserves special consideration, or may be recognized as a universal type. It is true, as already remarked, that in certain regions there are large bodies of rock having nearly uniform composition that assume local importance, and serve as types for reference in particular regions. But it must be admitted that the idea of type is subjective, inherent in the petrographer, not the rock. And when all known series of igneous rocks are treated as products of chemicophysical reactions universal in their application, the fortuitous character of the chemical composition of particular bodies of erupted magma becomes apparent, and the significance of such local types disappears in a systematic treatment of the whole body of petrographical facts involved in a comprehensive description of igneous rocks.

Recognizing the existence of continuous series of petrographical factors, chemical, mineral and textural, necessary to the complete description and definition of igneous rocks, the problem presents itself of dividing the complex series of rocks so characterized into parts that may be described in a comprehensive and systematic manner.

A familiar example of a physical series divided in a regular manner for purposes of exact use is that of temperature, partitioned in degrees of definite proportions of a continuous scale. It is undoubtedly an arbitrary method and differs distinctly in three commonly employed usages. It might be a more "natural" method to express temperature with reference to the melting points of a series of substances; and the value of certain of these definite points as datum points is well known. But the merits of the arbitrarily, but very naturally, divided scale are attested by its universal employment.

The proposal to partition the petrographical series into quantitatively definite parts, as has been done in the Quantitative System of Classification of Igneous Rocks, the size of the divisions being arbitrarily chosen, has excited criticism by some petrographers, who consider it arbitrary, artificial and not "natural." But the objection, that measured precision condemns a classification of igneous rocks, because it makes evident "its aloofness from the scheme of nature based not on arithmetical but on physical and chemical principles,"[1] suggests a lack of appreciation of the mathematical precision of stoichiometric chemistry, and a failure to grasp the definiteness of quantitative physics, whose natural expression is found in higher mathematics. Both of these sciences are fundamental to that of petrology; and as mathematics is the language, or expression, of quantitative relationships, the more definite the knowledge of the quantitative factors and relationships obtaining in igneous rocks, the more natural will become their expression in mathematical terms.

Acknowledging the usefulness of such terms as "consanguinity" and "parent" magmas, in emphasizing the fact that there is relationship between rocks in certain instances, it must be admitted that the too frequent use of these and other biological terms, as "families"

---

[1] Harker, A., "The Natural History of Igneous Rocks," 1909, p. 366.

of rocks, minerals of "first and second generation," and the like, tends to convey by implication the idea that there exists among igneous rocks genetic relationships analogous to those sustained by living organisms. In fact, this idea has been clearly formulated by Harker[2] in stating that the mutual relationships of igneous rocks will furnish a "fundamental principle analogous with that of descent, which lies at the root of natural classification in the organic world."

The significance of the term "natural" when applied by some petrographers to petrographic classification appears to be pregnant with biological conceptions. But what is proper and natural in the treatment of assemblages of organisms is not for that reason, necessarily, proper, or natural, in the treatment of a series of chemical solutions and their solidified phases, however much the various solutions may be related to one another by reason of differential diffusion or fractional crystallization.

3. Petrographical Provinces.

Although the fact has been recognized for twenty-five years that there are regions within which the rocks erupted during any particular period exhibit certain peculiarities of mineral composition and texture that distinguish them from rocks belonging to the same general group, erupted simultaneously in other regions,[3] little or no attempt has been made to define more precisely what constitutes the characteristics of any so-called petrographical province.

It has been pointed out that in some regions many of the igneous rocks are especially rich in alkalies; in some sodium being prominent; in others potassium. But nothing approaching completeness of definition, either as to composition of the rocks, or extent and limit of the region of occurrence, has ever been attempted.

And yet some very general and far-reaching speculations have been indulged in on the basis of hastily formed impressions, both as to the character of such groups of rocks and their relationship to assumed structural features of the earth. As a result certain petrographers have grouped all igneous rocks into two contrasted cate-

---

[2] *Ibid.*, p. 362.

[3] Judd, J. W., *Quar. Jour. Geol. Society*, London, 1886, Vol. 42, p. 54.

gories, without considering the probability of their being many phases of combination of the variable factors of igneous rocks that must characterize all petrographical provinces of the earth.

The assumption that rocks must either belong to what have been called the "Atlantic" or the "Pacific" provinces, without serious definition of either of these rather comprehensive terms, has led to the humorous conclusion that the igneous rocks of Great Britain belonged in some periods of geological history to the "Atlantic," in others to the "Pacific" provinces; indicating the flexible, one might say caoutchouc-like, nature of these provinces.

The igneous rocks of the Andes and of the western Cordillera of North America have been referred to as representing the "Pacific" province, while the more alkalic rocks of Scandinavia and of some other parts of Europe are considered to represent the "Atlantic." The igneous rocks of Great Britain belong to neither of these distinctive groups as a whole. And the rocks erupted at different geological periods in Great Britain, while they exhibit some variations in extremes of composition, which might result from different degrees of differentiation of chemically similar magmas, bear some of those resemblances to one another that are supposed to characterize rocks of one petrographical province.

The misconception underlying the generalization responsible for the terms "Atlantic" and "Pacific," as applied to petrographical provinces, appears from the facts brought out by Cross regarding the alkalic character of some of the lavas of Hawaii, and by Lacroix regarding alkalic rocks in Tahiti; to say nothing of similar rocks in New Zealand and elsewhere in the southern Pacific. Moreover, in the midst of Europe, in Hungary, there are groups of rocks identical in all respects with those of the Great Basin in western America.

From this it is evident that one of the most important and interesting problems before petrologists is the investigation and exact definition of the districts and regions of igneous rocks in all parts of the world, with the purpose of obtaining the data with which to form definite conceptions of what have been termed petrographical provinces. Enough is known already to make it evident that there are many kinds of such groups of igneous eruptions and not two strongly contrasted series; that they blend into one another in composition;

that the delimitation of the regions, or provinces, may be pronounced in some instances, and ill-defined in others.

The character of the rocks in different provinces, and the distribution of provinces throughout the earth, together with their relations to the geological structure and dynamical history of the region in which they occur, furnish problems of the first magnitude in petrology.

One of the questions to be answered is: the relation of the composition of igneous rocks of different parts of the earth to its isostasy. The configuration of the earth's surface demands the presence of material of different densities beneath the surface. Does this show itself in the character of the material erupted in different regions. An answer to this can not be given offhand. The requirements in density are relatively so slight when great volumes are concerned, as pointed out recently by Hayford;[4] the series of igneous magmas of any region is so diversified in composition and density; and the estimation of their several volumes is so hazardous an undertaking that a reasonable solution of the problem can only be expected after the accumulation of a great amount of exact data.

Whether there is any relation between the kinds of magma erupted in a particular region and the dynamical events within the region is another problem yet to be solved. Assertions to the effect that there is a definite relationship have been made, but they are in the nature of broad generalizations upon questionable premises, producing the results already discussed in connection with the terms "Atlantic" and "Pacific."

It is possible that differences in the sequence of dynamic events in various regions, or in one region at various periods of its history, may be accompanied by differences in the processes and results of differentiation of chemically similar magmas; that is, in series of erupted rocks, but the existence of such relationships has yet to be clearly established. For it is also possible that the material of the earth may be heterogeneous in composition, differing somewhat from place to place, and yielding different kinds of magmas in different

---

[4] Hayford, J. F., "The Relations of Isostasy to Geodesy, Geophysics and Geology," *Science,* N. S., Vol. 33, No. 841, 1911, pp. 199–208.

regions, each of which may undergo local differentiation according to conditions of its eruption. The apparent persistency of the major features of relief on the earth's surface and the demands of isostasy suggest an absence of homogeneity within the material of which it is composed. The solution of these fundamental problems in geology must rest on petrological research along the lines here indicated.

Such are some of the more obvious problems of petrology, the solution of which involves the coöperation of petrographers with the chemist, the geophysicist and the geologist.

A STUDY OF THE TERTIARY FLORAS OF THE ATLANTIC AND GULF COASTAL PLAIN.[1]

By EDWARD W. BERRY.

(*Read April 21, 1911.*)

INTRODUCTORY.

The observations recorded in the following pages may be said to represent a preliminary sketch of a small chapter in the study of the South Atlantic and Gulf Coastal plain undertaken by the United States Geological Survey in coöperation with the various state surveys under the direction of Dr. T. W. Vaughan.

Neither geologist nor biologist fully appreciates the magnitude, complexity or uniqueness of the coastal plain of the southeastern United States. The present coast line, a boundary first recognized by the aborigines and early explorers and so emphasized by geographers, is from the standpoint of the student of geologic history a continually shifting demarcation which does not, nor perhaps never, marked the seaward limit of the physiographic unit known as the Coastal Plain Province, for the gently sloping land surface continues seaward beneath the waves of the present Atlantic and Gulf waters varying distances up to 100 miles or more and then precipitately descends several thousand feet in a few miles, forming the majestic escarpment which is regarded as the continental boundary. In the past the coast line has advanced inland over the present emerged portion of the coastal plain and receded seaward over the present submerged margin, many times. At one time the waves of the Gulf of Mexico broke in southern Illinois, at another they were confined 100 miles south of the present sites of Mobile and New Orleans, 600 miles to the southward.

On the whole, the history of events in Tertiary times has been a progressive adding to the land area of the continent, the most im-

---

[1] Published with the permission of the director of the United States Geological Survey.

portant elevation being that of the early Miocene which was followed by a subsidence, which was, however, less in extent than those which had preceded it.

No part of the coastal plain is so favorably situated for the study of the floras which preceded the present, extending backward to a time which marks the first recorded appearance of angiosperms, as that of the Gulf states. No single part of North America contains so continuous a series of Tertiary deposits carrying fossil plants. Here we find abundant floras in the lower and middle stages of the Eocene, considerable floras in the Oligocene, some in the later Miocene, and rather abundant fossil plants in the Pliocene. The Rocky Mountain region is rich in Eocene fossil plants and there are some Miocene floras, but no Oligocene or Pliocene floras are known. The Pacific coast region likewise furnishes Eocene and Miocene fossil plants but none of Oligocene age. The fossil floras of the coastal plain are found in an area where it is possible to attain to some measure of accuracy in predicating the general character and course of ocean currents and winds and other physical features of the environment. On the other hand the western floras just mentioned grew in areas where vulcanism was great at times; in areas of great orogenic activity, where changes in topography were numerous and elevations of several thousands of feet are recorded; areas in which climatic conditions not only varied from place to place, but passed through a large cycle of secular changes. All these factors greatly complicate the floral history.

The floras of the southern coastal plain are moreover checked for the most part by very abundant marine faunas in intercalated beds, or the plant-bearing beds which represent the coastal swamps and the shallow water deposition of the old embayment merge laterally with the contemporaneous limestones or marls which were forming in more open waters along the coasts to the southward, so that there is a considerable body of facts bearing on depth, character of the bottom, and marine temperatures, with which to compare land temperatures. These criteria have been admirably worked out for the Florida area by Doctors Dall and Vaughan for the post-Eocene and their results furnished a reliable datum plane for the deductions to be derived from the study of the fossil floras of these times.

So far as I know I was the first paleobotanist to explore the south Atlantic and Gulf coastal plain and that exploration has only just begun. Professors Fontaine and Ward visited the region and collected a few Cretaceous plants a score of years ago. Professor Lesquereux a generation and a half ago described a few Eocene plants collected by Professor Hilgard in Mississippi and by Professor Safford in Tennessee, and Doctors Knowlton and Hollick have identified various small collections made by others in different parts of this vast area.

With the exception of fragments of the petrified stems of conifers, palms and dicotyledons the plant-remains are in the form of impressions, mostly of foliage, but with a goodly sprinkling of fruits and seeds, and in some few cases even flowers are preserved.

While the oscillations of the Gulf area have been numerous they have been, as I have just mentioned, inconsiderable in amount, only a few hundred feet at most, and the coastal region has uniformly been one of slight relief. The various floras show a complete absence of upland types. This is in striking contrast to the European older Tertiary floras. The only large area of the globe which has been thoroughly studied, Europe, was far less stable than this region in Tertiary times and lying much farther toward the pole was subjected to the rigors of Pleistocene conditions whose influence never reached our southern states.

The object of the writer's work may be classed under three heads: (1) To determine the correlation of the various Tertiary formations particularly in the upper portion of the Mississippi embayment where marine fossils are largely absent, (2) To obtain data regarding the physical conditions under which the various floras flourished. (3) To accumulate biological data regarding the geographical distribution, specific differentiation and evolution of the Tertiary floras.

Thus one of the principal phases of the study for the geologist might be embraced under the term paleoecology. The methods include a study of the old shore lines of the different epochs, of the character of the sediments and their genesis, of the contained animals and plants, and the alternative climatic and edaphic factors which their grouping may indicate.

It is the chronologic and ecologic aspects upon which I wish to dwell in the present connection.

The paleobotanical record of the Atlantic and Gulf coastal plain furnishes a history which extends back as I have just mentioned beyond the oldest known angiosperm to a time (Lower Cretaceous) when the flora was made up almost entirely of tree-ferns, conifers and those interesting cycadophytes (*Cycadeoidea*) whose trunks are sometimes preserved with such marvelous perfection that the outlines of the embryos in the ovules can often be made out in detail. Coming a step nearer my present theme, a step of some millions of years from the Lower into the Upper Cretaceous we find the first great modernization of the floras of the world due to the seemingly sudden evolution of the main types of angiosperms. These upper Cretaceous floras are well represented in the coastal plain from Marthas Vineyard to Texas. They extended northward to Greenland and southward to Argentina in South America, and are found to indicate very different physical conditions from those which prevail at the present time. I do not intend, however, to dwell upon the Upper Cretaceous floras in this connection but pass to a consideration of the succeeding Eocene stage of plant evolution. In this as in subsequent times the chief emphasis will be laid upon that section known as the embayment or old Mississippi Gulf, although where the record is more complete in other parts of the coastal plain I will not hesitate to use it.

BASAL EOCENE.

The Eocene as defined by Lyell was marked by the dawn of the recent species of marine mollusca. It is equally well marked by the sudden expansion and evolution of modern types of mammals and plants after a long antecedent Cretaceous development. The floras become thoroughly modernized as compared with those which preceded them, although they are still very different in their general facies and distribution from those of the present.

In the earliest stage of the Eocene known as the Midway, the relations of sea and land in the Gulf area differed in only minor particulars from that of the late Cretaceous. The waters of the Mississippi Gulf were, however, deeper. This factor combined with a much less influx of fresh water from the tributary streams, due in some measure to the low relief of the land, enabled marine faunas to reach well toward the head of the gulf. These faunas indicate subtropical bottom temperatures northward as far as Paducah, Ky. The known floras are very scanty and unsatisfactory and in the present state of our knowledge do not merit an extended discussion.

LOWER EOCENE.

The Midway Eocene was succeeded by a long interval during which a great thickness of deposits was laid down which are collectively known as the Wilcox Group. The character of these sediments and their faunas show that the gulf was somewhat restricted and much shallower than in the preceding stage, with true marine conditions prevalent only in its lower portion. The shores were low and relatively flat. They were flanked by current- or wave-built bars and separated from the mainland by shallow inlets or lagoons. The lower courses of the streams were transformed into shallow estuaries or broad swamps through which the smaller streams meandered. The accompanying sketch map (Fig. 1) shows the relation of land to water at this time. The shore line along which the strand flora migrated is approximately indicated, and some of the localities where fossil plants have been discovered in the littoral deposits of this age are indicated by stars, while the general movement of the warm ocean currents is indicated by arrows. A magnificent flora is preserved at a large number of localities in the clay lenses which were formed in these estuaries and marginal lagoons. This flora shows a mingling of tropical and subtropical types as far northward as where the Ohio River now flows into the Mississippi. It is of unparalleled richness and preservation and will bear a more extended analysis.

Among the ferns it contains representatives of the genera *Acrostichum, Pteris* and *Lygodium,* none of which appear to be common. Both feather and fan palms are not uncommon. Conifers are represented by a single occurrence of a species of *Arthrotaxis*—a genus which in the living flora is confined to the coastal swamps of Tasmania but which is widespread in European Eocene floras. A large variety of dicotyledonous forms are preserved, representatives of about two hundred different species of which about one third have thus far been satisfactorily identified. These include seven or eight species of leguminous shrubs and trees represented by pods as well as leaflets—evidently strand plants, as are numerous modern species of *Acacia*, *Cæsalpinia* and *Dalbergia*. Evergreen lauraceous forms are also abundant, the genera *Cinnamomum*, *Laurus*, *Malapoenna*, *Persea*, *Oreodaphne* (*Ocotea*), etc., being represented by several species. Figs are abundant and of several species, embracing both

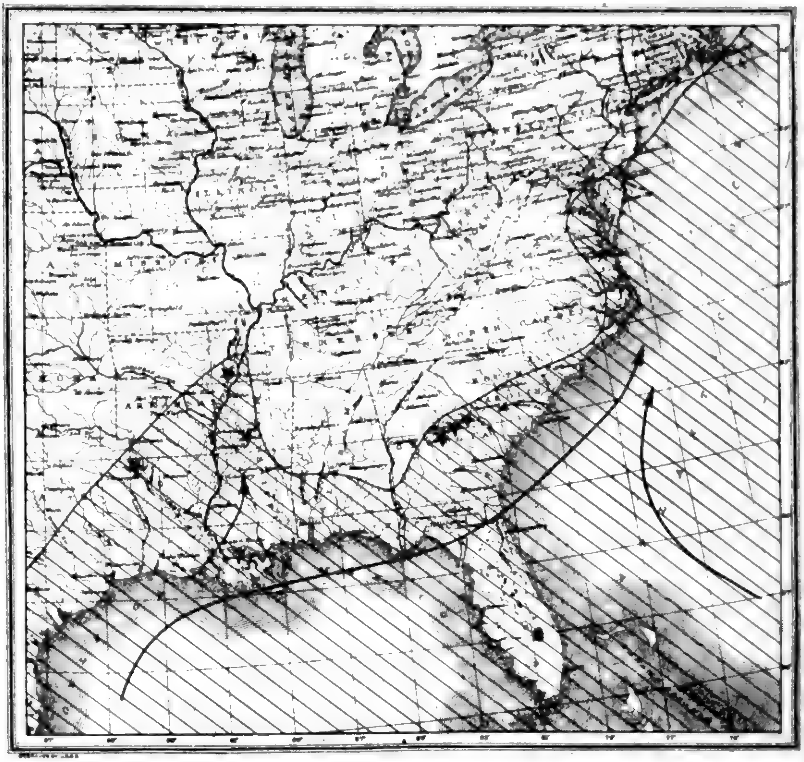


FIG. 1. Sketch map showing the approximate relation of land to water in the Lower Eocene. Stars indicate fossil plant localities, diagonal lining indicates submerged areas.

the pinnately veined and the palmately veined types. There are three or four species of *Sapindus*—another strand type of the modern equatorial and subequatorial zones. Other members of the strand flora include representatives of the genera *Conocarpus, Guetteria, Mimusops, Persoonia, Terminalia,* etc. Leaves of several species of live oaks (*Quercus*) are abundant. The collections also include fruits of the families Anacardiaceæ and Umbelliferæ, and of the genus *Aristolochia*. Curious elements common to Europe are several species of *Banksia*, an antipodean genus in the existing flora. There is a fine species of *Cercis*, a very common *Euonymus* and at least two species of *Engelhardtia* based upon the characteristic fruits as well as leaves. The latter genus has a single existing species in Central America and several in Asia, where they range from India to the East Indies. It is common in the European Tertiary, but has not previously been known with certainty from North America. An interesting member of this flora is a large digitate species of *Oreopanax*, a modern tropical type, abundant in Central America.

The flora as a whole contains no strictly temperate elements, although many of the genera contain modern forms which range for more or less considerable distances in the temperate zone. Such a flora could scarcely flourish under existing conditions north of latitude 29°. In its general facies it is subtropical and a number of the forms indicate a high percentage of humidity, and well distributed and abundant seasonal rains, although this latter feature tends to be obscured by the large number of the inhabitants of the sandy shores which are preserved while the inland and river bank dwellers are less fully represented. A majority of the elements in this Wilcox flora could be duplicated today on the Florida Keys and the southern peninsular mainland of Florida.

Additional members of this flora not enumerated in the preceding paragraphs include representatives of the genera *Apocynophyllum, Calamopsis, Ceanothus, Celastrus, Celtis, Cordia, Diospyros, Dryophyllum, Magnolia, Malpighiastrum, Nerium, Rhamnus, Rhus, Sabal, Sapotacites,* etc., nearly all of which are new to science.

MIDDLE EOCENE.

Middle Eocene floras are less abundant than those of the Lower Eocene since this period is marked by a considerable subsidence and deeper waters in the Mississippi Gulf, which, however, eventually became shallower again and duplicated in a measure the Lower Eocene conditions.

FIG. 2. Sketch map showing the approximate relation of land to water in the Middle Eocene. Stars indicate fossil plant localities, diagonal lining indicates submerged areas.

At a number of localities in Georgia and at two or three in northern Mississippi and in Arkansas representatives of the Middle Eocene flora have been collected. In Georgia where the plants are associated with shallow water and estuarine invertebrates I found the remains of a typical mangrove flora associated with types which today characterize the tropical and subtropical beach jungle. This flora includes an *Acrostichum* closely allied to the modern *Acrostichum aureum* Linné which is such an abundant fern in the mangrove and nipa tidal swamps. Other genera represented by fossil forms are *Conocarpus, Dodonæa, Ficus, Malapœnna, Pisonia, Momisia, Rhizophora, Sapindus, Terminalia,* and palms of the genus *Thrinax.* Botanists familiar with the flora of the torrid zone will recognize at once that this is a typical strand flora of the tropics which might almost have been taken bodily from Schimper's classic Indomalayan Strand Flora, or which can be seen today along the Florida Keys and in the West Indies.

The plants of this age from Mississippi and Arkansas do not indicate such a well marked ecological group nor quite such high temperatures as those from Georgia, nevertheless they also are largely subtropical coastal types and embrace species of *Sabal, Rhamnus, Panax, Ficus, Dryandroides, Persea, Sapindus,* etc. One of the most interesting forms abundantly represented in northeastern Arkansas is a citraceous form with alate petioles which I have named *Citrophyllum.* Additional genera which are present are *Nectandra* and the coniferous genus *Arthrotaxis.*

In Fig. 2 is shown the approximate position of the shore line along which the mangrove and the tropical beach flora migrated northward in the path of northerly flowing tropical ocean currents.

Upper Eocene.

No upper Eocene floras are known from the coastal plain but it is believed that future discovery will reveal their presence when the area where they are likely to occur shall have been examined in detail.

Lower Oligocene.

The Lower Oligocene has yielded no plants except petrified fragments of the wood of palms and dicotyledons. The sediments are more or less impure marine limestones, and if marginal deposits with plants were laid down they were subsequently destroyed by erosion, or have not yet been discovered.

Extensive marine faunas indicate even more torrid conditions than in the preceding epoch, uniformly distributed over this whole area.

MIDDLE OLIGOCENE.

The Middle Oligocene deposits are those of shallow tropical waters with a bottom temperature of at least 39° C. (70° F.), marine toward the east with true reef corals in Georgia, but becoming brackish or fresh toward the west, by reason of their shallowness and the increased volume of fresh water from the Oligocene Mississippi and Tennessee rivers and other streams. The flora is scanty but includes tropical swamp types, the fern genus *Acrostichum* being the most abundant form collected.

The accompanying sketch map (Fig. 3) shows in a generalized way the relation of land and water in the Middle and Upper Oligocene. It is to be noted that the great Mississippi Gulf had been reduced to a very wide and shallow reentrant.

UPPER OLIGOCENE.

Toward the close of the Oligocene a widespread emergence of the land was inaugurated accompanied by a slight lowering of temperatures. The floras are not abundant but are represented in western Florida and central Mississippi. They contain very abundant remains of several species of *Sabal*-like palms; the large leaves of a species of *Artocarpus* or breadfruit; leaves of figs; of the *Cinnamomum* or camphor tree; representatives of the genera *Acacia, Bumelia, Diospyros, Pisonia, Gyminda, Gleditsia, Nectandra, Sapotacites, Rhamnus, Ulmus,* etc.—the latter being the only genus which is a strictly temperate type in the modern flora, although most of the genera enumerated have representatives in the warmer parts of the temperate zone at the present time.

MIOCENE.

A long interval followed the close of the Oligocene, during which the coast line of southeastern North America was considerably seaward from its present position, in consequence of which deposits

FIG. 3. Sketch map showing the relation of land to water in the Middle and Upper Oligocene. Stars indicate fossil plant localities, diagonal lining indicates submerged areas.

of this age are unknown. This interval comprises the first half of the Miocene age and when renewed submergence furnishes us with a record we find very different conditions from those previously enumerated. Either because of the diversion of the gulf stream to the eastward due to the emergence of peninsular Florida or as a result of changes in depth off the Hatteras anticline, a cool inshore current seems to have swept southward along the coast and through the Suwannee Strait across northern peninsular Florida, carrying with it a northern marine fauna which replaced the tropical fauna that had previously occupied this region.

The fossil plants of this age are unfortunately rare and are as yet unknown south of the Maryland-Virginia area. The accompanying sketch map (Fig. 4) shows in a generalized way the upper Miocene conditions after the resubmergence of the area, the maximum emergence during the lower Miocene being unknown. The land masses southeast of the mainland are to be noted as well as the supposed directions of the ocean currents.

FIG. 4. Sketch map showing the approximate relation of land to water in the Upper Miocene. Stars indicate fossil plant localities, diagonal lining indicates submerged areas.

The known fossil plants from the Atlantic coast Miocene, exclusive of diatoms, include the following species from the Maryland area near Washington described by Hollick:[2]

---

[2] Hollick, Md. Geol. Surv., Miocene, 1904, pp. 483–486, tf. a–b.

Quercus Lehmanni Holl.
Ulmus basicordata Holl.
Cæsalpinia ovalifolia Holl.
Rhus Milleri Holl.
Pieris scrobiculata Holl.
Phyllites sp., Holl.

In addition to the above the following have been described from the same horizon at Richmond, Va., by Berry:[3]

Salvinia formosa Heer?
Taxodium distichum miocenum Heer.
Salix Raeana Heer.
Carpinus grandis Unger.
Quercus calvertonensis Berry.
Rhus Milleri Holl.
Planera Ungeri Ettings.
Ficus richmondensis Berry.
Platanus aceroides Goeppert.
Podogonium? virginianum Berry.
Dalbergia calvertonensis Berry.
Celastrus Bruckmanni Al. Br.
Nyssa gracilis Berry.
Fraxinus richmondensis Berry.

These plants indicate that the coast was low, which explains the absence of any but the finest terrigenous materials in the shallow water deposits which constitute the Calvert formation. The flora from Virginia indicates the presence of extensive cypress swamps, the latter type of plant being the most abundant fossil collected and the other plants identified being for the most part similar in their physiological demands upon their environment. The flora from Maryland is the natural counterpart of that from Virginia in containing several typical elements of just the sort of a plant association found on sands (inner beaches and more or less stationary dunes) along the present coasts in the temperate zone.

Regarding age the plants are clearly Middle Miocene according to European standards. They indicate less conclusively the climatic

---

[3] Berry, *Journ. Geol.*, Vol. 17, 1909, pp. 19–30, tf. 1–11.

conditions which prevailed along the Miocene coast in this latitude. There is considerable evidence of a scant rainfall, that is to say of less than 30 inches annually but this may well have been merely a coastal condition. Indirectly the lack of land derived sediments in the deposits points to the conclusion that relatively dry conditions extended over wider areas. The mean annual temperature is difficult to determine. Several of the closely allied modern plants such as the existing bald cypress do not extend north of Maryland in the existing flora, while *Ficus* does not fruit north of Virginia, which also marks the northern limit of *Planera.* However, the Miocene forms enumerated are all different specifically from the existing members of their respective genera and the conclusion is reached that the Calvert flora would grow under the climatic conditions prevailing at the present time between Sandy Hook, N. J., and Cape Henry, Va., and that the mean annual temperature which they indicate is between 50° and 55° F.

PLIOCENE.

Pliocene floras have been unknown from North America until last year when deposits of this age with abundant fossil plants were discovered in southern Alabama. The most remarkable form in this flora is the fruit of *Trapa,* the water nut, which Raimann in Engler and Prantl segregates from the family Onagraceæ to form the family Hydrocaryaceæ. In the existing flora this genus has only three species of southern Europe and southeastern Asia but it is well known in the older Tertiary of North America and Europe and in the later fossil floras of Europe. Another interesting species in this Alabama Pliocene flora is a species of *Glyptostrobus,* a coniferous genus allied to our bald cypress which is now confined to eastern Asia, but which appears to have been cosmopolitan in Tertiary times. Other elements of this flora are abundant live-oaks (*Quercus*); several species of elm (*Ulmus*); abundant twigs, seeds and cone scales of a species of cypress which is very close to the existing bald cypress (*Taxodium*). Additional elements are species of *Nyssa, Hicoria, Planera, Betula, Dioscorea, Prunus, Pinus,* etc. This flora is quite modern in its facies and is a mixture of swamp types and those of live-oak barrens. Among existing localities which I have visited which impress me as duplicating the climatic and other physical conditions indicated by this late Pliocene flora are the estuaries along the gulf coast of Alabama and western Florida, among which Apalachicola, Mobile, Perdido and Pensacola bays are the larger. The Santa Rosa peninsula which separates the latter from the Gulf of Mexico supports a flora that is very similar to this Pliocene flora and one or two of the species represented in both are closely allied and may even be identical.

Pleistocene.

Pleistocene plants are also common throughout most of the coastal plain and when they shall have been thoroughly studied they will yield a large body of exact facts which will throw much light upon the immediate ancestry and migrations of our existing flora. Already more than one hundred species have been recorded, most of which are still existing and these indicate a very different geographical distribution from that of the present coastal plain flora.

Conclusion.

I have only had time in the foregoing remarks for a very fragmentary and incomplete sketch of the present study which has really only just commenced. With the complete exploration of the area and the additional collections which it is hoped to make it is believed that the combined results of the speakers studies of the fossil floras and those of his associates on the fossil faunas and the areal geology will furnish a basis for reconstructing the physical, faunal and floral history of the southern states, during the several millions of years from the Cretaceous to the present, which will constitute a lasting contribution to the history of the earth.

AN OPTICAL PHENOMENON.

By FRANCIS E. NIPHER.

(*Read April 21, 1911.*)

In 1871 in a letter to Tyndall, Joseph LeConte gave an interesting discussion of an ocular illusion which had been previously described. Tyndall communicated it to the *Philosophical Magazine* (XLI., p. 266). The phenomenon was observed in the manner here described:

Pierce a card with a pin. Hold it before the eye at a distance of four to six inches, looking through the hole at a bright background. Place the pin in front of the eye with the head central in the pupil and in close proximity. The pin head will be "seen in the hole," and in an inverted position.

As was pointed out by LeConte, this is not an optical image but a shadow. As proof of this he cites the fact that if a series ot holes are made in the card, a similar appearance of the pin head is seen in each hole. He adopted the idea that objects are seen erect, because the nerve fibers at the lowest point on the image see the top of the object in the direction along which those rays have come. He also argued that the inverted appearance of this shadow, which was erect on the retina, was in harmony with this explanation.

The well-known fact that this point in the image is the vertex of a cone of rays, whose base is the pupil of the eye, and that this diverging bundle of rays, when traced outward, does not define the position of any external point, is sufficient explanation of the fact that this line of reasoning has not been generally adopted. Evidently the fact that there are no rays has also been taken into consideration. It does not seem quite evident that nerve fibers at the lower point of the image on which ether waves collapse and deliver their impulses could "see" that these waves had their origin at a definite point, at the top of an object, at a definite distance from the refracting media, in which the radii of curvature of these waves were reversed in direction. And these waves from this point on the object are involved in a summation of waves from other and adjoining points.

Many observers have doubtless had experiences like those which the writer had years ago while doing survey work. Two transit instruments were available, one of which showed the object viewed in erect, and the other in inverted position. A few days of use of either instrument enables the observer to give proper signals to the rod-man in a perfectly automatic way. After having thus become alternately educated, an attempt to use these instruments at random for brief intervals, relying wholly on what he sees through the instrument for the information which is to guide him in making his signals, leads to the most helpless confusion. The observer even seeks to find his way out of his difficulties by comparing what he sees through the instrument with the impression received by a direct view.

Such experience as this appears to justify the conclusion that we see external objects as we have learned how to see them, by help of our other senses. Even then it is a matter of never-ending wonder that we have in our possession certain nerve-fibers that can be trained to see.

There are many interesting features of the phenomenon which LeConte discussed which appear to have escaped his attention. His claim that the sharp outline of the pin head seen in the hole could not be an optical image, since such an image would be so much out of focus as to be invisible, is justified to this extent. The object is in fact also visible in its real position in shadowy outline. It appears transparent, and the inverted shadow of the pin head is mentally projected outward and appears to be visible through the object itself. Every detail of the letters on a printed page is visible through this enlarged and transparent appearance which the object itself presents, due to an out-of-focus image on the retina.

The sharpness of outline of the shadow decreases as the hole is made greater in area. This is due to penumbral effects. A black card gives more sharply defined results than a white one. A tube having the pierced card at one end and the pin head at the other may be applied to the eye, in such a way as to cut off all side light. The head may be covered with a black cloth, which is also wrapped around the tube. The shadows are then as sharply defined as an optical image could be. If the black sateen cloth be thrown over the head, and the eyes be directed towards a bright sky, a multitude of circular images like pin hole images will be seen between the crossed fibers. Some of these are due to the right eye and some to the left. A pin head in front of either eye will show multitudes of inverted pin head shadows.

A circular disk of white paper having a diameter of 1 mm. or slightly less, mounted upon a black card will also have upon it a sharply defined black shadow of the pin head, if the side facing the observer is illuminated. The paper disk must be near enough to the eye so that its image on the retina is out of focus, as in other cases where the pin hole is used. At various points on the glowing end of a cigar, when observation is made in a darkened room, similar shadows may be observed. A small blot of ink on a sheet of white paper will yield a white shadow of the pin head. The same result is given by a hole in a white card, if the card is illuminated and observation is made through the hole at a dark background.

If the reflected image of the full moon or of a bright star from the convex surface of a lens be used instead of the pin hole in a card, the inverted shadow will be observed. If the reflecting surface is concave, the shadow will appear erect if the eye is placed between the reflector and its principal focus. If the eye and pin are in the divergent beam beyond the principal focus, the shadow of the pin head will appear inverted.

It is evident that when the shadow on the retina is erect, it appears inverted, and *vice versa*.

The eye lens and retina may be replaced by a convex lens and a paper screen upon which an image of the moon may be cast. A pin closely in front of the lens will show no shadow. If another convex lens be now placed in front of the lens representing the eye, the moon's image will be out of focus. The moon's image may be in front of or behind the screen, according to the position of the second lens. The shadow of the pin will then appear.

The capacity for accommodation of this artificial eye is unlimited, and the second lens may be dispensed with. The screen being placed between the lens and the image, the shadow of the pin will appear erect on the screen. When placed beyond the image, it will appear inverted.

If an opera glass be focused on a street lamp 50 meters away a pin head between the eye and the eye-lens will produce no shadow on the retina. If the glass be focused for a nearer object, an erect shadow will appear. If focused for a more distant object, the shadow will appear inverted. A hole through a card and with a bright background may be viewed by means of the opera glass. The hole may have any diameter from 0.05 to 1.5 cm. The distance of the card must be adapted to the diameter of the hole, and may vary from close contact with the object lens to three or four meters, the glass being focused for a more distant object. The results are as indicated above. The setting sun surrounded by bright clouds may be used as an object, if viewed through the foliage of trees thirty or forty meters distant, the glass being focused for an object more distant than the trees. The mass of foliage will be dotted with pin head shadows. Each opening through the leaves acts in a manner similar to the pin hole.

In all of the cases described, the shadow upon the retina is by some mental act projected outward in space. An interesting question arises concerning its apparent position. LeConte says that in his experiments it appears in the hole in the card. Perhaps it would be proper to say that it is seen through the hole. The hole itself may have a diameter of about one third that of the pin head, and the pin head then appears smaller than the hole. Its apparent size depends somewhat on the diameter of the hole.

If a pin is placed back of the card and in erect position so that it is visible through the hole, it may be so placed that it has the same apparent size as the shadow. If the pin is at a distance of 30 cm. from the eye, and the card is at a distance of 15 cm., the shadow and the pin will have the same apparent size. The appearance of the inverted shadow and the erect pin is as shown in Fig. 1.

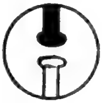


Fig. 1.

This suggests an interesting device whereby the line of sight of the two eyes and the capacity for muscular adjustment may be examined. Pierce a card with two pin holes, at such a distance from each other that when placed at half the distance of distinct vision from the eyes, they may be seen as one. This can be done by drawing lines across the ruled lines of a page of white paper, and crossing the ruled lines symmetrically so that at the top of the page the lines are farther apart and at the bottom they are nearer together than the two eyes. Pierce pin holes at each intersection of the ruled lines with the cross lines. If held in front of the eyes so that the cross lines are seen double, the two inner images of the lines will appear to cross. At this distance apart thus determined two holes will appear as one. Place a card having holes thus placed in front of the eyes. Mount two pins in front of the pupils so that the two shadows appear superposed in the superposed images of the holes. Two pins may now be placed back of the card so that when viewed through the holes they will also appear superposed. The two holes and the four pins will then present the appearance shown in Fig. 1. This arrangement locates two points along the line of sight of each eye. The holes may be in separate cards which close the ends of two tubes, through which the observations are made. These tubes, together with the pins, should be capable of screw adjustments.

When the pin hole is viewed through a tube which is lined with dark paper, the card serving to close the outer end of the tube, it may be used for an examination of certain imperfections in the eye. For example, in my own case one eye shows a minute hole with a bright background to be of uniform appearance. Viewed by the other eye a rather sharply defined shadow is shown in the center of the hole. This is due to a slight irregularity in the curvature of the outer surface of the cornea. This is due to a grain of gunpowder which was blown into the eye from a horse-pistol which was discharged from a distance of about 35 cm., into the lower part of the face, about fifty years ago. The grain of powder was visible for many years, but has been gradually absorbed. A slight distortion of closely ruled parallel lines indicates that an irregularity of the surface still persists. The shadow seen in the pin hole shows that light is not uniformly spread over the retina when a slightly divergent beam of light enters the pupil. Any opacity in the crystalline lens would also produce a shadow upon the retina.

PROCEEDINGS
OF THE
AMERICAN PHILOSOPHICAL SOCIETY
HELD AT PHILADELPHIA
FOR PROMOTING USEFUL KNOWLEDGE

VOL. L JULY–AUGUST, 1911 No. 200

SYMPOSIUM.

THE MODERN THEORY OF ELECTRICITY AND MATTER.

I.

THE GENERAL PRINCIPLES.

By DANIEL F. COMSTOCK.

(*Read April 22, 1911.*)

The field of the present discussion is so large and the time for it is so limited that I feel sure I can serve you best by foregoing the luxury of an historical introduction and by entering somewhat abruptly into the heart of the subject before us. I wish, then, to discuss before you the general ideas and beliefs respecting the ultimate nature and relations of matter and electricity which are in the foreground at the present time.

In dealing with progress of scientific explanation it is necessary to remember, what we too often forget, that the verb "to explain," when applied to a new complex phenomenon, means merely the expressing of it in terms of something else either more *familiar* or more *fundamental*. An exaggerated example of the first type is furnished by all the old anthropomorphic explanations of natural

PROC. AMER. PHIL. SOC., L. 200 U, PRINTED JULY 31, 1911.

phenomena in which the less familiar actions of the outside world were expressed in terms of the intimate and much more familiar workings of the human mind. "Nature abhors a vacuum," and like expressions, show the type.

The progress of science exhibits countless examples of the second type of explanation, for, wherever two or more concepts are merged into a profounder synthesis, there we have an expression in terms of something more *fundamental.* When, for instance, it is said that the phenomena of tidal action are caused by the gravitational attraction of the moon, it is stated merely that this action is really one with countless other phenomena which, although dissimilar on the surface, merge with it into the profounder synthesis known as the law of gravitation.

It is important also to remember in this connection, that *in* this process of explanation we always have left the one concept into which the many have merged, so that as time goes on the alternatives of explanation grow fewer and fewer, and in the end—if we can imagine an end—there is no explanation, because there is no more fundamental fact.

You will pardon me, I am sure, if I say one word more with reference to this question of ultimate explanation.

We have all heard people say, "Isn't it wonderful that so much is known *about* electricity, and yet no one knows what electricity *is*!" Now, doubtless the observation has some meaning, but certainly not as much as it seems to have; for, after all, what do they mean by "what electricity is"? Do they expect the announcement some day that electricity is a liquid similar to water, or a gas similar to air?

It is becoming more and more probable that electricity is the chief constituent of the atoms themselves, and an electron, which is a particle of electricity, if anything is, is certainly less than a ten-thousandth the size of one of the atoms in a water molecule. Therefore after the "*is,*" following the word "electricity," there is nothing to put which is already familiar, and when the profounder concept does come, it will be extremely fundamental, but it will cause the layman no thrill of long-anticipated disclosure.

A special type of critical attitude is necessary in dealing with fundamental physical concepts and it is an attitude which we seldom assume, so that these remarks have been necessary to introduce properly the three fundamental realities which modern physical theory now contemplates, namely: the *atom*, the *electron*, and that mysterious but perhaps even more fundamental entity known as *energy*.

A few years ago I would have mentioned also the *ether*, but I am a little reluctant to do so now. Not that there has been a sudden revolution in the realm of thought, resulting in the complete overthrow of the old regime, but rather that development has been such as to render the concept of an ether less and less impressive—one might say—and less and less important. Changes of opinion in such matters are, it seems to me, partly questions of emphasis, and radiant energy in all its nakedness is now usurping much that the ether has long stood for.

Of course, the loss, or rather the dimness, of the ether concept implies a certain loss of concreteness; but, as has been said, concreteness in new concepts, founded as it is on familiarity, is a secondary virtue and is of far less importance than the value of a concept in furthering the great process of induction which leads us to more and more general truths.

Although the concept of *the ether* is slowly dimming, the concept of *the atom* is becoming more and more definite and vivid. The study of the scintillations caused by radium rays and the work of Rutherford in counting the alpha particles give us, for the first time in the history of physics, definite observable results which apparently can only be due to the action of single atoms, and which therefore furnish proof beyond reasonable doubt that the atom and molecule are names of actual realities, and are not merely two prominent words in the statement of a useful hypothesis.

The kinetic theory of matter, carrying with it the concept of temperature as violence of atomic vibration, has also been strengthened enormously by the work of Perrin and Einstein on the Brownian movement. They find that microscopic particles in solutions have a perpetual motion in close agreement with the kinetic theory. Indeed, they act in all ways like big molecules, obeying the kinetic laws deducible from mechanics. Their observable agitation is part of the general vibratory motion which distinguishes a hot body from a cold one.

The electron, too, is now well within what we might call "the exclusive circle of the truly real." This minute charged body has by many researches, among them the recent one of Millikan, been shown to be a definite reality, present in all matter and entirely or largely responsible for all the phenomena we know as electrical.

The other fundamental entity, energy, is also, if I may be allowed the phrase, "mysteriously real." Radiant energy leaves the sun eight minutes before it reaches the earth, and must, therefore, exist during that time in the space between, dissociated from ordinary matter. When it finally strikes some object and is absorbed, it gives the object a thrust—that is, communicates momentum to it, as a bullet would do—and at the same time, of course, it increases the total energy of the body. In the same way, a body radiating energy recoils during the emission in a way similar to a gun.

All this is remarkably like the action of ordinary matter. We can, however, say even more. There is very good reason for believing that, were it possible to shut up a large amount of radiant energy in a hollow box, the inner surfaces of which were perfectly reflecting, so that the rays would be reflected back and forth indefinitely, we would find this confined energy to possess both mass and weight. Not many decades ago such an idea would have seemed absurd, but it is hard now to avoid the conclusion that such would be the case.

I can do no better now than to describe in a few words the picture which we have today of the ultimate structure of matter. A piece of matter is composed of particles called atoms, which, by uniting in groups in various ways, form the characteristic aggregates which we know as molecules. There are about one hundred different kinds of atoms, varying in relative weights from one to 240, and in relative volumes from one to about 16. The approximate diameter of an atom is one one-hundred-millionth of a centimeter.

These atoms are in ceaseless motion to and fro, the energy of this motion determining what we call the temperature of the body. Within the atoms and in the spaces between them are large numbers of very much smaller particles known as *electrons*. They each carry a negative charge, which is relatively enormous, considering the fact that the approximate electronic diameter can scarcely be more than one one-hundred-thousandth that of the atom.

When any cause sets up a general movement of the electrons within a body, we have a current of electricity, while the random vibratory heat motion of atom and electron is the cause of continual emission of radiant energy to other objects or to outside space.

A piece of matter is thus a complex system composed of an inconceivably large number of ultimate units, atoms and electrons, in ceaseless motion to and fro, and permeating all is the mysterious, matter-like entity which we have called *radiant energy*, and which ever seeks to escape with an enormous, though perfectly definite, velocity into the space outside. Some of it succeeds in escaping, but there appears to be a vast amount which in some way is imprisoned in the atom-electron aggregate and thus never becomes "radiant" in the strict sense of the word, though it resembles radiant energy so closely as almost to warrant the same name.

Having thus obtained an impressionistic view of the structure of a piece of matter, I would like to call attention to the properties of the space surrounding an electron, or, what is the same thing for our present purpose, the space surrounding any body, say a small sphere, possessing an electric charge. This space is the seat of what we call electric force, and is known as an "electric field." Now, it is a well-known conclusion and one which cannot at present be in any way avoided, that the energy which the body possesses, by virtue of its charge, that is, the energy originally required to charge it, resides in the electric field around the body, and not on or in the body itself. The existence, without apparent motion, of this energy in what seems to be empty space is very remarkable, but the conclusion that it *is* there is unavoidable, and after all there is no great difference between the discarnate state of this energy and the state of the radiant energy of the sun on its way to the earth. From the older point of view this energy in the electric field was "strain energy" in the ether, the so-called strain being similar to what we would get in an immense block of rubber if a pin-head embedded at its center were to swell into the size of an egg. The rubber would be pushed back in all directions and the energy of this compression would be stored up throughout the whole mass, a great deal of it near the center, but an appreciable amount even out at the very limits of the block. From the present point of view, we think more about the energy and less about the ether, but the general effect is the same.

Let us call this energy located in the space surrounding an electric charge "bound energy," to distinguish it from the closely similar type of self-propagating energy which can also exist in space and to which we apply the term "radiant," and let us then ask what properties, if any, this bound energy gives to the body which it surrounds.

I stated before that radiant energy, when it struck a body, communicated momentum to it in the same general way as a material body, say a flying bullet, would do. The radiant energy thus acts as if it had mass, and the question now is, "May the 'bound energy' surrounding our charged sphere also be considered to possess mass?" We may answer this question *in the affirmative*, for this bound energy is electric energy, and, thanks to the great founders of electrical science, we know the laws of electric action pretty completely.

Applying these well-known laws we find that when our charged sphere is moved, it acts like a current of elecricity and sets up a magnetic field about it, and the formation of this field acts, by the well-known laws of induction, to retard the motion of the charge. Thus the setting in motion of the sphere is made more difficult by reason of its charge, an effect which is equivalent to saying that the sphere has added mass.

If this were all, we might say that the added *charge* of electricity had mass, so that the mass increment is on the surface of the sphere where the charge is known to reside. This is *not* all, however, for by letting the sphere expand we can decrease the energy in the space about it without changing the magnitude of its charge; and we find, by further simple application of well-known electrical laws, that the new mass will change *exactly as the energy changes*. If the new mass had been proportional to the charge, it would remain constant with it instead of changing with the energy. Thus what is known as the electromagnetic mass of the sphere is proportional to its energy. I was able to show, several years ago, that, with certain limitations, this same result is true for any electric system.

It may be said, then, to follow from what might be called elementary electromagnetic principles, that the electromagnetic mass of an electric system is proportional to its electric energy. Now Hasenhorl, at Plancks's suggestion, I believe, had already shown that a similar result applied to radiant energy properly speaking; for he found that from known laws of radiation it followed that a hollow box, like that mentioned earlier, with perfectly reflecting walls, would, when filled with radiant energy, act as if it had added mass. That is, the pressure of radiation would be so changed by the increasing velocity of the box as to oppose the force causing this increase, and this inertia, this added mass, he found would be proportional to the amount of energy present. My proportionality constant agrees with his. Lewis, from a totally different point of view, has reached a similar conclusion.

It is, as you know, one of the profoundest generalizations in modern physics that light and other forms of radiant energy are in reality all forms of electromagnetic energy. Hasenhorl's results, therefore, that confined radiant energy possesses mass, combined with the result obtained in connection with the bound energy surrounding electric charges, *gives us the general result that all electromagnetic energy, whether bound or radiant, possesses mass,* and this mass is proportional to the quantity of energy present.

You see that the concept of energy, although in some ways very illusive, is getting singularly definite and persistent. Since we see that electric mass is proportional to electric energy, the question naturally arises: How much of the mass of the electron is due to the electric energy surrounding its relatively enormous charge, and how much is the "ordinary mechanical mass" of its body proper? We have a means of distinguishing between the two masses, for the electric mass does not remain constant when the velocity of the charge becomes great. Electrical laws tell us that it *increases,* very slowly at first, then more rapidly, and that as the velocity of light is approached it becomes very great. Of course, in ordinary mechanics, on the other hand, the mass of a body is considered to be a constant and to have nothing whatever to do with the velocity.

By studying experimentally the deflection of the beta-rays of radium, which consist of streams of electrons travelling at velocities very near that of light, Kaufmann has shown that the experimental change in mass fits the mathematically deduced change when, and only when, the "ordinary mechanical mass" is negligible. In other words, as near as measurement can yet go, the mass of the electron is *entirely* the electromagnetic mass of the surrounding energy, and it has no appreciable mass of what I might call "the old-fashioned mechanical kind."

This is a result of extraordinary importance in physical theory, for it immediately suggests the general question, "Is all mass of this origin?" Since an ordinary piece of matter is permeated with electrons and also with the radiant energy which all parts of it are constantly absorbing and emitting, it is an absolutely unavoidable conclusion that at least part of the total mass is of this electromagnetic type. But the question is, "Is *all* mass electromagnetic?" or, more properly speaking, *"Is all mass of the same type, and does it all depend upon the velocity in this same way?"* An affirmative answer would imply a profounder unity in physical phenomena than has hitherto been recognized and would thus correspond to the passage to a deeper synthesis. Of course, the deeper concept which unites two or more others should, in strictness, be made independent of these others; but, although definitely foreshadowed in the present case, the detailed statement of this deeper law is at present impossible *except as regards changes due to motion;* so that this, taken with the fact that electromagnetic phenomena are so familiar that we may be said to know their *modus operandi* in terms of magnetic fields, electric forces, and the like, renders it provisionally allowable to state the question in the form: "Are the laws of electricity and optics the laws of matter in general?"

We have, during the last few years, been attaining with greater and greater surety a definite answer to this question. It has come through the gradual adoption of a remarkable concept, profound in its meaning and very far-reaching in its consequences. I refer to the so-called "Principle of Relativity."

There are times in the history of science when various contradictions require that the process of building stop until the most fundamental concepts are reëxamined. This was true in the history of astronomy at the time of Copernicus. The prevailing conception of the earth as a fixed center about which all the other bodies revolve had been practically sufficient for a long time, but gradually difficulty after difficulty arose until it was no longer possible to patch up the old theory to meet the accumulation of stubborn facts. Only by a change in the most fundamental conception, namely, that of the earth as a fixed center, could harmony be brought out of chaos and a new period of development commenced. We seem to be passing through a somewhat similar period in physics, and the "Principle of Relativity" contains the modified concepts.

By way of transition, let me make one or two statements at this point about electric and magnetic systems in general. It can readily be shown to follow from known electromagnetic laws that two electric charges of the same sign moving side by side with the same velocity repel each other *less* than when the two are stationary. This is due largely to the fact that, when moving, each charge is surrounded by a magnetic field and this magnetic field introduces new forces.

This simple statement introduces a far more general one, for it may be shown that a steady motion of *any* electromagnetic system so changes the force between the various parts of the system that it tends to take up a new position of equilibrium. *The forces are such that the whole system tends to contract along the line of motion.* If it be allowed so to contract until it reaches this new position of equilibrium, then everything will be as before the system was set in motion, with two important exceptions, if the system has any internal motions caused by electromagnetic force. First, two motions, say the oscillation of two charges, one in the front of the system and the other behind, which in a stationary system take place simultaneously, will, in the moving system, take place not quite simultaneously; for the forward one will be somewhat behind in time; and, second, all such motions will take place a little slower than they did in the stationary system. The term electromagnetic system, used in this sense, includes, of course, all radiant energy, for it will be remembered that this type of energy is also electromagnetic.

Thus, on grounds of well-established electromagnetic theory and without any new fundamental conceptions whatever, we can make a general statement that *any electromagnetic system, when set in motion, tends to assume a new state of equilibrium, and if this change be allowed to take place, then all effects, electric and optical, take place in the changed system in a manner exactly corresponding to the way they did take place before the system was set in motion.*

A moment's thought will make it evident that we are here apparently in the presence of a fundamental lack of harmony between electromagnetic phenomena and the phenomena connected with matter in general; for, from the ordinary point of view, the parts of a "rigid body" maintain their mutual relations unaltered whether or not it is set in motion, while, as we have seen, this is not true of electromagnetic systems.

Now, we have no choice but to consider a *real* body as a combination made up of the two kinds of systems if there are two, the electromagnetic type and the "rigid body" type; hence it is clear that, when such a mixed system is set in motion, there will be a considerable amount of what we might term internal discord, owing to the conflicting tendency of the two types. It would be very easy to distinguish such a mixed moving system from the same system at rest, because its parts would bear quite different relations to each other than they did before. Setting a real system in motion would be like heating an object made up of two substances having different coefficients of expansion. The parts of such a system would then bear totally different relations to each other than when the whole thing was at rest, and the internal dissension would increase with the velocity and would depend on its direction.

Now as a matter of fact, we all live on such a moving mixed system, a system which is going around the sun with a velocity of nearly twenty miles a second; and yet, although many carefully planned and executed experiments have been carried out to detect differences in the actions of various electrical and optical systems, according as they are made to face with the earth's velocity or across it, every one of them has given negative results, and has thus shown that the relative parts of the system *bear the same relation to each other, no matter what the direction of motion is.*

It is like finding that an object made up of metal and glass had no strains set up in it when heated, a result which could only be attained if the metal and glass had the same coefficient of expansion.

What are we to conclude in the case before us? There seems to be no alternative. We already have seen that electrons are among the fundamental constituents of all atoms; we have seen that radiant energy is electromagnetic and that such energy permeates all matter. We have seen that energy resembles matter in possessing mass, and that, therefore, to the same degree, matter resembles energy. The necessary conclusion seems to be that *all physical phenomena obey the same general laws of which the known electromagnetic laws are as yet the completest expression.*

And now to what have we committed ourselves by this conclusion as regards changes due to motion? Merely this: that all real systems being ultimately "electromagnetic" in the above sense, undergo certain changes when set in motion, but these changes are such as to leave all parts bearing the same relation to each other. Thus since the knowledge of an observer travelling with the system is only relative, he is not able to detect such absolute changes, just as we are not able to detect the motion of the earth. The changes in his system would be noticeable to an observer whose instruments did not move, but cannot be detected by moving instruments.

The kind of change which we have said is produced in a system by setting it in motion has one property which is important and profoundly significant. It is that the moving observer sees precisely the same change in stationary systems which he is passing as the stationary observer sees in the moving system; so that not only can the moving observer not detect his motion by means of his instruments, but *the two observers together,* if their memory fail, can by no means tell which is moving. There is, in other words, a very complete symmetry with regard to what the two observers can actually find out about their systems, although we called one of them stationary in the beginning.

Because of this complete symmetry the most conservative among us will admit that the concept of absolute motion *need not be used very often*, at least, in the science of the future; if the foregoing views are true ones. The modern group of conceptions known as the "Principle of Relativity" teaches that the idea of absolute motion is entirely superfluous, and that the time honored concepts of space and time, as independent of all motions, do not accurately fit the real universe and should be modified.

Modified in what way? Real time is measured by real clocks and real distance is measured by real rigid bodies, and we find an unexpected discord between moving clocks and stationary clocks, and between moving rods and stationary ones. We have, therefore, no possible use for what might be called "universal time." We might form a vague concept of a "cosmic second" pervading the universe, but we could do nothing with it, and it would therefore be entirely artificial. Whenever we wished to think about an actual moving object and wished to measure some vibration frequency on it, let us say, we would have to use some actual clock-beat or other periodic phenomenon as a unit. So that the actual universe has us hopelessly in its grasp, and our concepts of space and time to be valuable must be in harmony with the habits of real things.

The principle of relativity, therefore, makes changes in the fundamental concepts of space and time for moving systems; the second in a moving system is longer, the meter, in the direction of motion, shorter, than in stationary systems. The units then are in harmony with real happenings in such systems, and this makes it possible to introduce the last great synthesis of modern theory, the deeper unity of physical law under the dominance of what we have known as electromagnetic principles; and this brings us one step nearer to the last, ultimate generalization which is the unattainable ideal of science.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
April 20, 1911.

II.

RADIOACTIVITY.

By BERTRAM B. BOLTWOOD.

(*Read April 22, 1911.*)

The study of the discharge of electricity through gases and the properties of radioactive substances has done much to broaden our knowledge of the relations of electricity and matter. It has served to throw a new light on the ultimate constitution of matter itself, and, while confirming the older theory of a discontinuous or atomic structure, has led to the presumption that the chemical atom is not only divisible into still smaller entities, but that in some cases it can undergo a spontaneous disruption accompanied by the ejectment of certain of its constituent parts at high velocities. All this has opened a broad and attractive field for more or less legitimate speculation and conjecture.

Since the first recognition by Becquerel in 1897 of the radioactive phenomena exhibited by the element uranium, the extension of our knowledge of the radioactive substances has steadily and progressively advanced. This development has been due in great part to the early formulation of the theory of atomic disintegration, proposed in 1902 by Rutherford and Soddy, which has served as a systematic foundation and has afforded an orderly basis for the interpretation of the otherwise somewhat complicated relations.

According to this hypothesis the atoms of the primary radioactive elements are considered to undergo spontaneous disintegration and in this manner to give rise to a series of successive radioactive products, differing from the parent substances as well as from one another in physical and chemical properties and in the relative stability of their atomic systems. Simultaneously with the disruption of the atoms certain characteristic radiations are emitted by the systems, and it is these radiations which led to the discovery of the radio-elements and which particularly distinguishes them from all other types of matter.

The characteristic radiations emitted by radioactive substances are three in number and are known as the alpha, the beta and the gamma rays.

For our knowledge of the alpha radiation we are indebted chiefly to the work of Rutherford and his associates, which has shown conclusively that these rays consist of discreet particles of atomic dimensions, projected with high velocities and bearing a positive charge. The earlier investigations were conducted with a view to determining the mass of the particles from the deflections suffered by the rays in electric and magnetic fields of known strengths. A value for the ratio of the charge to the mass (e/m) was obtained in this manner and this led to the conclusion that, if the charge on a particle was the same as that carried by the hydrogen ion in electrolysis, the mass of the particles was approximately twice that of the hydrogen atom. Strong evidence was also obtained that the alpha particles emitted by the different radio-elements are identical in nature irrespective of the character of the particular radio-element from which they originate.

A very ingenious experiment was then devised by Rutherford and Geiger, in which a known fraction of the alpha particles emitted by a radioactive source was allowed to enter a small ionization chamber containing a gas at low pressure. Under the influence of a strong electric field the ions formed by the entering particles acquired so high a velocity that additional ions were produced by their collision with neutral gas molecules and the electrical effect was increased to a point where the action of a single particle could be readily detected. It was shown, moreover, that each of the scintillations appearing on a screen of Sidot's blende placed in the path of the rays corresponded to the impact of a single alpha particle.

In this manner the actual number of alpha particles emitted by a radioactive substance was accurately counted, and it was found that one gram of radium itself emitted 3.4×10^{10} alpha particles per second.

By measuring the electric charge imparted to an insulated plate by the impact of a given number of alpha particles, the charge carried by each particle could be readily determined. This was found to be equal to 9.3×10^{-10} electrostatic units. It was then shown in an ingenious manner that this charge was twice that carried by an electron or by a hydrogen ion, although preceding determinations of the latter magnitude had indicated that its value was somewhat less than one half of 9.3×10^{-10}. The recent determinations made by Millikam of the charge on an ion have shown, however, that 4.65×10^{-10} is not far from correct and have confirmed the conclusion reached by Rutherford and Geiger that the charge on an alpha particle is equal to twice the unit charge of the hydrogen atom in electrolysis.

With this modification, the ratio of the charge to the mass of an alpha particle indicates that the mass is equivalent to an atomic weight of four. This corresponds to the mass of an atom of the gaseous element helium.

The final proof of the intimate connection of the alpha particle with the helium atom was supplied by Rutherford and Royds who proved by spectroscopic methods that readily detectible amounts of helium could always be obtained when large numbers of alpha particles were allowed to penetrate through a thin glass wall into a highly evacuated receptacle or into a screen of lead, from which the helium was ultimately released by fusion of the metal.

It is a significant fact that although the alpha particles from the different types of radioactive matter appear to be all of a similar nature and to consist of atoms of helium bearing a double, positive charge, the velocities at which they are ejected are different for the different radioactive substances. The velocity of the particles emitted by the atoms of any one type of matter undergoing transformation is, however, always the same and is a characteristic constant for that particular radio-element. Attention was first called to this important relation by Bragg and Kleeman and it is undoubtedly significant in its bearing on the constitution of the radio-atoms. The observed velocities of the particles appear to lie between the limits of 1.5×10^9 and 2.25×10^9 centimeters per second.

Owing to their high velocities the alpha particles are capable of passing through thin layers of ordinary matter, and can penetrate into air at atmospheric pressure for distances of from somewhat less than three to about eight centimeters. They produce phosphorescence and chemical action in substances on which they impinge and strongly ionize gases through which they pass.

Through measurements of their deflection in electric and magnetic fields the beta rays emitted by radioactive substances have been shown to consist of negatively electrified particles or electrons with an apparent mass about one eighteen-hundredth that of the hydrogen atom. The velocity with which they are projected is considerably higher than that of the alpha particles and in some cases exceeds nine tenths the velocity of light. They are capable of penetrating through moderate thicknesses of ordinary matter and for considerable distances in air. They cause phosphorescence and chemical action in substances on which they fall and produce ions in gases through which they pass.

Although the beta particles emitted by the different types of radioactive matter are in all respects identical in nature, they exhibit the same peculiarities with respect to the velocities with which they are initially projected that has been observed in the case of the alpha rays. The velocity of the beta rays from any given radio-element is the same within certain limits for every disintegrating atom of that element, but is different from the velocity of the rays emitted by other elements. The velocity of the beta rays is therefore characteristic for each of the substances which give rise to this type of radiation and has undoubtedly a significant bearing on the constitution of the radio-atoms. It appears probable from some recent experiments performed by Hahn and von Beyer, in which a magnetic spectrum of the beta rays emitted by certain radioactive substances was obtained, that the transformation of some of the radio-atoms is accompanied by the expulsion of a series of beta particles of different velocities. These results are very suggestive of the model atom devised by Sir J. J. Thomson in which the atom was assumed to be built up of concentric shells of electrons revolving with different velocities in circular orbits. It would seem quite possible that in such a system a rearrangement of the parts might result in the expulsion of electrons from several layers simultaneously.

The third type of radiation associated with radioactive transformations, known as the gamma rays, is similar to the X-rays and is supposed to consist of electromagnetic pulses in the ether. A rather ingenious corpuscular theory as to the nature of these rays has been proposed by Bragg, but has not met with general acceptance owing to the fact that it appears to be not altogether in accord with the experimental evidence.

The origin of gamma rays seems to be very intimately connected with the emission of beta particles, for the two types of radiation have been observed to appear simultaneously and bear a certain definite relation to one another. When the expelled beta particle has a high velocity the gamma ray is of a very penetrating character, while if the velocity of the beta particle is low the gamma ray emitted has but little power of penetrating ordinary matter.

The disintegration of the radio-elements takes place according to a very simple law and the number of atoms of any radio-element which undergo transformation in the unit time is a definite proportion of the total number of atoms initially present. The number of atoms N remaining unchanged after any time t is given by $N = No e^{-\lambda t}$, where No is the initial number of atoms and λ is the fraction undergoing transformation in the unit of time. This fraction has a fixed and invariable value for each separate radio-element and for this reason is known as the *constant of change* for the element in question. It is a relatively simple matter to determine the period of time required under these conditions for exactly half of any given quantity of a radio-element to be converted into other substances and this time is known as *the half value period*. The rate of change and the corresponding half value period is a definite characteristic for each of the radio-elements but is very different for the different radioactive substances. The half-value period of uranium, for example, is over five billion years while the half-value period of certain other radio-elements is only a few seconds.

Although the disintegration of some of the radio-elements has been examined over wide extremes of temperature and pressure, and under various other special conditions which would greatly influence the course of ordinary chemical reactions, it has not been found possible to definitely alter or effect the rate at which transformation takes place to the slightest measurable degree. It is therefore evident that the disintegration of the radio-active substances is of a wholly different character from the ordinary chemical changes. This is exactly what would be expected if the radioactive processes occur within the atoms themselves, for, in accordance with our general theories, chemical forces appear to be restricted in their action to the exterior of the atomic systems only.

We have thus far considered only the laws which govern the transformation of radioactive matter and the radiations which accompany the disintegration of the atoms; let us now turn our attention to the substances themselves. Investigation has brought to light three main groups of radioactive elements—the uranium series, the thorium series and the alkali metals. Of the last mentioned our knowledge is not very extensive. A type of beta radiation appears to be emitted by the salts of potassium and rubidium but their title to be considered as true radio-elements is not as yet entirely clear.

The uranium series, in addition to the parent substance, contains ten products which may be properly considered as in the main line of descent. These are uranium X, ionium, radium, radium emanation, radium A, radium B, radium C, radium D, radium E and radium F. Each of these products exhibits a characteristic chemical behavior which is different from that of the parent element uranium. The half value period of uranium has already been mentioned as exceeding five billions of years and the disintegration of its atoms is accompanied by the expulsion of alpha particles. Uranium X, ionium and radium are solids, the two first having chemical properties similar to thorium, while radium has those of an alkali earth and particularly resembles barium. Uranium X has a half value period of about twenty-four days, and it emits only beta and gamma rays. The rate of disintegration of ionium is not as yet known with any degree of accuracy but it is certainly a relatively stable product and is transformed but slowly. Its half value period is probably of the order of ten thousand years. It emits alpha rays only. The half value period of radium is approximately two thousand years. Rutherford and Geiger have deduced a somewhat lower value, namely 1,760 years, as a result of their experiments, but this value is probably an under estimate, as will be explained later in this paper. Radium emits alpha rays and probably very low velocity beta rays also. The change following radium is a striking one for the product in this case is gaseous. It is known as the radium emanation and has the inert chemical character of the rarer gases of the atmosphere, helium, neon, argon, krypton and xenon. When the atoms of radium emanation undergo transformation, the succeeding product known as radium A is formed. This is a solid and is deposited in the form of a thin coating of active matter on the walls of a vessel containing the emanation. This acquirement of activity by the surface of objects in contact with the emanation was observed some time before a satisfactory explanation of the phenomenon was suggested. It was therefore known as "imparted" or "induced" activity. It is now called the active deposit. Radium A, which has a half value period of three minutes and emits alpha rays, is followed by radium B, which emits beta rays and is half transformed in about twenty-six minutes, and this in turn is succeeded by radium C with a half value period of about nineteen minutes. The transformation of radium C is accompanied by the expulsion of alpha, beta and gamma rays. An interesting product known as radium D then ensues, its transformation being characterized by the absence of any detectible radiation whatever. A product of this sort is known as a *rayless change* and other examples to such a change occur in both the thorium and actinium series. On account of the similarity of its chemical properties to those of ordinary lead, radium D is known as radio-lead. It undergoes transformation more slowly than the immediately preceding products and has a half value period of about sixteen years. It is followed by radium E, a beta ray change, with a period of five days, and this is succeeded by radium F, otherwise known as polonium. Polonium emits alpha rays only and is half transformed in one hundred and forty-three days.

In addition to the ionium-radium series, uranium is also the progenitor of another group of radio-elements of which actinium is the first and most stable member. The rate of change of actinium has not yet been determined, but is comparatively slow and is probably of the same order as that of the radium. Actinium offers another example of the rayless changes which have already been referred to, and no radiations have been observed to accompany its transformation.

Six products subsequent to actinium have thus far been identified in this series. The first is radioactinium, an element having a half-value period of 19½ days and emitting both alpha and beta particles. The subsequent product is known as actinium X. The half value period of actinium X is about ten days and its atoms disintegrate with the expulsion of alpha particles. The next step in the series of transformation is the gaseous product known as the actinium emanation. This, like the radium emanation, is chemically inert and incapable of entering into combination with other elements. Actinium emanation is a very short lived substance and has a half value period of only 3.9 seconds. It is transformed successively into three other products, which are solids, known respectively as actinium A, B and C, and together constitute the so-called active deposit from the actinium emanation. Actinium A has a half value period of 36 minutes, actinium B of 3.1 minutes and actinium C of 5.1 minutes. The first emits beta rays, the second alpha rays, and the third beta and gamma rays.

As already stated, actinium and its products are genetically connected with uranium and are, in some manner as yet obscure, derived from it. The evidence in support of this conclusion is quite convincing. All uranium minerals contain definite quantities of actinium and in the older minerals the relative proportions of uranium and actinium present are so constant as to permit of no other explanation. But the actual genealogical history of actinium is still obscure and we are not yet in a position to clearly trace the line of descent. Whether actinium is formed directly from uranium by a special kind of transformation which involves only a small proportion of the total number of the atoms changing, or whether its production occurs at a later stage in the uranium-radium series, is at present an open question and the discovery of the true relations is one of the most interesting problems now awaiting solution.

The thorium series presents another group of radio-elements comprising ten successive members. I shall not stop to enumerate these in detail, but their principal physical and chemical characteristics have already been determined. Thorium itself, the parent substance, has a very slow rate of change, which is probably not more than a fifth that of uranium.

Its first product, mesothorium 1, is another example of a rayless change like radium D and actinium. Owing to the fact that large quantities of monazite are commercially treated for the extraction of thorium used in the manufacture of incandescent gas mantles and that the technical separation and isolation of mesothorium appears to be an economic possibility, there is some prospect that mesothorium may become a competitor of radium for scientific and therapeutic uses. Its life compared with radium is relatively short, however, its half value period being 5½ years, but this in itself is not necessarily a serious disadvantage. The chemical properties of mesothorium are similar to those of radium and barium.

The fifth product in the thorium series is known as the thorium emanation and is a chemically inert gas like the radium and actinium emanations. The remaining four products constitute the *thorium active deposit.*

The combined uranium and thorium series includes 28 radio-elements, of which only the two parent elements were known before the development of radioactive methods. Radioactivity has therefore added a considerable quota to the known types of matter.

An interesting relation which is met in the study of radioactive change is the so-called *radioactive equilibrium.* If a relatively long-lived radio-element A is the parent of a less stable product B, and if A is initially entirely freed from B, then a certain definite fraction of the atoms of A will undergo transformation each second to form atoms of the product B. The number of atoms of B produced from A in this manner each second will be essentially constant and the amount of B will increase. But the atoms of B also undergo transformation at a constant rate and, as the quantity of B increases, a continually increasing number of its atoms will be transformed in the unit of time. A point will finally be reached where the number of atoms of B which disintegrate in any given time will be exactly equal to the number of atoms of B formed from A in the same interval. The relative amounts of A and B will then remain constant and the conditions can be expressed by the equation

$$\lambda_1 P = \lambda_2 Q,$$

where P is the number of atoms of A and λ_1 its constant of change, and Q is the number of atoms of B and λ_2 the constant of change of the product B. Under these conditions the substances A and B are said to be in *equilibrium* with one another. The general mathematical theory of successive changes of this kind has been developed by Rutherford.

In the discussion of the characteristics of the alpha rays it has been pointed out that the evidence supplied by the determination of the ratio of the charge to the mass of these particles indicates that their nature is the same in all cases. Let us consider briefly the additional facts which are in support of this conclusion.

The presence of considerable proportions of helium in crystalline minerals containing uranium and thorium has been very frequently noticed. It was found by Ramsay and Soddy in 1903 that helium could be detected in the residual gas set free when a specimen of crystalline radium bromide was dissolved in water, and shortly after this they showed that the spectrum of helium appeared with time in a tube which initially contained only radium emanation. Debierne found that helium was produced by a strong preparation of actinium, and conclusive proof has also been obtained by Strutt and by Soddy that helium results from the disintegration of both thorium and uranium.

During the past year I was able to experimentally demonstrate the production of helium by ionium, and some earlier experiments carried out by Professor Rutherford and myself showed that helium appeared during the disintegration of polonium also. The latter conclusion has since been confirmed by the work of Mme. Curie and Debierne.

The data supplied by the counting experiments of Rutherford and Geiger afford a basis for the calculation of a number of important physical quantities, such as the mass of the hydrogen atom, the number of atoms in one gram of hydrogen and the number of molecules per cubic centimeter of any gas at standard pressure and temperature. In a similar matter Rutherford and Geiger have calculated the amount of helium produced per year by one gram of radium containing equilibrium amounts of its three alpha ray products, the emanation, radium A and radium C. The number obtained in this way was 158 cubic millimeters of helium per year per gram of radium. Measurements of the rate of production of helium by a radium salt have been carried out by Sir James Dewar and have given results somewhat in excess of this, namely 182 and 169 cubic millimeters. As a confirmation of the accuracy of Rutherford and Geiger's values, however, it may be stated that an investigation of the production of helium by radium made last year by Professor Rutherford and myself gave results in excellent agreement with the calculated value. An account of these experiments will be published shortly.

In connection with these results there is, however, one rather important point which should be mentioned. This is the fact that the rate of production of helium and the half value period of radium as calculated by Rutherford and Geiger from the results of their counting experiments, are directly dependent of the purity of the salt of radium used as a standard in their measurements. They assumed that the material of their radium standard was pure anhydrous radium bromide containing 58.5 per cent. of radium. If this was not the case and the material used as their standard contains less than the theoretical amount of radium, their calculation of the number of alpha particles emitted per gram of radium and the rate of production of helium is too low, and their estimate of the half value period of radium is too high. If, on the other hand, the material of their standard consists in part of some other compound of radium containing a higher proportion of this element than is contained in the bromide, their value for the number of alpha particles emitted and the rate of production of helium is too high and their calculated rate of disintegration of radium is too low.

There are certain reasons which lead me to believe that the radium standard used by Rutherford and Geiger actually contains a higher proportion of the element radium than they have assumed in their calculation, and that the true half value period of radium is greater than 1,760 years as they have deduced it. In 1908 I published an account of some experiments on the growth of radium in ionium preparations, which pointed to two thousand years as the half-value period of the former. This estimate was quite independent of any radium standard and I am of the opinion that it is nearer the true value than is the estimate made by Rutherford and Geiger.

The point can be definitely settled, however, by a comparison of Rutherford's standard with a standard of indisputable purity. Such a standard is in prospect in the not distant future and its preparation has been undertaken by Mme. Curie on behalf of the International Radium Standards Committee appointed at the recent Radiological Congress in Brussels.

A very interesting action which has been observed to accompany radioactive transformations is known as the *recoil phenomenon.* When a plate bearing a thin layer of very active material is placed in close proximity of another plate which is inactive, a portion of the active matter becomes detached from the film and is deposited on the surface of the second plate.

The effect is increased considerably if the receiving plate is charged negatively with respect to the plate bearing the active coating. This action is apparently due to the fact that, when the alpha or beta rays are expelled at a high velocity from a radio-atom undergoing transformation, the reaction on the residual atom causes this to move in the opposite direction with sufficient force to detach it from the plate. The action is analogous to the recoil of a rifle attending the expulsion of a high velocity bullet. When, for example, the active coating on the first plate consists of radium A then the active matter received on the second plate is composed almost exclusively of radium B; and when the film consists of radium B the material thrown off is for the most part radium C. This and other similar effects which have been noted are all of such a nature as to suggest that the explanation proposed for this interesting phenomenon is the correct one. The effect of the electric field indicates that in some way these "rest atoms" acquire positive electric charges.

From the standpoint of the disintegration theory, it is evident, when we consider the three principal groups of radioactive substances, the uranium-radium group, the actinium group, and the thorium group, that the radioactive phenomena exhibited by the atoms abruptly disappear after they have passed through a certain series of transformations, which terminates with radium F in one instance, with actinium C in another and with thorium D in the third. The apparent explanation of this circumstance would seem to be, that, following the last active change, the residual atomic nucleus finally attains a permanently stable form which undergoes no further alterations. If such is indeed the case, then we might expect that these ultimate end products of radioactive decay would accumulate in old radioactive minerals where the process of transformation has been proceeding for long geological periods. This line of reasoning has enabled us to identify at least one of these products and that is, in all probability, the one following radium F. The residual atom in this case appears to be no other than the atom of ordinary lead. There are, moreover, certain theoretical arguments which point to the same conclusion. The accepted atomic weight of uranium is 238.5. It has been found that two alpha particles are emitted during its transformation and one by the succeeding product, ionium. This would correspond to the loss of three alpha particles or helium atoms with an atomic weight of four or a total of twelve units. Two hundred and thirty-eight and one half less twelve give two hundred and twenty-six and one half for the atomic weight of radium, which corresponds to the value obtained in the actual determination of the atomic weight of this element by Mme. Curie. The transformations of the atoms of radium, the emanation, radium A, radium C and radium F are each accompanied by the expulsion of another alpha particle, making five in all. Five times four is twenty and two hundred and twenty-six and one half less twenty is two hundred and six and one half. The latter number is sufficiently near to two hundred and seven and one tenth, the most recently determined atomic weight of lead, to support the conclusion that lead is the ultimate disintegration product of radium. It has not yet been possible to determine the end products of the actinium or the thorium series but they will undoubtedly be identified among the various elements occurring in small proportions in the older uranium and thorium minerals.

Before completing this necessarily brief résumé of the present status of the study of radioactive phenomena it is necessary to make some reference to the series of papers published by Sir William Ramsay associated with A. T. Cameron and F. L. Usher. These papers, which deal with the action of radium emanation on various other substances, suggest the occurrence of certain changes, which if they really took place would be of fundamental importance to the theory of the constitution of matter. Unfortunately, so little weight can be attached to these results and the conclusions reached by these authors, that they have received no serious consideration from those most competent to judge their value.

In closing, a point which seems worthy of special emphasis may be briefly mentioned. This is the apparently important part played by the alpha or *material* particle emitted during radioactive transformations. In those cases where it has been possible to observe its influence, the loss of an alpha particle is always accompanied by a corresponding decrease in the mass of the atom from which it is separated. Although the disruption of a radio-atom is accompanied by the release of a relatively enormous amount of energy, still it appears that the fragments projected into space are always of one or the other of two quite distinct classes; either beta particles of extremely small mass, or helium atoms of a mass seven thousand times that of the beta particles. So far as the results of our experiments have enlightened us we have not yet been able to observe the resolving of the by far the greater proportion of the *effective* mass of an atom into anything other than a further subdivision of ordinary matter.

YALE UNIVERSITY,
April 22, 1911.

III.

THE DYNAMICAL EFFECTS OF AGGREGATES OF ELECTRONS.

By OWEN W. RICHARDSON.

(Read April 22, 1911.)

1. Electrons and Matter.

The enormous difference in the behavior of different materials towards electric force is a matter with which everyone is familiar; and it is one of the triumphs of the electron theory that it has given us a very satisfactory picture of the difference between insulators and conductors of electricity. We are to regard all matter as made up primarily out of electrons. They are the stones with which the material structure is built up, the electrodynamic forces are the cement which holds the stones together. There are, however, two different ways in which the electrons may exist in a given portion of matter. They may be located in position of stable equilibrium, in which case a very small force will displace them to a small extent but a perfectly enormous force would be required to dislodge them thoroughly and give rise to instability; or they may be so loosely held that they are able to move about in the interstices of the material, very much after the fashion in which we believe the molecules move about in a gas. In the former case, when the electrons are practically fixed, we say the substance is an insulator; in the latter case, where they are wandering about, the substance is a conductor.

A moment's reflection will show that this difference is sufficient to explain the difference between insulators and conductors. Consider what happens when a slab of the first kind is placed in an electric field. There will be a displacement of the electrons, it is true, but the displacement will be small and they will all return to their original equilibrium positions as soon as the external field is removed. There will be no transportation of electrons and that is what, on the electron theory, constitutes an electric current. The electric field across the slab is, nevertheless, different from what it would be if the material were not present. The difference between different insulating materials in this respect depends solely on the comparative ease of displacement of the electrons they contain. The specific inductive capacity of dielectrics, which, you will remember, was discovered by Cavendish and Faraday, is, in fact, a measure of the product of the number of electrons in unit volume of the material by the average displacement which they undergo in unit field.

The behavior of the second kind of material is quite different. Even in the absence of the electric field, the so-called free electrons are moving about in it in an irregular manner in all directions. The effect of an external field is to superpose on the irregular motion a definite drift, on the average, in the direction of the current. This drift of the electrons involves *transportation* of electricity and therefore implies the existence of an electric current.

All the laws which regulate the transference of electricity across conductors, such as, for example, Ohm's Law, which states that the current is proportional to the applied electromotive force, and Joule's Law, which states that the rate of production of heat by a current is equal to the product of the resistance of the circuit by the square of the current, follow at once from this simple hypothesis. It is not necessary to suppose that all the electrons in the material are present in the free condition; some of them may be, and in all probability the majority are, in a state of equilibrium similar to that which occurs in insulators. All that is necessary is that some of the electrons should be able to move without restraint. When the other conditions are the same the magnitude of the current which a given material will transport is proportional to the number of carriers available; that is, to the number of free electrons per unit volume.

It is in the explanation of the relation between the conductivity of substances for electricity and for heat that the electron theory has scored one of its most notable triumphs. Everybody knows that the best conductors for electricity are also the best conductors for heat. It is not so generally known how very close the relationship between the two phenomena is. In the accompanying table two columns of figures are shown.

Material.	Ratio: Thermal Conductivity, Electrical Conductivity.	Temperature Coefficient of this Ratio, Per Cent.
Copper, commercial	6.76×10^{10} at 18° C.	—
Copper (1) pure	6.65×10^{10} at 18° C.	.39
Copper (2) pure	6.71×10^{10} at 18° C.	.39
Silver, pure	6.86×10^{10} at 18° C.	.37
Gold (1)	7.27×10^{10} at 18° C.	.36
Gold (2) pure	7.09×10^{10} at 18° C.	.37
Nickel	6.99×10^{10} at 18° C.	.39
Zinc (1)	7.05×10^{10} at 18° C.	.38
Zinc (2) pure	6.72×10^{10} at 18° C.	.38
Cadmium, pure	7.06×10^{10} at 18° C.	.37
Lead, pure	7.15×10^{10} at 18° C.	.40
Tin, pure	7.35×10^{10} at 18° C.	.34
Aluminium	6.36×10^{10} at 18° C.	.43
Platinum (1)	7.76×10^{10} at 18° C.	—
Platinum (2) pure	7.53×10^{10} at 18° C.	.46
Palladium	7.54×10^{10} at 18° C.	.46
Iron (1)	8.02×10^{10} at 18° C.	.43
Iron (2)	8.38×10^{10} at 18° C.	.44
Steel	9.03×10^{10} at 18° C.	.35
Bismuth	9.64×10^{10} at 18° C.	.15
Constantan (60Cu, 40Ni)	11.06×10^{10} at 18° C.	.23
Manganin (84Cu, 4Ni, 12Mn)	9.14×10^{10} at 18° C.	.27

They represent the results of measurements by Jaeger and Dieselhorst of the electric and thermal conductivities of a large number of metals and alloys. The first column of figures gives the ratio of the thermal to the electrical conductivity for each of these substances and the second gives the percentage change of this ratio when the temperature is increased one degree. It will at once be noticed that the numbers in each column are almost equal, particularly if we keep to the pure metals. Thus for every pure metal the electrical conductivity bears to the thermal conductivity a proportion which is almost independent of the metal: and the ratio of the thermal conductivity to the electrical conductivity increases by almost the same amount for one degree rise of temperature for each metal. The coefficient of increase of this ratio with increase of temperature is also very nearly equal to the coefficient of increase of the volume of all gases with temperature, when the pressure is maintained constant.

These interesting relations were shown to be a consequence of the electron theory of conductors by Drude. He proved that they follow inevitably from the assumptions (1) that a metal contains electrons which move about freely like the molecules of a gas, (2) that they possess a certain average mean length of free path λ during the traversing of which they are only acted on by the external applied electric force, (3) that this path is terminated by a collision and that the new motion which then ensues is, on the average, independent of the previous motion; and lastly (4) that their average kinetic energy is the same as the average kinetic energy of translation of a molecule of any gas at the same temperatur as the metal.

A simplified form of Drude's deduction may be given here. If X is the electric intensity inside the metal, e the electric charge possessed by an electron and m its mass, then the force acting on the electron during its free path is Xe and its acceleration Xe/m. If the velocity of the particle at the beginning of the path is u its velocity at the end will be $u+\frac{Xe}{m}t$ where t is the average time between two collisions. The average velocity in the direction of the electric field is therefore $\frac{1}{2}X\frac{e}{m}t$ since the average value of u taken over a large number of electrons is zero. Now the free path λ is equal to vt where v is the mean speed. Thus the average drift velocity of the electrons in the direction of the electric field may be written in the form $\frac{1}{2}X\frac{e}{m}\frac{\lambda}{v}$. If n is the number of electrons in unit volume, the number of them which, in unit time, drift across a unit area drawn perpendicular to the direction of the electric force X will be $\frac{1}{2}nX\frac{e}{m}\frac{\lambda}{v}$. Each of these carries a charge e so that the quantity of electricity transported across unit area, or in other words, the electric current density will be

$$l=\frac{n}{2}\frac{e^2}{m}\frac{\lambda}{v}X.$$

Now it is a necessary consequence of the principles which underlie the kinetic theory of matter that $\frac{1}{2}mv^2$ should be equal to $\alpha\theta$ where θ is the absolute temperature and α is a universal constant which may be calculated from the properties of gases. This assertion is the mathematical statement of the relation (4) enumerated above. Making this substitution we find that the specific electrical conductivity of the material is $\sigma = \frac{i}{X} = \frac{ne^2\lambda v}{4\alpha\theta}$. In this formula e^2 and α have the same value for all substances, n and λ are constants characteristic of each substance, v is independent of the nature of the material but is proportional to the square root of the absolute temperature.

It is a well-known result of experiment that the specific conductivity of all substances is inversely proportional to the absolute temperature. We therefore conclude that the product $n\lambda$ for all metals must be inversely proportional to the square root of the absolute temperature.

It is a well-known result of the kinetic theory of gases that the thermal conductivity of a gas is equal to $\frac{1}{3}n\lambda v\alpha$. Hence $\frac{k}{\sigma} = \frac{4}{3}\frac{\alpha^2}{e^2}\theta$. Thus this ratio should have the same value for all metals at the same temperature and the temperature variation should be the same as that of the volume of a gas at constant pressure. These are the relations which are exhibited by the experimental results of Jaeger and Diesselherst.

The electron theory of metallic conduction has enabled us to understand a number of curious effects which occur when a conductor is placed in a magnetic field. One of these, the Hall effect, consists in a deflection of the line of flow of a current which is caused by the magnetic field. Another effect, which is especially marked in the case of Bismuth, is an alteration of the specific resistance of the material caused by a magnetic field. These effects are intimately connected together and have a simple explanation on the electron theory. It is well known that any electrified particle moving in a magnetic field is acted on by a force which is perpendicular to the plane containing the magnetic force and the direction of motion. The superposition of this force upon the other forces acting on the electrons in a metal carrying a current will cause all the electrons to curve round in the same general direction, giving rise to the Hall effect. It will also increase the average curvature of the paths of the electrons. In this way the time which is required for electricity to be transferred will be greater so that the specific electrical conductivity will be diminished. This is the explanation of the second effect. Both these effects are complicated by the action of the electrons on the atoms so that the foregoing description is only to be regarded as a rough outline of what really occurs.

So far we have only considered the way in which the electron theory of conduction explains a number of phenomena which were familiar before it was enunciated. The power to do this is a necessary attribute of every scientific theory. A scientific theory, however, is often much more useful than this in that it leads to the prediction of phenomena which would hardly have been foreseen without its aid. The present theory has been able to prove its usefulness in this way, as the principles underlying it have enabled us to develop a new chapter in physical science, a chapter to which I have ventured to give the name of Thermionics. Thermionics relates to the emission of electrified particles by hot bodies and the phenomena to which they give rise.

It is found that all bodies when heated to a sufficiently high temperature give rise to an emission of both negatively and positively charged particles. In many ways the negative emission is the more interesting as the particles emitted are negative electrons having properties identical with those of the carriers of the cathode rays. The connection between this emission of negative electrons and the transportation of electricity in a metallic conductor is very intimate. We have seen that, in order to explain the phenomena exhibited by metallic conduction, it is necessary to suppose that such conductors contain large numbers of "free" electrons. If these electrons are maving about freely inside the conductor, as we have supposed, the question at once arises as to why they do not escape into the surrounding atmosphere. It is clear that they do not do so, otherwise there would be a leakage of electricity from the surface of all conductors at ordinary temperatures. The answer must be that there are forces at the surface of the metal which are sufficiently great to prevent them from escaping. Now consider what we should expect to happen as the temperature of such a body is raised. We have supposed that the average kinetic energy of the contained electrons is higher the higher the temperature. Clearly, at a sufficiently high temperature some of the particles will have enough energy from their heat motion to be able to break through the surface. Moreover, the number which are able to escape will be greater the higher the temperature.

A theory following these lines has succeeded in predicting the way in which the emission of the electrons depends upon the temperature as well as a number of other interesting relations between the thermal and electrical behavior of substances. It will be remarked that the view which has been outlined is very similar to the view of the phenomenon of evaporation which is afforded by the kinetic theory of matter. According to that theory the particles of the liquid escape into the vapor when their kinetic energy (to be accurate we ought to say that part of it which depends on the component of velocity normal to the surface) exceeds the work they have to do in order to pass through the surface. Thermionic emission may be looked upon then simply as the evaporation of electrons which may be regarded as dissolved in the metal. Just as water is cooled when it evaporates and heated when steam condenses into it; so we should expect a conductor to be cooled when it emits electrons and heated when it absorbs them. Both these effects have recently been discovered, the former by Wehnelt and Jentzsch and the latter by Richardson and Cook.

There is one point in this connection which is worthy of further consideration. We have seen that it is necessary to suppose that the electrons in a metal behave like the molecules of a gas. The same will be at least as true of them after they have been emitted. Thus when a metal at a high temperature lies in an air-tight enclosure there will be two atmospheres of electrons, one at a high pressure inside the metal and the other at a low pressure in the enclosure outside of the metal. If the principles of the kinetic theory of matter are well grounded it can be shown that in both of these atmospheres the electrons are moving about with all possible speeds but that the proportion of them which have a given speed is the same for each atmosphere. Moreover, the proportion is the same known function of the temperature in each case and in each case also the average kinetic energy should be the same as the average kinetic energy of a molecule of any gas at the temperature of the enclosure.

In fact the laws of the kinetic theory of gases can be applied without change to the atmospheres of electrons; and the above assertions are simply statements of a theorem in the kinetic theory of gases called, after its discoverers, the Maxwell-Boltzmann Law. According to this law if a large number of molecules are selected at random out of any gas the proportion of them which have speeds lying between certain assigned values let us say u and u' is a certain definite function of u and u'. The value of this function, which in addition to u and u' depends only upon the temperature of the gas and the mass of its molecules, was first deduced by Maxwell. Maxwell's deduction of the value of this function, though sufficiently convincing to those who are familiar with the methods of mathematical physics, was, neverthless, a highly abstract piece of reasoning; and it has been impossible up to the present to make anything in the nature of a direct test of it by experiment on gases. With the atmospheres of electrons we are, however, able to do a great deal more than we could with a gas made up of uncharged molecules. By placing them in a suitable electric field we can bring forces to bear on each individual electron which are enormous compared with the forces exerted on a molecule by the earth's gravitational field. For example if the electrons are being emitted from a heated flat plate we can place another flat surface a little in front and charge it up, so that the electric field tends to drive the ions back into the surface at which they originated. Under these circumstances only those electrons will be able to cross from one plate to the other if their kinetic energy is greater than a certain value depending on the electric field between the plates; thus the current that gets across will be a measure of the number of electrons emitted whose kinetic energy exceeds a known value. By experiments of this kind, and others based on similar principles, we have succeeded in determining the law of distribution of speed among the individual electrons which are emitted. It is found to agree in every particular with that predicted by Maxwell for the case of a gas whose temperature is the same as that of the metal emitting the electrons and whose molecular weight is equal to the mass of an electron. In particular the average kinetic energy of the electrons is the same as that of the molecules of a gas at the temperature of the metal which emits them; and we can calculate the value of the well-known constant R in the gas equation $pv = R\theta$, where p is the pressure, v the volume and θ the absolute temperature of the gas, from purely electrical experiments of the kind indicated. It follows from the results of these experiments together with a simple application of the principles of the dynamical theory of gases that the free electrons inside a metal must have the distribution of velocity which is required by Maxwell's law and in particular must have the same average translational kinetic energy as the molecules of a gas at the temperature of the metal which contains them.

2. MATERIAL MEDIA AND ELECTROMAGNETIC RADIATIONS.

The action of light on insulating media is a rather complicated, but extremely important, phenomenon on which the electron theory has thrown a great deal of light. Maxwell showed, many years ago, that light is an electromagnetic phenomenon. A beam of light is in fact a wave of oscillating electric and magnetic force, the electric and magnetic forces being at right angles to one another and to the direction of propagation. When such a wave falls on an insulating medium the oscillating electric force will set into vibration the comparatively stable electrons which, as we have seen, are embedded in the medium. The electrons will execute what are appropriately called forced oscillations, about their original equilibrium positions, and these oscillations will have the same periodic time as the light. Thus when it traverses a material insulating medium the light has not only to keep itself going; it has to keep the electrons which make up the medium going as well. Roughly speaking one may say that the electrons in such a medium behave like a load on the luminiferous ether. We should therefore expect them to diminish the speed of propagation of light through it and this is found to be the case. The exact expression for the velocity cannot be obtained without going more deeply than we have time to into the electromagnetic theory of light. It was first given by Maxwell, who showed that the refractive index, to which the velocity of propagation is inversely proportional, was equal to the square root of the effective specific inductive capacity of the medium. Now the specific inductive capacity of an insulating medium is equal to unity plus the product of the number of electrons per unit volume by their average displacement in unit electric field. When the material is subjected to constant electric forces the displacements of the electrons are always proportional to the forces and the specific inductive capacity is therefore a constant quantity. When the force is an oscillating one the matter is complicated by the fact that the electrons try, as it were, to strike a balance between their own natural period of oscillation and that of the force acting on them. They end by oscillating with the same frequency as the force which excites them but the distance they travel from their equilibrium position depends a good deal on their natural periods as well. Thus the specific inductive capacity for oscillating forces will not be a constant quantity but will depend to some extent on the frequency of oscillation of the force. By the effective specific inductive capacity we mean the specific inductive capacity for electric forces which oscillate with the frequency of the light under consideration.

It is evident from what has been said that the refractive index of an insulating substance depends upon the frequency or, in other words, upon the color of the light. We see at once why a beam of white light is split up by a prism into the constituent spectral colors. For each ray is deviated by the prism according to the value of its refractive index.

Perhaps the most interesting question in this part of our subject is that of the behavior of a substance towards light whose frequency is close to that of the natural periods of the substance. In that case the electrons are set into violent motion owing to the occurrence of what are sometimes called sympathetic vibrations. The nature of this phenomenon may best be illustrated by considering a simple mechanical analogy. Imagine a spiral wire with a weight at one end to be hung from a shaking support. If the weight is pulled down and let go it will oscillate backwards and forwards with a definite natural frequency which depends on the stiffness of the spring and the heaviness of the weight. If the shakiness of the support arises from tremors in the building, to the walls of which we will suppose it bolted, as a rule the frequency of its vibrations will be very great compared with the natural frequency of the spring. In that case the shakiness of the support will have very little effect on the spring. If however the frequency of the tremors happens to be equal or nearly equal to the natural frequency of the spring the latter is set into very violent agitation, for the reason that the natural swings of the spring are continually being helped by the oscillations of the support.

A precisely analogous effect takes place when the period of the light is close to the natural period of the electrons. In fact it can be shown that, if there is nothing analogous to a frictional force to damp down the vibrations of the electrons, they will execute oscillations of infinite amplitude when there is exact coincidence between the periods. Since the displacement of the electrons in unit electric field is *the* important factor in determining the refractive index we should expect its value to change very considerably in this region. As a matter of fact, in the extreme case where there is no damping, the value of μ^2 falls rapidly from a small positive quantity on the short wave-length side of the position of coincidence to the value $-\infty$ at exact coincidence $(\lambda = \lambda_0)$. As the period of exact coincidence is passed μ^2 changes suddenly to $+\infty$ and on the long wave-length side falls rapidly to a rather larger positive value than the one that it had at a great distance from the natural period on the short wave-length side.

Several very important deductions can be drawn from the results which have just been described. In the first place we notice that provided we always keep to the same side of the natural period, no matter which side we choose, then the refractive index μ always diminishes as the wave-length λ increases. Hence, since the deviation of light by a prism is greater when the refractive index is greater it will be smaller the greater the wave-length. The blue light will therefore be deviated more than the red light in the spectrum. This is the well known kind of dispersion which is exhibited by prisms of glass and similar colorless transparent substances.

When part of the spectrum lies on one side of the natural period and part on the other there is a sudden increase in the value of the refractive index when the natural period is crossed. The spectrum will then consist of two groups of colors, that on the long wave-length side being more deviated than that on the short wave-length side, although in each group the colors are in the normal order. This is the so-called anomalous dispersion which was discovered by Kundt and which is exhibited by all transparent colored bodies, like the aniline dyes, which possess a metallic shimmer. Immediately on the short wave-length side of λ_0, we have seen that μ^2 has a negative value in the case we are contemplating. μ in this region has therefore what mathematicians call an imaginary value. It can be shown that this imaginary value means that the waves are incapable of entering the medium. When a train of waves of this wave-length falls on the medium they are not absorbed, properly speaking, but are completely reflected. The substance would appear to be opaque to light of this wave-length not because it absorbs the light which falls on it but because it reflects it completely. If mixed light which contained some of this particular wave-length were made to undergo a sufficient number of successive reflections from plates of the substance, only light of this particular region of frequency would ultimately be left over, since a certain percentage of the other wave-lengths always gets through. This principle has been utilised by Rubens to isolate radiations of definite wave-length in the infra-red part of the spectrum. These radiations are called, very appropriately, residual rays.

The foregoing discussion does not touch the very interesting questions of the absorption of light by insulating media. There will be no absorption, properly speaking, unless there are forces acting on the moving electrons which tend to dissipate the energy of the light. Such forces must in general exist and it is usually assumed that there is a retarding force proportional to the velocity of the moving electrons, chiefly because this is the simplest assumption which can be made which is not in contradiction with fact. The existence of forces of this kind modifies the foregoing conclusions to a considerable extent in detail but it does not affect their general character.

Planck has pointed out that it follows from the principles of the electromagnetic theory of light that the radiation from the moving electrons gives rise to a retarding force which may be taken to be proportional to their velocity. Such a force must unquestionably exist but its magnitude is quite small. It is of interest to see if it is sufficiently large to account for the known cases in which the dissipation of energy is smallest. These are unquestionly the cases in which residual rays are obtained. I have developed a formula which expresses the percentage of incident energy which goes into the residual rays, which includes the case where dissipation is taken account of. This formula leads to two separate methods of estimating the order of magnitude of the dissipation. Both these methods show that the dissipation must be of the order of 10^{12} in certain units where Planck's theory leads to a dissipation of the order 10^4 in the same units. Thus the source of dissipation pointed out by Planck is about 10^8 times too small to account for the smallest case of dissipation known to us.

I am inclined to think that the most general type of absorption of light by bodies of this class is of the following character. We have seen that the electrons execute forced vibrations under the influence of the incident light. When the period of the light approximates to the free period of the electron the electrons absorb a great deal of energy from the light. In general this absorption of energy will go on until the vibrations carry the electron out of its region of stability. A rearrangement of the system will then take place and during this rearrangement a great deal of the kinetic energy which the electron has accumulated will be transferred to other parts of the substance and will make itself felt as heat. As far as that particular electron is concerned the sympathetic vibrations will have to be established all over again. It is not necessary to suppose that during this process the electron is actually carried out of the atom when it breaks loose from the region of stability. The whole occurrence may take place in the one atom. On the other hand we know a great many cases of bodies which emit electrons under the influence of light and in these cases the electrons must get carried out of the atom. It seems to the writer to be an advantage of this view that it connects the absorption of light with the so-called photo-electric effect. As a first approximation this view of the absorption of light leads to the same relation between absorption and frequency as does the assumption of a retarding force proportional to the velocity.

There is another point in this connection that is not without interest. On any theory of absorption the natural periods of a substance are characterised by conferring on it either intense absorption or intense opacity. It is therefore evident that they can be detected very readily by experiment. From an analysis of the natural periods of a large number of substances which has been carried out by Drude it appears that there are two types of vibrations which occur. In the one the electron forms the vibrating system and in the other one of the constituent atoms or a group of atoms vibrate as a whole. Owing chiefly to the enormous difference between the mass of an electron and that of an atom there is an enormous difference between the frequency of the two types. The electronic type always gives rise to frequencies in the ultra-violet part of the spectrum and the atomic type to natural frequencies in the infra-red. It is therefore not an accidental circumstance that almost all chemically pure substances which are not conductors of electricity are transparent in the visible spectrum.

The action of Roentgen rays on matter is a subject of great interest. According to the ether pulse theory of these rays elaborated by Sir J. J. Thomson, the relation between the Roentgen rays and sodium light is similar to that between a series of sharp cracks and a musical tone. And on the modern view of the nature of white light the difference between white light and the Roentgen rays is one of degree rather than kind. The cracks corresponding to Roentgen rays are much sharper than those which correspond to white light. According to the principles of harmonic analysis which we owe to Fourier it should be possible to resolve either of these kinds of radiation into simple harmonic elements. I have estimated that the average frequency of these elements for the Rœntgen rays would be 10,000 times greater than that for those which form white light. This estimate is based on the view that the kinetic energy of the electrons emitted by bodies under the action of ultra-violet light and Roentgen rays is a function of the frequency of the equivalent vibrations. The experimental results indicate that the functionality is a linear one and there is considerable theoretical support for this view Some investigators have maintained that the square root of the energy is proportional to the frequency; but even if this extreme view is taken the estimated frequency is not changed enough to affect the general argument.

If the Roentgen rays are so much like white light you will at once ask why they are not deviated by a prism. The answer is very simple. It follows from the principles of the electron theory that the refractive index μ of a substance for electromagnetic vibrations of frequency p is given by $\mu^2 = 1 + \Sigma \dfrac{\nu_s e^2}{m(p_s^2 - p^2)}$ where e is the charge on an electron, m its mass, p_s its natural frequency and ν_s the number of electrons of type s in unit volume of the material. In general this formula will not be exact on account of the interactions of the electrons on one another but it will give results of the right order of magnitude. Now e and m have the same value for all electrons and in the part of the spectrum near the visible $\nu_s e^2/mp_s^2$ is of the order unity for such frequencies p_s as fall within that region. Now ν_s will always be of the order of the number of molecules per cubic centimeter whichever of the s classes of electrons we consider, so that we may draw the following conclusions: (1) On account of the very great absolute value of p, μ^2 will be equal to unity except for a very narrow range in the immediate neighborhood of $p = p_s$. (2) Only such substances will be capable of refracting the Roentgen rays as have natural frequencies p_s which lie within the range of values of p embraced by the Roentgen rays experimented on. In any event it is clear that with a mixed group of rays such as is emitted by an ordinary X-ray bulb, practically the whole of them will pass through a prism without deviation.

Barkla's experiments on secondary rays show that the Roentgen rays exhibit phenomena very much akin to fluorescence in optics. One interpretation of Barkla's results would be that there are in material atoms natural frequencies comparable with the frequencies in the Roentgen rays. In that case, although almost the whole of a beam of Roentgen rays would be undeviated by a prism there should be a small amount which would be deviated. At present I am making experiments to detect this effect.

Of course if one adopts the corpuscular view of the Roentgen rays recently developed by Bragg, effects of the kind described are not to be expected. At present the balance of evidence seems to be decidedly against the corpuscular view.

I am inclined to think that the primary Roentgen rays originate largely as the result of secondary actions due to the stirring up of the electrons in the atoms of the anti-cathode by the rapidly moving cathode rays which impinge on them. On this view the constituent frequencies of the rays would be, to a considerable extent, a matter of the atoms in which they originate; and it may be that the gap in electro-magnetic radiations between ultra-violet light and the Roentgen rays, which exists at present, may never be filled up; as there may be no atoms which have natural periods in the neighborhood of these frequencies.

Recent years have seen the accumulation of a very large quantity of material relating to optical effects which are produced by a magnetic field. It is impossible, within the limits of this discussion, to attempt to show the enormous usefulness of the electron theory in the development of the science of magneto-optics; but there is one phenomenon which we cannot afford to pass by entirely, if only on account of its historical importance. I refer to the Zeeman effect. This effect was called after its discoverer, who showed that the spectral lines which are emitted by all gaseous substances under suitable conditions of excitation, were slightly displaced by a very strong magnetic field. The true explanation of this phenomenon was at once given by H. A. Lorentz. He pointed out that if the monochromatic light was emitted by vibrating electrons the frequency of the vibrations would be altered if the atom which contained the electrons found itself in a magnetic field. This change in the frequency, of course, corresponds with a change in the wavelengths of the emitted light. He also predicted that the emitted light would be polarized in a certain way and this was confirmed by experiment. Lorentz showed, in addition, that the value of the electric charge of an electron, divided by its mass, could be calculated from the displacement of the spectral lines in the magnetic field. The results of these calculations showed that the value of this ratio was the same as that found by Sir J. J. Thomson and Wiechert for the cathode rays in a discharged tube. Thus the Zeeman effect and the cathode rays were the first two phenomena which afforded explicit evidence of the existence of these minute charged particles, whose mass is nearly 2,000 times smaller than that of the lightest known chemical atom.

The emission of ordinary heat radiation such as is given out by all substances, and in increasing amount the higher the temperature, is very intimately connected with the theory of electrons. As is well known this radiation is electromagnetic in character and includes visible light as a particular case. We also know that when an electron is accelerated it emits electromagnetic radiation. It is natural therefore to attribute the origin of this radiation to the motions of the electrons of which material bodies are made up. By making use of the principles of thermodynamics we can prove that the nature of the radiation of this character which is to be found in any enclosure maintained at a given temperature is independent of the nature of the walls of the enclosure. The amount and character of this radiation is thus independent of the material from which it originates. If therefore we can calculate the amount of this radiation of each wave-length for any particular substance, for a series of temperatures, we shall know what it is for all substances at the same temperatures. Unfortunately when such a calculation is carried out in the most logical and natural way it leads to results which are not in agreement with those given by experimental measurements. Another mode of calculation given by Planck leads to a formula which agrees with the experimental values. It has been shown however that Planck's calculation involves the implicit assumption that energy is an atomic or discontinuous quantity. This idea is distasteful to many physicists and it is so revolutionary that it is not desirable to adopt it without very convincing evidence. One of the authorities on this very intricate subject, Jeans, maintains that the reason for the discrepancy between the less revolutionary theory and experiment is due to the fact, as he asserts, that the experiments do not measure the true equilibrium radiation. However this may be, the difficulties which lie in the explanation of the connection between radiation and temperature do not belong to the electron theory proper but are outside of it. No matter how it may be decided the outcome of this question is not likely to shake the foundations of the electron theory of matter.

3. The Number of Electrons in an Atom.

The behavior of very rapidly moving electrons in their passage through matter is a very interesting subject of investigation. Thanks to the discovery of the radio-active substances we are able to experiment, if we wish, with electrons whose speed is almost equal to that of light (3×10^{10} centimeters per second). These rapidly moving electrons are able to shoot right through the atoms of bodies, but when in their flight they pass very close to one of the constituent electrons their paths are deviated. When a group of them passes through a considerable thickness of matter these deviations tend to accumulate; so that a group of electrons, all of which were moving parallel to one another to start with, becomes divergent. Sir J. J. Thomson showed how the average deviation arising from a single impact could be calculated and also how the average divergence of the beam, which was caused by its passage through a given amount of matter, would depend on the number of electrons present in the matter traversed.

Experiments made by Barkla showed that when matter, which was made up of elements of low atomic weight, was traversed by Rœntgen rays it was caused to emit so-called secondary Rœntgen rays, which were precisely similar in character to the primary Rœntgen rays which excited them. A careful study of these secondary rays showed that they were primary rays which had been scattered. The phenomenon is in fact very analogous to that which gives rise to the blue color of the sky, which was shown by Lord Rayleigh to arise from light scattered by innumerable small particles present in the atmosphere. The amount of such scattering depends on the number of particles which are engaged in doing it. In the case of the Rœntgen rays these particles are the electrons present in the matter, each one of which is set into violent motion by the Roentgen ray pulse. The exact way in which the amount of the scattering should depend on the number of electrons engaged in the operation was figured out by Thomson who showed from Barkla's experimental results that the number of electrons reckoned per atom of the material was comparable with the atomic weight.

We have seen already that information of a like nature may be obtained from the spreading out of a beam of rapidly moving electrons when they traverse a layer of matter. Working over such material as was then available Thomson found his conclusion, that the number per atom was comparable with the atomic weight, was strengthened. Quite recently J. A. Crowther has made a very careful experimental investigation covering both these lines of inquiry. He finds that Thomson's calculations are borne out very satisfactorily by his experiments and that the number of electrons which go to make up each atom is three times the atomic weight of the element.

PRINCETON UNIVERSITY,
April, 1911.

IV.

THE CONSTITUTION OF THE ATOM.

By HAROLD A. WILSON, F.R.S.

(Read April 22, 1911.)

According to Sir J. J. Thomson's theory[1] atoms may be regarded as rigid spheres of positive electricity containing negative electrons which can move about freely through the positive charge. The total negative charge on the electrons in an atom is equal to the positive charge on the sphere. This theory has many advantages over the theory of Sir J. Larmor, who regards atoms as systems of positive and negative electrons in rapid motion. In the first place the sphere of positive electricity provides a rigid and stable foundation which is lacking in the other theory and which seems very necessary to explain the extraordinary stability of atoms. It is difficult to see how Sir J. Larmor's atoms could possibly survive the shocks of continual violent collisions with other atoms.

Sir J. J. Thomson's theory has also the great advantage that it explains the fact that only negative electrons can be isolated and that positive electricity is always associated with atoms or molecules of matter.

It also explains the fact deduced from the Zeemann effect that spectral lines are emitted by vibrating negative electrons and not by positive electrons. It is consistent with the fact that atoms can lose a few negative electrons without their identity being destroyed which does not seem possible on Sir J. Larmor's view. The kinetic theory of gases agrees best with the facts when the atoms are regarded as rigid spheres which again is strongly in favour of Sir J. J. Thomson's theory.

This theory therefore may be used as a working hypothesis which enables a mental picture of the atom to be formed. It leaves the nature of electricity and of the æther an open question and is conse-

---

[1] "The Corpuscular Theory of Matter," 1907.

quently much less fundamental than, for example, Lord Kelvin's vortex ring theory. The negative electrons and the positive sphere may or may not turn out to be modes of motion of the æther; at present we cannot say.

One of the first questions which naturally arises in connection with this theory is, how many negative electrons are there in each atom? This question has been answered approximately by examining the effect of matter on light and Röntgen rays. When electric waves pass over electrons the electrons are acted on by the electric forces in the waves and so emit radiation. This means that the electrons scatter the incident radiation. The amount of radiation scattered by one electron can be calculated on the electromagnetic theory and hence from the amount observed to be scattered by a known amount of matter the number of electrons in the matter can be estimated, the number of atoms in a given amount of matter can be exactly calculated because we know the charge carried by one atom in electrolysis and the total charge carried by the matter. Hence we can get an estimate of the number of electrons per atom. The total energy scattered by a mass containing N electrons is $\frac{8\pi}{3}N\frac{e^4}{m^2}E$, where e is the charge on one electron, m its mass and E the incident energy. This formula is due to Sir J. J. Thomson.

The most recent determination of the energy scattered when Röntgen rays pass through matter is that by Crowther.[2] He finds that the number of electrons per atom of aluminium is 85, which is about three times the atomic weight. Previous experiments of a similar character have given nearly the same result for other elements. It seems very probable therefore that all atoms contain a number of electrons proportional to their atomic weights and not very much greater.

The mass of a negative electron is only one seventeen-hundredth part of that of an atom of hydrogen, so that the negative electrons only account for about one six-hundredth of the mass of any atom. The rest of the mass therefore must be the mass of the positive sphere. According to this theory therefore the mass of matter is not electromagnetic in its origin, for the electromagnetic mass of the

---

[2] *Proc. Roy. Soc.*, A, Vol. 85, p. 29, 1911.

positive sphere is negligible. This theory therefore does not support the view which is the basis of the "principle of relativity," that all phenomena are electromagnetic in character. The mass and rigidity of the positive spheres are assumed to exist and cannot be explained by electromagnetic forces. There is no reason why the motion of these spheres through the æther should not produce effects capable of being detected and which would enable us to determine the velocity of the earth relatively to the æther. The fact that this has not yet been done does not prove that it is impossible.

According to Sir J. J. Thomson's theory the properties of different atoms are due to the number and arrangement of the electrons in the positive sphere. The problem of the distribution of n electrons in a positive sphere has not been solved and is very complicated, so Sir J. J. Thomson investigated the much simpler problem of the distribution of n electrons in a plane when they are all acted on by forces of attraction proportional to their distances from a fixed point in the plane.

This problem can also be solved experimentally by means of Professor Mayer's floating magnets. The electrons arrange themselves in concentric rings. Thus six give a ring of five and one in the middle. Seventeen give a ring eleven, a ring of five and one in the middle. Thirty-two give rings of fifteen, eleven, five and one in the middle. Forty-nine give rings of seventeen, fifteen, eleven, five and one in the middle.

With two in the middle we get a series of rings containing 8, 12, 16, 19 and 22 electrons respectively and a similar series with three in the middle and so on.

This leads to a very interesting suggestion with regard to the series of elements which have similar properties for example:

Helium, neon, argon, krypton, xenon; hydrogen, lithium, sodium. potassium, rubidium, cæsium; fluorine, chlorine, bromine, iodine.

Sir J. J. Thomson suggests that each element in such a series may be derived from the one before it by the addition of another ring of electrons the arrangement of the inner rings remaining unchanged. This explains the similarity of the properties of the elements in such series.

On this view an atom of bromine is an atom of chlorine with the addition of one more ring of electrons together with the additional amount of positive electricity required to keep the atom neutral. Sir J. J. Thomson has shown that many of the facts connected with Mendeléeff's periodic law can be explained on this theory.

In the atoms of course the electrons are not really confined to one plane but are distributed throughout the volume of the positive sphere, so that instead of concentric rings of electrons there are concentric spherical layers. An atom of bromine is therefore derived from an atom of chlorine by the addition of one more layer, the inner layers remaining unchanged.

Although the exact solution of the problem of the distribution of n electrons inside a positive sphere is too complicated to be worked out I find that an approximate solution can be obtained without much difficulty, which enables the results of the theory to be compared with the atomic weights of the elements.

Consider an electron having a negative charge e inside a sphere of positive electricity of uniform density of charge ρ per c.c. Close to the electron the electric field is of strength e/r^2, where r is the distance from the electron, so that $4\pi e$ tubes of electric force come out of the electron, if the number of tubes per sq. cm. is taken to be equal to the field strength. Consider one of these tubes of force and let ds be an element of its length and α its cross section at ds. The charge in the length ds is $\rho\alpha ds$, so that

$$F\alpha-\left(F\alpha+\frac{d}{ds}(F\alpha)ds\right)=4\pi\rho\alpha ds,$$

where F is the electric force along ds. Hence

$$-d(F\alpha)=4\pi\rho\alpha ds,$$

which gives

$$F_1\alpha_1-F\alpha=4\pi\rho\int\alpha ds,$$

where $F_1\alpha_1$ denotes the value of $F\alpha$ at the surface of the electron. This shows that as we go along the tube $F\alpha$ diminishes and when $F_1\alpha_1=4\pi\rho\int\alpha ds$ it will be zero and the tube will end. Now $F_1=e/a^2$, where a is the radius of the electron and $\alpha_1=a^2/e$, so that $F_1\alpha_1=1$, hence $4\pi\rho\int\alpha ds$ from the surface of the electron to the end of the tube is equal to unity. Thus the positive charge in each tube is $1/4\pi$ so that its volume is $1/4\pi\rho$. The total volume of all the $4\pi e$ tubes is therefore e/ρ. Thus the tubes of force starting from the electron occupy a volume e/ρ and this is true in any case whether other electrons are near or not. Also since every tube of force must end on positive electricity it is clear that the volume e/ρ can only contain the one electron from which the tubes start. Thus when any number of electrons are present each one will be surrounded by its own field which will occupy the volume e/ρ. The positive charge in the volume e/ρ is equal to e, so that if the sphere has a positive charge equal to the total negative charge on the n electrons in it, it will be divided up into n equal volumes, each containing one electron.

The energy in an element of a tube of force is equal to $F^2 \alpha ds/8\pi$, and if the tube is slightly distorted this element will still have the same volume and also $(F\alpha)$ will remain unchanged so that the change in the energy in the element will be due to the change in F. The energy will be a minimum when the tube is in equilibrium so that F will be as small as possible and therefore a as large as possible. This means that the tubes tend to become as short as possible, their volumes remaining constant. The effect of this will evidently be to make the field round each electron tend to become as nearly spherical as possible with the electron in the middle.

Consequently to determine approximately the distribution of the n electrons in the positive sphere it is sufficient to find how the sphere can be divided up into N equal volumes, all as nearly spherical as possible and put an electron at the center of each of the n volumes.

When n is large it is easy to see that this requires the electrons to be arranged like the centers of the shot in a pile of shot. Thus with thirteen electrons we should have one in the middle and twelve arranged around it, all at the same distance from it.

Suppose the volume of the field of one electron is v, and let n_1, n_2, n_3, etc., denote the number of electrons in the atoms of a series of similar elements. Each element is formed by the addition of a spherical layer to the one before it and it is clear that all the layers must be of nearly the same thickness if the fields of all the electrons are to be nearly spherical. Consequently if r_1, r_2, r_3, etc., denote the radii of the atoms in the series we should expect to have

$$r_2 - r_1 = r_3 - r_2 = r_4 - r_3 = \text{etc.}$$

Let A_1, A_2, A_3, etc., denote the atomic weights and suppose $\beta A_1 = n_1$, $\beta A_2 = n_2$, etc., where β is a constant. Then we have

$$\tfrac{4}{3}\pi r_m^{\,3} = n_m v = \beta v A_m,$$

$$\tfrac{4}{3}\pi r_{m+1}^{\,3} = n_{m+1} v = \beta v A_{m+1}.$$

Hence

$$\left(\frac{4\pi}{3\beta v}\right)^{\frac{1}{3}}(r_{m+1} - r_m) = A_{m+1}^{\frac{1}{3}} - A_m^{\frac{1}{3}} = C,$$

where C is a constant which should be the same for all series of similar elements.

Also $(r_{m+1} - r_m)^3 = v$ approximately, so that

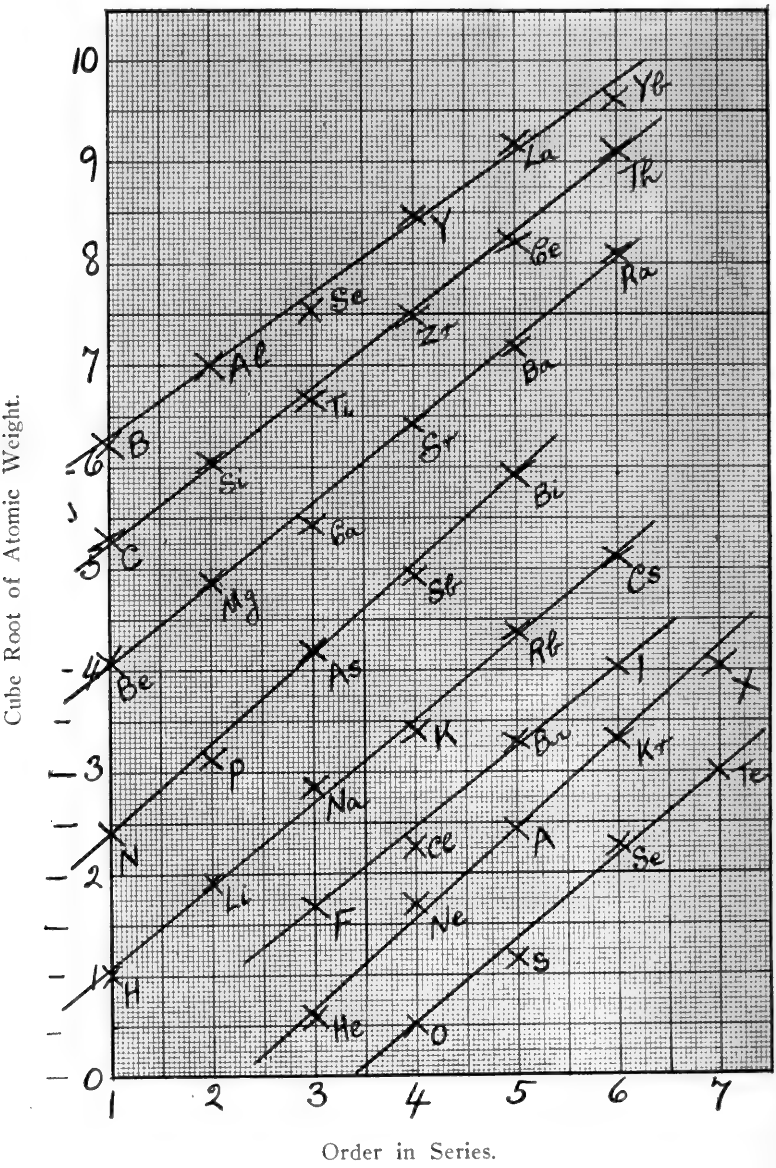
$$\beta = \frac{4\pi}{3C^3}.$$

According to the theory therefore we ought to be able to find the number of electrons per atom from the atomic weights.

In the figure the values of $A^{\frac{1}{3}}$ for series of similar elements are plotted against the order of the elements in the series. For some series a constant has been added to the values of $A^{\frac{1}{3}}$ to prevent the different lines falling too close together. It will be seen that the values of $A^{\frac{1}{3}}$ for each series fall nearly on straight lines and that the different lines are nearly parallel. This shows that $A_{m+1}^{\frac{1}{3}} - A_m^{\frac{1}{3}} = C$ is nearly constant, as was to be expected from the theory. The mean value of C is 0.81. Hence we get $\beta = 8$ so that the number of electrons per atom comes out 8 times the atomic weight in all cases.

This estimate agrees as well as could be expected with the numbers deduced from the optical properties of the elements which might be expected to be too low.

We have assumed that the electrical density of the positive spheres is uniform so that the approximate agreement of the atomic weights with the theory confirms this assumption. It is easy to see that the arrangement of the electrons in the positive sphere is not affected by a change in the size of the sphere provided its density remains uniform and its total charge the same as before. It is



possible therefore that the addition of new layers increases the density of the positive spheres instead of increasing their size. If this were so the calculation of β given above would not be affected as can be easily seen.

The equation $(4\pi/3\beta)^{\frac{1}{3}} = A_m^{\frac{1}{3}} - A_{m-1}^{\frac{1}{3}}$ gives

$$A_m = \left(A_1^{\frac{1}{3}} + (m - 1)\left(\frac{4\pi}{3\beta}\right)^{\frac{1}{3}}\right)^3.$$

This equation enables the atomic weights of a series of similar elements to be approximately calculated if that of the first in the series is known. For example, if we take $A_1 = 1$ we obtain the following numbers:

m	A_m	
1	1	H = 1
2	6	Li = 7
3	18	Na = 23
4	40	K = 39
5	77	Rb = 85
6	129	Cs = 133

If we take $A_1 = 9$ we obtain the following numbers:

m	A_m	
1	9	Be = 9
2	24	Mg = 24
3	51	Ca = 40
4	92	Sr = 87
5	150	Ba = 137
6	230	Ra = 226

It will be seen that the numbers given by the approximate formula deduced from Sir J. J. Thomson's theory agree approximately with the atomic weights. I think this must be regarded as strong evidence that there is a considerable element of truth in the theory.

I believe that this is the first time that a definite theory of atomic structure has been worked out sufficiently to enable a comparison between theoretical results and the known atomic weights to be made.

McGill University,
Montreal.

THE HIGH VOLTAGE CORONA IN AIR.

By J. B. WHITEHEAD.

(*Read April 21, 1911.*)

The term "corona" as employed by electrical engineers refers to the luminous envelope which surrounds a bare electrical conductor when its potential is raised above a certain value. As the voltage of long-distance transmission lines has been raised to higher and higher values in order to reduce the size and cost of the conductors and so increase the distance of economical transmission, a limiting condition has been found in the insulating properties of the atmosphere. For each definite space separation and size of conductors, above a certain value of voltage the regions immediately surrounding the conductors become luminous, and a power loss sets in which increases rapidly with further increase in voltage.

These facts were first noted by electrical engineers in this country in 1896. It was promptly recognized that the region in the immediate neighborhood of the conductors is subject to the greatest electric intensity and that the phenomena are due to local though restricted break-down of the air. This was corroborated not only by the presence of the luminous envelope immediately around the conductors, for voltages above that at which the loss begins, but by study of the effect of changing the size and separation of conductors; decreasing separation and size both increase the surface electric intensity and therefore lower the voltage at which loss begins. The electric intensity at the surface of the conductor may be readily calculated in most cases that occur from the voltage and from the separation and sizes of the conductors. It is directly proportional to the voltage in all cases. The term "corona" was first used by Steinmetz in 1898 to describe the luminous envelope and has been generally adopted by engineers.

Many measurements have been made on electric power transmission lines in efforts to determine the law connecting the voltage at which loss begins with the physical constants of the line. These measurements have shown marked inconsistencies among themselves, the results on the same lines on different days being often at variance. A number of laboratory investigations, in which the widely varying conditions of a transmission line are under control, have naturally followed. They have indicated with a rather wide variation in numerical values that the critical voltage or voltage at which corona begins on round wires varies inversely as the temperature and directly as the pressure; also that the electric intensity under which the air near the surface of the conductor breaks down has not a constant value but increases markedly for conductors of small diameter; and further that the value of the intensity at which break-down begins is that corresponding to the maximum value of the alternating wave, and is independent of the material of the conductor.

The general nature of the influence of temperature and pressure could probably have been predicted from numerous investigations of the discharge of electricity through gases; the quantitative relations for pressures near that of the atmosphere do not, however, appear to have attracted the physicist, nor indeed have they as yet been satisfactorily determined for the voltage of corona formation by experimental engineers. The accumulated results of physical investigation and theory, however, offer no obvious explanation of the rise of the critical surface intensity for smaller wires, nor of the influences of the form and frequency of alternating voltage. The fact that the corona voltage is that corresponding to the maximum value of the alternating wave has been proven by stroboscopic methods and by the use of distorted wave shapes. It indicates that the time element involved in the process of break-down of the air is short compared with the periods of the common alternating current circuits. The apparent sharpness of the connection removes many objections to the use of the alternating electromotive force as a means of investigation, and renders available its many advantages. It is only necessary to know the shape of the alternating wave and this may be obtained readily by several well known methods. Effective values as read on direct reading instruments may thus be used and the corrective factor for the maximum value is obtained from the shape of the wave.

Many of the inconsistencies among the measurements on existing transmission lines and those made in laboratories arise in the difficulties of measuring the power in high voltage circuits; the instruments must be placed in the low voltage side of transforming apparatus, the losses in which, being generally greater than those to be measured, introduct a troublesome source of error. The appearance of the visible corona has been used by laboratory workers as an indication of the beginning of loss through the air. With proper precautions this method may be very reliable but its use is generally attended by danger of subjective and other error. As a result of the discrepancies among these approximate determinations of various investigators, there has appeared much speculative suggestion of the presence of other unrecognized influences, as for example the moisture content of the air, the presence of "free" or natural ionization, an abnormal property of air when near a small wire, etc.

The present problem therefore resolves itself into two parts: first, a satisfactory method for the determination of the law under which the air in the neighborhood of a long straight and usually cylindrical conductor breaks down under electric strain; and second, the law governing the amount of loss when the voltage is carried above the critical value. A year ago the writer[1] described a method by which it is possible to determine the voltage at which the air breaks down near a round wire to a maximum inaccuracy of a few tenths of one per cent. The original paper may be consulted for the details, but the principle is simple and may be described briefly. The wire is stretched along the axis of a metal cylinder and the voltage is applied between them. Air may be passed through the cylinder by means of two lateral tubes near the ends, the walls of the cylinder at these points being drilled with a number of small holes. Close to one set of these holes and outside the cylinder a wire mesh electrode connected to a sensitive electroscope is placed. As soon as the air around the wire breaks down under increasing voltage, copious ionization sets in which causes a rapid leak from the

---

[1] J. B. Whitehead, *Proc. A.I.E.E.*, p. 1059, July, 1910.

charged electroscope. The initial discharge of the electroscope is very sharply marked. Observations may be repeated at will and after any interval; when corrected for temperature and pressure a most satisfactory constancy of results is obtained. Fig. 1 indicates the essential parts of the apparatus. In the following a short description is given of the results of investigations of the influence of the diameter of the conductor, of stranding the conductor, of the alternating frequency, of wave form, of pressure, of moisture content and of temperature on the electric intensity at which atmospheric air breaks down. The experiments on temperature, moisture content and diameter of conductor are given in the paper mentioned above. The results of the remaining investigations are first given here. No attempt is made to describe the details of the experiments. For these the reader may refer to the earlier paper and also to one shortly to be presented to the American Institute of Electrical Engineers in which the practical bearing of the results will be discussed.

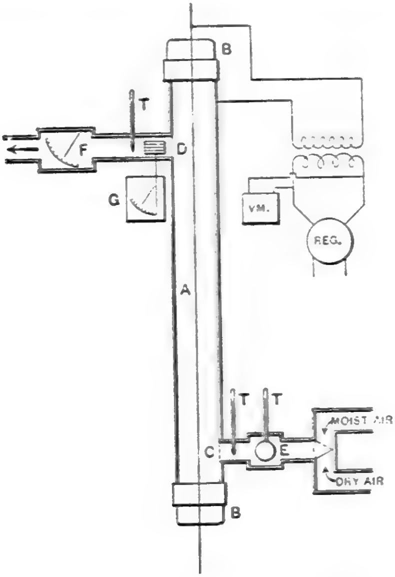


FIG. 1. Arrangement of apparatus.

Influence of Diameter of Conductor.—For convenience of reference a condensed table of the results on this portion of the work is given in Table I. and the results are plotted graphically in Fig. 2. For comparison, points observed by other investigators are also shown. The values are all corrected for temperature, pressure and wave form and give the maximum values of the electric intensity at which the air breaks down under a pressure of 760 mm. of mercury, and at temperature 21° C. I am indebted to Professor Alexander Russell for pointing out that these results obey a very simple law. If E be the critical electric intensity in kilovolts per centimeter and d the diameter of the conductor in centimeters, the curve of Fig. 2 obeys closely the equation:

TABLE I.

Relation Between Diameter and Critical Surface Intensity.

Diameter, cm.	Material of Wire.	Diameter of Tube, cm.	Material of Tube.	Critical Primary Volts Corrected.	Ratio.	Maximum Critical Surface Intensity.
0.089	Copper	4.9	Brass	74.5	125.09	77,100
0.122	“	“	“	44.0	250.18	70,950
“	“	“	“	87.8	125.09	70,800
0.156	“	“	“	97.0	“	65,880
“	“	“	“	97.0	“	55,880
0.205	“	“	“	109.5	“	61,350
“	“	“	“	55.0	250.18	61,500
“	“	6.35	“	60.5	“	62,080
“	“	“	“	60.2	“	61,780
“	“	“	“	(8) 59.9	“	61,680
0.254	Aluminum	“	“	65.9	“	58,750
0.276	Copper	“	“	68.9	“	58,080
“	“	“	“	68.8	“	
“	“	“	“	68.5	“	
“	“	“	“	69.0	“	
“	“	“	“	(8) 68.9	“	58,080
“	“	9.52	Steel	77.3	“	57,650
0.325	Aluminum	6.35	Brass	72.8	“	55,000
0.347	Copper	6.35	“	75.13	“	54,500
0 3405	“	9.52	Steel	85.7	“	55.100
0.399	Steel	“	“	92.5	“	53,050
0.475	“	“	“	100.6	“	51.400

$$E = 32 + 13.4\ 1/\sqrt{d}. \tag{1}$$

The observed values of Table I. are compared with the values calculated from the above formula in Table II. The percentage error is also given, and it is seen that with one exception the difference is well within one per cent. The exception refers to an aluminum wire which could not be polished to a clean surface; a rough sur-

TABLE II.

Diameter, cm.	Kilovolts per Centimeter.		Difference, Per Cent.
	Calculated.	Observed.	
.089	76,950	77,100	+ 0.19
.122	70,400	70,875	+ .67
.156	65,950	65,880	— .1
.205	61,600	61,680	+ .13
.254	58,600	58,750	+ .25
.276	57,500	58,000	+ .87
.325	55,600	55,000	— 1.08
.340	54,980	55,100	+ .21
.347	54,780	54,500	— .51
.399	53,230	53,050	— .23
.475	51,460	51,400	— .11

face invariably lowers the critical intensity. The corresponding point falls below the curve of Fig. 2.

The closeness with which this simple law is followed by the measurements suggest a considerable value of the method for a

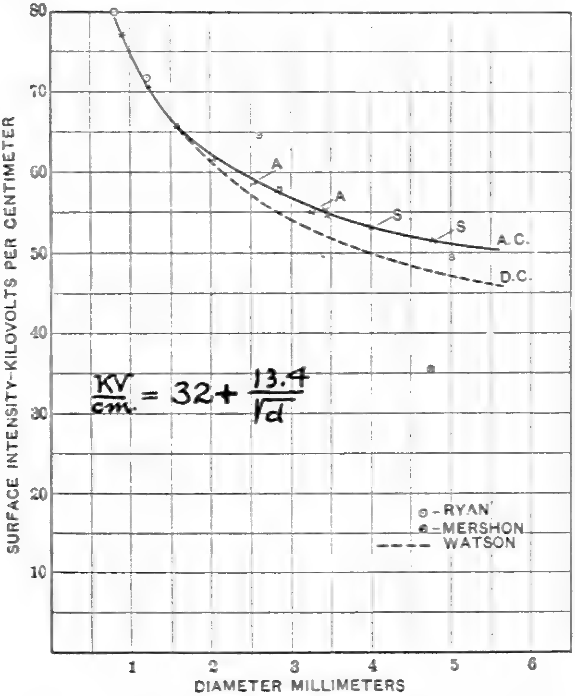


FIG. 2. Relation of critical intensity and diameter.

physical investigation of the nature of the process involved in the electrical break down of the air. The formula indicates that the value of electric intensity of a uniform field or near the surface of a plane conductor, at which air would break down is 32 kilovolts per centimeter. The work of von Scweidler, Townsend and others indicates that at about 30 kilovolts per centimeter, secondary ionization or ionization by collision sets in between parallel plates subjected to a difference of potential. In a later paragraph several other experiments are described which indicate that the start of the corona in air is due to secondary ionization. So far as the writer is aware however no theory has been advanced to explain the influence of the curvature of the conductor. That the nature of the molecular structure of the air is concerned there can be no doubt, but the variation of values of critical intensity occurs within a range of diameter many orders of magnitude greater than molecular dimensions, and is related to the diameter in a way which offers no suggestion of explanation.

Effect of Stranding the Conductor.—It is quite obvious that if the surface intensity is the determining factor in the voltage at which corona occurs, then a stranded conductor should have a critical voltage lower than that of a solid conductor of a diameter equal to that of a circle tangent to the strands. On the other hand it is not obvious that the critical voltage of a stranded conductor would be less than that of a solid conductor of equivalent cross section, for the diameter of the latter will always be less than that of the enclosing circle of the former. Evidently also the relations will vary with the number of strands. The question is of importance since all of the larger transmission lines consist of cables or stranded conductors.

A series of observations was made on a number of cables of stranding ranging from three to nine conductors uniformly filling the outer layer. The interior space was filled with a single wire or several wires of suitable size, but in each conductor the wires of the outer layer were all of the same size, .162 cm. diameter. The cables were clean and smooth and drawn tight along the central axis of the outer cylinder of the apparatus. The results are condensed in Table III, in which comparison is made between the diameter of a solid

TABLE III.

Strands.	(*a*)	(*b*)	(*c*)	(*b c*)	(*c a*)	Spiral Pitch, Diams.
3	.349	.272	.247	1.10	.708	10.9
4	.404	.332	.32	1.04	.792	8.65
5	.45	.381	.37	1.03	.822	9.89
6	.49	.430	.42	1.026	.857	12.3
7	.541	.48	.465	1.032	.868	12.3
8	.589	.53	.516	1.027	.877	10.78
9	.64	.581	.567	1.025	.886	10.9
3	.336	.27	.207	1.305	.616	none
4	.378	.312	.25	1.248	.665	none

circular conductor having the same critical voltage as that observed for the cable (column *c*) and the diameters of the circle just enclosing the cable (*a*) and that given its equivalent section (*b*). The ratios *b*/*c* and *c*/*a* are given in the last two columns, and are plotted in their relation to the number of strands in Figs. 3 and 4 respectively. Fig. 3 indicates that if instead of a solid conductor a stranded conductor of equivalent cross section be used the critical voltage will be lowered, but by less than three per cent. if the number of strands is greater than 5. For a three-strand cable the lowering is ten per cent.

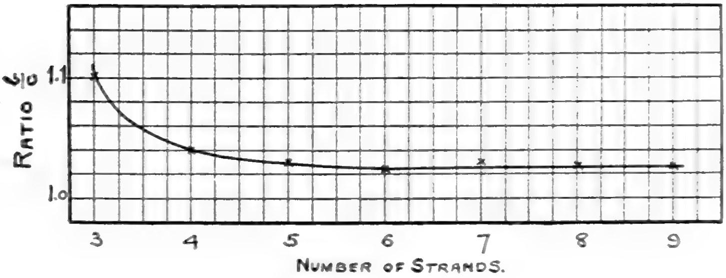


FIG. 3.

The ratio *c*/*a* is more important however. This ratio compares the diameter of a solid conductor having the same critical voltage as the cable, with the actual overall diameter of the cable. It therefore refers the behavior of a given cable, with regards critical voltage, to a solid round wire whose diameter is expressed as a fraction of the overall diameter of the cable. This is a more logical basis of comparison than the other since the interior of a multistrand cable may be made up in such manner as to cause a considerable variation in its cross section. In fact many transmission cables have centers of hemp, or other material, the entire conducting section residing in the single outer layer of strands. Thus Fig. 4 shows that a three-strand cable has a critical voltage which is that of a single wire of seven tenths the overall diameter of the cable. At nine strands the equivalent single diameter is still less than .9 that of the cable.

In a stranded conductor the strands are always spiralled. The pitch of the spiral for the cables described above is given in Table III. The spiral arrangement of the strands tends to lessen the value of the electric intensity on the outer surfaces of the strands since the equipotential surfaces are rendered more nearly cylindrical about the axis of the cable. The values of maximum surface electric intensity for cables of various numbers of strands and in which there is no spiral may be computed from an expression given by Jona[2] and due to Levi-Civita. This expression involves a hypergeometrical series whose evaluation requires some labor. As it makes no allowance for the spiralling of the strands no deduction may be drawn from the present observations as to the actual intensity at which corona occurs on the stranded conductor. Values deduced from the expression should, however, be of great value in the study of the nature of the breakdown of the air when taken in conjunction with measurements on cables without spirals. For in these cases the maximum electric intensity at the outer edge of a strand would obtain over a narrow circumferential distance, while the same intensity reached at the surface of a single wire obtains over a whole circumference. A comparison of corona voltages in the two cases should throw light on the distances involved in the process of secondary ionization and kindred phenomena.

At the bottom of Table III. there are given the results of observations on a three- and a four-strand conductor in which there was no spiral. The size of the strands was the same as that of the foregoing cables. The strands were carefully straightened, polished,

---

[2] Jona, *Trans. Int. Elect. Congress, St. Louis,* 1904, Vol. II., p. 550.

and built up by soldering with a fine blow flame so that the strands were uniformly tangent to each other throughout. The results indicate the further lowering of the critical voltage when spiralling is absent. The ratio c/a falls from .71 for the spiralled three-strand to .61, and the difference for the four-strand is somewhat greater. The pitch of the spirals of the cables investigated does not appear to follow any regular rule. This irregularity however does not appear to have any corresponding effect on the points of the curve

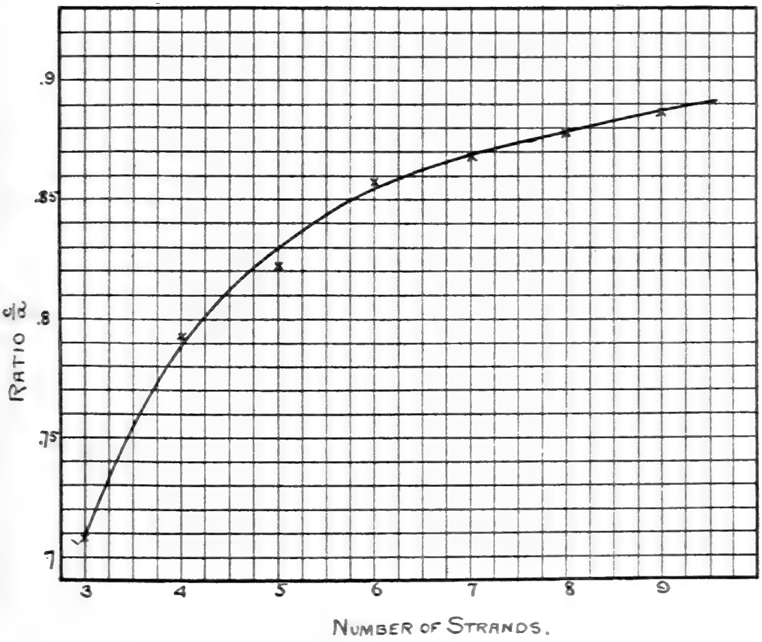


Fig. 4.

of Fig. 4. From this it may be concluded that for a pitch of spiral less than twelve diameters there is no gain on the ground of lessened surface intensity due to the more uniform distribution of the electric field.

At this writing the author has been unable to obtain solutions of Levi-Civita's expression as applied to three and four strands. These would permit by the foregoing results a knowledge as to how the maximum corona intensity for a round wire compares with that at the surface of the same wire when made up into a three- or four-strand cable without spiral.

Influence of Frequency and Wave Form.—By the use of a cathode ray oscillograph in the high voltage circuit Ryan in 1904 showed that the appearance of corona was accompanied by a hump or peak on the charging current wave in the neighborhood of the maximum of voltage. The writer by stroboscopic methods has shown that the corona is periodic, appearing every half cycle and that its first appearance with rising voltage coincides accurately with the maximum of the voltage wave. Also the duration of the corona, with steady circuit conditions, may be reduced with lessening voltage to a very small fraction of the period of the alternating electromotive force. Thus a corona which was found to exist for only one twentieth of a period at the crest of the voltage wave of a 60-cycle circuit was plainly visible in a darkened room. It is evident, therefore, that the interval of time involved in corona formation and cessation is extremely short. For these reasons it has been supposed that the appearance of corona depends only on the maximum value of voltage occurring in the cycle, and is therefore independent of the frequency. Experience with existing lines indicates that if there is an influence of frequency it is small for the range between 25 and 60 cycles. The closeness with which the critical voltage may be read by the method described gave promise of discovering any comparatively small differences due to variation of frequency. Several series of tests were therefore made with different sizes of wire. The observations are not recorded here as the points on the curve of Fig. 5 are a sufficient indication of their accuracy. The range from 15 to 90 cycles was obtained from two generators, and the voltage from a 10-KW. 25-cycle 100,000-volt transformer. The transformer had also a low voltage secondary coil. On the curves the values of voltage are those measured at the terminals of this coil; these values are therefore proportional to the voltage in the high tension winding and therefore to the electric intensity at the surface of the wire. These observations were made with rods .716 cm. and .635 cm. in diameter placed at the center of a pipe 120 cm. long and 30 cm. in diameter. The observations were taken as a continuous set, interruption being necessary for only a few seconds to change generators. There were consequently no appreciable variations in temperature or pressure.

The results as taken are plotted in the lower curves of Fig. 5 in which observations for ascending and descending values of frequency are plotted as crosses and circles respectively. The irregular shape of these curves repeated itself accurately in experiments over the same range of frequency with other wires. Since the transformer was operating over a wide range of frequency at approximately the same value of voltage, and its magnetizing current was therefore variable, a variation of wave form due to the armature reaction of the generator appeared probable. Oscillograms were therefore taken of the voltage at the terminals of the low voltage secondary coil at frequencies 20, 35, 55, 60, 65 and 91 cycles, and at transformer excitation corresponding to 50 volts on the same coil. The ratios of maximum to effective values of these waves were

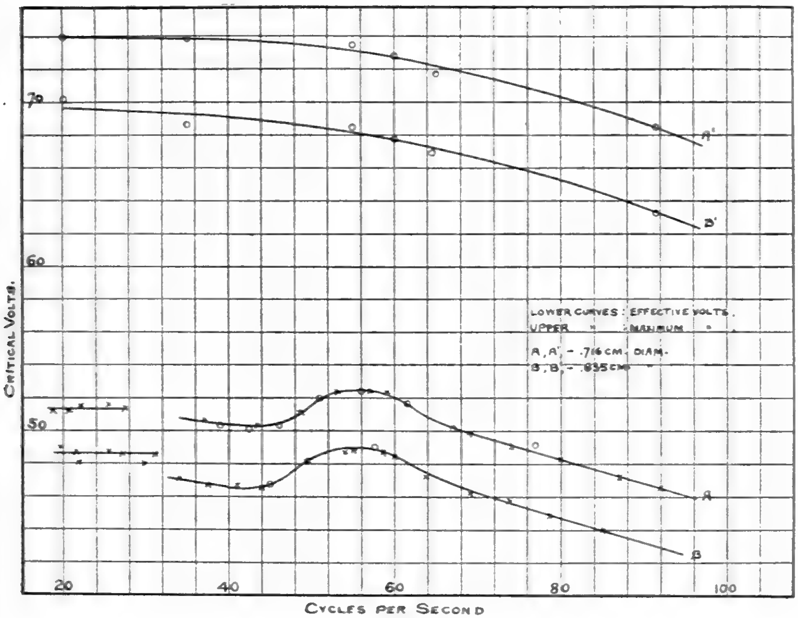


Fig. 5.

then determined by micrometer measurements of ordinates taken every 7.5 degrees over two half waves. The several values of this ratio so obtained revealed a minimum at 55 cycles thus explaining the rise in the lower curves of Fig. 5 at that frequency. In the upper curves the points indicated are the voltage of the lower curve multiplied by the ratio of maximum to effective value as calculated from measurements of the oscillograms for the corresponding frequencies.

The upper corrected curves of Fig. 5 show a lowering of the critical voltage with increasing frequency. The result leaves something to be desired in the accuracy of location of the points upon the curve. It should be noted however that owing to the magnification of the scale, the error of the points off the upper curves and the 25-cycle portion of the lower curves is only about 1 per cent. Several other sets of observations for different sizes of wire reveal curves of the same general characteristics. The measurement of the ratio of maximum to effective value from an oscillogram is subject to considerable error. The maximum at 55 cycles, however, on the lower curves is brought below the values for lower frequencies when the correcting factor is introduced, and particularly, the lowering at 91 cycles is far too great to be questioned on the score of a possible error of this nature. The curves therefore show with a fair accuracy the nature of the variation of the critical voltage with the frequency. This variation within the range of the present commercial frequencies 25 to 60 cycles per second, is only about 2 per cent.

Influnce of Pressure.—The influence of pressure on the various forms of spark discharge has been closely studied. Paschen's[3] law states that the sparking potential for a given spark length is directly proportional to the pressure; his investigations covered the range of pressure between 10 and 75 cm. of mercury. Carr[4] has shown that this linear relation extends down to pressures of a few millimeters if the spark lengths are not greater than 1 cm. but does not obtain for lower pressures. Townsend[5] has shown that the potential

---

[3] Paschen, *Wied. Ann.*, XXXVII., 79, 1889.

[4] Carr, *Proc. Roy. Soc.*, LXXI., 374, 1903.

[5] Townsend, *Phil. Mag.*, VI., 1, 198, 1901.

gradient at which secondary ionization sets in when electricity is passing through a gas is directly proportional to the pressure. Watson[6] investigated the spark length between spheres up to fifteen atmospheres and found that the spark potential increases with the pressure in an approximately linear relation. From the general similarity between the corona and the brush form of spark discharge, therefore, a linear relation between pressure and critical surface intensity, or the potential gradient at which corona begins is to be expected. Apparently the only study of the influence of pressure on the formation of the alternating corona is a single set of observations by Ryan[7] on a wire .32 cm. in diameter placed at the center of a cylinder 22.2 cm. in diameter. He observed the alternating voltage at which the visible corona appeared for the range of pressure between 45 and 90 cm. of mercury; the alternating frequency was 130. The resulting linear relation is given as between the kilovolts K actually applied and the pressure in inches of mercury, $K = 2.93 + .902\,b$.

In Table IV. are given the results of a typical series of observations on the influence of pressure on corona voltage; the values are those for a wire .152 cm. in diameter. The wires were clean and straight and centered accurately on the axis of the outer cylinder of the apparatus which has been briefly described. This cylinder has a diameter of 9.52 cm. The ends were closed with ebonite caps of the same diameter and 5 cm. deep. The side tubes were also closed by caps, and the leading-in wire to the discharge electrode passed through a column of sulphur supported in hard rubber; no troubles with either insulation or air leak were encountered with this arrangement. All joints were sealed with a mixture of bees wax and resin and pressures between 30 and 100 cm. of mercury were reached without trouble. The discharge electrode was placed inside the upper side tube and within one or two millimeters of the grating formed by the holes drilled in the outer cylinder; in the earlier work it was found that a flow of air from the cylinder over the electrode contributed little to the sharpness with which the condition of

---

[6] Watson, *Electrician*, 62, 851, 1909.

[7] Ryan, *Proc. A.I.E.E.*, XXIII., 101, 1904.

breakdown was indicated, the initial discharge of the electroscope occurring at the same value for both moving and stationary air. The results of Table IV. are plotted in the lower line of Fig. 6

TABLE IV.

Crit. Prin. Volts. Ratio, 1 : 125.			Manometer.			Pressure, mm.
			Right.	Left.	Diff.	
102.2	102.2	102.2	487.5	587.5	—100	659.5
97.5	97.5	97.2	459.5	605.5	146	613.5
91.3	91.3	91.2	427	628.5	201.5	558
87.2	87.5	87.8	407.5	642	234.5	525
83	83.2	83.4	386.5	656	269.5	490
79.9	80	80	367.5	669.5	302	457.5
80.5	80.7	80.6	371	666.5	295.5	464
74	74	74	340	688.5	348.5	411
68.1	68.1	68.1	313.5	707	393.5	366
94.2	94.2	94.2	439	617	178	581.5
106.5	106	106.2	499	576.5	77.5	682
114.5	114.9	114.8	545.5	545.5	0	759.5
Ratio 1 : 250.						
57.5	57.4	57.5	545.5	545.5	0	759.5
59.8	59.9	59.8	570.5	530.5	+ 40	799.5
61.8	61.6	61.7	592	516.5	75.5	835
64	64	63.8	618.5	499.5	119	878.5
66			641	486	155	914.5
67.7	67.7	67.7	661	473.5	197.5	957
69.8	70	69.9	687.5	457	230.5	989.5
71.6	71.6	71.7	710	444	266	1025.5

between the values of voltage at the primary terminals of the transformer and the pressure in millimeters of mercury. This voltage is directly proportional to the corresponding value of potential gradient at the surface of the wire. The ratios of transformation were 1 to 125 and 1 to 250, the frequency 60, and the ratio of the maximum to the effective value of the alternating wave of electromotive force, as measured from an oscillogram as already described, was 1.46. The temperature was 24° C. The results for a .276-cm. wire are also plotted in Fig. 6. The equations of the lines as drawn in Fig. 6 have no significance since they apply to a particular combination of wire and outer cylinder. The values of surface potential gradient have therefore been calculated from the expression:

$$\frac{dV}{dr} = \frac{E}{r \log \frac{R}{r}}, \qquad (2)$$

in which E is the maximum value of the potential difference between wire of radius r and outer cylinder of radius R, and which in this case is the effective voltage multiplied by 1.46. Expressed in terms of electric intensity at which corona begins, in kilovolts per centimeter, and pressure in centimeters of mercury, the equation for the .152 cm. wire is:

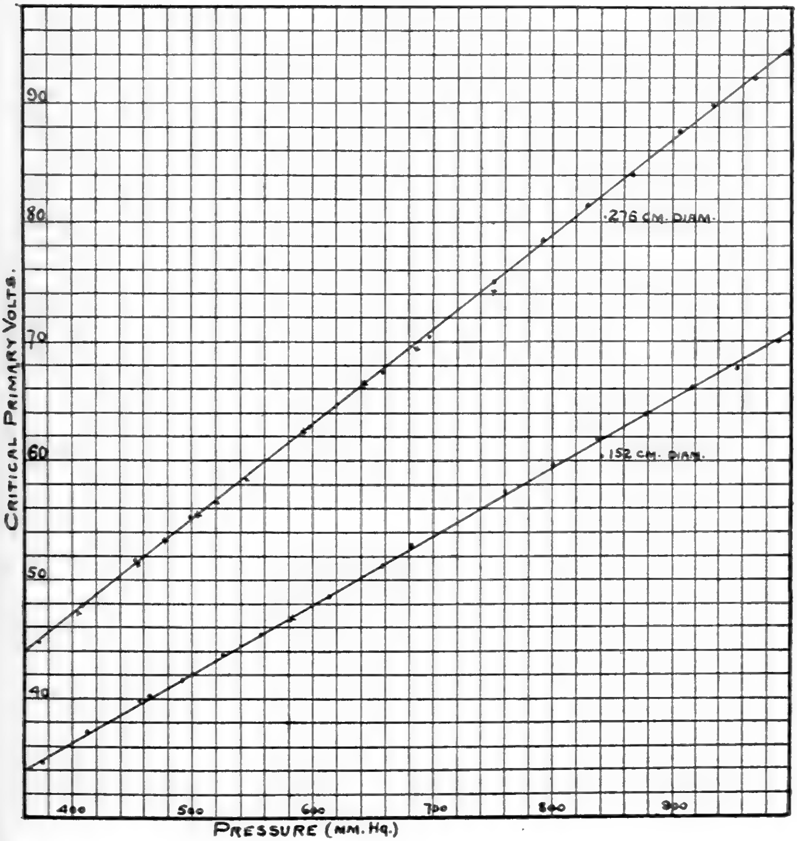


Fig. 6.

$$\frac{d(KV)}{dr} = 15.2 + .673\,p, \tag{3}$$

and for the .276 wire:

$$\frac{d(KV)}{dr} = 11.6 + .595\,p, \tag{4}$$

While both equations are linear it is seen that the slope of that for the smaller wire is the steeper, that is that the variation of the critical surface intensity with the pressure is greater the smaller the wire. It is interesting to note that the values at 76 cm. pressure 66.2 and 57 correspond extremely closely with the values 66.4 and 57.7 observed a year before and so calculated from the equation of Fig. 2.

If Ryan's results for a .317-cm. wire be expressed in the same terms used in the above formulae, the resulting equation of the line is:

$$\frac{d(KV)}{dr} = 6.15 + .744\,p. \qquad (5)$$

The slope of this line is greater than that of either the .152-cm. or the .276-cm. wire as expressed in equations (3) and (4), although the larger size of wire should cause the slope to be less; also the initial constant term is considerably less; further the value of critical surface intensity at 76 cm. pressure indicated by formula (5) is 62.6, while that calculated from formula (1) and therefore frequently observed by the writer is 55.7. Ryan used invariably the visible corona for indication of initial breakdown; some of his results on wires of different size are plotted as circles in Fig. 2 where they are seen to be very irregularly located. Aside from the uncertainty of the method of observation, the wave form and frequency may have introduced considerable error in the results as reported, although that due to frequency would have tended to a lower rather than a higher value than for 60 cycles.

Further experiments on the variation of the pressure equation with the size of wire are in progress.

Influence of Temperature and Moisture.—No satisfactory investigation has been made of the influence of temperature on corona voltage. Ryan reports a series of observations on the visible corona for temperatures between 70° and 200° Fahrenheit. The size of wire is not stated. The results are admittedly wanting in accuracy, but indicate a linear relation between corona voltage and temperature; in fact, Ryan states that the maximum value of corona voltage varies inversely as the absolute temperature.

The writer has conducted a short series of tests between 6° and 41° C. on a .27-cm. wire for the purpose of obtaining a correction factor for his various observations as taken at different temperatures. The result as stated in the paper already referred to is that the relation is linear and that for each degree rise or fall from 21° C. there is a lowering or raising in the value of the critical voltage of 0.22 per cent.; Ryan's results indicate 0.27 per cent. for this value. Expressed in terms of surface intensity in kilovolts per centimeter and temperature in degrees Centigrade the writer's results may be expressed by the formula:

$$KV./Cm. = 61 - .132\,t. \tag{6}$$

In view of the observations of the effect of variation of pressure on different sizes of wire, it is not improbable that the constants of equation (6) will also vary with the size of wire. Further investigation in this direction is therefore desirable.

Moisture content up to amounts quite close to saturation have no effect on the values of voltage at which corona begins. While there is still some dissent from this opinion among electrical engineers, the author's results on this question, described in the earlier paper, appear very conclusive, and have been widely accepted. An influence of moisture on the amount of power loss above the critical voltage appears quite probable, in the light of the ionization theory in which the mass of the ionic carriers, which make up the current are an important factor in its value.

DISCUSSION.

So far as the question of the value of voltage at which corona will start on a given transmission line is concerned, it is probable that a solution will be reached sooner or later by means of experiments of the general character as those described above, supplemented by observations on existing lines. Also, there is good reason to suppose that a comparatively simple law will be found. For the surface intensity for any arrangement and size of cylindrical conductors, corresponding to a given voltage, may be expressed in terms of these constants; and the critical or corona intensity, under standard conditions of temperature and pressure, is a simple function of the diameter of the conductor. The relation between pressure within the range of the atmosphere, and critical voltage, for a given size wire, is linear; and although the slope of the linear relation changes with the size of wire there is good reason to suppose that a simple law connecting them can be found. Much the same may be said of the influence of temperature; preliminary experiments showing that the linear relation exists over a fairly wide range. The effect of stranding the conductor has been studied for only one size of strand as yet, but it seems a simple matter, with some further investigation, to express the effect of each of these influences in terms of the diameter of the conductor.

The influence of the frequency does not offer promise of expression as a simple relation; this influence is small however within the limits of frequency met in practice. The state of the atmosphere appears to be of small importance, for moisture does not influence the critical voltage, nor does its state as regards ionization, as is indicated by several considerations given in a later paragraph. Dirt and impurities which on settling cause irregularities on the surface of the wire, may lead to localized brush discharges; and if these are sufficient in number they may cause a noticeable loss below the normal critical voltage.

It is of great interest, however, to consider the results in their relation to present theories of the nature of the electric conductivity and breakdown of a gas. It is assumed that the reader is familiar with the general features of the theory of ionization. Under this theory the neutral atoms and molecules of matter may be separated into smaller charged particles, and the motion of these particles under electric force constitutes an electric current. In a gas there are always a small number of these free ions present; this number may be greatly augmented by Röntgen rays, ultra-violet light and other well known ionizing agents. When so ionized currents of magnitudes within easy measuring range are obtained between terminals subject to a difference of potential. If this difference of potential is increased, a point is reached where the current increases sharply, showing the presence of some new saurce of ionization. The theory states that these new ions are formed by the impact of those already existing, and moving with higher velocity in the increased electric field, with the neutral molecules of the gas. This phenomenon has been called ionization by collision or secondary ionization.

The results of the experiments which have been described above are for the most part consistent with the ionization theory. The various circumstances surrounding the appearance of corona all indicate that it is an instance of secondary ionization. Formula (1) indicates that near a conductor of large radius or near a plane, the corona intensity approaches a value 32 kilovolts per centimeter; secondary ionization between plane electrodes in closed vessels at atmospheric pressure has been noticed by several physicists to begin in the neighborhood of 30,000 volts per centimeter. The mass of elementary negative ion or electron is approximately 5.9×10^{-28} gms. and the charge it carries is 4.6×10^{-10} electrostatic units. In an electric field the mechanical force acting on the electron is the product of its charge and the strength of field. Hence by the laws of simple mechanics it is possible to calculate the acceleration, the velocity and the kinetic energy attained by an electron in moving a given distance under a given electric intensity. If the mean free path of the electron, about 6×10^{-5} cm. at atmospheric pressure, be the distance between collisions, it is thus easy to calculate the kinetic energy of the electron due to the electric field, when it collides with a molecule. This energy is readily seen to be equal to pVe, where p is the mean free path, V the electric intensity in electrostatic units, and e the charge of the electron. If now the voltage between plane parallel electrodes be raised until secondary ionization begins, the value of the voltage makes it possible to calculate the energy required to ionize a molecule of a gas. In fact the values of the energy required to ionize a molecule which are now generally accepted are largely based on determinations of the value of electric intensity at which secondary ionization begins. It has been pointed out above that the values of this intensity as determined by Townsend and others are in close agreement with the value 32,000 volts per centimeter indicated by equation (1) as the lowest value at which corona appears. To one skeptical as to the correctness of the theory of ionization therefore (and there are many such) all that may be said so far is that the phenomena of sudden increase of current above a certain value of electric intensity as observed by Townsend, and that of corona formation, are probably due to the same causes. But there are several other independent methods of determining the energy required to ionize a gas. The values are commonly expressed in terms of the potential difference in volts through which the electron must pass in order to acquire energy sufficient to produce an ion by collision. The value pertaining to the method described above is from 10 to 12 volts. Rutherford, from the relation between the heating effect of radium and the number of ions it produces, gives the value 24 volts. Stark and Langevin by independent methods conclude that the values are 45 and 60 volts respectively. While the extreme values differ by the factor 5 or 6 it must be remembered that the actual amount of energy required to produce an ion is about 5×10^{-11} ergs, so that all of these values indicate the same order of magnitude; therefore when taken together they constitute a very strong reason for supposing the value 5×10^{-11} ergs is close to the correct one. If this be true it is good evidence that the formation of the corona is actually due to the liberation of ions from the neutral molecules of the gas, when the latter suffer collision from a free electron moving under the force of the electric field. That the electron and not a gaseous ion or aggregate is the active agent is shown by the shorter free paths of these latter which by the relation already given results in a lower value of kinetic energy at the time of collision than those given above.

The writer has shown by stroboscopic methods that above the critical voltage the corona begins and ends at a point on the alternating current wave which corresponds very closely in every case with this critical value. It is well known that since secondary ionization depends only on the velocity of the ions and thus on the electric intensity, it should within wide limits be independent of the number of ions already existing in the gas. The corona stops sharply on the descending side of the voltage wave showing that the copious ionization present during the existence of corona does not aid it in persisting to a lower voltage than that at which it starts. The presence of a greater or less amount of free or spontaneous ionization in the atmosphere has been advanced by some writers to explain the discrepancies, among different observers, in the voltage at which the corona starts. The foregoing facts seem fairly conclusive that this supposition is not correct. In order, however, to further remove doubt on this point a simple experiment was performed in which the air surrounding the conductor was ionized from an independent source. A clean polished wire 15 cm. in diameter was stretched vertically along the axis of a cylinder 17.5 cm. in diameter and about 120 cm. long, made of woven wire with a 1 cm. mesh. The high voltage was applied between them, the wire cylinder being also connected to ground. A large Röntgen ray tube was enclosed in a light-tight box and placed close to the cylinder. When this tube was excited a crude electroscope placed 20 or 30 cm. on the other side of the cylinder was immediately discharged showing that the air of the neighborhood was strongly ionized. In the darkened room the starting of the visible corona on the wire could be located readily and the corresponding voltage determined by successive trials within an error of two or three tenths of one per cent. By the use of independent observers it was established without doubt that the presence of the Röntgen ray tube caused no variation in the value of voltage at which the corona starts.

The general influence of a decrease in pressure or an increase in temperature toward a lower critical voltage is quite consistent with the ionization theory. For under the kinetic theory of gases the free paths of the vibrating molecules and ions are lengthened in these two conditions. During the free path or interval between collisions the ions are acted on by the electric force, and the longer the interval the greater the velocity acquired and the more kinetic energy and ionizing power. Hence a given amount of energy will be acquired at a lower voltage if the free path is lengthened.

The lowering of the critical voltage by an increase in frequency is not to be explained so simply. However if within the molecule or atom there are a number of electrons in motion or free to move, and there is some indirect evidence to this effect, it is evident that the forced vibrations set up by an external alternating field will, with the increasing frequency of these vibrations, cause the mutual attractions within the structure of the atom to become less and less strong, and therefore more liable to be broken when in collision with an extraneous ion. It is surprising however that this effect should be noticeable at frequencies so low as 60 to 90 cycles, for they are incomparably slower than those suggested by theory for the vibrations within the atom. The close relation between the first appearance of corona and the peak or maximum of the voltage wave is natural in the light of theory, for at atmospheric pressure the mean free path of an electron is about 6×10^{-5} cm. long, and under a field sufficiently strong to ionize this path is traversed in about 2×10^{-12} seconds.

Perhaps the most interesting problem in connection with the phenomenon of corona formation is the explanation of the greater values of electric intensity required to start corona around smaller wires, *i. e.,* the upward trend of the curve of Fig. 2. Why should the properties of the air change with a slight alteration in the size of a conductor whose diameter is fifty thousand times as great as the mean free path of a molecule? No tenable explanation has been offered. The attraction to the conductor of oppositely charged ions which pile up as it were and reduce the actual gradient below that calculated, and at the same time increase the gas pressure, has been suggested. Both suppositions immediately include an influence on corona voltage of the amount of ionization already present, and this as already noticed is contrary to observation. Simple calculation also will show that the charge sufficient to materially reduce the gradient at the surface of a conductor at corona potential would require a number of ions far in excess of the numbers commonly present in the atmosphere. The writer by a sensitive optical method could find no indication of an increase of pressure at the surface of the conductor. It appears probable that the explanation will be found in the decreasing surface of the smaller conductors. Secondary ionization probably begins with the collisions of a few electrons which have free paths longer than the average. With decreasing area of conductor, the number of neighboring electrons whose free paths exceed a certain length, and at the same time are subject to the maximum electric intensity, will be decreased, and consequently the corona forming electric intensity must be higher.

Johns Hopkins University,
April 20, 1911.

DISRUPTIVE DISCHARGES OF ELECTRICITY THROUGH FLAMES.

By FRANCIS E. NIPHER.

(*Read April 21, 1911.*)

In a paper published by the Academy of Science of St. Louis[1] the author pointed out the essential difference in character between the effects of X-rays in the ionization of air and that produced in a column of air exposed to the positive terminal of an influence machine.

The action of X-rays is to dislodge negative corpuscles from some of the air molecules and load them upon others. Such a mass of air is said to have the property of conduction. Some of the molecules in it will accept negative corpuscles from those to whom they have delivered them or from the terminal of a negatively charged electrometer. Other molecules will deliver their overload of negative corpuscles to an electrometer terminal from which negative corpuscles have been drained, or to the molecules which they have robbed. If left to itself such a mass of air soon loses its property of conduction. The average corpuscular charge of a molecule in such a mass of air is the normal amount.

In a mass of air which forms the positive column due to the action of an influence machine the negative corpuscles have been drained, or are being drained into the positive or exhaust terminal. In air of ordinary pressure it is found that in air thus drained of negative corpuscles, a disruptive discharge diffuses into the drained region. The disruptive channel widens and apparently ceases to have a disruptive character within the region thus drained. In a few cases the disruptive channel has re-formed on the other side of such a cloud-like mass which had apparently drifted over the photographic plate and away from the positive terminal.

---

[1] *Trans.*, Nos. 1 and 4, Vol. XIX., and No. 1, Vol. XX.

An illustration of this action is shown in Fig. 1. A photographic plate had the heads of two pins resting upon the film. They formed the terminals in a gap in a discharge line from the negative terminal of an eight-plate influence machine to ground. Between this gap and the machine was another gap of about 1 mm., which was at the large knob of the machine.

In order to produce the effect shown in the figure, the machine was turned very slowly for several minutes. Small discharges occurred at the small gap. When there was danger of a spark between the pin-heads, the machine was stopped for twenty or thirty seconds and then continued. This resulted in draining the negative corpuscles from the air around the grounded pin-head. A progressive elongation of these drainage lines was examined in a series of plates in which this operation was continued for an increasing time interval, the plates being then developed.

In Fig. 1 after continuing the slow driving of the machine for about three minutes, its speed was then suddenly increased and a disruptive discharge passed over the photographic film between the pin-heads.

This plate is one of many hundreds that have shown this phenomenon of a diffused conduction in the region around the positive end of the disruptive channel. This channel began at the negative pin-head, in the midst of the negative glow. That region was not in a condition of conduction for the negative discharge, and has not been in any case observed. Fig. 1 is one of a few cases where the discharge wandered considerably from the line joining the pin-heads. In some cases the plate was in the positive line. In some cases the two pin-head terminals were directly connected to the positive terminals of the machine with minute gaps at the machine. In all cases the diffusion area was formed at the positive pin-head terminal. In all cases the appearance shown in Fig. 1 was observed. The appearance is that which might be caused by a volley of negative corpuscles discharged from the end of the disruptive channel, and aimed at the pin-head forming the positive, in this case the grounded, terminal. The pin-head shielded that portion of the film which was behind it and in line with this discharge from the fogging effect observable around it. The air-film which carried the discharge was in close contact with the film, as is shown by the character of the shadow. The lowest part of the rounded pin-head only was effective in this shielding of the film, as is shown in Fig. 1.

The interior of the disruptive channel is also a drainage or conduction channel. It is in a highly rarified condition, approaching that of a vacuum tube. The discharge which passes through it is in the nature of a cathode discharge. The air molecules which form the stepping stones for this conduction discharge are urged in the opposite direction from that in which the corpuscular discharge is passing. This is incidental to the fact that the conductor is in gaseous form. These air molecules have in some cases produced effects at the negative terminal, similar to those shown in Fig. 1. They are, however, less marked in character. They are in the nature of "canal rays," as observed in a vacuum tube. A photographic plate showing such effects was reproduced in a former paper.[2] In a copper wire the transfer from atom to atom likewise occurs. There the atoms cannot yield, they are nearer together, and the phenomena of conduction are much more simple.

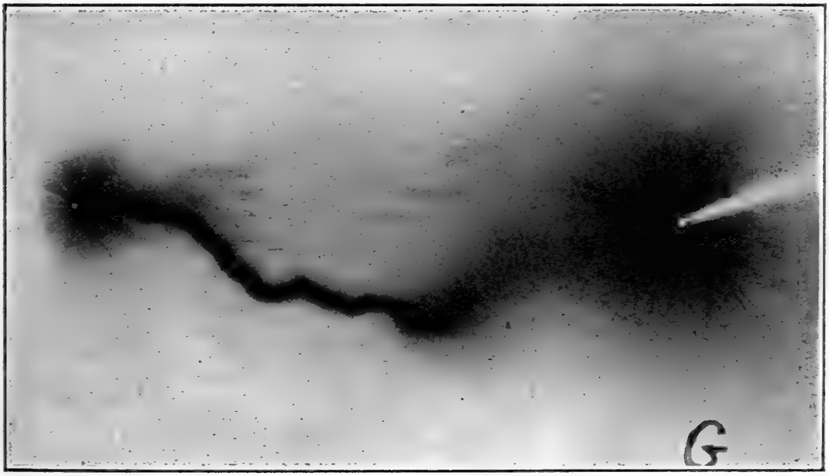


Fig. 1.

---

[2] *Trans. Acad. of Sci. of St. Louis,* Vol. XIX., No. 4, plate XXII., Fig. A.

An attempt was made to compare the conduction-properties of a drainage column of air like that shown in Fig. 1, with those of the flame of a blast lamp. Fig. 2 shows a camera photograph of disruptive discharges between a red-hot ball of iron hung on a wire suspension by means of which it was grounded, and the negative terminal of the influence machine. The ball was heated by a blast lamp, the air being fed from a tank at about two atmospheres pressure. A similar flame was placed between the hot ball and the negative terminal, so that the discharges passed through it. On account of the long exposure, the contrast between the flame and the individual sparks is not very distinct. Some of the sparks show a partial photographic reversal. The discharge lines are, however, all more or less clearly visible within the flame. Fig. 3 shows a single spark, made under the same conditions, although the flame was exposed for nearly half a minute before the spark passed. Fig. 4 shows a similar photograph in which the exposure to the flame was not over half of a second. There are two discharge lines visible,

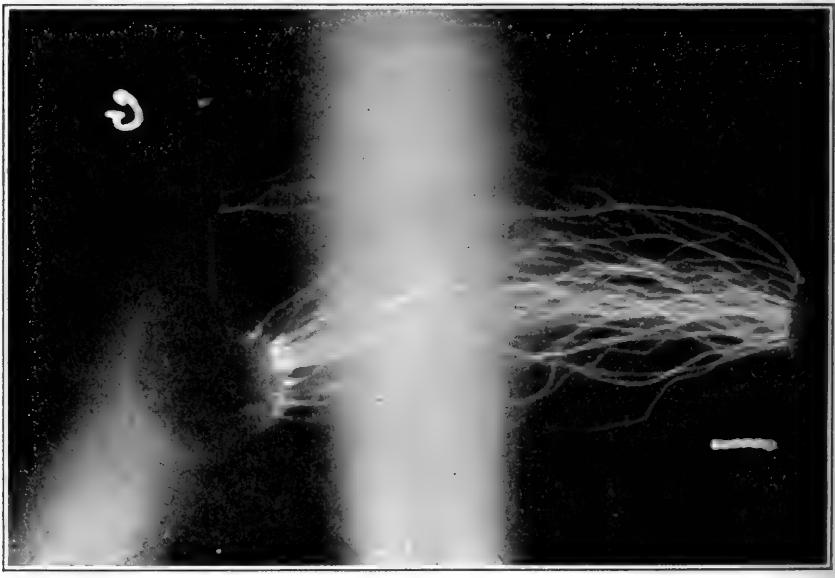


FIG. 2.

although only one discharge could be distinguished by the sound. The fainter discharge came from the red-hot ball, and crossed the track of the brighter spark, which came from a hook serving for suspension of the ball on a grounded wire. The track of the fainter spark is as sharply defined within the flame as that of the brighter one. In Figs. 3 and 4 the discharge was in the positive line. The hot ball was grounded.

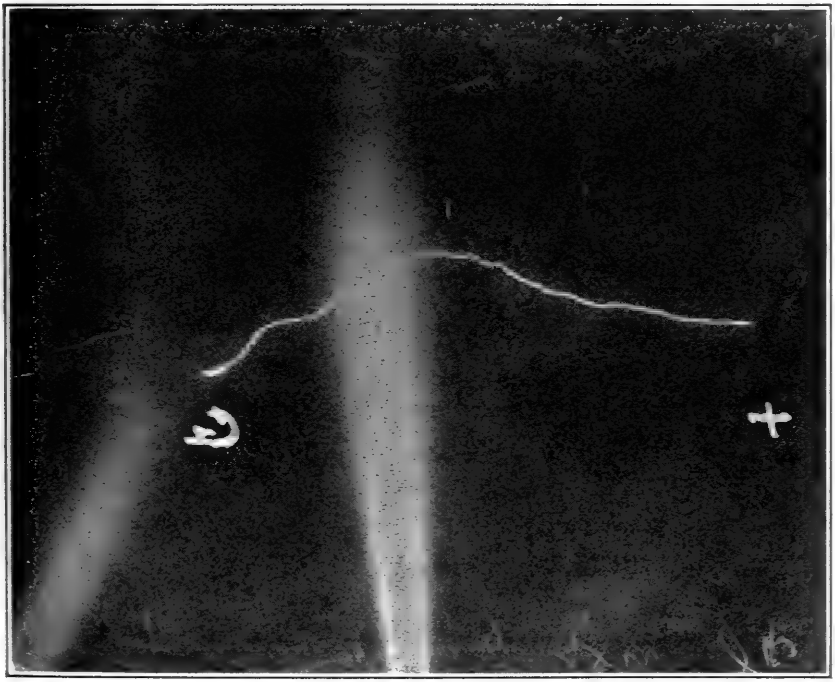


Fig. 3.

It is evident from these results that the conduction of the gases within the flame of the lamp is very much less than is shown in the positive column near the anode terminal in Fig. 1. In that figure, the air within the disruptive channel is highly rarefied. This channel is a hole bored through the air. The discharge through this channel issued from the end and continued as "sheet lightning" across the drainage area surrounding the grounded anode. This drainage area is not in the rarefied condition which exists within the disruptive spark channel. This part of the discharge must be practically noiseless. The sound produced by the spark is caused by the collapse of the spark channel in a manner similar to that caused by the crack produced by the end of a whip-lash, which also cuts a hole in the air. When an electrical discharge occurs between clouds or between a region containing an excess and one having a deficiency of electrical corpuscles, the latter region must be in a condition like that surrounding the grounded anode in Fig. 1. The disruptive channel will diffuse into it. This region is one which is properly called a region of conduction.

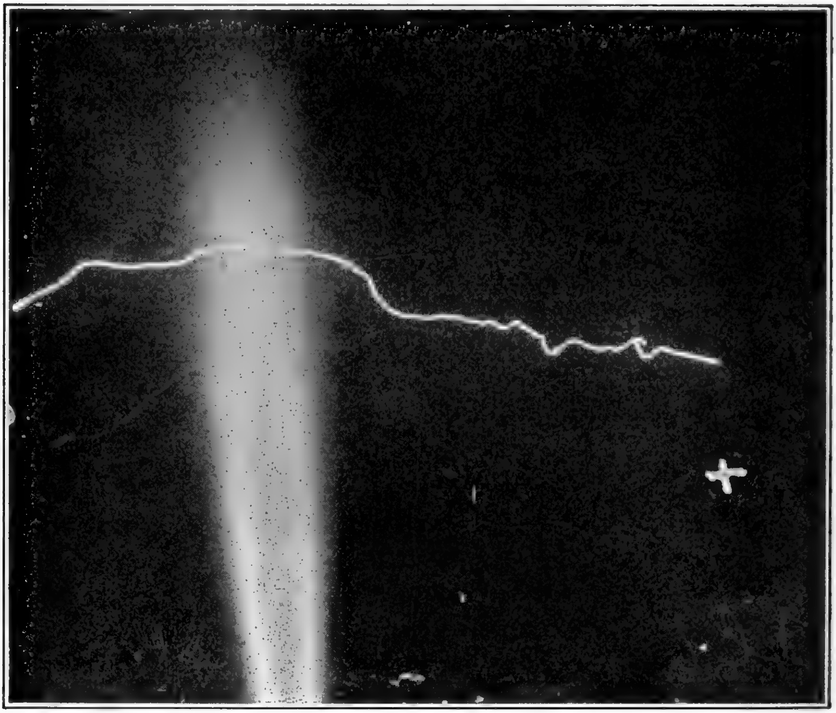
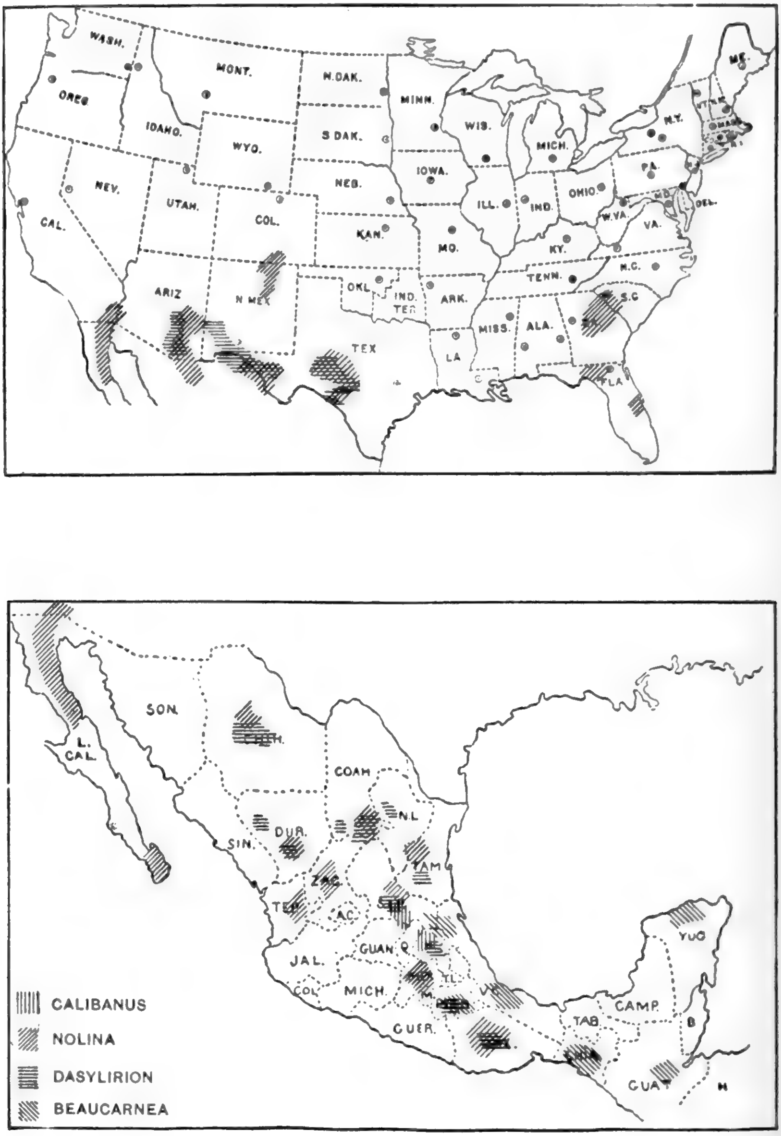


FIG. 4.

The other end of the discharge channel must penetrate regions where the air is super-charged with corpuscles. It is not in the same sense a region of conduction. Here tributary discharge channels will form. These discharge channels branch out from the main channel and elongate in a direction opposite to that in which the corpuscular stream is flowing. This end of the discharge is called forked lightning. Probably in most cases the ends of the discharge are hidden by clouds.

Fig. 1 is a reproduction of the original plate. Figs, 2, 3 and 4 are reproductions of photographic reversals of the originals.



DISTRIBUTION OF NOLINEAE

THE DESERT GROUP NOLINEÆ.

(Plates I–XVII.)

By WILLIAM TRELEASE.

(*Read April 21, 1911.*)

History.

The four genera *Nolina* (Michaux, 1803), *Dasylirion* (Zuccarini, 1838), *Beaucarnea* (Lemaire, 1861) and *Calibanus* (Rose, 1906) form so natural a group that many botanists have considered a single generic name, *Dasylirion*, sufficient for all, though they differ enough in fruit to have caused the founder of this genus to question the propriety of including in it all of the species that were known even in his day; and they show marked differences in habit.

Except that *Dasylirion* was based in part on a *Hechtia*, which led its author—who later recognized the error—to place it among the Bromeliaceæ, and that on his suggestion it has been connected transiently with the Juncaceæ, this genus and its immediate relatives have been accorded place generally among what are now considered as Liliaceæ,—though not always under that family when its rather heterogeneous components have suffered temporary segregation. No better arrangement has been found than that of Engler and Prantl[5] who locate the Nolineæ between Yucceæ and Dracæneæ as part of the Draceanoid Liliaceæ. From the Yucceæ they are sharply differentiated, among other characters, by their small polygamo-dioecious flowers (never 10 mm. in diameter), few-ovuled pistil, and small usually indehiscent fruit rarely more than one-seeded: and the Dracæneæ differ from them in a usually somewhat gamophyllous perianth, perfect flowers, and prevailingly fleshy fruit,—but in all of these respects the group of Dracæneæ offers a good deal of latitude.

DISTRIBUTION AND ORIGIN.

Like the Yucceæ, the Nolineæ are all North American, and they are comparably distributed except that none are known from the West Indies. They are among the characteristic plants of the dry temperate backbone of the continent. None extend north of southern Colorado, and no species is known to have a very extended range. Their focal center is evidently the temperate Mexican tableland, on which the genera are all represented and to which the majority of their species are confined, *Beaucarnea* alone, in its most typical form, being characteristic of the hot country and ranging into Central America. Of the two genera that reach the United States, *Nolina* only enters into the Californian flora, and that only in the southern desert. Though unrepresented in the intermediate region, from which it may be assumed to have disappeared, this genus also appears in the South Atlantic states, apparently as an offset from the grass-leaved Texan stock, rather than indicating its primal home (*map*).

The ontogeny of the group is scarcely more than a matter of speculation. No reason is apparent for considering it to be very ancient. Though evidently related to the typically septicidal Yucceæ, it seems rather more likely to have had a closer evolutionary connection with the typically loculicidal Dracæneæ. More satisfactory hypotheses may be held concerning the affinities of the component genera. *Nolina* may be taken as most closely approaching the prototype of the group because of its extensive range, large number of species composing differentiated groups, and conformity to the liliaceous plan in its 3-celled pistil and cotyledonary arch. *Calibanus* appears to be an offset of *Nolina*. *Beaucarnea* and *Dasylirion*, with a single-celled pistil, may represent parallel offshoots from *Nolina* or a no-longer recognized derivative of that genus; and the question may be raised whether *Beaucarnea* is more than a well-marked subgenus of *Dasylirion* which, strictly limited, itself consists of two quite dissimilar groups. These affinities may be indicated as follows:

BIOLOGY.

All Nolineæ are perennial, and, as would be expected from their habitats, they are pronounced xerophytes with a rather succulent caudex,[7] either small and insignificant or moderately developed, and then either prostrate or erect, or even of tree size (*pl. 1–4*), and rather hard usually rough-edged or even prickly leaves[3,6] covered by a well-cuticularized epidermis, the stomata usually arranged in lines overlying the parenchyma between strong fibrous bundles and either furnished with an outer vestibule as in *Agave*, etc. (*Dasylirion*), or located between prominent ribs that, especially in *Nolina*, are often covered with more or less interlocking papillae.[13,16] They occur most strikingly in such desert associations[2] as count *Agave*, *Yucca* and *Hechtia* among their characteristic components (*pl. 2, 4*). In many species the tip of the leaf shreds into a sometimes brush-like bunch of fibers, and in one (*Nolina Bigelovii*) the margin breaks away sparingly—in kind, rather than quantity, recalling the fibrous exfoliation characteristic of many yuccas and of one large group of spicate agaves. From a study of the leaf-tip of *Dasylirion acrotriche*, Zuccarini[24] was led to believe that what passes for the leaf is really a petiole with ventral ligule, the blade, considered as peltate, being represented by the more dorsal shreds only. The prevalent dorsal insertion of the haustorium on the cotyledonary sheath in seedlings of this group is worthy of note in connection with this opinion (*pl. 15*).

Though sometimes weakened or even destroyed by flowering under cultivation, all of the Nolineæ appear to be normally polycarpic. The terminal inflorescence[1,24] is essentially of one type though varied from a thin lax raceme-like wand into a stout compound spike with short and broad divisions or an open simple, compound or even decompound panicle (*pl. 5*). Whatever its form, the flowers are clustered, usually two or three together, in the axils of small prevailingly denticulate bractlets, either on cushions so short that they appear to come from the main axis, or, more commonly, on evident secondary or tertiary branches (*pl. 6, 7*). The primary branches appear to be 8-ranked[17] and the bracts are often large and conspicuous, those which support the ultimate flower clusters being scarcely larger than the bractlets.

The sometimes slightly fragrant[11] polygamo-diœcious flowers are borne on slender pedicels never greatly exceeding their own length, which are always distinctly jointed, usually about the middle. Though the flowers are small, their at first petaloid, then scarious-persistent distinct entire or toothed segments are usually whitish, though more or less tinged with green, violet, rose or cream—a coloration supported by the usual whiteness of the scarious bractlets and, often, by similarly colored large bracts. The small elliptical anthers are introrsely versatile, their filaments slightly adnate to the base of the perianth segments. Three connate carpels, with typically two anatropous basal ovules each, constitute the pistil which is 1- or 3-celled in different genera. The stigmas are essentially apical, on more or less free and divergent style tips in *Nolina,* crowning the rather narrowed ovary in *Beaucarnea,* along the rim of a distinct funnel-like though sometimes cleft style in *Dasylirion,* or as sessile points in *Calibanus* (*pl. 8*).

Essentially unisexual and often diœcious, the flowers are perfect in plan; and abortive stamens are found in the fertile flowers, and more or less recognizable rudimentary pistils in those that are functionally staminate. In fertile flowers nectar is secreted by small septal nectar-slits in the base of the pistil,—often very evident after this has enlarged into a fruit (*pl. 9*); and in staminate flowers it is the rudiments of the carpels that perform the same function.[24]

Though prevailingly 3-merous, the flowers may show deviation from this pattern. Preda[17] noted that about one-fifth of the flowers of a pistillate plant of *Dasylirion glaucum* were 4-merous; and in examining large numbers of the fruits of this genus I have observed 2-, 4- or 5-winged fruits of several species and one 4-carpellary fruit of *Calibanus* (*pl. 11*). Several observers have found that partly developed fruits may occur now and then on staminate plants[8]; my own observation shows that well developed stamens may be found in some pistillate flowers; and Bouché[1] records the transformation of staminate into pistillate individuals,—suggesting an interesting line of study for those who may observe and experiment with these plants as they grow under natural conditions.

Observations on pollination do not appear to have been recorded, but the flowers are clearly entomophilous and their pollinators are to be sought probably among the Hymenoptera and Diptera, as has been suggested to me for *Dasylirion* by Sr. Patoni, of Durango.

Normally fertilized, the ovules develop into 3-sided or 3-grooved seeds with micropyle by the side of the hilum, a slender often scarcely discernible raphe, and thin and smooth or somewhat thickened and wrinkled envelopes composed of thin-walled cells and representing essentially the seed-coats though often with a terminal umbo or apiculus representing the base of the nucellar tissue. The bulk of the seed consists of rather firm endosperm through which the finger-like embryo passes upward from near the micropyle toward the morphological base of the nucellus. The endosperm consists of moderate-sized polygonal cells with glistening white rather thick pitted walls and coarsely granular contents destitute of starch. The walls of these cells are of the " reserve-cellulose " type, but they are colored blue by neither iodine nor chlor-iodide of zinc, though they swell so greatly in the latter reagent that in a thick section the contents, in which large and abundant oil drops separate out, promptly extrude, sausage-like, from any chance break (*pl. 10*). Went and Blaauw[22] have reported partial embryo formation in some ovules and much more complete endosperm development in others, in a pistillate *Dasylirion,*—apparently without concurrence of male nuclei. Usually only one of the six ovules produced by a normal pistil matures in the 1-celled fruit of *Dasylirion* and *Beaucarnea* or the 3-celled ovary of *Calibanus;* but with the 3-celled fruit in *Nolina,* though a single seed is the rule, two or three are not infrequently seen,—usually only one to a cell, though exceptionally both ovules of a carpel develop.

The ripened fruit is dry-walled: subglobose with three low ribs in *Calibanus,* triangular with strongly developed dorsal wings on the carpels in *Dasylirion* and *Beaucarnea,* and deeply 3-lobed between the wingless carpels in *Nolina.* In the first three genera it does not dehisce, but in *Nolina,* though the delicate walls are often irregularly torn—sometimes even before maturity of the rather firmly attached seed, or the fruit may remain long unopened—loculicidal dehiscence is more or less prevalent (*pl. 11, 12*).

If observations on dissemination have been published, they have escaped my search, but the process may be inferred with some probability from the character of the fruit. In all, the ripened fruit, with its enclosed or attached seed or seeds and the persistent but unenlarged perianth, falls by disarticulation of the pedicel,—close to the fruit in *Dasylirion* and *Calibanus*, somewhat further from it in *Beaucarnea*, and usually at a still greater distance in *Nolina*. No provision for dissemination other than through rolling or being blown over the ground appears in the round fruit of *Calibanus*. The winged fruits of *Dasylirion* and *Beaucarnea* are as evidently wind-scattered as the similarly disarticulating and equally small fruits of *Rumex*,—though in the latter the wings are not carpellary but consist of the enlarged persistent sepals. The very different fruits of *Nolina* are likewise evidently wind-disseminated, their more or less inflated carpels giving them a character intermediate between winged and balloon fruits.

Germination, of which no published records have been found, is of Klebs' *Asphodelus-Tradescantia* type,[10,20] the seed—freed from the remnants of the fruit in *Nolina* or still contained in them in the other genera—remaining in the ground with the arched haustorium elongating with the cotyledonary sheath so as to reach a length of even 10 mm. In *Nolina longifolia* and in specimens of *N. parviflora* preserved by Dr. Rose, the haustorium is apical, though a slight elbowing is sometimes seen near the the top of the arch; and it sometimes straightens and lifts the seed from the ground. Seedlings of *Beaucarnea* and *Calibanus* preserved by Dr. Rose show that in these genera the sheath is produced above the arch in form of a pointed ventral ligule, as is true in such species of *Dasylirion* as I have observed. In these cases the haustorium appears to be distinctly dorsal on the sheath, along which it is often sharply refracted (*pl. 13–15*). Initial growth is evidently at the principal expense of the granular protoplasm, oil and "reserve-cellulose" of the endosperm. In *Calibanus* and *Beaucarnea*, as is shown in excellent specimens in the National Herbarium prepared by Dr. Rose, the formation of the thick trunk follows germination quickly.

USES.

Though none of the Nolineæ can be considered as of great present economic importance, many of them are utilized in one way or another and it is probable that more use can be made of some species than is now the case. In the great bend of the Rio Grande I have seen the trunks of *Dasylirion* split open to give stock access to the rather watery pith; and they are sometimes cut for feeding.[2,7,23] In Mexico the trunks of *Dasylirion* are roasted and eaten similarly to those of the mezcal agaves; and Dr. Gregg notes a similar use of a *Nolina* on the label accompanying a specimen of it. From such roasted trunks of *Dasylirion*, after fermentation, an alcoholic beverage very similar to mezcal spirits is distilled, and under the name of sotol[12,14,18,21] it is very commonly used through the extensive Mexican territory over which this genus occurs. As in *Yucca, Agave,* and some other plants, the sap of those now under consideration contains, as a water conservation provision, a saponifying substance, and the roots of *Nolina Palmeri* are said to serve as an amole.[15] The leaves of *Dasylirion* and *Nolina*—and presumably of *Beaucarnea*—are used for thatching,[18] basket work, coarse hats and similar plaited-ware, either entire or shredded.[9,12,19] Though less employed than that of yuccas and agaves, their fiber is also somewhat used locally, and the narrow leaves of the eastern bear-grass have long been used in their entirety for hanging meat and similar domestic purposes for which strength rather than finished cordage is needed. Some thought seems to have been given also to the preparation of paper pulp from the fiber of *Dasylirion*.[4]

SYSTEMATIC REVISION.

In revising the forms known to me I have had the privilege of seeing an unusual amount of typical material, for which I am greatly indebted to Professor Radlkofer of Munich (Zuccarini types), Dr. Robinson of Cambridge (Watson types), Dr. Rose of the National Herbarium (types of his own species) and Mr. Brandegee of Berkeley, whose collection contains numerous critical forms. Owing to Engelmann's early interest in the vegetation of the Texano-Mexican region, his herbarium, now at the Missouri Botanical

Garden, is rich in representatives of this, as of other groups characteristic of that arid region,—as herbarium representation of such plants goes: and in it, as well as in the herbarium of the New York Botanical Garden and in the National Herbarium, have been found types or cotypes of the species of Scheele and Torrey.

I do not venture to think that anything like the last word on the group is here said,—the sparse occurrence of the representatives of admitted species through a vast and greatly diversified area, as shown by the distribution map, would speak against such a view; but the following rather tersely cast synopsis is published in the hope that it may render the work of filling gaps in both range and forms easier than it has proved in the past. Space is not taken for a full bibliography,—though this would not have been very extensive; but the principal revisions of each genus are noted, as well as the various names under which a species has appeared; and references are given to all illustrations that have been found.

Synopsis of Genera.

Ovary 3-celled. Fruit wingless.

- Fruit deeply 3-lobed, often inflated: seed nearly globose, rather fleshy-walled. Pedicels articulated rather far below the flowers. Perianth segments entire, papillate-pointed. Leaves strongly ribbed with usually papillate grooves, at most serrulately roughened on the margin. Inflorescence a panicle (or racemosely reduced). **Nolina.**
- Fruit globose-triangular, not lobed or inflated; seed melon-shaped, thin-walled, occluding the sterile cells. Pedicels articulated close to the flowers. Perianth segments nearly entire, rounded. Leaves as in *Nolina*. Inflorescence a panicle. **Calibanus.**

Ovary 1-celled. Fruit 3-sided and 3-winged, not lobed or inflated.

- Pedicels articulated somewhat below the flowers. Perianth segments entire, acute. Seeds 3-grooved or 3-lobed. Leaves somewhat ribbed, the grooves not usually papillate, at most serrulately roughened on the margin. Inflorescence a panicle. **Beaucarnea.**
- Pedicels articulated close to the flowers. Perianth segments denticulated, rather obtuse. Seeds 3-grooved or 3-sided. Leaves not ribbed, their margin (in all except one square-leaved species) armed with strong prickles and usually also serrulate-roughened. Inflorescence a stout compound spike. **Dasylirion.**

Nolina.

Michaux, Fl. Bor.-Amer. **1**: 208. 1803.—Watson, Proc. Amer. Acad. **14**: 246–8. 1879.—Rose, Contr. U. S. Nat. Herb. **10**: 92.

1906.—Sometimes merged in *Dasylirion* or *Beaucarnea*, and made to include the latter genus by Hemsley, Biol. Centr.-Amer. **3**: 371, which is conformed to the views of Bentham and Hooker, Gen. Plant. **3**: 780.—At first monotypic, based on *N. georgiana*.

Leaves thin and grass-like (but hard-fibrous), linear, rarely over 5 mm. wide, rather flat, usually not brush-like at tip. Bracts not very showy. Acaulescent (pp. 413–416). GRAMINIFOLIÆ.

Inflorescence commonly as long as the minutely serrulate-scabrous essentially green spreading leaves, peduncled, unbranched or with slender usually simple branches 15–25 cm. long. Floriferous bracts small, not imbricated. Pedicels remaining filiform, increasing to 8 or 10 mm. and equaling or exceeding the usually rather large and inflated fruit. Seed not prominently exposed.

Leaves smooth and rather open between the ribs. Panicle not compound. Lower bracts much shorter than the subtended branches. Bractlets barely serrulate.

NOLINA GEORGIANA Michaux, Fl. Bor.-Amer. **1**: 208. 1803.—M(asters), Gard. Chron. n. s. **15**: 688, 697. *f. 126.*

Phalangium virgatum Poiret in Lamarck, Encycl. Méth. **5**: 246. 1804.

Leaves 3–5 mm. wide. Inflorescence simply panicled with rather spreading branches. Flowers rather large. Fruit subelliptical, rather pointed. 7–9 × 8–10 mm. Seed 2 × 4 mm.—*Pl. 5, 11.*

Central South Carolina and across central Georgia.

Specimens examined: GEORGIA. Milledgeville (*Boykin*, 1836). Augusta (*Cuthbert*, 1877). Belair (*Eggert*, 1899). Big Lott's Creek (*Harper, 965*, 1901). Columbia County (*Chapman*). Thomson (*Bartlett, 1174*, 1907).

N. ATOPOCARPA Bartlett, Rhodora. **11**: 81. 1909.

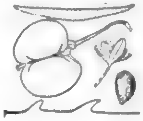
Leaves 2–4 mm. wide. Inflorescence unbranched or simply panicled. Fruit more or less unsymmetrically obovate, shallowly notched, or pointed, scarcely inflated. 5 × 6 mm. Seed 3 × 4 mm.

Eastern Florida.

Specimens examined: FLORIDA. Eau Gallie (*Curtiss, 5702*, 1896,—the type; *2937*). Without locality (*?Rugel, 124*, 1842–9; *Chapman*). Tacoi (*Palmer, 566*, 1874; *Garber*, 1876). Tampa Bay (*Burrows*).

Leaves (as in all except the two preceding) with the sides of the ribs microscopically papillate. Lower bracts sometimes about equaling the subtended branches. Bractlets toothed. Fruit (as in all except the two preceding) conspicuously notched.

N. BRITTONIANA Nash, Bull. Torr. Bot. Cl. **22**: 158. 1895.



Leaves 5–10 mm. wide. Inflorescence simply panicled with rather erect branches. Fruit depressed-orbicular, 8 × 10 mm. Seed 3 × 4 mm.

North-central Florida.

Specimens examined: FLORIDA. Eustis (*Nash, 459,* 1894,—the type; *Webber, 406,* 1896). Clermont (?*MacElwee,* 1895; *Williamson,* with the close-ribbed leaves of this species, but fruit rather of *georgiana*).

N. LINDHEIMERIANA Watson, Proc. Amer. Acad. **14**: 247. 1879.
Dasylirion Lindheimerianum Scheele, Linnæa. **25**: 262. 1852.
D. tenuifolium Torrey, Bot. Mex. Bound. 215. 1859.
Beaucarnea Lindheimeriana Baker, Journ. Bot. **10**: 328. 1872.

Leaves 2–5 (exceptionally 9) mm. wide. Inflorescence simply panicled with spreading branches often less than 10 cm. long, or the lower of these with slender branchlets less than half as long. Fruit somewhat depressed-orbicular, 7–8 × 8–10 mm. Seed 2 × 3 mm.—*Pl. 12.*

Central Texas.—In the region of *N. texana* and *Dasylirion texanum.*

Specimens examined: TEXAS. Vicinity of New Braunfels (*Lindheimer, 213,* 1846,—the type of *D. Lindheimerianum; 551, 552,* 1846; *1214–1217,* 1849). Sabinal River (*Wright, 1919,* 1851–2,—the type of *D. tenuifolium*). Austin (*Hall, 634,* 1872). Bandera's Pass (*Reverchon, 1606,* 1884). Cherry Spring (*Jermy, 831*). Edwards County (*Hill, 39,* 1895). North of San Antonio (*Hastings, 81,* 1910).—Gillespie County (*Jermy,*—with leaves 4–9 mm. wide). Western Texas (*Wright, 673,* 1849).

Inflorescence rather dwarf, panicled. Bractlets rather conspicuous, more or less lacerate. Leaves glaucescent, raggedly serrulate-scabrous.

Pedicels rather slender, at length equaling or exceeding the fruit.
Floriferous bracts not imbricated.
Lower bracts linear, leaf-like. Panicle simple.

N. PUMILA Rose, Contr. U. S. Nat. Herb. **10**: 92. 1906.

Leaves 2–4 mm. wide. Inflorescence 30 cm. long, the upper two-thirds narrowly and simply panicled with short weak branches scarcely 2 cm. long. Fruit suborbicular, 6–7 mm. in diameter, the pedicels somewhat thickened upwards. Seed (immature) 2 × 3 mm.

West-central Mexico.

Specimens examined: TEPIC. Sierra Madre Mountains near Santa Teresa (*Rose, 2165*, 1897,—the type).

Lower bracts dilated and scarious. Panicle compound.

N. HARTWEGIANA Hemsley, Biol. Centr.-Amer. **3**: 371. 1884.

Cordyline longifolia Bentham, Plant. Hartweg. 53. 1840.

Roulinia longifolia Brongniart, Ann. Sc. Nat., Bot. ii. **14**: 320. 1840.

Dasylirion junceum Zuccarini, Abhandl. Akad. München. Cl. II. **4** (=Denkschr. **19**): 19. 1845.

D. Hartwegianum Zuccarini, *l. c.* 21. 1845.—Bentham, *l. c.* 348. 1857.

Beaucarnea Hartwegiana Baker, Journ. Bot. **10**: 327. 1872.

Shortly caulescent? Leaves 3–4 mm. wide, somewhat fibrous-shredding at tip. Inflorescence 25–50 cm. long, short-stalked, ovoidly compound-panicled with pyramidal divisions 8–15 cm. long and short stiffish branchlets.—*Pl. 16.*

Central Mexico. Collected about Zacatecas by Hartweg in 1837.

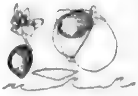
The characters are extracted from the descriptions of Zuccarini and Baker and from a photograph of a Hartweg co-type (*406*) in the Delessert herbarium which I owe to the obliging kindness of M. de Candolle and reproduce here with his permission.

Pedicels thickened, about half as long as the rather large fruit.
Floriferous bracts imbricated. Panicle simple, scarcely half as long as the leaves.

N. HUMILIS Watson, Proc. Amer. Acad. **14**: 248. 1879.—Hemsley, Biol. Centr.-Amer. **5**. *pl. 93.*

Beaucarnea humilis Baker, Journ. Linn. Soc., Bot. **18**: 237. 1880.

Leaves 2–3 mm. wide. Inflorescence 15 cm. long, with a few suberect basal branches one-third as long. Fruit suborbicular, 7 × 9 mm., scarcely inflated. Seed very large, 3–4 × 5 mm., prominently exposed.



East-central Mexico. In the region of *N. Watsoni, Calibanus,* and *Dasylirion Parryanum* and *graminifolium.*

Specimens examined: SAN LUIS POTOSI. Vicinity of San Luis Potosi (*Parry & Palmer, 875,* 1878,—the type).

N. WATSONI Hemsley, Biol. Centr.-Amer. **3**: 372. 1884; **5**. *pl. 94.*

Beaucarnea Watsoni Baker, Journ. Linn. Soc., Bot. **18**: 236. 1880.

Leaves 5 mm. wide, rather concave and unusually rough-margined. Inflorescence 25–30 cm. long, with rather numerous strict branches scarcely one-third as long, smooth or somewhat scabrid on the short peduncle. Fruit more or less ovate-orbicular, cordately notched, 8 × 8–10 mm., inflated. Seed (immature) 2 × 3 mm.

East-central Mexico. In the region of *N. humilis,* etc.

Specimens examined: SAN LUIS POTOSI. Vicinity of San Luis Potosi (*Parry & Palmer, 874,* 1878,—the type, *502,* 1878; *Schaffner, 261,* 1879).

Leaves rather thick, linear or narrowly oblong-triangular, scarcely over 12 mm. wide, green, more or less concave and unequally keeled on one or both faces, raggedly dentate-scabrous in most species and in age often fibrous-lacerate at tip. Inflorescence usually about as long as the leaves, peduncled, compound-panicled. Bracts not usually very showy. Bractlets more or less lacerate.

Fruit small, not inflated, the relatively large seed early exposed and prominent (pp. 416–420). ERUMPENTES.

Inflorescence (as in the last preceding species) often roughened in lines. Pedicels rather thickened in fruit. Acaulescent.

Lower bracts firmly long-attenuate from a somewhat dilated scarious-margined base.

Lower panicle divisions much shorter than the subtending bracts, with rather weak strongly ascending branchlets.

N. TEXANA Watson, Proc. Amer. Acad. **14**: 248. 1879.—Nash, Journ. N. Y. Bot. Gard. **6**: 48. *f. 16.*

Beaucarnea texana Baker, Journ. Linn. Soc., Bot. **18**: 236. 1880.

Leaves very narrow, 2–5 mm. wide, smooth-edged or slightly roughened, from half-round becoming triquetrous. Inflorescence often much shorter than the leaves, with oblong divisions often 15 cm. long and lower branchlets half as long, or subsimple. Fruit somewhat depressed, 4 × 5–6 mm. Seed 3 mm. in diameter.—*Pl. 12, 15.*

Central Texas. In the region of *N. Lindheimeriana* and *Dasylirion texanum.*

Specimens examined: TEXAS. Vicinity of New Braunfels (*Lindheimer, 550,* 1846, *712,* 1847,—the types; *1218,* 1849). Austin (*Hall, 635,* 1872). Hamilton County (*Reverchon, 967,* 1882). Cibolo (*Havard,* 1883). Blanco County (*Reverchon,* mixed with *1606*). Kerr County (*Bray, 184,* 1899). Davis Mountains (*Earle & Tracy, 322,* 1902). Gillespie County (*Jermy, 327*). Comstock (*Thompson,* 1911). Without locality (*Buckley*).

Lower bracts mostly triangular, becoming friable.
  Lowest panicle division much shorter than the long-caudate subtending bract, with rather weak finally ascending branchlets.

N. affinis Trelease.

Leaves very narrow, 3–4 mm. wide, sometimes smooth-edged. Inflorescence at length with broad divisions 10 cm. long and lower branchlets scarcely half as long. Fruit depressed, 5 × 6–7 mm. Seed 3 mm. in diameter.

North-central Mexico. On the outskirts of the range of *N. erumpens, N. microcarpa* and *Dasylirion leiophyllum.*

Specimens examined: CHIHUAHUA. Rocky hills near Chihuahua (*Pringle, 1, 2,* 1885,—the type). Santa Eulalia (*Palmer, 139,* 1908; *Rose, 11672,* 1908).

N. caudata Trelease.

?*Nolina* sp. Rose, Contr. U. S. Nat. Herb. **20.** *pl. 46–8.*

Leaves very narrow, 4 mm. wide, somewhat rough-edged. Inflorescence slender, with narrow divisions scarcely 10 cm. long and lower branchlets 2–5 cm. long. Fruit rather depressed, 4 × 5–6 mm. Seed 3 mm. in diameter.—*Pl. 6.*

Southern Arizona. In the region of *N. microcarpa* and *Dasylirion Wheeleri.*

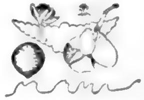
Specimens examined: ARIZONA. Mule Mountains (*Toumey,* 1894,—the type). Huachuca Mountains (?*Wilcox,* 1892, and *257,* 1894; *Griffiths, 4831,* 1903). Dragoon Summit (?*Vasey,* 1881,—leaves). Nogales (?*Brandegee,* 1892; *Ferriss,* 1902; *Coville, 1624,* 1903; *Thompson,* 1911). Sierra del Pajarito (?*Trelease, 387,* 1900). BOUNDARY LINE (?*Parry, Bigelow, Wright & Schott, 1443; Mearns, 258, 290,* 1892).

Lower panicle divisions more or less equaling the attenuate subtending bracts, with rather stiff spreading branchlets.

N. ERUMPENS Watson, Proc. Amer. Acad. **14**: 248. 1879.

Dasylirion erumpens Torrey, Bot. Mex. Bound. 216. 1859.

Beaucarnea erumpens Baker, Journ. Bot. **10**: 326. 1872.



Leaves usually 6–10 mm. wide and very rough-edged, exceptionally narrower or smooth-edged. Inflorescence with pyramidal divisions 15 cm. long and lower branchlets half as long. Fruit rather depressed, 5 × 5–7 mm. Seed very large, 4 mm. in diameter.

Western Texas and adjacent Mexico. In the region of *Dasylirion leiophyllum* and *D. Wheeleri Wislizeni.*

Specimens examined: TEXAS. Western Texas (*Wright, 1918,* 1851–2,—the type of *D. erumpens; 692,* 1849). Chisos Mountains (*Bailey, 391,* 1901). Eagle Mountain (*Bigelow,* 1852). Eagle Spring (*Hayes,* 1858). Podrero (?*Schott,* 1855). CHIHUAHUA. Between El Paso and Chihuahua (*Wislizenus, 219,* 1846).

N. erumpens compacta Trelease.

Leaves almost as in *texana,* sometimes scarcely 5 mm. wide, the edge either rough or smooth. Inflorescence with very compact ovoid divisions scarcely 6 cm. long and branchlets about 1 cm. long.

Extreme western Texas.

Specimens examined: TEXAS. El Paso (*Ferriss,* 1902,—the type). Sierra Blanca (*Trelease, 386,* 1900). Sanderson (?*Thompson,* 1911). Marathon (*Lloyd,* 1910). Presidio (*Havard,* 1880).

N. GREENEI Watson in herb. Greene, Bot. Gaz. **5**: 56. 1880.—Name only.

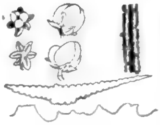
Leaves 6–7 mm. wide, smooth-edged. Inflorescence with rather narrow divisions scarcely 10 cm. long and lower branchlets nearly half as long. Fruit depressed, 4 × 6 mm. Seed 2 × 3 mm.

Southeastern Colorado to northeastern New Mexico. The northernmost species of the group.

Specimens examined: COLORADO. Between the Purgatory and Apishipa rivers, north of Trinidad (*Greene,* Jan., 1880,—the type). NEW MEXICO. San Miguel County (*Brandegee,* 1879). Lincoln County (*Wooton, 656,* 1897).

Lower panicle divisions considerably shorter than the subtending bracts, with short stiff spreading branchlets.

N. cespitifera Trelease.



Leaves 6–10 mm. wide, with dorsal as well as marginal roughening. Inflorescence very rough from compound tussocks, with narrow divisions 10 cm. long and lower branchlets scarcely one-third as long. Fruit nearly orbicular, about 5 mm. in diameter. Seed ?

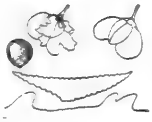
North-central Mexico. On the margin of the range of *Dasylirion cedrosanum.*

Specimens examined: COAHUILA. Battlefield of Buena Vista (*Wislizenus, 308,* 1847,—the type). High dry lands near Saltillo (*Gregg, 81,* 1847).

Inflorescence (as usual in the genus) essentially smooth. Lower bracts triangular, scarcely equaling the panicle divisions. Pedicels slender. Acaulescent with one exception.

N. PALMERI Watson, Proc. Amer. Acad. **14**: 248. 1879.

Beaucarnea Palmeri Baker, Journ. Linn. Soc., Bot. **18**: 235. 1880.



Leaves 8–10 mm. wide, serrulate-scabrous. Inflorescence with narrow divisions 15 cm. long and rather stiff ascending lower branchlets scarcely one fourth as long. Fruit depressed, 4 × 5 mm. Seed 3 mm. in diameter.

Lower California. Overlapping the region of *N. Bigelovii* and

N. Beldingi deserticola.—The type locality is given as Tantillas Mountains.

Specimens examined: LOWER CALIFORNIA. Piñon district (*Orcutt, 713,* 1882,—determined by Mr. Watson). San Pedro Martir (*Brandegee,* 1893). Paraiso (?*Brandegee,* 1890).

N. Palmeri Brandegeei Trelease.

Nolina sp. Brandegee, Proc. Cal. Acad. ii. **2**: 209. 1889.

?*N. Palmeri* Brandegee, Zoe. **1**: 306.

Arborescent. Trunk about 5 m. high, at length few-branched above. Leaves 7–8 cm. wide, rather glossy, denticulate-scabrous. Inflorescence with divisions 15 cm. long and lower branchlets about one-third as long.

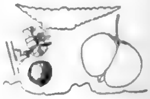
Lower California.

Specimens examined: LOWER CALIFORNIA. San Julio (*Brandegee,* Apr. 11, 1890,—the type). Northern Lower California (*Orcutt,* July 3, 1885).

Fruit moderate in size, somewhat inflated, the relatively small seed not protruding if early exposed. Panicle divisions with rather weak mostly elongated and ascending branchlets (pp. 420–422). MICROCARPÆ.
Lower panicle divisions more or less equaling the friable triangular bracts. Acaulescent. Leaves elongated.

N. MICROCARPA Watson, Proc. Amer. Acad. **14**: 247. 1879.

Beaucarnea microcarpa Baker, Journ. Linn. Soc., Bot. **18**: 236. 1880.



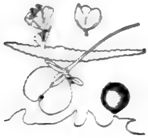
Leaves 6–12 mm. wide, raggedly denticulate-scabrous. Inflorescence with often broad divisions 15–30 to even 45 cm. long, and lower branchlets—sometimes again branched at base—half as long or less. Fruit nearly as long as the pedicels, depressed, 5 × 7–8 mm. Seed 3 mm. in diameter, attached and exposed after dehiscence of fruit.—*Pl. 1, 12.*

Southeastern Arizona and adjacent New Mexico and Mexico. Overlapping the region of *N. caudata* and associated with *Dasylirion Wheeleri.* The type locality is Rock Cañon, Arizona.

Specimens examined: ARIZONA. Rocky Cañon (*Rothrock, 278,* 1874). Chiricahua Mountains (*Toumey,* 1894; *Blumer, 1316,* 1906).

Santa Catalina Mountains (*Pringle*, 1881, 1882, 1884). Santa Rita Mountains (*Pringle*, 1882; *Brandegee*, 1891). Without locality (*Toumey, 447*, 1892). Sun Flower Valley (*Girard, 1*, 1873). Blue River (*Davidson, 775*, 1902). NEW MEXICO. Santa Rita del Cobre (*Greene*, 1880). Burro Mountains (*Rusby, 413*, 1881,—fruit; *Goldman, 1530*, 1908). Dog Mountains (*Mearns, 294*, 1892). Lone Mountain (*Mulford, 427, 429*, 1895). Otero County (*Rehn & Viereck*, 1902). Round Mountain (?*Wooton*, 1905,—very narrow-leaved, as in *texana*). Mogollon Mountains (*Rusby, 412*, 1881; *Metcalfe, 232*, 1903). Mimbres River (*Metcalfe, 1025*, 1904). San Luis Pass (*Mearns, 186*, 1892; *Wooton*, 1906). Twin Sisters (?*Blumer*, 1905). Silver City (?*Bailey*, 1906). Big Hatchet Mountains (*Goldman, 1341*, 1908). BOUNDARY LINE (*Parry, Bigelow, Wright & Schott, 1442*). CHIHUAHUA. Colonia Garcia (*Townsend & Barber, 76*, 1899). Vicinity of Chihuahua (?*Pringle, 159*, 1885; *Palmer, 355*, 1908).

N. durangensis Trelease.

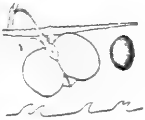


Leaves very thin, 7–11 or even 20 mm. wide, irregularly serrulate-scabrous. Inflorescence with broad divisions at length 15–20 cm. long and chiefly basal branchlets 10–12 cm. long. Fruit usually considerably shorter than the rather slender pedicels, more or less depressed, small, 5–6 × 6–7 mm. Seed 3 mm. in diameter.—*Pl. 10.*

Northwestern Mexico. In the region of *Dasylirion durangense* and *simplex*.

Specimens examined: DURANGO. Vicinity of Durango (*Palmer, 249*, 1896,—the type; *Ochoterena*, 1911; *Patoni*, 1911). Tepehuanes (*Palmer, 329*, 1906). CHIHUAHUA. Southwestern Chihuahua (?*Endlich, 1162a, 1162b*, 1906).

N. ELEGANS Rose, Contr. U. S. Nat. Herb. **10**: 91. *f. 6.* 1906.



Leaves very thin, 12 mm wide, sometimes lanceolately narrowed above the base, serrulate-scabrous. Inflorescence with broad divisions 10–15 cm. long and rather few branchlets scarcely half as long. Fruit about equaling the pedicels, rather large. 7 × 8–10 mm. Seed 3 × 4 mm.

Central Mexico. In the region of *N. Hartwegiana?*

Specimens examined: Zacatecas. Sierra Madre Mountains (*Rose, 2396,* 1897,—the type).

Lower panicle divisions considerably longer than the triangular bracts. Shortly caulescent. Leaves much shorter than the inflorescence.

N. rigida Trelease.

Anatis rigida Brongniart, Ann. Sc. Nat., Bot. ii. **14**: 320. 1840.

Leaves 4–5 mm., scarcely 10 cm. long, ciliate-scabrous. Inflorescence much surpassing the leaves, sessile, with broad divisions about 10 cm. long and rather few branchlets scarcely half as long. Fruit about equaling the slender pedicels, moderate, about 6 mm. in diameter. Seed 2 mm. in diameter.—*Pl. 17.*

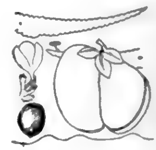
Mexico? Known only from the unpublished figures of Sese and Moçiño and Node-véran, which M. de Candolle has placed in my hands for study, and of which he has furnished for publication an excellent photographic copy.

Leaves relatively or actually thin, 15–40 mm. wide, serrulate-scabrous, not usually brush-like at tip. Inflorescence ample, often peduncled, compound-panicled or occasionally decompound. Bracts usually dilated and papery, often showy. Bractlets fimbriate-lacerate, conspicuous. Fruit large, inflated, the seed not protruded. Trees (with one exception?) (pp. 422–426). Arborescentes.

Leaves rather thick, little shredded at tip. Pedicels scarcely half as long as the fruit.

N. Parryi Watson, Proc. Amer. Acad. **14**: 247. 1879.

Trunk 1–2 m. high. Leaves almost pungent, rather thick, concave, keeled, 15–25 or even 35 mm. wide, serrulate-scabrous. Inflorescence with rather narrow divisions 15–30 cm. long and spreading densely flowered branchlets scarcely 4 cm. long. Flowers large, with perianth segments 4 mm. long. Fruit very large, orbicular, deeply notched at both ends, 12–15 mm. in diameter. Seed 3 × 4 mm.—*Pl. 5, 12.*



Colorado desert. In the region with *N. Bigelovii.*

Specimens examined: California. Desert east of San Bernardino (*Parry,* 1876,—the type). Whitewater (*Vasey,* 1881,—

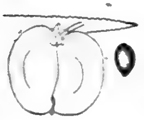
leaf). San Gorgonio Pass (*Engelmann*, 1880). San Bernardino Mountains (*Parish*, 1879: *910*, 1882; *3145*, *3165*, 1894). San Felipe (*Brandegee*, 1894). Pala (*Orcutt*). San Jacinto Mountains (*Hall*, *1819*, *2432*, 1901). ARIZONA. Fort Whipple (*Coues & Palmer*, 1865). Between Sandy and Bill Williams Forks (*Mrs. Stephens*, 1902).

N. BIGELOVII Watson, Proc. Amer. Acad. **14**: 247. 1879.

Dasylirion Bigelovii Torrey, Bot. Whipple. 151. 1857; Bot. Mex. Bound. 216. 1859.

Beaucarnea Bigelovii Baker, Journ. Bot. **10**: 326. 1872.

Trunk 1–2 m. high. Leaves almost pungent, scarcely concave or keeled, 15–25 mm. wide, often roughened on the surface, the at first rough margin shredding away in brown fibers. Inflorescence with rather narrow divisions 15–30 cm. long and branchlets scarcely 4 cm. long. Perianth segments about 3 mm. long. Fruit large, orbicular, deeply notched at both ends, usually 10–12 mm. but occasionally 15 mm. in diameter. Seed 3 × 4 mm.

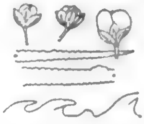


Western Arizona, across the Colorado desert, and into Lower California. In the region of *N. Parryi* and overlapping the ranges of *N. Palmeri* and *N. Beldingi*. A sketchy picture of it, in the Tinajas Altas, is given by Schott in Emory, Rept. Bound. Surv. **1**. *pl.* 59.

Specimens examined: ARIZONA. Bill Williams Fork (*Bigelow*, 1853–4,—the type of *D. Bigelovii*). Union Pass (*Palmer*, 1870). Havasupai Cañon (*Kinner*, 1900). Gold Road (*Mrs. Stephens*, 1902). Little Meadows (*Mrs. Stephens*, 1902). CALIFORNIA. Mountain Springs, near the boundary (*Parish*, 1880; *Vasey*, 1880; *Mearns*, *2980*, *3015*, *3066*, *3146*, 1894). LOWER CALIFORNIA. Cantillas Cañon (*Orcutt*, July 8, 1884). Yubay (*Brandegee*, 1889).—BOUNDARY LINE. Tule (*Mearns*, *320*, 1894).—SONORA. (?*Schott*, *1441*,—with fruit scarcely 8 mm. in diameter.)

Leaves rather thin, sometimes shredded at tip. Pedicels nearly or quite equaling the fruit.

N. Nelsoni Rose, Contr. U. S. Nat. Herb. **10**: 92. 1906.



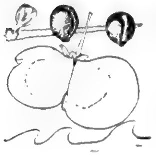
Trunk 1–3 m. high. Leaves 30–40 mm. wide, strongly serrulate-scabrous. Inflorescence with narrow ascending divisions 15 cm. long, and branchlets —chiefly upwards—scarcely half as long. Fruit?

Northeastern Mexico. In the region of *Dasylirion longissimum.*

Specimens examined: Tamaulipas. Mountains near Miquihuana (*Nelson, 4489,* 1898,—the type).

N. Beldingi Brandegee, Zoe. **1**: 305. 1890.

N. Beldingii Brandegee in Bailey, Cycl. Amer. Hort. **3**: 1092. 1901; Gard. Chron. iii. **34**: 43. *f. 18.* 1903.



Trunk 3–5 m. high, rather openly branched. Leaves very slightly glaucous, 15–20 mm. wide. Inflorescence long-peduncled, narrow, with narrow divisions 50 cm. long and branches 8–10 cm. long, often again branched with branchlets 1–2 cm. long. Fruit much depressed, retuse at base, very large, 8–10 × 15 mm. or more. Seed large, 4 × 5 mm.

Lower California. The type locality is mountain tops in the Cape Region.

Specimens examined: Lower California. Sierra de San Francisquito (*Brandegee, 583,* 1892). La Chuparosa (*Brandegee,* 1893, 1905).

N. Beldingi deserticola Trelease.

Subacaulescent with leaves scarcely 50 cm. long, otherwise resembling the type.

Lower California. In the desert association of *N. Palmeri* and *N. Bigelovii.*

Specimens examined: Lower California. Yubay (*Brandegee,* 1889,—the type).

N. parviflora Hemsley, Biol. Centr.-Amer. **3**: 372. 1884.

Cordyline parviflora HBK., Nov. Gen. Sp. **1**: 268. 1815; **7**. *pl. 674.* 1825.

Dracæna parviflora Willdenow in Schultes, Syst. **7**: 348. 1829.

Roulinia Humboldtiana Brongniart, Ann. Sci. Nat., Bot. ii. **14**: 320. 1840.

Dasylirium Humboldtii Kunth, Enum. **5**: 42. 1850.

Nolina Altamiranoa Rose, Proc. U. S. Nat. Mus. **29**: 438. 1905.

?*Beaucarnea recurvata stricta* Baker, Journ. Linn. Soc., Bot. **18**: 234. 1880.—As to localities cited.

Trunk 2–4 m. high. Leaves 15–20 or 25 mm. wide. Inflorescence with divisions 25 cm. long and lower branchlets half as long. Bracts very showy, nearly 50 cm. long, caudate-attenuate. Fruit very large, 8–10–12 × 14 mm. Seed 3 × 4 mm.

South-central Mexico. The type locality is between Hauhtitlan and Tanepantla.

Specimens examined: FEDERAL DISTRICT. Above Santa Fe (*Pringle, 8060,* 1899,—the type of *N. Altamiranoa; 13620,* 1905; *Rose & Hay, 5388,* 1901; *Rose & Painter, 8659,* 1905). Rio Hondo Cañon (*Pringle, 6787,* 1898). Chalchicomula (*J. G. Smith, 451,* 1892). Guadalupe (*Bourgeau, 520,* 1865–6). PUEBLA. Esperanza (*Purpus, 821,* 1907). VERA CRUZ. Limon (?*Trelease, 80,* 1905).

N. LONGIFOLIA Hemsley, Biol. Centr.-Amer. **3**: 373. 1884.

Yucca longifolia Schultes, Syst. **7**: 1715. 1830.—Zuccarini, Allgem. Gartenzeit. **6**: 258.

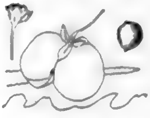
Dasylirion longifolium Zuccarini, Abhandl. Akad. München. Cl. II. **3** (=Denkschr, **16**): 224. *pl. 1. f. 2.* 1840; **4** (=Denkschr. **19**): 20, 21.—Morren, Belg. Hort. **1865**: 321. *pl. 20.*—Garden. **11**: 291. *f.*—Gard. Chron. n. s. **7**: 493. *f. 73,* 567. *f. 90.*—Fenzi, Bull. Soc. Ort. Tosc. **1890**: 112. *pl. 6.*—Rehnelt, Gartenwelt. **11**: 14. *f.*—Urban, Gart. Zeit. **3**: 66. *f. 20.*—Die Natur. **34**: 340. *f.*—Murison, Garden. **24**: 433. *f.*—Gartenflora. **29**: 117. *f.*; **33**: 68. *f.*—Roezl, Belg. Hort. **33**: 139.—Gérome, Rev. Hort. **83**: 206. *f. 82.*

Roulinia Karwinskiana Brongniart, Ann. Sc. Nat., Bot. ii. **14**: 320. 1840.

?*Yucca Barrancasecca* Pasquale, Cat. R. Ort. Bot. Napoli. 108. 1867.—See also Zuccarini, *l. c.,* and Rept. Mo. Bot. Gard. **13**: 114.

Beaucarnea longifolia Baker, Journ. Bot. **10**: 324. 1872.

Trunk 2–3 m. high, swollen at base, at length closely few-branched at top. Leaves 20–30 mm. wide, very long and recurving over the trunk; green. Inflorescence nearly sessile with divisions 30 cm. long and lower branchlets scarcely one-fifth as long. Fruit suborbicular or rather depressed, large, 8 × 10–12 mm. Seed 3 × 4 mm.—*Pl. 3, 8, 13.*



South-central Mexico. In the region of *Dasylirion serratifolium.* The type locality is given as San Jose del Oro by Schultes, on authority of Karwinski. Roezl gives its occurrence at about 3,000 m. altitude in Puebla, Oaxaca and Mexico.

Specimens examined: OAXACA. Huachilla (*Conzatti*). PUEBLA. Esperanza (*Purpus, 5077, A, ?5076, ?5078*). San Luis Tultitlanapa (*Purpus, 432,* 1907, *5079, B,* 1908). CULTIVATED. Munich Botanical Garden, from Karwinski's seed (*Radlkofer,* 1901,—semi-typical). Palermo Botanical Garden (*Trelease, 1,* 1905). Bushey House Gardens (*Blake,* 1909).

Certain questionable thin- but narrow-leaved forms grown in gardens under this name, or, in a glaucous form, as var. *glauca* or as *Pincenectitia glauca,* appear to be forms of *Beaucarnea.*

CALIBANUS.

Rose, Contr. U. S. Nat. Herb. **10**: 90. 1906.—Monotypic, based on the species figured by Hooker for *Dasylirium Hartwegianum.*

Calibanus Hookerii Trelease.

Dasylirium Hartwegianum Hooker, Bot. Mag. iii. **15**. *pl. 5099.* 1859.

D. Hookerii Lemaire, Ill. Hort. **6**. misc. p. 24. 1859.

D. caespitosum Scheidweiler, Wochenschr. Verein Beförd. Gartenbau. **4**: 286. 1861.

D. Hookeri Lemaire, Ill. Hort. **12**. misc. p. 52. 1865.

?*D. flexile* Koch, Ind. Sem. Berol. **1867.** Append. 1: 5.

Beaucarnea Hookeri Baker, Journ. Bot. **10**: 327. 1872.

Calibanus caespitosus Rose, Contr. U. S. Nat. Herb. **10**: 90. *f. 4. pl. 24–5.* 1906.

Shortly caulescent. Trunk depressed globose with numerous crowns of leaves. Leaves rather thin, somewhat concave and keeled, narrowly linear, 2–3 mm. wide, serrulate-scabrous on the margin, not brush-like at tip, blue. Inflorescence scarcely 25 cm. long, shorter than the leaves, very short-peduncled, simply panicled with thin spreading branches 6–8 cm. long, or with exceptional very short and few basal branchlets. Bracts scarious, much shorter than the subtended branches, the floriferous ones and the bractlets inconspicuous, ovate or lanceolate, little-toothed. Flowers minute. Perianth segments about 1 mm. long. Fruit triquetrously subglobose, 3-ribbed, 4–5 × 5–7 mm. Seed melon-shaped, 3 × 3–4 mm.—*Pl. 6, 8, 9, 11, 14.*

East-central Mexico. The type locality is Real del Monte.

Specimens examined: HIDALGO. Ixmiquilpan (*Rose, Painter & Rose, 8954,* 1905; *Purpus, 1200, 4775,* 1905). SAN LUIS POTOSI. San Luis Potosi (*Orcutt,* 1903; *Palmer,* 1905).

BEAUCARNEA.

Lemaire, Ill. Hort. **8.** misc. p. 57, with plate. 1861.—Baker, Journ. Bot. **10**: 323. 1872; Journ. Linn. Soc., Bot. **18**: 233. 1880, —in both cases including *Nolina.*—Rose, Contr. U. S. Nat. Herb. **10**: 87. 1906.—Though not monotypic, based primarily on *B. recurvata,* and capable of precise definition.

Leaves with essentially smooth grooves and nearly smooth margins, thin, nearly flat, recurved, green. Floriferous bracts rather elongated. Fruit large, rather long-stalked before falling. Slender trees, about 10 m. high, moderately enlarged at base. EUBEAUCARNEA.

BEAUCARNEA RECURVATA Lemaire, Ill. Hort. **8.** misc. p. 61. *1 pl.* 1861.—Gard. Chron. **1870**: 1445. *f. 254;* iii. **46**: 4. *f. 3.*—Deutsch. Gart. Mag. **1871**: 288. *pl.*—Gartenflora. **28**: 210. *f.*—Croucher, Garden. **19**: 372. *f.*

Pincenectitia tuberculata Lemaire, *l. c.,* as synonym.

Beaucarnea tuberculata Roezl, Belg. Hort. **33**: 138. 1883.

Nolina recurvata Hemsley, Biol. Centr.-Amer. **3**: 372. 1884.—Rehnelt, Gartenwelt. **11**: 78. *f.*—Gard. & Forest. **9**: 94. *f.*—Fl. des Serres. **18.** misc. p. 26. *f.*—Karsten & Schenck, Vegetationsbilder. **1.** *pl. 34.*—Gérome, Rev. Hort. **83**: 207. *f. 83.*

N. tuberculata Hort.

Trunk openly slender-branched above. Leaves 15–20 mm. wide, 1.5–2 m. long. Inflorescence nearly sessile, broadly ovoid-panicled, decompound with divisions 30 cm. long, lower branches nearly half as long and branchlets 5 cm. long. Perianth segments 3 mm. long. Fruit?

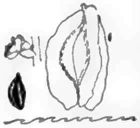
Southeastern Mexico. Noted by Roezl at Paso del Macho and by Karsten at Sta. Maria, in the State of Vera Cruz.—The type of the genus.—Two garden varieties, *intermedia* and *rubra,* are noted by Baker, Journn. Linn. Soc., Bot. **18**: 234. 1880.

Specimens examined: Cultivated. Palermo Botanical Garden (*Trelease,* 1905). Missouri Botanical Garden.

B. inermis Rose, Contr. U. S. Nat. Herb. **10**: 88. *f. 2.* 1906.

Dasylirion inerme Watson, Proc. Amer. Acad. **26**: 157. 1891.

Trunk rather closely few-branched at top. Leaves 12–15 mm. wide, about 1 m. long. Inflorescence long-stalked, narrowly pyramidal-panicled, somewhat decompound with divisions 30 cm. long, slender lower branches half as long and few branchlets 3–4 cm. long. Perianth segments scarcely 2 mm. long. Fruit elongated-elliptical, 10 × 14 mm. Seed (immature) 2 × 3 mm.



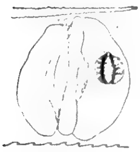
East-central Mexico.

Specimens examined: San Luis Potosi. Las Palmas (*Pringle, 3108,* 1890,—the type of *Dasylirion inerme*). San Dieguito (*Palmer, 644,* 1905). Vera Cruz. Zacuapam (*?Purpus, 4432,* 1907). East of Huatusco (*?Endlich, 1162,* 1906). Carrizal (*?Goldman, 708,* 1901).—The incomplete Vera Cruz material perhaps belongs to the preceding, though short-leaved.

B. pliabilis Rose, Contr. U. S. Nat. Herb. **10**: 89. 1906.

Dasylirion pliabile Baker, Journ. Linn. Soc., Bot. **18**: 240. 1880.

Trunk openly slender-branched at top. Leaves 15 mm. wide, less than 1 m. long. Inflorescence compound-panicled with broad divisions 30 cm. long and few rather short spreading branches. Perianth segments 3 mm. long. Fruit somewhat obovately round-elliptical. 11–12 × 13–15 mm. Seed 3 × 4 mm., irregularly 3-lobed, transversely wrinkled.—*Pl. 10.*



Southeastern Mexico.

Specimens examined: Yucatan. Near Sisal (*Schott. 892,*—the type of *Dasylirion pliabile*). Progreso (*Goldman, 607,* 1901).

B. guatemalensis Rose, Contr. U. S. Nat. Herb. **10**: 88. *f. 1.* 1906.

Trunk often with slender multiple stems, variously branched. Leaves 25–30 mm. wide, less than 1 m. long, smooth-edged. Inflorescence short-stalked, broadly ovoid-panicled, decompound with divisions 30 cm. long, rather spreading branches sometimes half as long, and few branchlets 6 cm. long. Perianth segments 3 mm. long. Fruit elliptical-obovate, 13–15 × 15–18 mm., at length openly notched at top and base. Seed 5 mm. in diameter, irregularly 3-lobed, smooth.—*Pl. 7.*

Guatemala. The southernmost species of the group.

Specimens examined: Guatemala. El Rancho (*Kellerman, 4320,* 1905,—the type; *5398,* 1906; *7015,* 1907, and *7029,* 1908). Cultivated. Guatemala City (*Kellerman, 6069,* 1907).

B. Goldmanii Rose, Contr. U. S. Nat. Herb. **12**: 261. *pl. 20.* 1909.

Trunk openly slender-branched above. Leaves 15 mm. wide, scarcely 1 m. long, essentially smooth-edged. Inflorescence nearly sessile, compound-panicled with narrow ascending divisions 15–20 cm. long and few strict branches about half as long. Perianth segments about 2 mm. long. Fruit elliptical, very large, 12–15 × 18–20 mm. Seed?

Southern Mexico.

Specimens examined: Chiapas. San Vicente (*Goldman, 887,* 1904,—the type).

Leaves papillate-grooved as in *Nolina,* rather rough-margined, firm, more or less concave, keeled or plicate, nearly straight, pale or glaucous. Floriferous bracts short. Fruit small for the genus, very short-stalked. Trees about 10 m. high, greatly swollen at base. Papillatæ.

B. stricta Lemaire, Ill. Hort. **8.** misc. p. 61. 1861.

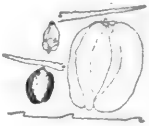
Pincenectitia glauca Lemaire, *l. c.,* as synonym.

Beaucarnea recurvata stricta Baker, Journ. Linn. Soc., Bot. **18**: 234. 1880.

B. glauca Roezl, Belg. Hort. **33**: 138. 1883.

B. Purpusi Rose, Contr. U. S. Nat. Herb. **10**: 89. 1906.—Purpus, Möller's Deutsch. Gärtn.-Zeit. **23**: 223. *f.*

Trunk moderately swollen, irregularly rather few-branched. Leaves more or less keeled or plicate, 8–15 mm. wide, scarcely 1 m. long, the yellowish margin usually minutely serrulate-scabrous. Inflorescence short-stalked, ovoid-panicled, decompound with narrow divisions 20 cm. long and short branches, the lower with branchlets 3 cm. long. Perianth segments 2 mm. long. Fruit broadly elliptical, 8–10 × 12 mm. Seed 3 × 4–5 mm. irregularly 3-lobed, smooth.—*Pl. 8, 14.*



South-central Mexico. Associated with the next and *Dasylirion lucidum.*

Specimens examined: Puebla. Tehuacan (*Rose, Painter & Rose, 10156,* 1905,—the type of *B. Purpusi; Rose & Rose, 11220,* 1906; *Purpus, 2397,* 1907). San Luis Tultitlanapa (*Purpus, 5080,* 1908). Oaxaca. Tomellin Cañon (*Rose & Rose, 11427a* and *b,* 1906). Almoloyas to Sta. Catarina (*?Conzatti, 1644,* 1906).

B. gracilis Lemaire, Ill. Hort. **8**. misc. p. 61. 1861.

B. œdipus Rose, Contr. U. S. Nat. Herb. **10**: 88. *pl. 23.* 1906.—MacDougal, Publ. Carnegie Inst. 99. *pl. 19.*

?*Nolina histrix* Hort.

Trunk enormously swollen below, variously and irregularly branched. Leaves very glaucous, 4–7 mm. wide, scarcely 50 cm. long, minutely but sharply serrulate-scabrous on the paler margin. Inflorescence short-stalked, ovoid- or oblong-panicled, decompound with divisions scarcely 30 cm. long and weak branches half as long, the lower often similarly branched. Perianth segments scarcely 2 mm. long. Fruit round-elliptical, 7–9 × 10 mm. Seed 2 × 3 mm., smooth.—*Pl. 4, 11.*

South-central Mexico. Associated with the preceding.

Specimens examined: Puebla. Tehuacan (*Rose, Painter &*

Rose, 10157, 1905,—the type of *B. œdipus; Trelease, 1,* 1903; *Purpus, 1253a* in part, 1905, and *2503,* 1907). CULTIVATED. New York Botanical Garden (*Taylor, 25734,* 1906).

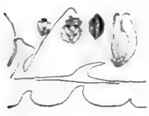
DASYLIRION.

Zuccarini, Allgem. Gartenzeit. **6**: 258, 303. 1838.—Plant. Nov. vel Minus Cognit. 4: 221. *pl. 1* (Abhandl. Akad. München. Cl. II. **3**. = Denkschr. **16**). 1840;—Plant. Nov. etc. 5: 19. (Abhandl. Akad. München. Cl. II. **4**. = Denkschr. **19**). 1845.—Kunth, Enum. Plant. **5**: 38. 1850,—as *Dasylirium.*—Baker, Journ. Bot. **10**: 296. 1872; Journ. Linn. Soc., Bot. **18**: 237. 1880.—Rose, Contr. U. S. Nat. Herb. **10**: 89. 1906.—Though primarily based on *Yucca pitcairniæfolia* (*Hechtia glomerata*) and made to include with question *Yucca* [*Nolina*] *longifolia,* it finally stood with its author for the prickly-leaved sotols, of which *D. serratifolium* and *D. graminifolium* were definitely included in his first publication on the genus and mark its type.

Leaves 2-edged, usually somewhat concave and irregularly keeled, prickly-margined and usually roughened with minute intervening denticles or serratures (pp. 431–440). EUDASYLIRION.
  Fruit small (3–5 mm. wide).
    Fruit normally with moderately deep notch, narrowly elliptical to obovate, the style not surpassing the wings. Perianth segments about 2 mm. long. Leaves elongated, rather wide (usually 15–20 mm.).
      Prickles prevailingly upcurved.

Dasylirion cedrosanum Trelease.

Dasylirion sp. Kirkwood, Pop. Sci. Monthly. **75**: 438, 445. *f.*



Shortly caulescent. Trunk 1–1.5 m. high. Leaves 20 mm. wide, upwards of 1 m. long, slightly brush-tipped, glaucous, slightly rough-keeled, dull; prickles mostly 10–15 mm. apart, 2–5 mm. long, yellow, becoming red upwards. Inflorescence 5 m. high. Fruit very narrowly elliptical, 4–5 × 7–9 mm., the style barely half as long as the narrow deep notch. Seed 2 × 3.5 mm. *Pl. 5, 12, 15.*

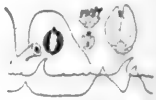
Northeastern Mexico. Overlapping the range of *Nolina cespitifera.*

Specimens examined: ZACATECAS. Cedros (*Lloyd, 118*,—the type, and *82*, 1908; *Kirkwood, 96*, 1908). COAHUILA. Rancho La Luz (?*Endlich, 7*, 1905). Saltillo (?*Gregg, 78*, 1846). Angostura (?*Wislizenus, 307*, 1847).

D. LUCIDUM Rose, Contr. U. S. Nat. Herb. **10**: 90. 1906.

Dasylirion sp. Schenck & Karsten, Vegetationsbilder. **1**. *pl. 46*.

Shortly caulescent. Trunk 1–2 m. high or sometimes prostrately elongated. Leaves 10–17 mm. wide, scarcely 1 m. long, strongly brush-tipped, typically yellowish, smooth and glossy: prickles mostly 10–15 mm. apart, 2–3 mm. long, from yellow passing through red to almost chestnut, the margin often reddish. Inflorescence 2–3 m. high. Fruit narrowly elliptical-obovate, 4–5 × 7–8 mm., the rather slender style about half as long as the rather narrow deep notch. Seed 2.5–3.5 mm.—*Pl. 2, 10, 12.*



South-central Mexico. With *Beaucarnea gracilis* and *stricta*.

Specimens examined: PUEBLA. Tehuacan (*Rose, Painter & Rose, 10009*, 1905,—the type; *Trelease*, 1903, 1905; *Purpus, 3947*, 1909). Esperanza (??*Purpus*, 1907). San Luis Tultitlanapa (?*Purpus, 5082*, 1908).

D. Palmeri Trelease.

Habit? Leaves 25 mm. or more wide, scarcely 1 m. long, somewhat brush-tipped, green or lightly glaucous, smooth, dull: prickles mostly 15–25 mm. apart, 3–5 mm. long, yellow, becoming brown upwards, the intervening margin rather smooth. Inflorescence moderately high. Fruit narrowly elliptical- or triangular-obovate, 3–4 × 6 mm., the stout style about equaling the rather open shallow notch. Seed 2 × 3 mm.—*Pl. 12.*

Northeastern Mexico.

Specimens examined: COAHUILA. San Lorenzo Cañon (*Palmer, 696*, 1905,—the type).

D. Parryanum Trelease.

Habit? Leaves becoming 10–15 mm. wide, scarcely 50 cm. long,

brush-tipped, whitened, minutely roughened and dull: prickles about 5 mm. apart, 2 mm. long, yellow, becoming red upwards, the margin very rough between them. Inflorescence moderate, exceptionally sub-simple. Perianth segments scarcely 2 mm. long. Fruit elliptical or somewhat obovate, 4 × 6 mm., the style scarcely equaling the narrow moderately deep notch. Seed?

East-central Mexico. In the region of *D. graminifolium* and *Nolina humilis* and *Watsoni.*

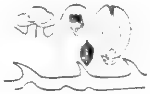
Specimens examined: SAN LUIS POTOSI. Vicinity of San Luis Potosi (*Parry & Palmer, 876,* 1878,—the type; *Schaffner, 242,* 1878,—mixed with *D. graminifolium?*).

Prickles prevailingly recurved.

D. leiophyllum Engelmann in herb.

Dasylirion sp. Trelease, Pop. Sci. Monthly. **70**: *220. f. 14.*

Shortly caulescent. Leaves becoming 15–20 mm. wide, scarcely 1 m. long, somewhat brush-tipped, green or at first somewhat glaucous, smooth, rather glossy: prickles usually 10–15 mm. apart, 3–4 mm. long, yellow, usually becoming orange or red at least above the middle, the margin sometimes smooth between them. Inflorescence rather high. Perianth segments scarcely 2 mm. long. Fruit obovately subelliptical, 4–5 × 6–8 mm., the thick style about equaling the moderately open and deep notch or exserted if the wings have not fully developed. Seed 2 × 3 mm.—*Pl. 12.*



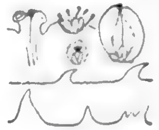
Southern Texas, in the Rio Grande region, passing into New Mexico and reaching or reappearing in central Chihuahua.—Adjoining or overlapping the range of *D. Wheeleri Wislizeni* and *Nolina erumpens* and *affinis.*

Specimens examined: TEXAS. Presidio (*Havard,* 1880,—the type). Eagle Pass (*?Havard,* 1883). Sierra Blanca (*Trelease,* 1892, *388,* 1900; *Mulford, 275,* 1895; *Rose, Standley & Russell, 12222,* 1910). Van Horn (*Eggert,* 1900). NEW MEXICO. Central (*Mulford, 424,* 1895). Florida Mountains (*Mulford, 1037,* 1895). CHIHUAHUA. Sta. Eulalia Mts. (*Pringle, 149,* 1885; *Williamson,* 1885).

Fruit with very shallow notch, broadly elliptical, the style rather surpassing the wings. Prickles prevailingly upcurved.

D. TEXANUM Scheele, Linnæa. **23**: 140. 1850.—Bray, Bull. Univ. Tex. 82. *pl. 13;* Bot. Gaz. **32**: 288. *f.*

Shortly caulescent or with buried trunk. Leaves 10–15 mm. wide, scarcely 1 m. long, somewhat brush-tipped, green, smooth or rough-keeled, glossy: prickles 5–10 mm. apart, 2–3 mm. long, yellow, becoming brownish. Inflorescence 3–5 m. high. Fruit elliptical, 4–6 × 7–8 mm., the very short style equaling or surpassing the open shallow notch. Seed ?—*Pl. 12, 15.*



South-central Texas. In the range of *Nolina texana* and *Lindheimeriana.*

Specimens examined: TEXAS. Vicinity of New Braunfels (*Lindheimer, 548,* 1845,—apparently the type, *549,* 1846, *1211–1213,* 1849). Blanco Cañon (*Reverchon, 1605,* 1885). Putnam (*Trelease,* 1892). Gillespie County (*Jermy*). Kerr County (*Heller, 1929,* 1894; *Bray, 228,* 1899). Hueco Tanks (*Mulford, 90,* 1895). Sanderson (*Weinberg,* 1907; *Thompson,* 1911). Marathon (*Lloyd,* 1910). Comstock (*Thompson,* 1911). Ft. Davis (*Blake*).

D. texanum aberrans Trelease.

Differing from the type in its dull somewhat glaucous leaves, 15 mm. wide.

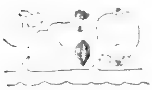
Northern Mexico.

Specimens examined: "States of Coahuila and Nuevo Leon" (*Palmer, 1315,* 1880,—the type).

Fruit rather small (5–6 mm. wide), subcordate, the style not surpassing the wings.

D. simplex Trelease.

Acaulescent. Leaves 7–10 mm. wide, scarcely 1 m. long, rather sparsely very long-fibrous at tip, green, smooth, glossy: prickles 10–15 or 20 mm. apart, 2–3 mm. long, rather straight, prevailingly upcurved, yellow, the upper half becoming brown or finally almost black, the margin nearly smooth between them. Inflorescence (typically?) small, the staminate with one to three small branches to each division



and the pistillate simple or its divisions with a short basal branch. Fruit broadly obovate, 5–6 × 7 mm., the thick style about equaling the open moderate notch. Seed (immature) 2 × 3 mm.—*Pl. 12.*

North-central Mexico. In the region of *Nolina durangensis.*

Specimens examined: DURANGO. Tepehuanes (*Palmer, 310,* 1906,—the type). Santiago Papasquiaro (*Palmer, 422,* 1896).

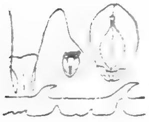
Fruit moderately large (usually 6–8 mm. wide), the style not surpassing the wings. Prickles prevailingly upcurved.
Leaves not brush-tipped, glaucous.

D. GLAUCOPHYLLUM Hooker, Bot. Mag. iii. **14**. *pl. 5041.* 1858.—[As *Dasylirium*].—Baker, Journ. Bot. **10**: 298. 1872.—?Gard. Chron. iii. **40**: 247. *f. 101.*

D. glaucum Carrière, Revue Hort. **44**: 435. *f.* 1872.—Copied in Garden. **3**: 23. *f.*, and Florist and Pomol. **1874**: 17. *f.*—Gard. Chron. n. s. **13**: 82, 205. *f. 37.*—??Roezl, Belg. Hort. **33**: 139.

?*D. serratifolium* Rept. Mo. Bot. Gard. **14**: 12. *f.*

Bonapartea glauca Hort.



Shortly caulescent. Trunk scarcely 5 m. high. Leaves as much as 12 mm. wide, over 1 m. long, glaucous, nearly or quite smooth, dull: prickles 5–10 mm. apart, 2 mm. long, yellowish white or the tips becoming slightly brownish. Inflorescence 4–6 m. high. Fruit subelliptical, 6 × 9–10 mm., the thick style about half as long as the closed deep notch. Seed 2.5 × 4 mm.—*Pl. 12.*

East-central Mexico. In the region of *D. acrotriche* and *Calibanus.*—The type locality is Real del Monte.

Known to me only in cultivation. The fruit description is based on material cultivated at La Mortola (*Berger, 560,* 1911).

Leaves more or less brush-tipped.
Leaves narrow (scarcely 10 mm.), strongly brush-tipped.

D. ACROTRICHE Zuccarini, Abhandl. Akad. München. Cl. II. **3** (= Denkschr. **16**): 226, 228. *pl. 1. f. iv.* 1840.

Yucca acrotricha Schiede, Linnæa. **4**: 230. 1829; **6**: 52.—Schultes, Syst. **7**: 1716. 1830.

Roulinia gracilis Brongniart, Ann. Sc. Nat., Bot. ii. **14**: 320. 1840.

Barbacenia gracilis Brongniart, *l. c.*—As synonym.

Yucca gracilis Otto, Allgem. Gartenzeit. **9**: 123. 1841.—As synonym.

Bonapartea gracilis Otto, *l. c.*—As synonym.

Dasylirion gracile Zuccarini, Abhandl. Akad. München. Cl. II. **4** (= Denkschr. **19**) : 22. 1845.

Dasylirium acrotrichum Kunth, Enum. Pl. **5**: 40. 1850.—Hooker, Bot. Mag. iii. **14**. *pl. 5030.*—Copied in Fl. des Serres. **14**. *pl. 1448.*—Schlotthauber, Deutsch. Mag. f. Gart.-u. Blumenkunde. **1871**: 49, 64, 81, 96. *2 pl.*—Koopmann, Gartenwelt. **3**: 375–6. *f.*

Dasylirium gracile Planchon, Fl. des Serres. **7**: 6, 10. *f.* 1851–2.

Littæa gracilis Verschaffelt, Cat. **1864**.—Hansgirg, Phyllobiologie. 422.

Dasylirion acrotrichum Baker, Journ. Bot. **10**: 297. 1872.—Regel, Gartenflora. **30**: 24. *f.*—Gard. Chron. iii. **19**: 204. *pl.*—Deutsch. Gärtner-Zeit. **20**: 536. *f.*

?*D. robustum* Hort.—(Perhaps = *serratifolium.*)

Caulescent. Trunk at length 1 m. or more high. Leaves 6–10 or rarely 15 mm. wide, less than 1 m. long, green and glossy or somewhat glaucous and dull, often rough on the keels: prickles 5–10 or 15 mm. apart, scarcely 2 mm. long, rather straight, pale yellowish, with slightly brown tips. Inflorescence 3–5 m. or more high. Perianth segments 2–3 mm. long. Fruit round-cordate, 6–7 × 8–9 mm., the thick style about equaling the shallow notch. Seed 3 × 3.5 mm.—*Pl. 11, 12.*

East-central Mexico. Collected by Schiede and Deppe on the Serro de la Ventana, on the flanks of Mt. Orizaba, by Karwinski at Ixmiquilpan, and by Reppert at Real del Monte. Deppe's original seed collection, in 1825 (Otto, Allgem. Gartenzeit, **16**: 276. 1848) was made between Real del Monte and Pachuca, and most of the earlier plants of European gardens were raised from this at Berlin (Bouché, Monatsschr. Verein Beförd. Gartenbau. **1880**: 481).—Range of the preceding.

Specimens examined: HIDALGO. Dublan (*Pringle, 11196,* 1902;

Rose & Hay, 5305, 1901). Metepec (*Pringle, 10001,* 1904). *Tula* (*Pringle, 6637,* 1897; *Rose, Painter & Rose, 8280,* 1905). Ixmiquilpan (*Rose, Painter & Rose, 8969, 9029,* 1905). Sierra de Pachuca (*Rose, Painter & Rose, 5571,* 1901; *8801,* 1905; *Rose & Rose, 11484,* 1906). QUERETARO. Cadereyta (*Rose, Painter & Rose, 9714,* 1905). SAN LUIS POTOSI. San Luis Potosi (*Parry & Palmer, 876,* 1878).

Leaves wide (rarely under 15 mm.), only moderately brush tipped.
  Fruit elliptical or obovate.
    Prickles small.

D. GRAMINIFOLIUM Zuccarini, Allgem. Gartenzeit. **6**: 259, 303. 1833; Abhandl. Akad. München. Cl. II. 3 (= Denkschr. **16**): 225. *pl. 1, f. 1.* 1840.—Kunth, Allgem. Gartenzeit. **9**: 121. *pl. 1.*

Yucca graminifolia Zuccarini, Cat. Hort. Monac. **1837**.

Dasylirium graminifolium Kunth, Enum. Pl. **5**: 39. 1850.

Subcaulescent? Leaves 12 mm. wide, about 1 m. long, green, smooth, glossy: prickles mostly 5–10 mm. apart, 1 mm. long, yellowish white or with slightly darkened tips. Inflorescence moderately high. Fruit broadly elliptical, 6 × 8–9 mm., the thick style equaling the rather open shallow notch. Seed ?—*Pl. 12.*

East-central Mexico. The type is said by Otto to have been raised from seed sent with that of *D. acrotriche* by Deppe in 1827.—As the earliest well-characterized and figured species, this may perhaps be accepted as the type of the genus, though it follows *D. serratifolium* in position.—In the region of *D. Parryanum, Calibanus* and *Nolina humilis* and *Watsoni.*

Specimens examined: SAN LUIS POTOSI. Vicinity of San Luis Potosi (*Parry & Palmer, 876,* 1878; *?Schaffner, 242,* 1878,—mixed with *D. Parryanum*). Las Canoas (*Pringle, 3746,* 1891).

Leaves of *D. hybridum* of the Botanical Garden of Rome do not differ from this except in being 15–20 mm. wide, nearly dull and scarcely brush-tipped. It is said to be a hybrid between *D.* [*Nolina*] *longifolium* and *D. serratifolium,* but in foliage shows no characters of the former, and it is unlike the latter as I understand it.

Prickles moderate.

D. durangense Trelease.

Habit? Leaves 20 mm. wide, scarcely 1 m. long, lightly glaucous, nearly smooth, dull: prickles 5–10 mm. apart, 2–3 mm. long, yellow, with orange tips. Inflorescence tall. Fruit broadly elliptical-cordate, 7–8 × 9 mm., the thick style scarcely half as long as the rather open deep notch. Seed 2 × 3 mm.—*Pl. 11, 12.*

North-central Mexico. In the region of *Nolina durangensis.*

Specimens examined: DURANGO. Durango (*Palmer, 557,* 1896,—the type).

D. SERRATIFOLIUM Zuccarini, Allgem. Gartenzeit. **6**: 258, 303,—name only. 1838; Abhandl. Akad. München. Cl. II. **3** (= Denkschr. **16**): 225, 228. *pl. 1. f. iii.* 1840.—Roezl, Belg. Hort. **33**: 139.

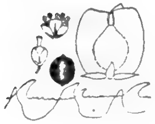
Yucca serratifolia Schultes, Syst. **7**. 1716. 1830.

Roulinia serratifolia Brongniart, Ann. Sc. Nat., Bot. ii. **14**: 319. 1840.

Dasylirium serratifolium Kunth, Enum. Pl. **5**: 41. 1850.

Dasylirion laxiflorum Baker, Journ. Bot. **10**: 299. 1872.

?*D. robustum* Hort.



Subacaulescent. Leaves 15–20 or even 35 mm. wide, scarcely 1 m. long, whitish, finely roughened on one or both faces, dull: prickles 5–10 or even 20 mm. apart, 2–3 mm. long. Inflorescence ample. Fruit quadrately round-obovate, the style equaling the narrow rather deep notch. Seed 3 × 4 mm.

Southeastern Mexico. Collected by Andrieux near Oaxaca, and by Karwinsky at San Jose del Oro.—Region of *Nolina longifolia.*

Specimens examined: OAXACA. Las Sedas (*Pringle, 6697,* 1897). Nochistlan (*Conzatti & Gonzales,* 1899).

D. WHEELERI Watson in Rothrock, Rept. Wheeler. **6**: 378. 1878; Proc. Amer. Acad. **14**: 249. 1879.—Wooton, Bull. N. Mex. Exper. Sta. 18: 92. *pl.*—Lloyd, Plant World. **10**: 254. *f. 51.*—MacDougal, Publ. Carnegie Inst. 99: 74, *pl. 58.*—De Wildeman, Icones Sel. Hort. Thenensis. **6**: 91. *pl. 225.*—Sketchy habit figures, without name, are given by Schott in Emory, Rept. Bound. Surv. **1**. *pl. 37, 42.*

Shortly caulescent. Trunk scarcely 1 m. high. Leaves 15–20 or 25 mm. wide, scarcely 1 m. long, glaucous, nearly smooth, dull: prickles 5–10 mm. apart, 2–3 mm. long, yellow, becoming brown upwards. Inflorescence 3–5 m. high. Fruit round-obovate, 6–7 × 7–9 mm., the style normally about equaling the open moderately deep notch. Seed (immature) 3 mm. long.—*Pl. 7, 8, 11, 12.*

Southeastern Arizona and adjoining Mexico, New Mexico and Texas. Region of *Nolina microcarpa* and *caudata.*

Specimens examined: ARIZONA. Ash Creek, etc. (*Rothrock, 329, 655,*—the types). Rio Grande to Gila Rivers (*Emory,* 1846). Sunflower Valley (*Girard,* 1873). Dragoon Summit (*Vasey,* 1881). Sta. Catalina Mountains (*Lemmon,* 1881; *Pringle,* 1881; *Toumey,* 1894). Without locality (*Pringle,* 1884). Sta. Rita Mountains (*Brandegee,* 1891). Ft. Huachuca (*Wilcox, 208, 264,* 1894). Chiricahua Mountains (*Toumey,* 1894). San Carlos (*Straub,* 1895). Nogales (*Coville, 1623,* 1903; *Thompson,* 1911). White Tail (*Pilsbry,* 1906). Benson (*Rose, Standley & Russell, 12326,* 1910). NEW MEXICO. Silver City (*Greene,* 1880; *Metcalfe, 637,* 1903). Burro Mountains (*Rusby, 413,* 1881,—leaves). Pinal Mountains (*Toumey, 449,* 1892). Las Cruces (*Wooton, 72,* 1897). Mangos (*Metcalfe,* 1897). Kingston (*Metcalfe, 1014,* 1904). Alamogordo (*Rehn & Viereck,* 1902). Organ Mountains (*Standley,* 1906). TEXAS. El Paso (*Evans,* 1891). Tortugas Mountains (*Rose, Standley & Russell, 12254,* 1910). BOUNDARY LINE (*Parry et al.*). CHIHUAHUA. Lake Sta. Maria (*Nelson, 6393,* 1899).

Fruit triangular-obcordate: prickles moderate.

D. Wheeleri Wislizeni Trelease.

Shortly caulescent. Leaves 15–20 mm. wide, scarcely 1 m. long, green or slightly glaucous, typically smooth and rather glossy: prickles 5–10 mm. apart, 2–3 mm. long, red-brown or with yellow base, the intervening denticles often reddish. Inflorescence ample. Fruit triangular-obcordate, 6–7 × 8–9 mm., the thick style about equaling the open moderately deep notch. Seed (immature) 3 mm. long.—*Pl. 12.*

North-central Mexico and adjacent Texas,—apparently grading into *D. Wheeleri*. Adjoining or overlapping the area of *D. Wheeleri* and *Nolina erumpens*.

Specimens examined: CHIHUAHUA. Paso del Norte [Juarez] (*Wislizenus, 218,* 1846,—the type; ?*Stearns,* 1910,—with smaller, slightly roughened dull leaves). Without locality (*Thurber,* 1852). TEXAS. El Paso (*Dewey,* 1891; *Wagner, 985,* 1892). Franklin Mountains (*Rose, Standley & Russell, 12280,* 1910).

Fruit large (8–9 mm. wide), the style surpassing the wings.

D. BERLANDIERI Watson, Proc. Amer. Acad. **14**: 249. 1879.

Habit? Leaves? Inflorescence apparently ample. Bractlets rather long, lanceolate, finely toothed. Perianth segments 2–4 mm. long. Fruit round-elliptical, 7–9 × 7–10 mm., the style rather exceeding the very open moderately deep notch. Seed ?—*Pl. 12.*

Northeastern Mexico.

Specimens examined: NUEVO LEON. La Silla, Monterey (*Berlandier, 3218,* June, 1843,—the type).

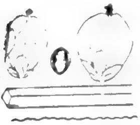
Leaves 4-sided, unarmed. QUADRANGULATÆ.

D. LONGISSIMUM Lemaire, Ill. Hort. **3**. misc. p. 91. 1856.

D. quadrangulatum Watson, Proc. Amer. Acad. **14**: 250. 1879.—*Gartenflora.* **36**: 280. *f. 75.*—Bull. Soc. Tosc. Ort. **9**: 236. *f.*; **35**: 331. *pl. 6.*—Die Natur. **34**: 340. *f.*—Hooker, Bot. Mag. iii. **56**. *pl. 7749.*

D. juncifolium Rehnelt, Gartenwelt. **11**: 77. *f.* 1906.

Caulescent. Trunk 1–2 m. high. Leaves narrowly linear, 3–8 mm. wide, at length 2 m. long, not brush-tipped, green, dull, rhombic or square in section, smooth, the edges minutely granular-roughened or further with very low elevations 10–30 mm. apart representing the prickles of other species. Inflorescence 2–6 m. high. Perianth segments 3–4 mm. long. Fruit broadly obovate or elliptical, 5–8 × 7–10 mm., the style surpassing the open very shallow notch. Seed 3 × 3–4 mm.—*Pl. 9, 12.*



Eastern Mexico. Of wide range, overlapping the regions of *Nolina Nelsoni, Calibanus* and *D. acrotriche.*

Specimens examined: TAMAULIPAS. Sierra Nolas, between San Luis Potosi and Tampico (*Palmer*, 1878–9.—the type of *D. quadrangulatum*). Miquihuana (*Nelson, 4480*, 1898). SAN LUIS POTOSI. Minas de San Rafael (*Purpus, 5009*, 1910,—a form with small fruit, 4 × 4 mm., with style and wings abbreviated and equal). HIDALGO. Sierra de la Mesa (*Rose, Painter & Rose, 9097*, 1905,—called "junquillo").

TEXT REFERENCES.

[1] Bouché, Sitzungsber. Ges. Naturf. Freunde, Berlin. **1875**: 118.—Monatsschr. Verein Beförd. Gartenbau. **23**: 482. 1880.

[2] Bray, Bull. Torr. Bot. Club. **30**: 627. *f. 6.* 1903.—Bull. Univ. Texas. 60: 22–24. 1905.

[3] Bruno, Boll. Soc. Natural. Napoli. **19**: 159. 1906.

[4] Christy, New Commercial Plants and Drugs. **6**: 42. 1882.

[5] Engler & Prantl, Natürl. Pflanzenfam. 2 Teil. 5 Abteil. p. 71. *f. 51.* 1887.

[6] Hansgirg, Sitzungsber. Böhm. Gesellsch. **1901**^{24}: 31.—Phyllobiologie. 421. 1903.

[7] Havard, Bull. Torr. Bot. Club. **23**: 43. 1896.—Amer. Journ. Pharm. **68**: 267. 1896.

[8] Hooker, Curtis's Bot. Mag. iii. **14**. *pl. 5041.* 1858.

[9] Kirkwood, Pop. Sci. Monthly. **75**: 446. 1909.

[10] Klebs, Unters. Bot. Inst. Tübingen. **1**: 568. *f. 13.* 1885.

[11] Lemaire, Ill. Hort. **8**. misc. p. 61. 1861.—See also Gard. & For. **9**: 94. 1896.

[12] Lloyd, Plant World. **10**: 254–5. *f. 51.* 1907.

[13] McClendon, Amer. Nat. **42**: 308. *ff.* 1908.

[14] Newberry, Bull. Torr. Bot. Club. **10**: 123–4. 1883.

[15] Orcutt, Bull. Torr. Bot. Club. **10**: 106–7. 1883.

[16] Pirotta, Ann. R. Ist. Bot. Roma. **3**: 170. *pl. 20, 21.* 1888.

[17] Preda, Bull. Soc. Bot. Ital. **1896**: 135–141.

[18] Reverchon, Bot. Gaz. **11**: 213, 216. 1886.

[19] Rose, Contr. U. S. Nat. Herb. **5**: 224, 240. *pl. 36, 37.* 1889.

[20] Solms Laubach, Bot. Zeit. **36**: 69. *pl. 4.* 1878.

[21] Trelease, Pop. Sci. Monthly. **70**: 219. 1907.

[22] Went & Blaauw, Proc. Sect. Sci. K. Akad. Amsterdam. **8**: 684; Rec. Trav. Bot. Neerland. **2**: 223. *pl. 5.* 1906.

[23] Wooton, Bull. N. Mex. Agr. Exp. Sta. 18: 92. 1896.

[24] Zuccarini, Allgem. Gartenzeit. **6**: 303. 1838; Abhandl. Akad. München. Cl. II. **3**: 224, 228. 1840.

In addition to those noted in the above papers, histological studies are to be found in De Bary, Vergl. Anat. 636–640.—Cedervall, Anat.-Fys. Unters.—Cerulli-Irelli, Ann. R. Ist. Bot. Roma. **5**: 414.—Falkenberg, Vergleich. Unters.

Monocot.—Giovannozzi, Nuov. Giorn. Bot. Ital. n.s. **18**; 9, 53. *f. 14.*—Grevillius, Bot. Notiser. **1887**: 140.—Haberlandt, Ber. Deutsch. Bot. Ges. **4**: *223.*—Hausmann, Beih. Bot. Centralbl. **23**. Abt. 2: 43–80. *ff.*—Kny, Bot. Wandtafeln. Abt. 5.—Möbius, Ber. Deutsch. Bot. Ges. **5**: *22.*—Morot, Ann. Sci. Nat., Bot. vi. **20**: *272.*—Schoute, Flora. **92**: 42, 46. *pl. 4. f. 5, 10.*—Schwendener, Abhandl. Akad. Berlin. **1882**.

EXPLANATION OF ILLUSTRATIONS.

The distribution map indicates the occurrence of specimens actually examined. Half-tone plates are from unpublished photographs by the author unless otherwise credited. Text-cuts are uniformly reduced from enlarged camera lucida drawings to natural size except that leaf sections are × 2, the finer arming of leaf margins × 20, and the style and wing tips of *Dasylirion* × 6; and a few exceptional details with other enlargement are introduced.

Plates 1–4. Habit of growth: 1, Trunkless (*Nolina microcarpa,* Arizona, MacDougal); 2, with elongated finally erect caudex (*Dasylirion lucidum,* Tehuacan); 3, arborescent (*Nolina longifolia,* cultivated in the Palermo botanical garden); 4 arboreous (*Beaucarnea gracilis,* Tehuacan). All greatly reduced.

Plate 5. Habit of inflorescence:—A, Simply panicled (*Nolina georgiana* Georgia, Harper); B, Compoundly panicled (*N. Parryi,* California, Jepson); C, Compoundly spicate (*Dasylirion cedrosanum,* Mexico, Lloyd).—All greatly reduced.

Plates 6–7. Inflorescence details:—6 A, *Nolina caudata* (type); 6 B, *Calibanus Hookerii* (Purpus, 4775); 7 A, *Beaucarnea guatemalensis* (Kellerman, 6069); 7 B, *Dasylirion Wheeleri* ♂ and ♀ (Wooton, 72).—All natural size.

Plate 8. Flowers.—A, *Nolina longifolia* (Radlkofer); B, *Calibanus Hookerii* (Rose, 8954); C, *Beaucarnea stricta* (Purpus, 2397); D, *Dasylirion Wheeleri* (Toumey).—All × 10.

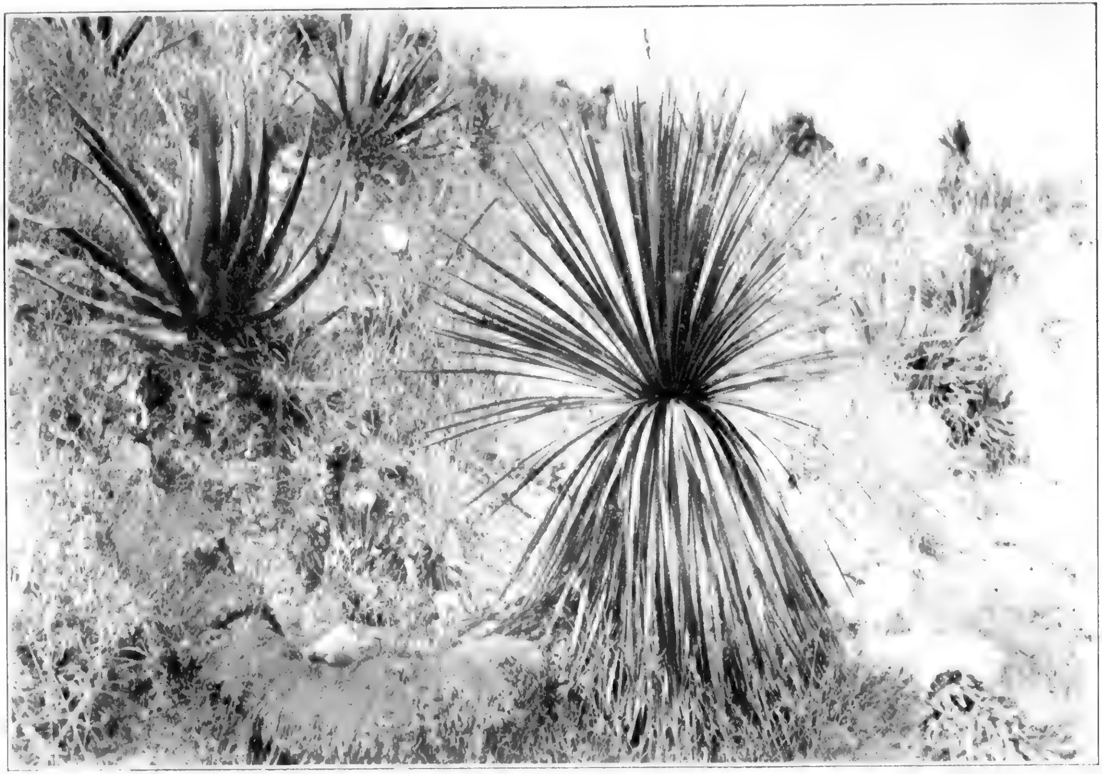
Plate 9. Septal nectar slits as shown on the matured fruit. A, *Dasylirion longissimum* (Palmer); B, *Calibanus Hookerii* (Purpus, 1200).—Both × 25.

Plate 10. Seeds. A, three seeds of *Nolina durangensis,*—the middle one sectioned to show coat, endosperm and embryo; a seed of *Beaucarnea pliabilis;* and two seeds of *Dasylirion lucidum.*—All × 3. B, endosperm of *Dasylirion lucidum,* with "reserve-cellulose" walls. × 200. C, cross section of seed of *Nolina durangensis* showing embryo cavity with much extruded protoplasm and oil—in chlor-iodide of zinc. × 20. D, endosperm of *Nolina durangensis* swollen in chlor-iodide of zinc, with extruded oil. × 200.

Plate 11. Fruit characters. A, four fruits and a seed of *Nolina georgiana;* six fruits and two seeds of *Dasylirion Wheeleri;* six fruits and two seeds of *Beaucarnea gracilis;* and four fruits and a seed of *Calibanus Hookerii.*—All natural size. B, 1, *Dasylirion acrotriche* (3 and 4-winged); 2, *D. acrotriche* (4- and 5-winged); 3, *D. durangense* (2- and 5-winged); 4, *D. Wheeleri* (4- and 5-winged); 5, *Calibanus Hookerii* (4-carpellary).—All × 2.

NOLINA MICROCARPA

PLATE II

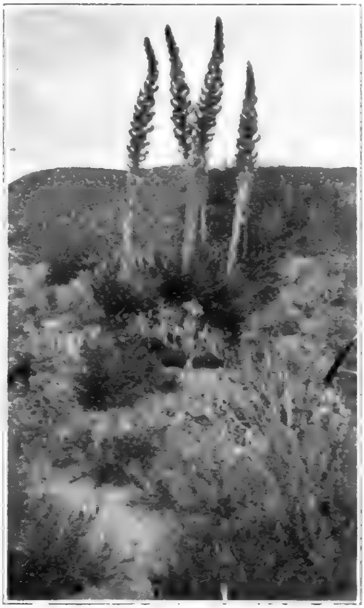


DASYLIRION LUCIDUM

NOLINA LONGIFOLIA

BEAUCARNEA GRACILIS

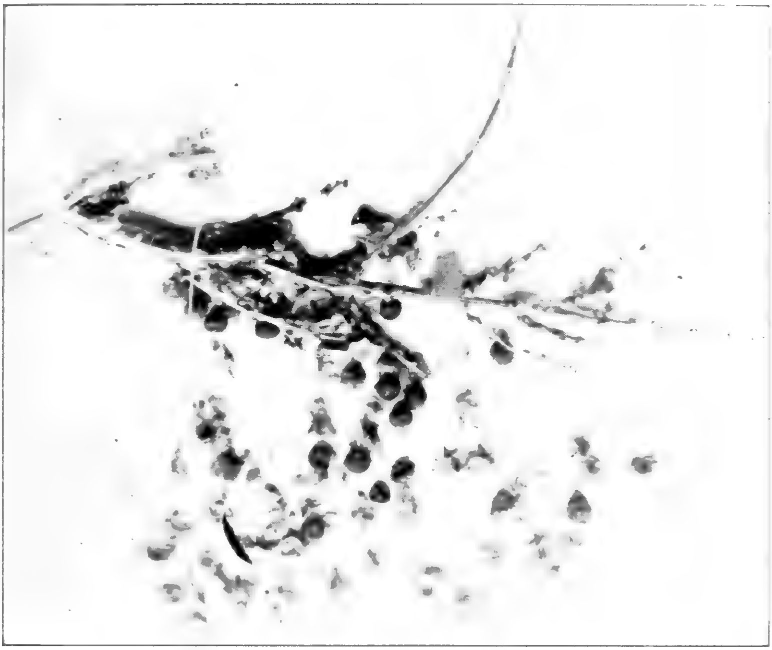
A.—Nolina



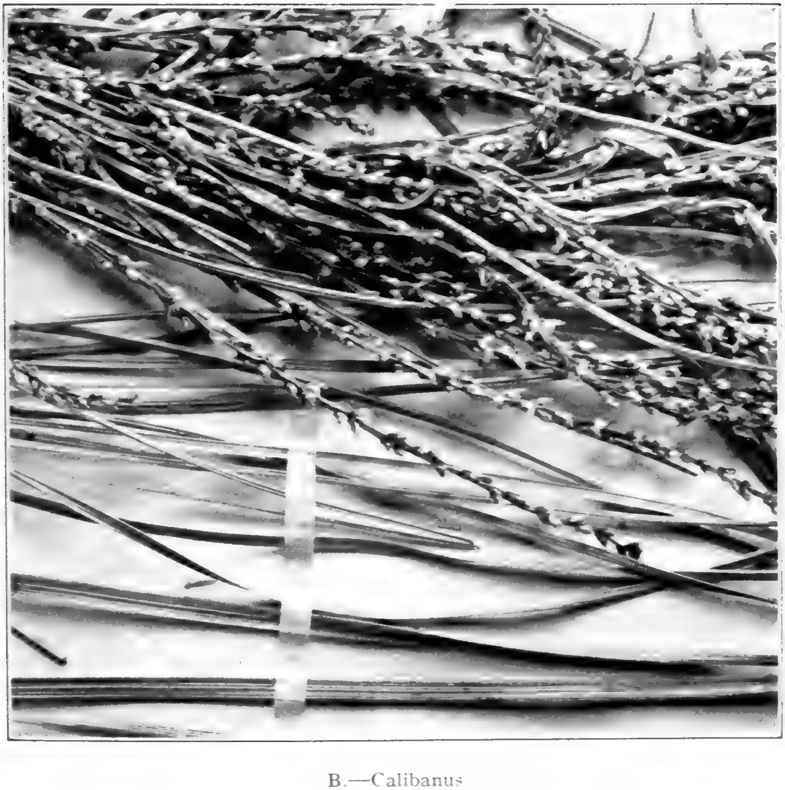
B.—Nolina

C.—Dasylirion

INFLORESCENCE OF NOLINEAE

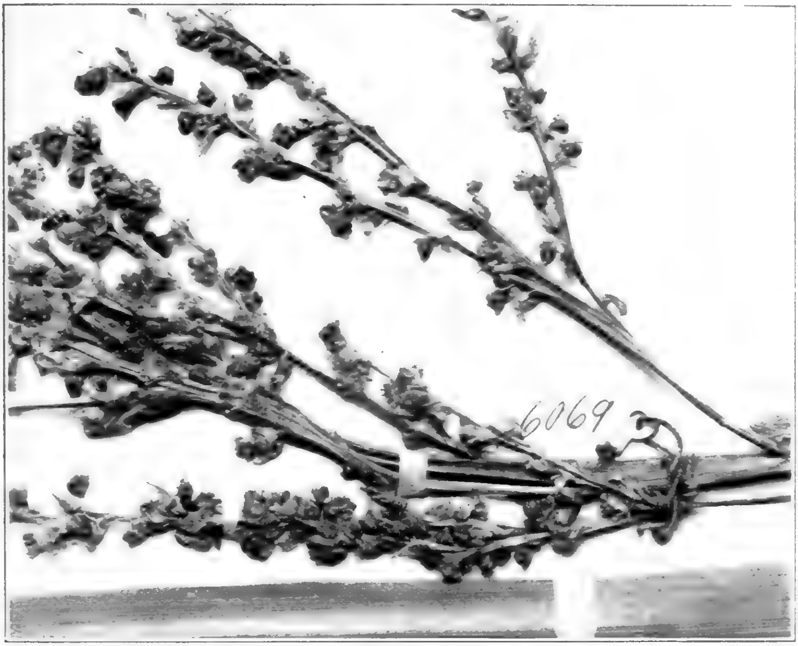


A.—Nolina

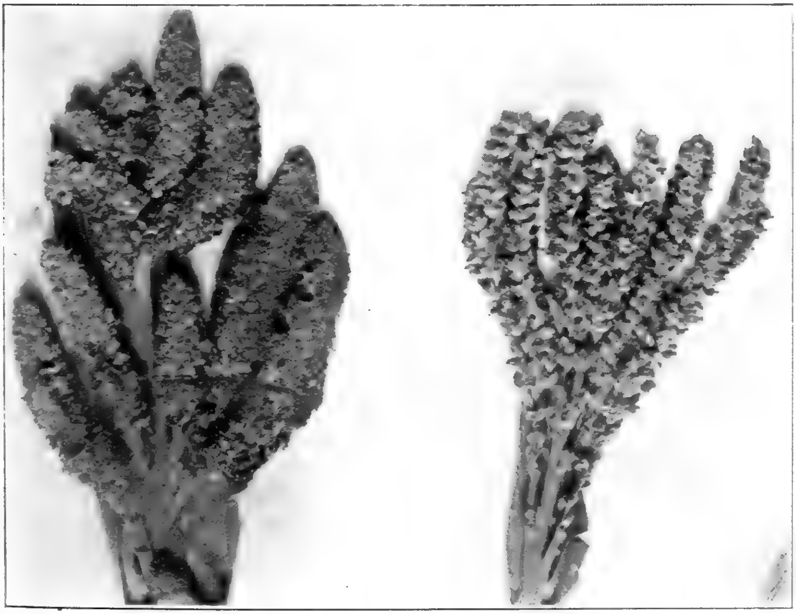


B.—Calibanus

INFLORESCENCE OF NOLINEAE



A —Beaucarnea

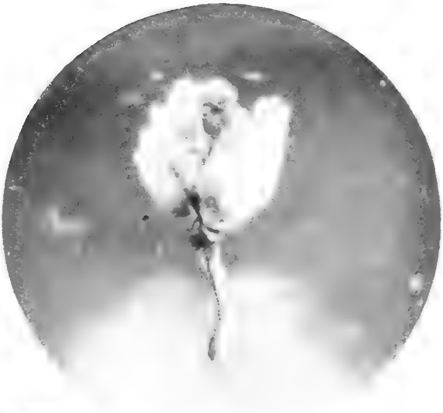


B.—Dasylirion

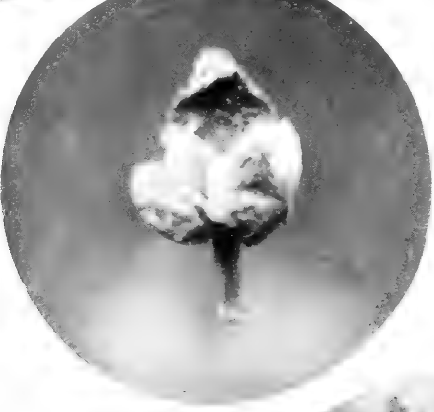
INFLORESCENCE OF NOLINEAE

Plate VIII

A

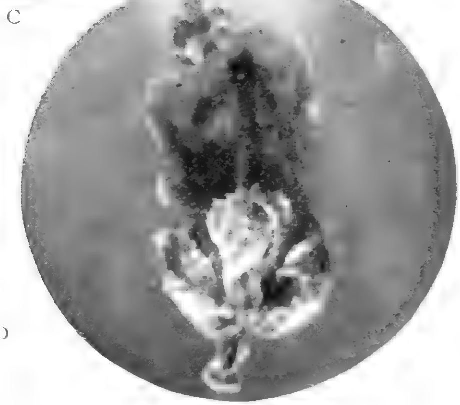


B

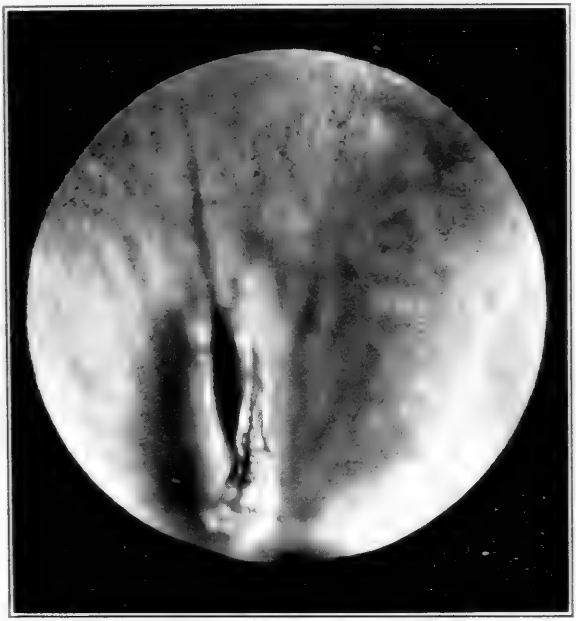


C

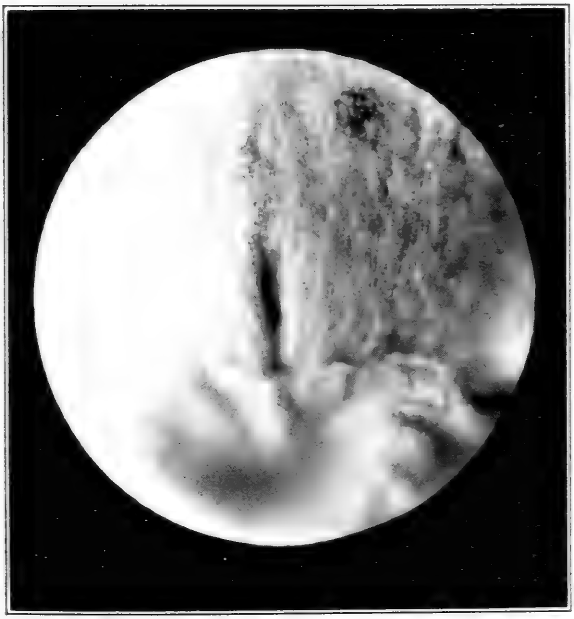
D



Flowers of Nolineae

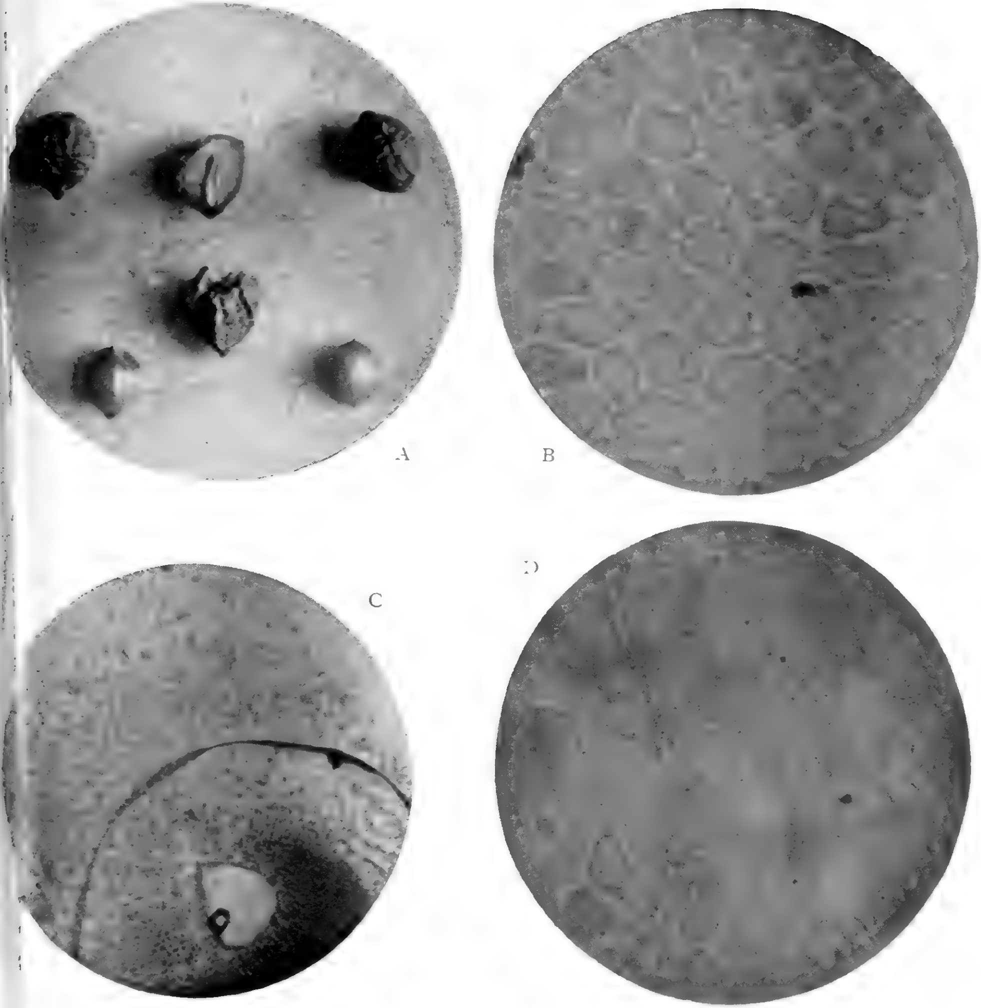


A.—Dasylirion

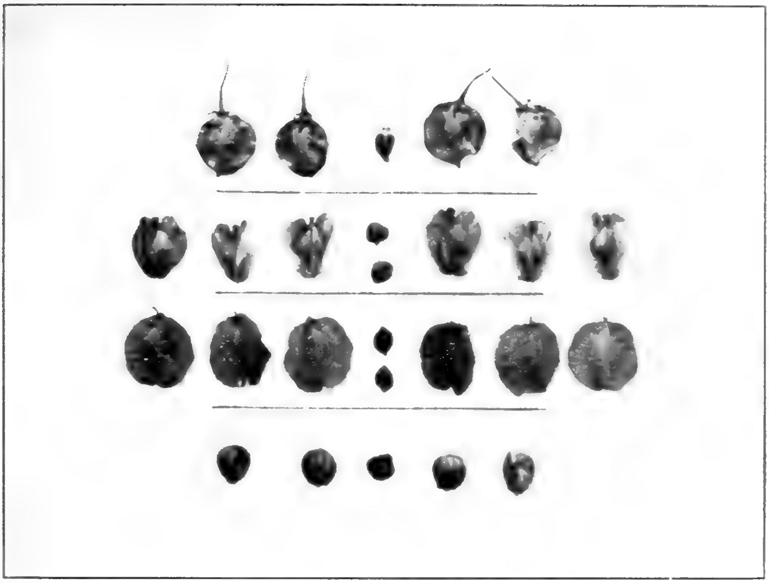


B.—Calibanus

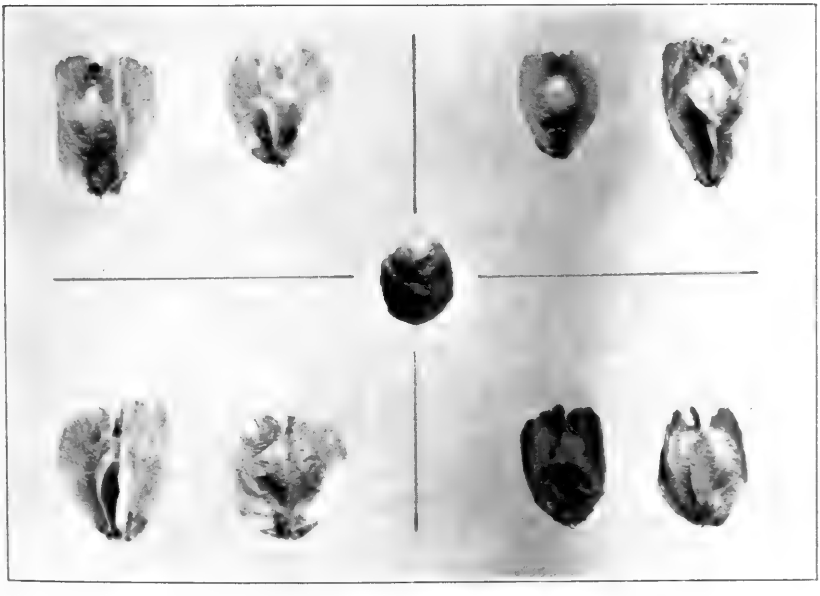
NECTARY OF NOLINEAE



Seeds of Nolineae

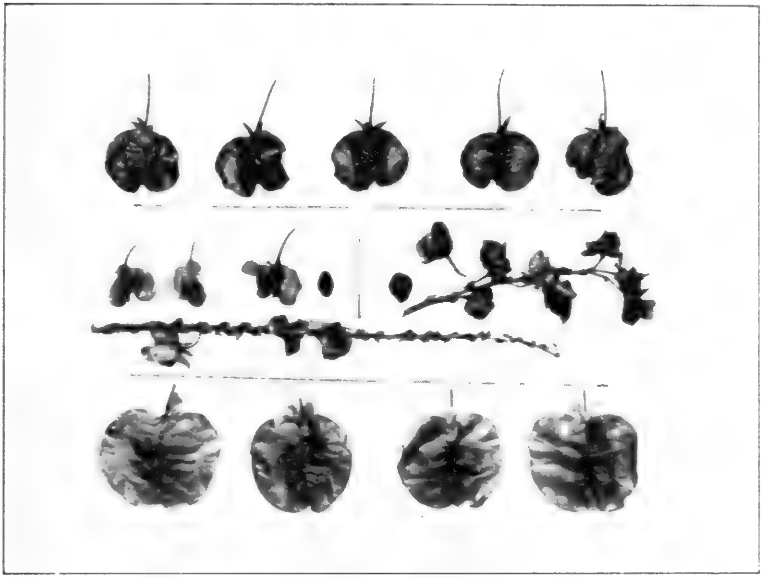


A.—Normal

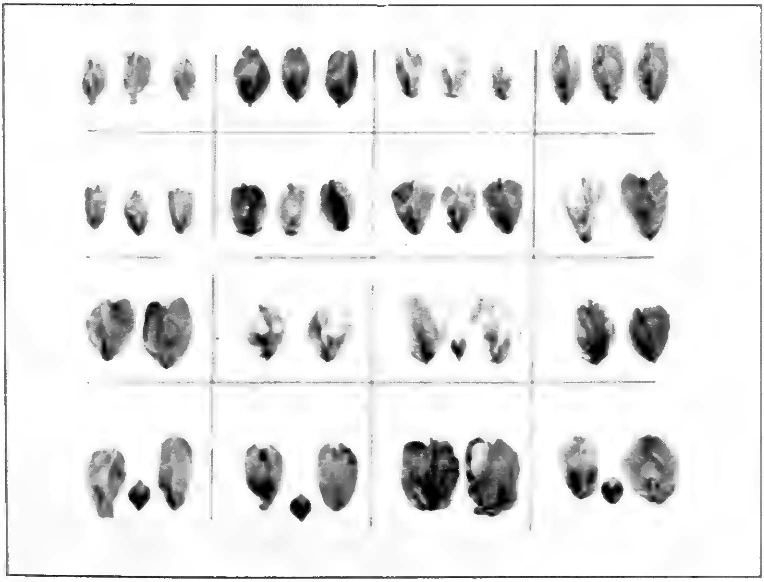


B.—Teratological

FRUITS OF NOLINEAE

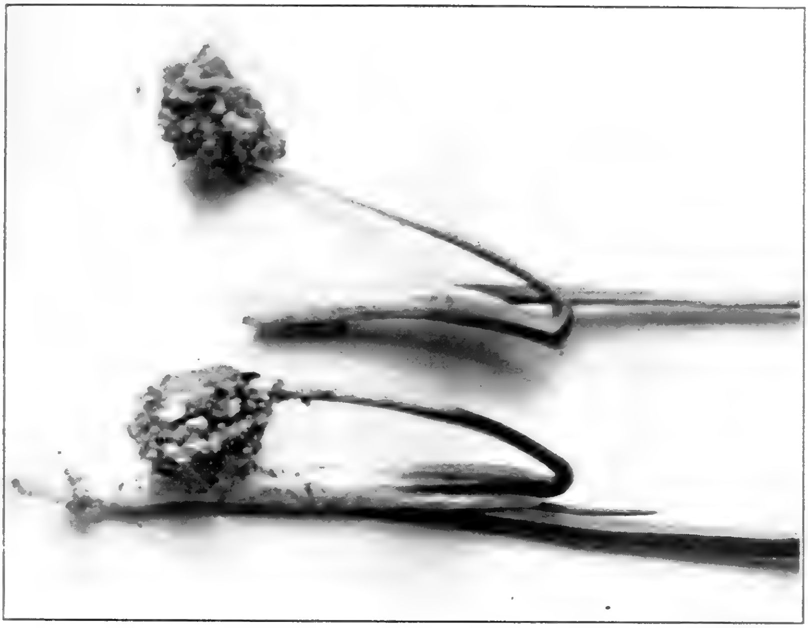


A.—Nolina

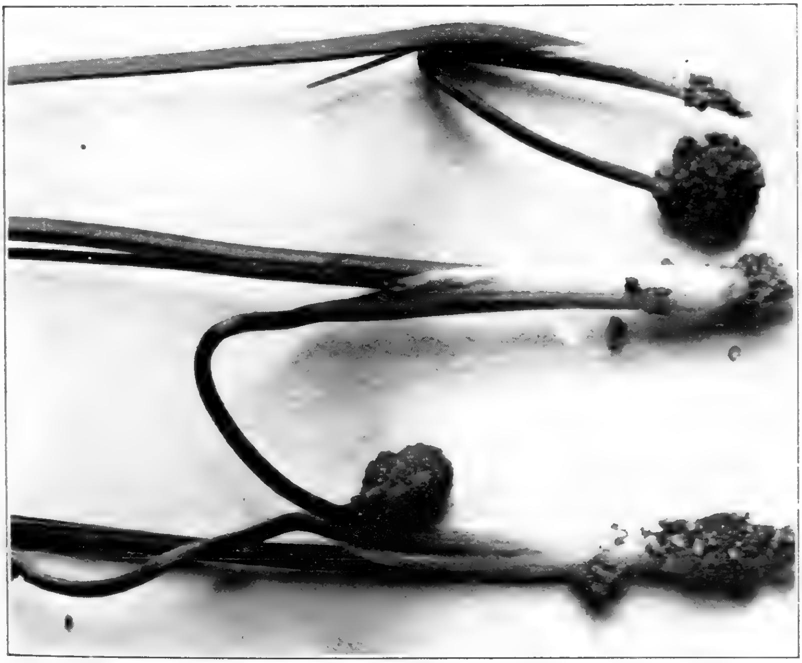


B.—Dasylirion

FRUITS OF NOLINEAE

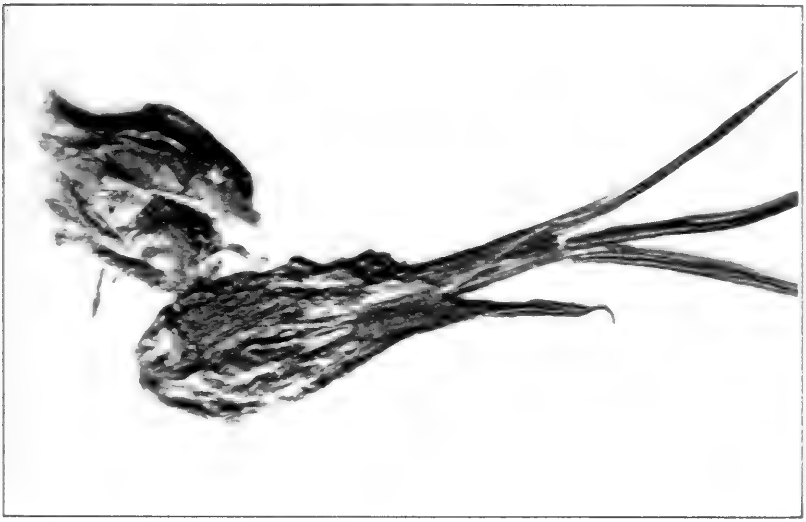


A



B

GERMINATION OF NOLINA LONGIFOLIA

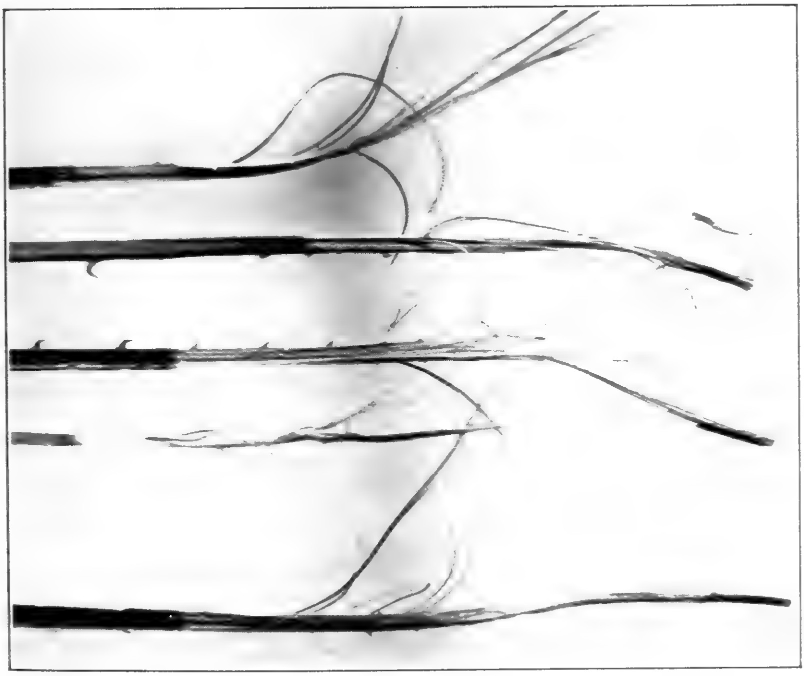


A.—Beaucarnea

B.—Calibanus

GERMINATION OF NOLINEAE

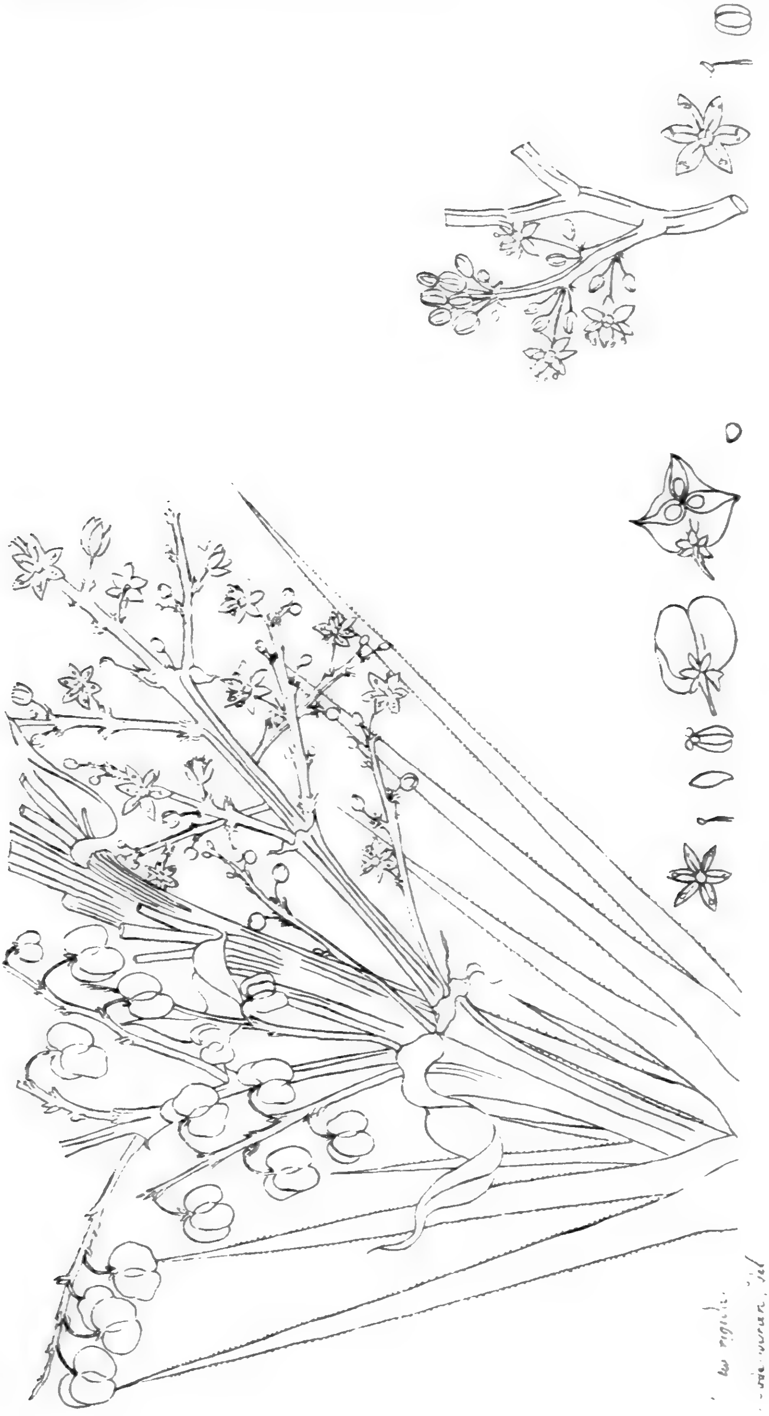
A



B

HAUSTORIUM AND LEAF TIPS OF DASYLIRION

NOLINA HARTWEGIANA



NOLINA RIGIDA

Plate 12. Fruit characters. A, *Nolina:* Graminifoliæ (four fruits of *N. Lindheimeriana*),—Microcarpæ (branchlet of *N. microcarpa*),—Erumpentes (branchlet of *N. texana*),—and Arborescentes (four fruits of *N. Parryi*).—All natural size. B, *Dasylirion:* 1, *D. cedrosanum* (type),—2, *D. lucidum* (Trelease, 26),—3, 4, *D. leiophyllum* (3, Van Horn, Eggert, 4, type),—5, *D. Palmeri* (type),—6, *D. texanum* (Lindheimer, 1213),—7, *D. simplex* (type), —8, *D. Wheeleri Wislizeni* (type),—9, 10, *D. Wheeleri* (9, Girard, 10, Wooton, 72),—11, *D. durangense* (type),—12, *D. graminifolium* (Pringle, 3746), 13, *D. glaucophyllum* (Berger), 14, *D. acrotriche* (Haage & Schmidt), —15, *D. Berlandieri* (type),—16, *D. longissimum* (type),—All natural size; four numbers in a row, from left to right.

Plate 13. Germination of *Nolina longifolia.*—A, normal seedlings, one with slightly shouldered haustorium. B, various straightening of the cotyledon from normal arch to erect form.—All × 3.

Plate 14. Germination. A, *Beaucarnea stricta,*—the haustorium in place, though broken off (Rose). B, *Calibanus Hookerii* (Rose). The haustorium deeply dorsal on the cotyledonary sheath.—Both × 3.

Plate 15. A, *Dasylirion cedrosanum,* seedling with deeply dorsal haustorium, × 3; B, *D. texanum,* mature leaf tips showing dorsal exfoliation of fibers, natural size.

Plate 16. *Nolina Hartwegiana.* (Hartweg, 406, in Herb. Delessert). C. de Candolle.—Reduced.

Plate 17. *Nolina rigida.* Anatis rigida. (Plate XVIII of the Sese and Moçiño drawings in Herb. DC., by Node-véran.) C. de Candolle. —Natural size.

ISOSTASY AND MOUNTAIN RANGES.

By HARRY FIELDING REID.

(*Read April 21, 1911.*)

The cause of the elevation of mountains has always been a most fascinating subject of study, and we find the earlier geologists giving much attention to it. In the first half of the nineteenth century the prevailing idea was that mountain ranges were due to the upward pressure of liquid lava and that their elevation was closely related to the volcanic forces. As late as the middle of the century Elie de Beaumont upheld this idea with all the prestige of his great authority.

But a more detailed study of the structure of the rocks which make up the mountains led to different conceptions. It was found that the whole mass had been subjected to tremendous compressional forces in a line at right angles to the mountain range. This was shown by the immense folding of the rocks, the existence of thrust-faults and of cleavage and the evident flattening out of fossils; so that the existence of these tangential forces was thoroughly proven. This led then to the idea that mountains owe their origin not to vertical forces, but to the great tangential forces which folded the rock and squeezed it upwards. Professors Heim and Suess in Europe, and Dana, Hall and Le Conte in America, were all very active in developing this point of view, though Dana realized that vertical forces also played some part in the elevation of mountains; but the dominant influence of the tangential forces was recognized in the name *orogenic,* or *mountain-making* forces, which was reserved entirely for them. Without doubt, confidence in the efficiency of tangential forces was greatly strengthened by the fact that these forces could be satisfactorily accounted for by the cooling of the earth; for the cooling is greatest at a short distance below the surface and the exterior layers are subjected to tangential crushing to accommodate themselves to the shrinking interior.

There are great areas of the earth, such as the high plateau regions in the west of the United States, where the rock has been elevated many thousands of feet but without suffering any compression whatever, which makes it quite evident that there are vertical forces which produce many movements in the earth's crust. Mr. Gilbert has given to these forces the name of *epeirogenic,* or *continent-making* forces, to distinguish them from orogenic forces; but we must not forget that epeirogenic forces are apparently alone active in the elevation of certain mountain ranges. The Sierra Nevada, for instance, although its strata are much folded, owes its present elevation to the vertical forces which seem still to be tilting the great block. Mt. St. Elias also seems to have been tilted up by vertical forces without any folding of its strata.

The American geologists showed that a mountain range does not rise haphazard in any part of the earth, but that it appears where there was earlier a great geosynclinal, which had gradually subsided and accumulated sediments to an extraordinary thickness, all of them being laid down in comparatively shallow waters; and it was only after this preparatory step that the foldings and elevation of the mountain range took place.

But there is one important factor to which geologists have not given proper attention, that is, the revelations of the plumb-line. About the middle of the nineteenth century Archdeacon Pratt pointed out that in the south of India the plumb-line was deflected toward the Indian Ocean, and in the north of India, although it was deflected somewhat toward the Himalaya mountains, still the gravitational attraction of these mountains was considerably less than it should have been, if the density of the material in and under them had been the same as in other parts of the earth's crust; and he, therefore, suggested that the oceans were deep because the material under them was heavy, and the mountains were high because the material which composed them was light, and that in general the amount of material under any two equal segments of the earth was the same. But these facts did not make a great impression upon geologists and did not prevent the further advocacy of compression and the consequent accumulation of material as the cause of mountain elevation.

In 1880 Mr. Faye showed that the so-called "anomalies" of gravity would practically disappear if, in reducing observations on land to sea-level, no account were taken of the land mass above sea-level; and if, in reducing observations made on islands in mid ocean, the excess of attraction of the island mass over an equal amount of sea-water were subtracted. This is equivalent to assuming that the continental areas stand up on account of their low densities, but that the small islands are supported by the rigidity of the crust.[1]

In 1889 Major Dutton read a very remarkable paper before the Philosophical Society of Washington,[2] in which he pointed out that the mountain regions were probably continuing to rise as a result of the lightening of their weight by erosional transportation and that regions of deposition near the coasts were probably sinking on account of the added material which they were receiving, and that the forces thus brought into play would set up slow currents from the regions under the sea towards the region under the mountains; and he held that the earth was not strong enough to sustain the weight of great mountain ranges but that these owed their elevation to the fact, as already suggested by Archdeacon Pratt, that they were lighter than the material under the lowlands, or under the oceans; and that there was, therefore a certain equality of weight in the various segments of the earth. He gave to this theory the name of *isostasy,* which has served to give it definiteness ever since. It is to be noticed that Major Dutton considered the elevation of mountains to be due to vertical, and not to tangential forces.

The theory of isostasy has been much discussed by geologists since Major Dutton's paper; many papers have been written on the subject, and the available geological evidence has been invoked in support of, or against, the idea; but it was not until very recently that the real evidence, which lies in the variations of the force of gravity and the deviation of the vertical, has led to definite conclusions.

Mr. Putnam and Mr. Gilbert[3] discussed a series of gravity ob-

---

[1] "Sur la reduction des observations du pendule au niveau de la mer," *C. R. de l'Acad. des Sciences,* 1880, Vol. 90, pp. 1443–1447.

[2] "Some of the Greater Problems of Physical Geology," *Bull. Philos. Soc. of Washington,* 1889, Volume XI., pp. 51–64.

[3] "Results of a Trans-Continental Series of Gravity Measures," *Bull. Philos. Soc. of Washington,* 1895, Volume XIII., pp. 31–76.

servations made across the United States, which led them to the conclusion that isostasy was true only in so far as the very largest features of the earth's crust, such as the continents and ocean basins, were concerned, but that mountain ranges were at least in part supported by the rigidity of the crust.

When Dr. Nansen drifted across the North Polar basin in the *Fram* he provided pendulums to determine the force of gravity when the ship was frozen in ice; and the discussion of his observations showed that gravity was normal over that basin, or, at least, where his observations were made.[4]

Professor Helmert,[5] in Germany, has done much in the discussion of gravity measures and Dr. Hecker has made some notable voyages and has determined the forces of gravity at sea, over the Atlantic, Indian and Pacific oceans, and over the Black Sea, the results showing that on the whole the force of gravity is normal over these bodies; only in special and limited areas, in the neighborhood of very steep slopes, was any marked anomaly found.[6]

But the most important work which has been done along this line is the work of Dr. John F. Hayford,[7] who, while connected with the United States Coast and Geodetic Survey, discussed in a thorough and able manner the deflections of the vertical at a large number of stations in different parts of the United States, and his results show definitely that over this region isostatic equilibrium actually exists. He has concluded that this is true even for areas as small as a square degree, that is, seventy miles on the side. He believed

---

[4] "The Norwegian North Polar Expedition of 1893–96," Volume II., Part VIII., Results of the Pendulum Observations, by E. O. Schiotz.

[5] "Hohere Geodesie," Leipzig, 1880.

[6] "Bestimmung der Schwerkraft auf dem Atlantischen Ozean," *Veröff. des König. Preuss. Geodet. Instit.*, Neue Folge, No. 11. "Bestimmung der Schwerkraft auf dem Indischen und Groszen Ozean," *Veröff. des Zentral Bureaus der Internat. Erdmessung*. Neue Folge, No. 18. "Bestimmung der Schwerkraft auf dem Schwarzen Meere," same, No. 20.

[7] "The Geodetic Evidence of Isostasy, etc.," *Proc. Washington Acad Sci.*, 1906, Vol. VIII., pp. 25–40. "The Earth a Failing Structure," *Bull. Philos. Soc.*, Washington, 1907, Vol. XV., pp. 57–74. "The Figure of the Earth and Isostasy," United States Coast and Geodetic Survey, 1909. "Supplementary Investigation in 1909 on the Figure of the Earth and Isostasy," same, 1910. "The Relation of Isostasy to Geodesy, Geophysics and Geology," *Science*, February 10, 1911.

that the earth is not strong enough to sustain an added thickness of more than about two hundred and fifty feet of rock over an area as large as a square degree without slowly yielding. The stations where the observations were made are scattered over various parts of this country, on the eastern coast, in the Appalachian mountain range, in the region of the Great Lakes, near the Gulf of Mexico, in the great plains of the Mississippi basin, on the great elevations of the Rocky Mountains, the plateaux of Utah, the Sierra Nevada mountains and the Pacific coast, regions exhibiting a great variety of topographic forms and differing greatly as to geologic activity. Whatever movements may be going on in the Rocky mountains, and in the region between them and the Atlantic ocean, are certainly very small; whereas to the west, and particularly in the state of California, the movements seem to be very active. The eastern edge of the Sierra Nevada received additional elevation at the time of the Owens Valley earthquake in 1872, and the comparatively frequent earthquakes in the Sierras and the Coast ranges make it quite possible that these mountains are now being elevated as actively as at any time in their history. In view of the great variety of the country in which the stations were located, both as to topography and geologic activity, in view of the great amount of material being continually eroded from one region and deposited in another, thus tending to overthrow the isostatic equilibrium, and in view of observations in other parts of the world, we are driven, with Dr. Hayford, to the conclusion that isostasy is not an accidental condition existing at the present time within this country, but is due to the fact that the earth yields plastically to the long continued action of even small forces. We feel justified, therefore, in believing that isostatic equilibrium exists in other parts of the world and existed in other geologic ages, and in saying that the whole earth is, and always has been in isostatic equilibrium.

This conclusion carries with it many important consequences and has a very direct bearing on the theories of the origin of mountain ranges; for it tells us that every segment of the earth, having an equal area of surface and with its apex at the center, contains the same amount of material, which it is impossible either to increase or decrease. If by erosional transportation a large quantity of material is removed from a high land and deposited in the oceans, then the increase of weight under the ocean and the decrease under the mountains will, as Major Dutton explained, set up a subterranean counter flow, which will restore the equality of material in the segments. If by the exercise of tangential forces a portion of the earth's crust is compressed and folded and the quantity of material in the segment thus increased, the added weight will cause a slow sinking of the region and material will flow out from below and reduce the mass of the segment to its proper value. Indeed, the folding up of the rock by tangential pressure would not elevate a mountain range, but would cause the folded region to sink; not, however, necessarily below its former level.

When we consider the origin of the mountain ranges the theory of isostasy requires that all hypotheses, which call for more than the normal amount of material in any segment, be excluded. The folding of rock under tangential forces, and the increase of material by subterranean flow are necessarily debarred. Dana noticed that the great mountain ranges of the world were opposite the great oceans and, in some cases, were opposite the great depths of the oceans. The inference was natural that material was taken from the ocean bed, increasing its depth and added to the land increasing its height; but the theory of isostasy forbids this inference. He also suggested that the segments of the earth forming the oceans were sinking more rapidly, as the earth cooled, than the segments forming the continents and also that they were stronger; so that they compressed the continents, folding the rock and making mountain ranges around their borders. Besides other objections to this idea, the theory of isostasy excludes it on account of the increased material required in the land segment. Professor Charles Davison[8] has suggested that the oceans owe their existence to the stretching and consequent thinning of the strata below them, but the theory of isostasy does not permit the withdrawal of material from the ocean

---

[8] "On the Distribution of Strain in the Earth's Crust resulting from Secular Cooling, with special reference to the Growth of Continents and the Formation of Mountain Chains," *Phil. Trans. R. S.*, 1887, Vol. 178(A), pp. 231–242.

bottoms. Sir George Darwin[9] has suggested that the continental areas of the earth may be due to elevations caused by the differential retarding effect of lunar tidal action. But the theory of isostasy tells us that they could not have maintained themselves unless they were especially light; and in this case they would have existed independently of the tidal forces. Although these elevations, or "wrinkles," as Sir George Darwin calls them, might have been distorted by the different tidal effects in different latitudes, their original meridional direction still requires explanation.

The foldings and contortions of the rock have been so intimately associated, in the minds of geologists, with mountain ranges, that a low-lying region of folded rock has been looked upon as the remains of a mountain range removed by erosion; but as mountains are not due to rock folding, this inference may be entirely wrong.

Only a few of the consequences of the theory of isostasy have been mentioned; but the principle is of such fundamental importance that it will surely exercise a strong influence over our future theories, and will be applicable in directions not now suspected. Unfortunately, it does not tell us definitely what is the cause of the elevation of mountains and plateaux; but it limits our inquiries by excluding all theories which assume the addition of matter to a segment. It tells us, quite definitely, that the elevation of mountains, or the depression of the oceans, must be due to vertical forces brought about by a decrease, or increase, in the density of the material under these regions. According to it, the mountains are high because their material is light; and as geological history tells us that the mountains have not always existed, we must conclude that they were elevated by an expansion of the material in and under them. And the great deeps of the oceans are deep because the material under them is dense and they have become deep by an increase in the density of this material. Since all mountain areas are being lowered by active erosion and many of the great ocean deeps are being filled by depositions, the great heights of the former must be due to the fact that they are still in the process of elevation or that they have only

---

[9] "Problems connected with the Tides of a Viscous Spheroid," *Phil. Trans. R. S.*, 1879, Vol. 170, p. 589.

recently been raised; and the great depths of the latter to the fact that they are in the act of sinking, or have only recently sunk. As the centres of the great majority of strong earthquakes are along the boundaries of high mountain ranges, or of great ocean deeps, it seems most probable that the forces which have produced these very interesting features of the earth's surface are still in active operation.

A FOSSIL SPECIMEN OF THE ALLIGATOR SNAPPER (MACROCHELYS TEMMINCKII) FROM TEXAS.

(PLATES XVIII AND XIX.)

BY OLIVER P. HAY.

(*Received May 23, 1911.*)

The writer has received for examination from Professor Mark Francis, of the Texas Agricultural Experiment Station, at College Station, Tex., a nearly complete skull of the great fresh-water tortoise known as the alligator snapper. This fine specimen was discovered last summer or autumn during some dredging operations in the Brazos River, between College Station and Navasota. After passing through various hands it came into the possession of Professor Francis, who, on application, kindly transmitted it to me. With the skull came also a part of a carapace, which doubtless belonged to the same animal. The skull was found in a mass of gravel, and had undoubtedly been washed out of the river bank not far away. This proximity of the place of burial is evident from the little damage done to the skull, and is made more probable from the presence of a part of the shell.

The cavities of the skull, when it came into Professor Francis' hands, were full of gravel, wedged in very tightly. Some of this gravel was sent with the skull. It was strongly colored with iron oxide; and this oxide served to cement the bits of gravel together and to the bone. The bone is also colored with the oxide, and it is so thoroughly mineralized that, on being struck, it rings like a piece of porcelain.

It would be interesting to know exactly the geological age of this specimen; but it appears now impossible to determine this. Professor Alexander Deussen, of the University of Texas, has been engaged in studying the Quaternary and Recent deposits of some of the rivers of Texas; and a part of his results is soon to be published by the United States Geological Survey. He has kindly informed the present writer that there occur along the Brazos River three principal terraces. The oldest and highest of these, the Hidalgo Falls terrace, lies at a height of 100 or more feet above the present water line of the river. In the materials of this terrace have been found remains of *Mammut, Elephas, Megalonyx, Equus,* etc. About 75 feet below this terrace is found another, the Port Hudson, whose thickness is from 20 to 30 feet. The upper terrace is regarded as older Pleistocene; the Port Hudson, as newer Pleistocene. At a level some 15 to 20 feet below that of the Port Hudson, is a terrace which Professor Deussen considers as of early Recent time. It constitutes the real "bottom lands" of the Brazos and is subject to overflow.

It is very probable that the remains described here were derived from the lowest and youngest terrace and that the individual lived at some time about the beginning of the Recent epoch. The species probably lives today in the Brazos River.

The skull (plates XVIII and XIX) lacks the lower jaw, a part of the temporal roof of the left side, most of the occipital condyle, and the hinder part of the supraoccipital process. A close examination reveals no characters by which it can be distinguished specifically from the alligator snapper. The profile (Pl. XIX, Fig. 2) is much less concave than in most specimens of the species collected in the rivers of the Southern States; but there is in the United States National Museum a skull of considerable size, no. 3769, from Mississippi, which presents no greater concavity than does the Brazos River specimen. There are two other skulls, the one considerably larger than the skull from Mississippi, the other considerably smaller, both of which are much more concave than the specimen from Mississippi. Hence, the amount of concavity seems not to depend on youth or old age.

The skull of the fossil is, relative to the length, slightly both broader and higher than are two skulls with which it is compared, as is here shown:

Specimen.	Snout to condyle.	Width.	Height.
Brazos River skull............................	1	1.19	.84
No. 3769 U. S. N. M., from Mississippi..........	1	1.14	.78
No. 3444 U. S. N. M., from Red R., Ark........	1	1.08	.74

It will be observed that the last two skulls differ from each other about as much as the second differs from the fossil.

The same three skulls furnish the following measurements.

Measurements.	Brazos R. skull.	No. 3769.	No. 3444.
Snout to occipital condyle	183±	170	177
Snout to hinder end of supraoccipital process	262±	236	226
Least width pterygoid region	33	29	29.5
Outside to outside of quadrates	187	166	163
Distance between hinder ends of cutting edges of upper jaws	142	128	126
Width in front of ear cavity	218	195	191
Width of temporal arch where narrowest	77	71	68
Orbit to excavation of postorbital arch	87	82	80
Horizontal diameter of orbit	32	30	32
Distance between fronts of orbits	55	50	53

Fig. 1 of Plate XIX represents the fragment of the carapace that accompanied the skull. This is reduced to five twelfths the natural size. It consists of a part each of the third and fourth costal plates, and of a part each of the sixth and seventh peripherals. On these parts are present areas representing the outer and hinder angle of the third costal scute, a little of the third and the whole of the fourth supramarginal scutes, the whole of the eighth marginal scute and a part each of the seventh and the ninth. These structures are almost identical with the corresponding ones of a mounted specimen of the species in the United States National Museum.

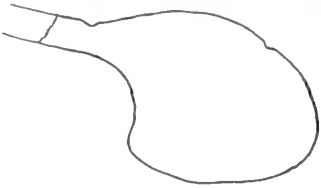


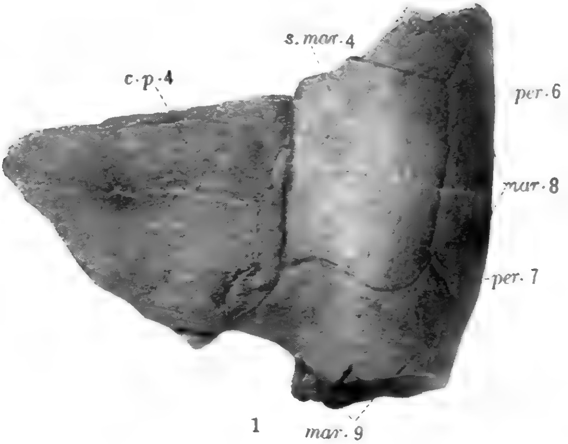
FIG. 1. Section of rim of carapace between sixth and seventh peripherals.

Fig. 1 represents a transverse section of the rim of the carapace taken between the sixth and the seventh peripherals.

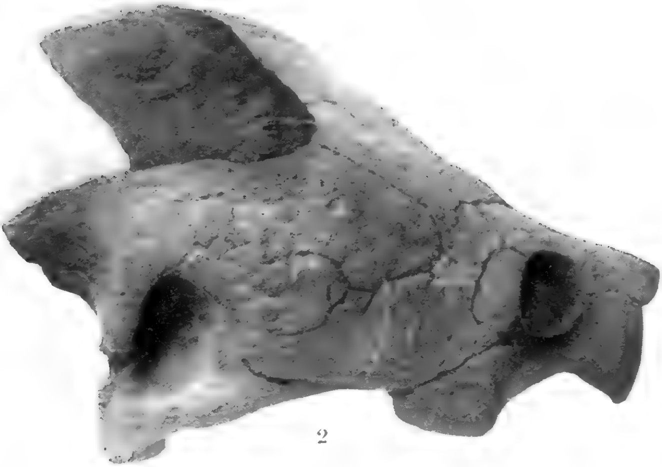
1

2

MACROCHELYS TEMMINCKII



1



2

MACROCHELYS TEMMINCKII. × $\frac{5}{8}$

EXPLANATION OF THE PLATES.

MACROCHELYS TEMMINCKII, fossil.

In the figures of these plates the sutures between the bones are represented by narrow white lines; the seams between the horny scutes by wider dark lines. All the figures are two-fifths of the natural size.

PLATE XVIII.

FIG. 1. Skull seen from above.
FIG. 2. Skull seen from below.

PLATE XIX.

FIG. 1. Fragment of right side of carapace. *c. p. 4*. part of fourth costal plate, or bone; behind it is a part of the fifth. *mar. 8, mar. 9*, the eighth marginal horny scute and a part of the ninth. *per. 6, per. 7*, the sixth and seventh peripheral bones, but only a part of each. *s. mar. 4*, the fourth supramarginal horny scute; in front of it is a part of the third. The third costal horny scute area occupies the portions of the costal plates present, except the hinder border of the fifth.

FIG. 2. Skull seen from the right side.

PROCEEDINGS
OF THE
AMERICAN PHILOSOPHICAL SOCIETY
HELD AT PHILADELPHIA
FOR PROMOTING USEFUL KNOWLEDGE

VOL. L SEPTEMBER–DECEMBER, 1911 No. 201

AN HYDROMETRIC INVESTIGATION OF THE INFLUENCE OF SEA WATER ON THE DISTRIBUTION OF SALT MARSH AND ESTUARINE PLANTS.

(PLATES XX AND XXI.)

BY JOHN W. HARSHBERGER, PH.D.

(*Read April 22, 1910.*)

Elsewhere[1] I have discussed the general character of the vegetation of the salt marshes of the northern New Jersey coast and the factors controlling the distribution of marsh plants in that area. This earlier study was based largely on physiographic and floristic considerations, although reference is made on page 379 of that paper to the use of the hydrometer in the investigation of the actual influence of sea water, or salty soil, on the distribution of a limited number of plants. The investigation begun in 1909 has been continued until sufficient facts have accumulated to warrant their publication.

The use of a special kind of hydrometer was suggested as a simple but efficient method of investigating the salt content of salt marsh soils and of the estuarine water which, at first strongly saline, becomes largely diluted, as it mingles with that of streams flowing in a seaward direction. This is the first actual use of the hydrometer

---

[1] Harshberger, John W., "The Vegetation of the Salt Marshes and of the Salt and Fresh Water Ponds of Northern Coastal New Jersey," *Proceedings Academy of Natural Sciences of Philadelphia,* 1909, 373–400, with 6 figures.

in phytogeographic and phytoecologic investigation. The method is applicable not only to a study of salt marsh soils, but also to an investigation of salt lakes and alkaline soils, which are found in many parts of our western arid districts and in other parts of the world (Fig. 1). The use of the hydrometer supplements, if it does not replace, the employment of the more expensive and cumbersome apparatus which determines by electric means the salt content of soils. Although this investigation was made in the salt marshes of

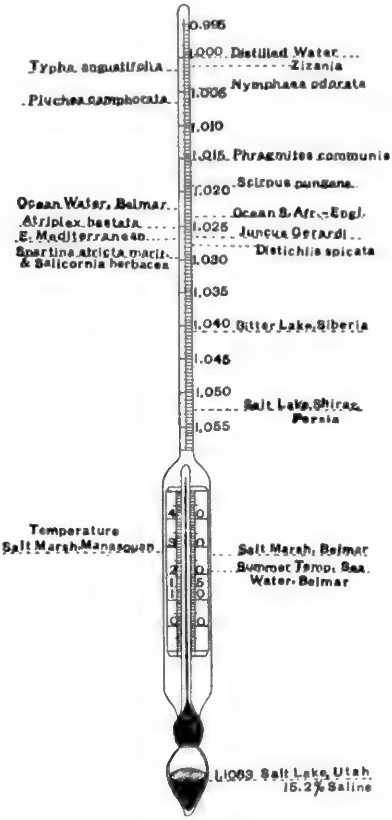


FIG. 1. Special hydrometer and thermometer used in the investigation of the salt marsh vegetation of the New Jersey coast. The names of plants are arranged along the scale to graphically represent the maximum density of salt water to which these plants are subjected in their marsh environment. Other data are given for comparison.

northern coastal New Jersey, the results obtained are equally applicable to the same salt marsh species as they are found distributed along our eastern Atlantic coast. For stretching from the Bay of Fundy along the New England, middle and southern Atlantic coasts, as far south as Jupiter Inlet in Florida, are extensive salt marshes covered with a vegetation which consists with minor differences of almost the same and characteristic species.

POSSIBLE METHODS OF INVESTIGATIONS.

There are four possible methods open to the investigator of the salt content of salt marsh soils and estuarine waters. These methods have been used by chemists, soil analysts and plant physiologists.

Method of Titration.—The determination of salt content by volumetric analysis has been the favorite one of chemists. For this purpose, a tenth-normal silver nitrate volumetric solution is used, prepared as follows: Dissolve 16.869 grams of silver nitrate, which previous to weighing has been pulverized and dried in a covered porcelain crucible in an air-bath at 130° C. (260° F.) for one hour in sufficient water to measure at 25° C. (77° F.), exactly 1,000 c.c. This solution is kept in dark amber-colored, glass-stoppered bottles, carefully protected from dust and sunlight. A tenth-normal potassium bichromate test solution is prepared by dissolving 4.8713 grams of pure potassium bichromate, which has been pulverized and dried at 120° C. (248° F.) in sufficient water to measure at 25° C. (77° F.) exactly 1,000 c.c. To a definite volume of salt water, sufficient potassium bichromate test solution is added to impart a yellow tint, then the tenth-normal silver nitrate solution is slowly added from a burette, stirring or agitating until the mixture acquires a permanent tint, due to the formation of red silver chromate. The fluid to be tested must be neutral, as free acids dissolve the silver chromate. The cubic centimeters of silver nitrate solution used must now be multiplied by .005850 Fresenius (.005837 Sutton, .005806 National Dispensatory) to give the weight of the sodium chloride, because .005850 Fresenius (.005837 Sutton, .005806 N. D.) grams of sodium chloride is the equivalent of one cubic centimeter of tenth-normal silver nitrate volumetric solution.[2] This is the method adopted I am told by the botanists at Johns Hopkins University in studying the salt marsh vegetation of Maryland, the results of which investigation have not yet been published.

Method of the Electric Bridge.—The Bureau of Soils, United States Department of Agriculture, adopted some years ago the principle of the slide wire bridge to the measurement of the salt content of soils.[3] The earlier instruments have been described in various bulletins and the results obtained with them are scattered through various publications of the bureau. Since 1899, when the electric bridge was put first into practical use, various improvements have been made, so that the improved instrument is the result of the experience gained by its use in the actual field study of soils. The use of the electric methods for determining the soluble content of a soil depends on the fact that the electric current is conducted by the salt in solution and that the conduction of the solution, or conversely, its resistance to the passage of the current, is largely determined by its concentration. The magnitude of current that will pass is increased by an increase of salt in solution; or the resistance to the passage of the current decreases with the increase of salt. The experience gained by the use of the modified instrument is embodied in the recent bulletin of the Bureau of Soils noted above and its general utility in the study of alkali soils, the salt content of irrigation and seepage waters is given.

Method of Plasmolysis.—It is a well-known physiologic fact that dilute solutions of potassium nitrate, sodium chloride and cane sugar cause a removal of water from living plant cells, so that the protoplasm contracts away from the inside of the cell wall. The per-

---

[2] Consult Hare, Hobart A., Caspari, Charles, Rusby, H. H., "The National Standard Dispensatory," 1905, 1684; Fresenius, C. Remigius, "A System of Instruction in Quantitative Chemical Analysis," 1894, 430; Sutton, Francis, "A Systemic Handbook of Volumetric Analysis," 1890, 124; Fraps, G. S., see bibliography.

[3] Davis, R. O. E., and Bryan, H., "The Electrical Bridge for the Determination of Soluble Salts in Soils," Bull. 61, Bureau of Soils, 1910, where reference is made to previous bulletins; Cannon, W. A., "On the Electrical Resistance of Salt Plants and Solutions of Alkali Soils," *The Plant World*, 11, 10–14.

centage of substance in solution necessary to cause plasmolysis varies not only with the plasmolyzing substance, but also with the plant used in the experiments. The protoplasm in some plants plasmolyzes quickly; in other cases with difficulty, so that stronger solutions are necessary to produce a change in the more refractory plants. If we know, therefore, that a certain percentage strength of sodium chloride in solution will produce plasmolysis in say the cells of the staminal hairs of *Tradescantia,* then if raw or diluted sea water be used and a similar plasmolysis occurs, the percentage of sodium chloride in the sea water must be equivalent to that of the salt solution known to produce similar plasmolytic effects. A comparative table can be constructed by which the varying percentages of sea water can be ascertained. An extensive literature, part of it noticed in the bibliography, is concerned with such plasmolytic studies.[4]

Hydrometric Method.—The use of the hydrometer in determining the salt content of salt marsh soils suggested itself to me, as a simple but efficient method of making a phytogeographic survey of the vegetation of salt marshes upon purely ecologic lines. The advantage of the hydrometer is that it is light, can be carried easily from place to place and lends itself to immediate use, the record depending upon two simple readings, one of specific gravity and one of temperature. The hydrometer is plunged into a vessel containing the water to be tested.

Styles of Hydrometers.—After a simple hydrometer had been used in a number of preliminary tests, search was made for a hydrometer which would record accurately the density of sea water. It was found that there are many kinds of hydrometers in use to test acids, alcohol, alkali, ammonia, bark liquor (tannometer), beer, benzine, chlorine, cider, coal oil, ether, gasoline, glycerine, milk (lactometer), naptha oil, salt solutions (salimeter), silver solution, sugar, sugar and syrup. Some are constructed with Baume's scales, others with Richter and Trolle's scales and those used to test sugar with Balling's and Brix's scales. Finally, after testing several different kinds of

---

[4] Drabble, E., and Lake, H., "The Osmotic Strength of Cell-sap in Plants growing under Different Conditions." *The New Phytologist,* October, 1905, 189; Duggar, B. M., "The Relation of Certain Marine Algae to Various Salt Solutions," *Trans. Acad. Sci. St. Louis,* XVI., 473–479.

hydrometers, one was obtained which fulfilled all the conditions of experimentation most perfectly. The hydrometer purchased of Arthur H. Thomas Company is one designed to test the specific gravity of liquids heavier than water. The scale reads from 0.995 to 1.065 and is divided into single units and half units (Fig. 1). For example, beginning at 1.0000, the divisions of the scale read as follows: 1.0005, 1.0010, 1.0015, 1.0020, 1.0025, 1.0030, 1.0035, 1.0040, 1.0045, 1.0050. The last figure is the next prominent figure on the scale printed in black letters. Altogether 140 separate readings can be made from this scale, and if the observer wished to test the salinity of the water of Salt Lake, Utah, the length of the scale would have to be increased to the point indicated in Fig. 1, and the size of the bulbs would have to be increased correspondingly. There are three bulbs blown in the hydrometer tube. The lower one is the sinker with metallic mercury. The middle one carries the mercury of the thermometer, which is inclosed in the third and upper bulb. The thermometer scales reads from — 5° C. to + 45° C., and is divided into degrees with the fifteenth marked in red. With this instrument temperature and specific gravity can be determined simultaneously.

Corrections to Readings.—In actual use, the experimenter finds that the hydrometric readings vary with the temperature of the water, and that to make the results harmonious all of the readings for specific gravity must be reduced to the uniform temperature of 15° C. No table exists by which the reduction can be made directly without calculation. Such a table for all temperature degrees and degrees of specific gravity is a desideratum. A mechanic rule, or sliding scale, might be constructed from which corrected readings might be taken directly by adjusting the movable parts of the scale to corresponding degrees of specific gravity and of temperature. In the absence of such a table and mechanic scale after a prolonged search through theoretic text-books of chemistry, the following one was discovered, which enabled me to standardize all of the readings made by the hydrometer by reference to the specific gravity at 15° C.

TABLE FOR THE REDUCTION OF SPECIFIC GRAVITY AT ANY TEMPERATURE TO THE SPECIFIC GRAVITY AT 15° C.

(Table B, Landolt-Börnstein Physikalisch-Chemische Tabellen, Berlin, 1905, page 323.)

"Reducktion der Dichte $d\frac{t}{4}$ auf die Dichte bei 15° nach den Beob. von Dittmar" (Challenger Exped.), Ekman (*Vetensk. Handl.*, 1870), Lenz u. Reszof (*Mém. Petersb.*, 1881), Thorpe u. Rücker (*Phil. Trans.*, 166, II; 1876), Tornoë (Norw. Atlantic Exped., 1880) berechnet von Makarof (J. Russ, *Phys. Chem. Ges.*, 23, 30; 1891). Auszug.

	0°	5°	10°	15°	20°	25°	30°
Dest Wasser	0.99988	99979	99974	99915	99828	99714	99577
Seewasser	1.00077	00087	00060	00000	99911	99796	99659
"	1.01130	01120	01075	01000	00898	00774	00630
"	1.02182	02152	02090	02000	01886	01751	01600
"	1.03228	03179	03102	03000	02876	02732	02572

This fact should be noted in connection with the use of the above table, viz., the specific gravity of a sample of sea water is the number representing its weight as compared with an equal volume of pure water at the same temperature. The latter is usually called 1.000 so that the specific gravity of a sample of sea water may be some such number as 1.025. The density is the weight in grams of one cubic centimeter of water at the temperature in situ (t°) compared with that of 1 c.c. of pure water at 40° C. It is usually expressed as $D\frac{t^\circ}{4^\circ}$. The salinity is the total weight in grams of the matter dissolved in 1,000 grams of water.

Mathematic Calculation.—Through the kindness of a graduate student, Mr. John C. Bechtel, to whom my thanks are due, I was relieved of the labor of making the mathematic calculations necessary to reduce the hydrometric readings to 15° C. His method of procedure is herewith given in a sample case.

To determine density at 15° C. of salt water whose density at 23° is 1.0155.

From the table we see that this corresponds to a solution whose density at 15° lies between 1.01 and 1.02.

We therefore find figures for density of salt water at 23°, if density at 15° is 1.01, and also if density is 1.02.

Density at 20° is 1.00898 for first and 1.01886 for second.

Density at 25° is 1.00774 for first and 1.01751 for second.

For first, the change in density for 5° is

$$1.00898 - 1.00774 = .00124.$$

For 3° it is $\frac{3}{5}$ of $.00124 = .00740$.

Hence density is $1.00898 - .00740 = 1.00824$ at 23°.

For second change in density for 5° is

$$1.01886 - 1.01751 = .00135.$$

For 3° it is $\frac{3}{5}$ of $.00135 = .00081$.

Hence density at 23° is equal to density at 20° — loss for 3° or 1.01805.

We now have densities at 15° as 1.01 and 1.02 as limits and from observations we see that at 23° the density of our solution is 1.0155.

We also have this proportion which will give a sufficiently approximate result:

If y is the density of this solution at 15°

$$\frac{y - 1.01}{1.02 - 1.01} = \frac{1.0155 - 1.00824}{1.01805 - 1.00824},$$

$$\frac{y - 1.01}{.01} = \frac{.00726}{.00981},$$

$$y = 1.01 + .0074,$$

$$y = 1.0174,$$

therefore density at 15° = 1.0174.

As the above computation is a rather long one and must be made for each of the actual readings obtained by the hydrometer, it has been thought advisable to give the entire set of original readings at various temperature and the corrected specific gravity at 15° C. Such a table may enable future workers in the same field to make their corrections at once by omitting the long computation otherwise necessary. The numbers in the first column of the table refer to the observations as recorded in the field note book and which have been added as subnumbers to the specific gravities placed on the map of Shark River and Bay which comprises Fig. 4 of the text.

TABLE GIVING HYDROMETRIC OBSERVATIONS ON SALT MARSH PLANTS OF NEW JERSEY WITH CORRECTIONS AT 15° BY MR. JOHN C. BECHTEL.

No.	Observed Sp. Gr.	Temp. °C.	Sp. Gr. at 15°.	No.	Observed Sp. Gr.	Temp. °C.	Sp. Gr. at 15°.
71	1.0155	23	1.0174	108	1.0005	14	1.0004
72	1.0160	23	1.0179	109	1.0025	24	1.0044
73	1.0180	21	1.0194	110	1.0025	20	1.0034
75	1.0170	20	1.0182	112	1.0120	28	1.0153
76	1.0175	19	1.0184	113	1.0035	25	1.0057
77	1.0260	29	1.02996	114	1.0015	25	1.0036
78	1 0150	22	1.0166	115	1.0000	23	1.0016
80	1.0165	19	1.0174	116	0.9990	25	1.0011
81	1.0160	26	1.0188	117	1.0005	21	1.0016
82	1 0105	21	1.0117	118	1.0160	27	1.0181
83	1.0090	20	1.0102	119	1.0165	26	1.0193
84	1.0020	20	1.0029	120	1.0160	27	1.0191
85	1.0010	20	1.0019	121	1.0415	24	—
86	1.0000	18	1 0005	—	1.0150	25	1.0175
87	1.0140	25	1.0164	124	1.0155	29	1.0192
88	1.0030	23	1.0046	125	1.0010	22	1.0024
89	1.0000	22	1.0014	126	1.0190	23	1.0210
90	1.0000	20	1.0009	127	1.0110	21	1.0022
91	1.0005	20	1.0014	128	1.0035	22	1.0049
92	1.0140	22	1.0156	129	1.0205	23	1.0225
93	1.0205	20	1.0217	130	1.0255	20	1.0267
94	1.0200	20	1.0212	131	1.0065	20	1.0075
95	1.0215	19	1.0224	132	1.0110	19	1.0180
96	1.0050	19	1.0058	133	1.0250	21	1.0265
97	1.0110	19	1.0118	134	1.0205	22	1.0222
98	1.0165	18	1.0172	135	1.0250	21	1.0265
99	1.0215	18	1.0223	136	1.0240	20	1.0252
100	1.0180	18	1.0187	—	1.0210	22	1.0224
101	1.0210	21	1.0224	137	1.0245	27	1.0278
102	1.0245	20	1.0257	138	1.0215	24	1.0238
103	1.0185	20	1.0196	139	1.0180	25	1.0205
104	1.0195	21	1.0209	140	1.0055	20	1.0065
107	1.0150	25	1.0175				

After having discussed the theoretic methods, we must next consider the actual study of the vegetation in the field by the use of the hydrometer.

Aids to Field Study.—The equipment which was carried into the field for the study of the edaphic conditions under which salt marsh vegetation grows was accommodated in a light basket and consisted of a meter measure, reading to decimeters, centimeters and millimeters; a narrow, but deep, glass cylinder to hold the water upon which the specific gravity determinations were made; a tin dipper to collect the water and a field note book. A narrow trenching spade was carried in the hand and by this spade it was possible to dig deep holes in the tough resisting marsh sod. The water for study was dipped either directly from holes in the marsh or taken from the ocean and open bays along the New Jersey coast. The hole was dug in all cases deep enough to allow the soil water to percolate into it, and upon this water the specific gravity readings were made. The region especially traversed in this way extended from Manasquan Inlet on the south to Sandy Hook Bay on the north, and thus an insight was obtained of the problems concerned in the distribution of the various species of salt marsh plants.

FIELD OBSERVATIONS AND DATA.

Altogether sixty readings were made with the first style of salinometer used. This type had such a small range of scale divisions that it was discarded as being too inaccurate for the purposes of the salt marsh investigation where the total salt content of the water increased, or decreased, by almost inappreciable amounts. Although many of these observations are of interest, they are not incorporated here. The second style of hydrometer was like the final one adopted, as to the divisions of the scale, but it lacked a thermometer. The data obtained by this hydrometer are considered here, but they are only of comparative value, because they lack the accuracy of the later readings which were made for both specific gravity and temperature. They are of value because they give habitat relationships not included in the more accurate data obtained later.

For the above reasons the field observations will be considered under two heads: (1) the readings made by the hydrometer without the thermometer, and (2) the readings which include both hydrometric and thermometric measurements.

Hydrometric Readings without Thermometer.—The readings which are numbered consecutively from 1–70 inclusive are arranged geographically as affording more interesting comparative data. They stand as follows: Beginning in the north readings were obtained along the Shrewsbury River, starting at the railroad bridge connecting Highland Beach with the Navesink Highlands proper. Plum Island, where the first measurements were made, is a small island back of the Sandy Hook peninsuula in Sandy Hook Bay. Undoubtedly, the water of this bay is less strongly saline because influenced by large fresh water rivers, such as the Hudson River.

55. *Spartina stricta maritima,* association on Plum Island. Sp. gr. 1.016.

56. *Baccharis halimifolia,* association with *Salicornia herbacea, Suaeda maritima,* water covering plants at high tide two inches deep. Sp. gr. 1.0155.

57. Salt Pond on Plum Island, fringed by *Spartina stricta maritima.* Sp. gr. 1.016.

59. Water from a hole two feet deep in tension strip between *Spartina stricta maritima* and *Baccharis halimifolia.* Sp. gr. 1.018.

60. Water from hole eighteen inches deep in middle of a *Spartina patens* association. Sp. gr. 1.020.

61. Water from a hole eighteen inches deep on the tension line between *Spartina patens* and *Spartina stricta maritima.* Sp. gr. 1.019.

62. Water from a hole on the tension line between *Spartina patens* and *Baccharis halimifolia.* Sp. gr. 1.0185.

64. Water from a hole eighteen inches deep in the middle of an association of *Salicornia mucronata, Limonium carolinianum, Spartina patens* and near by on the same level *Atriplex hastata, Suaeda maritima* and *Baccharis halimifolia.* Sp. gr. 1.003.

The following observations were made in ascending the Shrewsbury River toward Pleasure Bay:

53. Salt water at Highlands Pier. Sp. gr. 1.019.[5]

66. Water surrounding *Spartina stricta maritima* fringing beach in front of the Navesink Highlands. Sp. gr. 1.0185.

68. At the confluence of the Navesink and Shrewsbury rivers with a lot of *Fucus vesiculosus* attached to pilings and also *Spartina stricta maritima.* Sp. gr. 1.0185.

69 and 70. At this point water submerged an association of *Limonium carolinianum, Suaeda maritima, Spartina patens, Salicornia herbacea, Plantago maritima* and *Atriplex hastata.* Sp. gr. 1.018.

Ascending the Shrewsbury River, the head of navigation is reached at Pleasure Bay. From here to the head of the bay the

---

[5] For comparison, the sea water from the ocean at Belmar read sp. gr. 1.0215 at Temp. 20.6° C. corrected to 15° the sp. gr. = 1.0224.

water becomes gradually fresher and the salt marsh vegetation is replaced gradually by fresh water marsh plants.

32. Water from Pleasure Bay at the head of navigation. Sp. gr. 1.010.

33. Water from ditch two feet deep in middle of *Spartina patens* association. Sp. gr. 1.010.

35. Water at head of small ditch with *Scirpus pungens, Cicuta maculata, Scirpus robustus.* Sp. gr. 1.005.

37. Slue with *Baccharis halimifolia* and *Spartina stricta maritima.* Sp. gr. 1.010.

42. Hole in salt meadow on tension line between *Juncus Gerardi* (cut for hay) and an association of *Scirpus pungens, Pluchea camphorata, Atriplex hastata* and *Spartina patens* on the other side. Sp. gr. 1.005.

44. Water from bases of plants of *Typha angustifolia* and *Scirpus pungens.* Sp. gr. 1.015.[6]

45. Water at third bridge above Pleasure Bay in the middle of an association of *Spartina stricta maritima, Scirpus pungens, S. robustus.* Sp. gr. 1.005.

46. Above the fourth bridge in middle of a *Spartina stricta maritima* association. Sp. gr. 1.0005.

47. Here a pure association of *Scirpus robustus.* Sp. gr. 1.0005.

48. Association of *Zizania aquatica* and *Scirpus robustus.* Sp. gr. 1.0005.

50. Water from inner edge of an association of *Typha angustifolia* (tall), *Peltandra virginica* and *Cicuta maculata.* Sp. gr. 1.000.

51. Muddy cold water from a hole in an association of *Sagittaria latifolia* (=*S. variabilis*), *Cicuta maculata, Typha angustifolia, Polygonum sagittatum.* Sp. gr. 1.0015.

52. Water from channel under last bridge. Sp. gr. 1.0015.

The fact that such salt marsh species as *Spartina stricta maritima* mingles with fresh-water marsh species under almost fresh-water conditions is to be explained by the occasional inundation of such plants by more strongly saline water at exceptionally high tides, so that the exceptionally high tides enable the salt grass to persist surrounded by fresh-water marsh species. The salt marsh species can

---

[6] Probably due to evaporation.

withstand fresh water better than the fresh-water species can salt water. These latter plants are able also to withstand an occasional flooding, although normally they are controlled by fresh water. This is probably to be accounted for by the resistance of the leaves that surround the stem, while the roots are in practically fresh water, which saturates the ground and prevents the entrance of salt water into it for some time. The occasional flooding of salt water is not for a sufficiently long time to effect the character of the ground water in which the roots of such plants as *Sagittaria latifolia, Cicuta maculata* grow.

The observations at Belmar began with an estimation of the salinity of the ocean water. The readings from 4–19 are interesting because they were made while Shark River Inlet was closed to the sea by a sand bar.

FIG. 2. Basin-like slue along Fifth Avenue, Belmar, N. J., fringed by salt marsh vegetation and backed by forest trees. Several of the stations for hydrometric determinations were chosen along this shore.

2. Sea water from surf at Belmar. Sp. gr. 1.0215 at 20.6° C. (69° F.); corrected to 15° C. Sp. gr. = 1.0224.

4. Water in Shark River Inlet flooding *Spartina stricta maritima* association. Sp. gr. 1.015.

5. Water from channel opposite B Street, Belmar. Sp. gr. 1.0185.

7. Water from seaward end of marsh island in Shark River. Sp. gr. 1.017. With *Spartina stricta maritima.*

8. Water submerging *Juncus Gerardi.* Sp. gr. 1.016.

9. Water covering *Spartina patens.* Sp. gr. 1.017.

12. Water in large slue along Fifth Avenue, Belmar. Sp. gr. 1.016.

13. Water from bay at Casino Landing, where a rise of eighteen inches was noted after the inlet closed. Sp. gr. 1.0175.

These several readings show the condition of salinity when the inlet through which the tidal salt water enters Shark River is closed and the salt water thus inclosed is diluted by rain and river water until the river shows a perceptible rise of eighteen inches above the level of normal high tide. In such rivers the salt marsh vegetation for considerable periods of time is exposed to fresh water, which would ultimately control, if the inlet would remain permanently closed. But when the inlet is reopened the original conditions of salinity are restored by the tidal flow of sea water in and out of the landlocked bay. This is an interesting corroboration of the recent work of D. W. Johnson,[7] who believes that the indications of apparent subsidence are due to fluctuations in the tidal level due to a change in the configuration of the coast. During the closure of Shark River there was a rise of water level in the river which might account for the rise in the height of the salt marsh layers. After the causal influences had been obliterated, an examination of the layers of salt marsh soil would indicate, according to the older views, a total submergence of the coast line equal to the depth of newly formed marsh peat.

The observations on the salinity of the water at the western end of Newberry (Stockton) Lake, an arm of Manasquan River, are of interest as displaying the edaphic conditions which control the distribution of *Typha angustifolia.* The size of this plant is also directly conditioned by the amount of salinity as measurements later to be presented will show. However, if we begin near the outlet

---

[7] Johnson, D. W., "The Supposed Recent Subsidence of the Massachusetts and New Jersey Coasts," *Science,* N. S., XXXII., 721–723; Bartlett, H. H., "Botanical Evidence of Coastal Subsidence," *Science,* N. S., XXXIII., 29–31; Johnson, D. W., *Science,* XXXIII., 300–302.

of the lake where the cat-tails occur, the following series of readings are suggestive.

28. (Position I.) Association of *Typha angustifolia*—base of plant covered by water at high tide. Sp. gr. 1.0145.

27. (Position III.) *Typha angustifolia.* Sp. gr. 1.014.

26. (Position V.) *Typha angustifolia.* Sp. gr. 1.014.

25. Position VI.) *Typha angustifolia* with *Atriplex hastata.* Submerging water with sp. gr. 1.012.

24. (Position VII*a*.) Association of *Typha angustifolia, Atriplex hastata, Salicornia herbacea, Spartina stricta maritima.* Sp. gr. 1.0135.

23. (Position VII*b*.) Association of *Typha angustifolia, Scirpus lacustris, S. pungens.* Sp. gr. 1.0125.

22. Outer edge of *Typha angustifolia* association at the head of the lake. Sp. gr. 1.0115.

21. Head of Newberry Lake at inner edge of dense masses of *Typha angustifolia* with *Hibiscus moscheutos* (third lot). Sp. gr. 1.0050.

Influence of Saline Water on Typha angustifolia.—Before beginning a consideration of the data obtained by using the hydrometer and thermometer combined, it is important to consider the influence

FIG. 3. Cat-tail, *Typha angustifolia,* at the head of Stockton Lake near Sea Girt, N. J. The tall plants are growing at Position III.

of the varying salinity of the water upon the plants which are subjected to the different densities of salt water. For this purpose, I have chosen *Typha angustifolia* because it seems to show in a marked degree the influence of the variation in the saline environment. Six series of measurements were taken at this plant. Three series are based on plants from Stockton Lake and three upon plants from Pleasure Bay.

In all the measurements the height of the plant is measured to the top of the fertile part of the terminal spike. The upper sterile and staminate portion is included, but it is only temporarily present. Measurements are metric.

FIRST SERIES. *Typha angustifolia* FROM STOCKTON LAKE SHORE. (POSITION I.) SP. GR. 1.0145.

No.	Height of Plant.	Length of Spike, ♀.	Breadth of Spike, ♀.	Width of Third Leaf from Top.	No. of Leaves.		Sterile Part.
					Dry.	Green.	
1	.929	.087	.016	.004	6	6	.020
2	1.030	.075	.020	.006	6	5	.025
3	Broken	Broken	Broken	.004	7	5	—
4	1.353	.124	.020	.006	6	6	.015
5	1.015	.080	.019	.006	8	5	.018
6	1.119	.090	.018	.005	7	6	.026
8	1.100	.098	.022	.006	7	5	.022
7	1.124	.082	.020	.005	9	4	.027
9	1.008	.076	.018	.004	6	6	.020
10	.922	.075	.019	.005	4	6	.021

Series of heights: .922, .929, 1.008, 1.015, 1.030, 1.100, 1.119, 1.124, 1.353. Arithmetic mean = 1.066.

Length of spikes, ♀: .075, .076, .080, .082, .087, .090, .098, .124. Arithmetic mean = .089.

Breadth of spikes, ♀: .016, .018, .019, .020, .022. Arithmetic mean = .019.

SECOND SERIES. *Typha angustifolia* FROM STOCKTON LAKE SHORE. (POSITION II.) SP. GR. 1.014.

No.	Height of Plant.	Length of Spike, ♀.	Breadth of Spike, ♀.	Width of Third Leaf from Top.	No. of Leaves.		Sterile Part.
					Dry.	Green.	
1	1.398	.090	.023	.005	7	6	.023
2	1.288	.113	.023	.006	8	5	.015
3	1.430	.091	.021	.006	10	5	.032
4	1.473	.095	.025	.007	13	7	.023
5	1.545	.145	.024	.007	7	5	.013
6	1.293	.087	.022	.006	7	5	.015
7	1.572	.084	.023	.007	9	5	.025
8	1.413	.130	.025	.008	9	5	.024
9	1.300	.126	.023	.008	6	5	.021
10	1.560	.120	.025	.007	12	6	.020

Series of heights: 1.288, 1.293, 1.300, 1.398, 1.413, 1.430, 1.473, 1.545, 1.560, 1.572. Arithmetic mean = 1.427.

Length of spikes, ♀: .084, .087, .090, .091, .095, .113, .120, .126, .130, .145. Arithmetic mean = .108.

Breadth of spikes, ♀: .021, .022, .023, .024, .025. Arithmetic mean = .023.

Third Series. *Typha angustifolia* from Stockton Lake Shore (Position III.) at Head of Lake. Sp. gr. 1.005.

No.	Height of Plant.	Length of Spike, ♀.	Breadth of Spike, ♀.	Width of Third Leaf from Top.	No. of Leaves.		Sterile Part.
					Dry.	Green.	
1	2.026	.164	.023	.009	8	7	.016
2	2.108	.162	.025	.010	10	7	.024
3	1.862	.154	.018	.011	9	5	.016
4	1.882	.146	.022	.010	7	6	.026
5	1.803	.169	.022	.010	9	7	.031
6	1.789	.141	.025	.011	8	8	.022
7	1.668	.161	.020	.009	8	6	.027
8	1.678	.138	.021	.008	10	6	.028
9	1.920	.182	.024	.009	7	7	.030
10	1.815	.166	.026	.008	6	6	.012

Series of heights: 1.668, 1.678, 1.789, 1.803, 1.815, 1.862, 1.882, 1.920, 2.026, 2.108. Arithmetic mean = 1.885.

Length of spikes, ♀: .138, .141, .146, .154, .161, .162, .164, .166, .169, .182. Arithmetic mean = .158.

Breadth of spikes, ♀: .018, .020, .021, .022, .023, .024, .025, .026. Arithmetic mean = .022.

If we take the arithmetic means of the plant heights, lengths of pistillate spike portions and breadths of pistillate spike portions of the thirty plants taken from three separate localities along the shores of Stockton Lake, we will appreciate the influence of the saline conditions of the soil upon the relative size of the plants of these three sets.

Mean Dimensions of 30 Plants.

	Height of Plant.	Length of Spike, ♀.	Breadth of Spike. ♀.	Sp. Gr.
Position I.	1.066	.089	.019	1.0145
Position II.	1.427	.108	.023	1.0140
Position III.	1.855	.158	.022	1.0050

This table clearly shows that the cat-tails in fresh water are much taller than those growing under more saline conditions, and this applies not only to the heights of the plants, but to the other dimensions as well.

The next three series of *Typha angustifolia* were collected along the shores of Pleasure Bay under somewhat similar conditions to those along the shores of Stockton Lake.

FOURTH SERIES. *Typha angustifolia* IN SALT MARSH. SP. GR. 1.015.

No.	Height of Plant.	Length of Spike, ♀.	Breadth of Spike, ♀.	No. of Leaves.		Length of Sterile Part.
				Dry.	Green.	
1	.788	.110	.005	4	7	.025
2	.962	.209	.010	7	2	.035
3	.980	.100	.005	5	6	.040
4	.910	.119	.010	7	4	.035
5	.888	.135	.009	6	3	.020
6	.768	.096	.006	5	4	.063
7	.925	.120	.007	6	5	.100[8]
8	.857	.100	.009	6	4	.100[8]
9	1.005	.119	.006	3	6	.104[8]
10	.904	.130	.006	4	6	.010

Series of heights: .768, .788, .857, .888, .904, .910, .925, .962, .980, 1.005. Arithmetic mean = .898.

Length of spikes, ♀: .096, .100, .110, .119, .120, .130, .135, .209. Arithmetic mean = .127.

Breadth of spikes, ♀: .005, .006, .007, .009, .010. Arithmetic mean = .007.

FIFTH SERIES. *Typha angustifolia* NEAR MIDDLE PART OF UPPER PLEASURE BAY. SP. GR. 1.005.

No.	Height of Plant.	Length of Spike, ♀.	Breadth of Spike, ♀.	No. of Leaves.		Length of Sterile Part.
				Dry.	Green.	
1	.910	.102	.010	5	4	.029
2	1.030	.112	.012	6	4	.046
3	1.130	.128	.014	4	6	.034
4	.879	.090	.011	5	4	.027
5	.877	.089	.010	4	5	.042
6	.833	.087	.007	6	4	.045
7	.932	.081	.009	5	4	.040
8	1.102	.115	.014	5	5	.034
9	1.096	.114	.013	5	6	.030
10	1.180	.133	.015	5	5	.034

Series of heights: .833, .877, .879, .910, .932, 1.030, 1.096, 1.102, 1.130, 1.180. Arithmetic mean = .996.

Length of spikes, ♀: .081, .087, .089, .090, .102, .112, .114, .115, .128, .133. Arithmetic mean = .105.

Breadth of spikes, ♀: .007, .009, .010, .011, .012, .013, .014, .015. Arithmetic mean = .011.

---

[8] Measurements include sterile and staminate part of the spike.

Sixth Series. *Typha angustifolia* Collected at Head of Pleasure Bay. Sp. Gr. 1.000.

No.	Height of Plant.	Length of Spike, ♀.	Breadth of Spike, ♀.	No. of Leaves.		Length of Sterile Part.
				Dry.	Green.	
1	1.564	.145	.015	5	8	.028
2	1.642	.193	.016	5	6	.040
3	1.430	.147	.020	6	5	.032
4	1.688	.117	.018	6	6	.035
5	1.543	.148	.019	6	6	.031
6	1.467	.134	.018	5	5	.052
7	1.615	.144	.019	6	7	.032
8	1.307	.148	.020	5	6	.030
9	1.632	.173	.016	7	6	.021
10	1.657	.182	.015	5	5	.026

Series of heights: 1.307, 1.430, 1.467, 1.543, 1.564, 1.615, 1.632, 1.642, 1.657, 1.688. Arithmetic mean = 1.554.

Length of spikes, ♀: .117, .134, .144, .145, .147, .148, .173, .182, .193. Arithmetic mean = .154.

Breadth of spikes, ♀: .015, .016, .018, .019, .020. Arithmetic mean = .018.

Constructing a table of means of the last three series, we discover that the heights of the cat-tails and the dimensions of the spike increase with the decrease in the salinity of the water.

Mean Dimensions of 30 Plants.

	Height of Plant.	Length of Spike, ♀.	Breadth of Spike, ♀.	Sp. Gr.
Position IV.	.898	.127	.007	1.015
Position V.	.996	.105	.011	1.005
Position IV.	1.554	.154	.018	1.000

Now, if we combine the two tables which demonstrate the mean dimensions of the sixty measured plants collected from six widely diverse positions, we will see at a glance that *Typha angustifolia* when found in soil with saline conditions, as indicated by the specific gravity of the soil water, is reduced in size compared with other plants growing under more, or less, fresh-water conditions. All of the dimensions of the plants are influenced, but not in corresponding proportions, and it is also noteworthy that the cat-tails in a more saline soil are not only smaller in size, but show a more yellowish-green appearance than the taller, darker green plants controlled by fresh water.

TABLE SHOWING INFLUENCE OF SALINITY OF WATER ON THE DIMENSIONS OF SIXTY PLANTS OF *Typha angustifolia.* MEASUREMENTS IN METERS.

Habitat.	Position.	Specific Graivty.	Height of Plants.	Mean Height of Plants.	Length of Spikes, ♀.	Mean Length of ♀ Spikes.	Breadth of Spikes, ♀.	Mean Breadth of ♀ Spikes.
Most saline	I.	1.0145	1.066	.982	.089	.108	.019	.013
	IV.	1.0150	.898		.127		.007	
Medium saline.	II.	1.0140	1.427	1.211	.108	.106	.023	.017
	V.	1.0050	.996		.105		.011	
Fresh water.	III.	1.0050	1.855	1.710	.158	.156	.022	.020
	VI.	1.0000	1.554		.154		.018	

Having presented the results obtained by using the hydrometer without the attached thermometer, it next concerns this paper to discuss and tabulate the results obtained by the hydrometer so constructed as to combine with the hydrometer scale a thermometer, whereby density and temperature can be estimated at the same time. This enables us then to reduce all of our specific gravity determinations to the uniform temperature of 15° C., so that the second series of observations are far more accurate as giving the actual salinity of the water which bathes the roots of a number of typic salt marsh plants. In all of the following data, the corrected specific gravity determinations are placed within brackets.

OBSERVATIONS WITH HYDROMETER AND ATTACHED THERMOMETER.

The numbered data given below were collected at three localities convenient to Belmar, N. J., easily reached by trolley, viz., Manasquan Inlet, Wreck Pond and Shark River. The same plan was adopted of working from the most saline conditions of environment to the least saline conditions and the gradual change of the vegetation will be noted, if we follow the sequence of the numbered stations at which hydrometric readings were made.

81. Salt water in north arm Manasquan River. Thoroughfare fringed with *Spartina stricta maritima* and *Salicornia herbacea.* Sp. gr. 1.016; temp. 26°. [Sp. gr. 1.0188.]

71. Salt Creek at bridge back of Manasquan Life Saving Station. Meadow sod is here 45 cm. deep, with sand below. Sp. gr. 1.0155; temp. 23°. [Sp. gr. 1.0174.]

72. Salt Creek, nearer Manasquan Inlet, below the bridge. Here is *Spartina stricta maritima* associated with *Salicornia herbacea.* Sp. gr. 1.0160; temp. 23°. [Sp. gr. 1.0179.]

73. Hole dug in middle of *Spartina patens* association. Water reached at 82 cm. At same level of the marsh, but in a slightly different position were found *Salicornia herbacea* and *Limonium carolinianum.* Sp. gr. 1.018; temp. 21°. [Sp. gr. 1.0194.]

74. Hole dug in the middle of a patch of *Salicornia herbacea,* surrounded by *Distichlis spicata, Limonium carolianum.* No free water obtained after digging to a depth of 82 cm.

75. Water from ditch cut through *Spartina stricta maritima, Spartina patens, Salicornia herbacea.* Sp. gr. 1.017; temp. 20°. [Sp. gr. 1.0182.]

76. Hole 56 cm. deep in association of *Spartina stricta maritima, Salicornia herbacea, Distichlis spicata.* Sp. gr. 1.0175; temp. 19°. [Sp. gr. 1.0184.]

77. Small marsh pool (7 cm. deep) with *Spartina stricta maritima, Salicornia herbacea, Spartina patens.* The high specific gravity of the water in this pool due to strong evaporation. Sp. gr. 1.026; temp. 29°. [Sp. gr. 1.02996.]

78. At head of drainage ditch with *Spartina patens.* Sp. gr. 1.015; temp. 22°. [Sp. gr. 1.0166.]

79. Hole in *Juncus Gerardi* association which fringes *Spartina patens* inwardly and touches an association of *Baccharis halimifolia, Panicum virgatum, Solidago sempervirens.*

80. At head of drainage ditch with *Juncus Gerardi* (as in 79). Sp. gr. 1.0165; temp. 19°. [Sp. gr. 1.0174.]

82. Water from a drainage ditch in *Juncus Gerardi* association. Soil 49 cm. deep. Sp. gr. 1.0105; temp. 21°. [Sp. gr. 1.0117.]

The observations at Wreck Point were made on August 13, 1909, six days after the inlet, which had been closed for some time, was opened. The first three tests were made of the water from the pond proper without relating them to the nearby vegetation.

83. Water at trolley bridge. Sp. gr. 1.0090; temp. 20°. [Sp. gr. 1.0102.]

84. Water at railroad bridge. Sp. gr. 1.0020; temp. 20°. [Sp. gr. 1.0029.]

85. Water at carriage bridge. Sp. gr. 1.0010; temp. 20°. [Sp. gr. 1.0019.]

87. Water in *Spartina stricta maritima* association at high tide, just above the railroad bridge. Sp. gr. 1.0140; temp. 25°. [Sp. gr. 1.0164.]

88. Water in *Spartina stricta maritima* association at high tide, at carriage bridge. Sp. gr. 1.0030; temp. 23°. [Sp. gr. 1.0046.]

86. Stream entering Wreck Pond at tension line between salt marsh and fresh-water marsh at low tide. Here were found *Spartina stricta maritima* in broken patches being gradually replaced by *Scirpus lacustris, Scirpus pungens* and *Spartina polystachya.* Sp. gr. 1.0000; temp. 18°. [Sp. gr. 1.0005.]

89. Water in *Spartina stricta maritima* association along high bank fronted with *Panicum virgatum.* Sp. gr. 1.0000; temp. 22°. [Sp. gr. 1.0014.]

The observations begun on Shark River were delayed by a severe northeast shifting to southeast storm, August 17, 1909, so that the tides were exceptionally high and all of the typic salt marsh plants along Shark River were submerged. Unusual opportunities were presented, therefore, to determine the salinity of the water which flooded the salt marsh species.

93. Frontal association of *Spartina stricta maritima* near opening of the inlet. Sp. gr. 1.0205; temp. 20°. [Sp. gr. 1.0217.]

94. Somewhat back from inlet water covering *Spartina stricta maritima, Solidago sempervirens.* Sp. gr. 1.020; temp. 20°. [Sp. gr. 1.0212.]

95. All of the salt marsh associations of plants on the Belmar side of Shark River, such as *Spartina patens, Juncus Gerardi, Salicornia herbacea,* including *Atriplex hastata* and *Myrica carolinensis,* submerged excepting the tops of *Spartina stricta maritima* and the low sand dunes on which grow *Ammophila arenaria, Baccharis halimifolia, Solidago sempervirens.* Sp. gr. 1.0215; temp. 19°. [Sp. gr. 1.0224.]

97. Some distance back from the inlet along Fifth Avenue, Belmar, the following plants were found submerged: *Scirpus pungens, Cicuta maculata, Hibiscus moscheutos, Panicum virgatum,*

Baccharis halimifolia. Sp. gr. 1.011; temp. 19°. [Sp. gr. 1.0118.]

It will be seen by reference to the above observations that even the least typic of the salt marsh species which usually grow subjected to the influence of fresh water are placed occasionally under more trying conditions during exceptionally severe storms, when they are subjected to the action of almost pure sea water. On August 19, 1909, the storm having subsided, the normal flow of the tide in and out of the inlet was reëstablished and the following series of observations were then made.

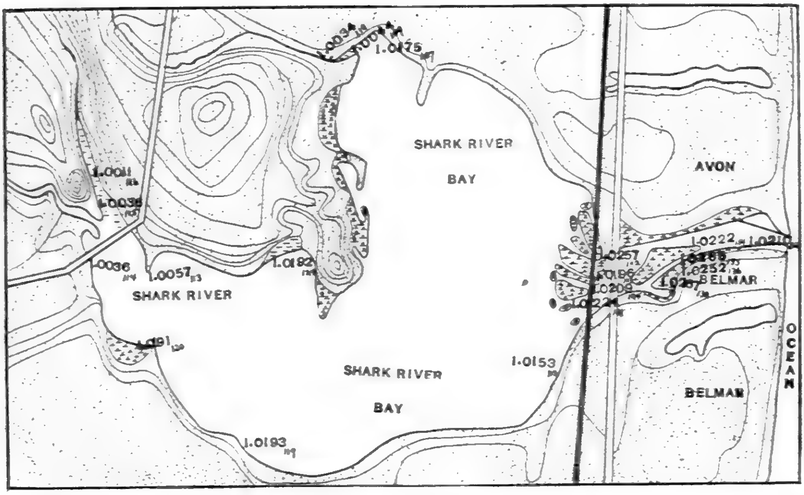


FIG. 4. Map of Shark River and Bay, N. J., showing stations at which hydrometric determinations of the salinity of the water were made. Numbers indicate specific gravities at the points directly under the first figure and the subnumbers indicate the observational stations as noted in the paper and in the original field note-book.*

126. Water from lagoon inside jetty at Shark River Inlet at high tide. Sp. gr. 1.0190; temp. 23°. [Sp. gr. 1.0210.]

127. Hole dug 20 cm. deep in an association of *Scirpus pungens, Solidago sempervirens, Spartina patens, Atriplex hastata, Suaeda maritima.* Water rising from a sandy gravel. Sp. gr. 1.0010; temp. 21°. [Sp. gr. 1.0022.]

130. Water from a hole 46 cm. deep in an association of *Juncus*

Gerardi, Limonium carolinianum. Sp. gr. 1.0255; temp. 20°. [Sp. gr. 1.0267.]

131. Water from hole 28 cm. deep in an association of *Distichlis spicata, Salicornia herbacea.* Sp. gr. 1.0065; temp. 20°. [Sp. gr. 1.0075.]

133. Water from a hole 50 cm. deep in a *Spartina stricta maritima* association. At 20 cm. a hard pan of gravel stones was reached, then a layer of sand was passed and at the bottom a hard gravel layer. Sp. gr. 1.025; temp. 21°. [Sp. gr. 1.0265.]

134. Water from Shark River. Sp. gr. 1.0205; temp. 22°. [Sp. gr. 1.0222.]

135. Water from a ditch along back of Shark River marsh, Belmar side, lined with *Spartina stricta maritima, Spartina patens, Salicornia herbacea.* Sp. gr. 1.0015; temp. 20°. [Sp. gr. 1.0024.]

136. Water from hole in marsh 61 cm. deep at the base of a clump of *Baccharis halimifolia* associated with *Distichlis spicata, Aster tenuifolius, Salicornia herbacea, Limonium carolinianum.* Top soil brown and loose, subsoil sandy. Sp. gr. 1.024; temp. 20°. [Sp. gr. 1.0252.]

137. Water covering surface of the marsh in middle of a *Distichlis spicata* association with *Spartina stricta maritima, Salicornia herbacea, Limonium carolinianum.* Sp. gr. 1.0245; temp. 27°. [Sp. gr. 1.0278.]

138. The last test recorded here was to determine if there was any difference in the salinity of the water between ebb and flow. Tide receding rapidly. Sp. gr. 1.0215; temp. 20°. [Sp. gr. 1.0238.]

101. Shark River Bay water in channel through salt marsh bounded by *Spartina stricta maritima* and *Spartina juncea.* Sp. gr. 1.021; temp. 21°. [Sp. gr. 1.0224.]

102. Hole dug in marsh 30 cm. deep in an association of *Spartina stricta maritima, Limonium carolinianum, Salicornia herbacea.* Sp. gr. 1.0245; temp. 20°. [Sp. gr. 1.0257.]

103. Hole dug in marsh 30 cm. deep in an association of *Distichlis spicata* and *Limonium carolinianum.* Sp. gr. 1.0185; temp. 20°. [Sp. gr. 1.0196.]

104. Hole dug 20 cm. deep in a pure association of *Juncus Gerardi.* Sp. gr. 1.0195; temp. 21°. [Sp. gr. 1.0209.]

107. Water at head of north arm of Shark River Bay (see map, Fig. 4) in middle of an association of *Spartina stricta maritima* and *Spartina patens*. Sp. gr. 1.0150; temp. 25°. [Sp. gr. 1.0175.]

FIG. 5. View of salt marsh island fringed with *Spartina stricta maritima* and covered by associations of *Spartina patens, Juncus Gerardi, Distichlis spicata,* etc. Shark River, New Jersey.

109. Contracted portion of the north arm of Shark River Bay, where *Spartina stricta maritima* breaks up into patches between which grow *Scirpus pungens, Spartina patens* and *Nymphæa odorata*. Sp. gr. 1.0025; temp. 24°. [Sp. gr. 1.0044.]

110. Water at base of a patch of *Spartina polystachya*. Sp. gr. 1.0025; temp. 20°. [Sp. gr. 1.0034.]

112. Water from hole 20 cm. deep at the base of an association of *Phragmites communis* (see Fig. 4). Sp. gr. 1.0010; temp. 28°. [Sp. gr. 1.0153.]

113. Water in upper portion of the south arm of Shark River Bay. Sp. gr. 1.0035; temp. 25°. [Sp. gr. 1.0057.]

114. Water from middle of *Spartina stricta maritima* associa-

tion, south arm of Shark River Bay at carriage bridge. Sp. gr. 1.0015; temp. 25°. [Sp. gr. 1.0036.]

115. Water from last extensive patch of *Spartina stricta maritima* merging with *Typha angustifolia.* Sp. gr. 1.0000; temp. 23°. [Sp. gr. 1.0016.]

116. Water tested at the head of the south arm of Shark River Bay (Fig. 6), where the vegetation becomes continuous and the patches of *Spartina stricta maritima* are divided by narrow lines of *Scirpus fluviatilis, Typha angustifolia, Zizania aquatica,* touching a forest growth of *Nyssa sylvatica, Sassafras variifolium, Pinus rigida, Quercus prinus, Q. alba.* Sp. gr. 0.9990; temp. 25°. [Sp. gr. 1.0011.]

FIG. 6. Association of *Spartina stricta maritima* in upper part of the south arm of Shark River Bay, showing blending and transition of salt-water and fresh-water vegetation.

119. Water 60 cm. deep at a point along south shore of Shark

River Bay with *Vallisneria spiralis* abundant. Sp. gr. 1.0165; temp. 26°. [Sp. gr. 1.0193.]

120. Hole dug in a marsh at base of a clump of *Peltandra virginica.* Sp. gr. 1.016; temp. 27°. [Sp. gr. 1.0191.]

124. Water from a marsh lagoon at base of a steep bluff subjected to evaporation between the daily tides. Lagoon surrounded by *Spartina stricta maritima.* Sp. gr. 1.0155; temp. 29°. [Sp. gr. 1.0192.]

Fig. 7. Clump of *Panicum virgatum* growing along shore of Stockton Lake controlled by fresh water.

The above observations give the geographic data upon which the study of the distribution of the salt marsh species has been based. It will be seen that proceeding from the ocean up the various bays and inlets there is a general decrease in the saltiness of the controlling water as revealed by the use of the hydrometer and the amount of salt which controls in general the habitats of the several species is graphically shown in the sketch map until a point is reached where the salt marsh vegetation mingles with that of the fresh water marshes until it is gradually replaced by vegetation controlled by fresh water (Fig. 7).

Sequence of Hydrometric Readings.

It is important to give now in sequence the various specific gravities corrected to 15° C. to which readings are appended, the name of the plant or the names of the plants subjected to that specific density of salt water. The subnumber indicates in all cases the number of the observation in the series previously given.

1.02996$_{77}$ *Spartina stricta maritima, Spartina patens, Salicornia herbacea.*

1.02780$_{137}$ *Distichlis spicata, Spartina stricta maritima, Salicornia herbacea, Limonium carolinianum.*

1.02670$_{130}$ *Juncus Gerardi, Limonium carolinianum.*

1.02650$_{133}$ *Spartina stricta maritima, Limonium carolinianum.*

1.02570$_{102}$ *Spartina stricta maritima, Limonium carolinianum, Salicornia herbacea.*

1.02520$_{136}$ *Baccharis halimifolia, Aster tenuifolius, Salicornia herbacea, Limonium carolinianum, Atriplex hastata.*

1.0224$_{101}$ *Spartina stricta maritima, Spartina patens,* ocean water from surf at Belmar.

1.0224$_{136}$ water in thoroughfare.

1.02170$_{93}$ water at high tide. Shark River Inlet, covering base of *Spartina stricta maritima.*

1.02090$_{104}$ *Juncus Gerardi.*

1.01960$_{103}$ *Spartina patens, Salicornia herbacea, Limonium carolinianum.*

1.01930$_{119}$ *Vallisneria spiralis.*

1.01920$_{124}$ *Spartina stricta maritima.*

1.01910$_{118}$ *Spartina stricta maritima, Scirpus pungens.*

1.01910$_{120}$ *Peltandra virginica.*

1.01880$_{81}$ water in channel connecting Manasquan River and Stockton Lake fringed with *Spartina stricta maritima, Salicornia herbacea.*

1.01820_{75} *Spartina stricta maritima, Spartina patens, Salicornia herbacea.*
1.01800_{132} *Spartina stricta maritima.*
1.01790_{72} *Spartina stricta maritima, Salicornia herbacea.*
1.01750_{107} *Spartina stricta maritima, Spartina patens, Distichlis spicata.*
1.01740_{80} *Juncus Gerardi.*
1.01660_{78} *Spartina patens.*
1.01640_{87} *Spartina stricta maritima.*
1.01530_{112} *Phragmites communis.*
1.01170_{82} *Juncus Gerardi.*
1.00750_{131} *Distichlis spicata, Salicornia herbacea.*
1.00650_{140} *Scirpus maritima, Pluchea camphorata.*
1.00490_{128} *Spartina stricta maritima, Spartina patens.*
1.00460_{88} *Spartina stricta maritima.*
1.00440_{109} *Spartina stricta maritima, Spartina patens, Scirpus pungens, Nymphæa odorata.*
1.00360_{114} *Spartina stricta maritima.*
1.00340_{110} *Spartina polystachya.*
1.00240_{135} *Spartina stricta maritima, Spartina patens, Salicornia herbacea.*
1.00240_{125} *Spartina stricta maritima.*
1.00220_{127} *Scirpus pungens, Solidago sempervirens, Atriplex hastata, Spartina patens, Suaeda maritima.*
1.00160_{116} *Spartina stricta maritima, Typha angustifolia.*
1.00160_{117} *Phragmites communis.*
1.00140_{89} *Panicum virgatum, Spartina stricta maritima.*
1.00140_{91} *Scirpus lacustris, Scirpus pungens, Spartina polystachya.*
1.0118_{97} *Hibiscus moscheutos.*
1.00110_{116} *Scirpus fluviatilis, Zizania aquatica, Typha angustifolia.*
1.00050_{86} *Spartina polystachya, Scirpus lacustris, Scirpus pungens, Spartina stricta maritima.*
1.00040_{108} iron-sulphur spring water.

Sequence of Salt Marsh Plants Arranged According to Maximum Density of Salt Water.

In order to make what follows more general and intelligible, the specific gravity of saline solutions at 15° C. and the corresponding percentages of sodium chloride in solution is displayed in the following table for converting specific gravities of salt solutions into per cent. of sodium chloride taken from Landolt-Börnstein, "Physikalisch-Chemische Tabellen," p. 322.

Per Cent.	$d\frac{15^\circ}{4^\circ}$	Per Cent.	$d\frac{15^\circ}{4^\circ}$
0.5	1.0034	3.0	1.0209
1.0	1.0064	3.5	1.0246
1.5	1.0100	4.0	1.0282
2.0	1.0137	4.5	1.0319
2.5	1.0173	5.0	1.0355

Now, if we place the salt marsh plants according to their ability to withstand degrees of salinity of water, we can appreciate better the factors which control their distribution in the bays and estuaries of the New Jersey coast. The first figures show the greatest degree of salinity to which the various species are subjected and the second number indicates the limit toward the fresh water end of the series. The range varies in the different species to a marked extent.

Spartina stricta maritima	1.02996–1.00140
Spartina patens	1.02996–1.00220
Salicornia herbacea	1.02996–1.00240
Distichlis spicata	1.02780–1.00750
Limonium carolinianum	1.02780–1.01940
Juncus Gerardi	1.02670–1.01170
Baccharis halimifolia	1.02520–
Aster tenuifolius	1.02520–
Atriplex hastata	1.02520–1.00220
Ocean water, Belmar	1.02240–
**Vallisneria spiralis*	1.01930–1.00000
Scirpus pungens	1.01910–1.00000
**Peltandra virginica*	1.01910–1.00000
**Phragmites communis*	1.01530–1.00160
**Hibiscus moscheutos*	1.01180–1.00500
Pluchea camphorata	1.00650–

Nymphæa odorata	1.00440–1.00000
Spartina polystachya	1.00240–1.00050

Solidago sempervirens	1.00220–
Suaeda maritima	1.00220–
Typha angustifolia	1.00160–1.00110
Panicum virgatum	1.00140–
Scirpus lacustris	1.00140–1.00050
Scirpus fluviatilis	1.00110–
Zizania aquatica	1.00110–1.00000

All of the plants *above the line* are able to withstand a maximum of over 1 per cent. of sodium chloride in the salt water, and may be reckoned as the true salt marsh species, while *Vallisneria spiralis, Hibiscus moscheutos, Phragmites communis*, and *Peltandra virginica* are excluded, because their habitat is frequently an inland, not a salt marsh one. All below the line, according to the accurate data presented for the first time, are not able to grow in salt water the sodium chloride content of which approximates 1 per cent.[9]

By this arrangement we are able to segregate the plants found on the New Jersey salt marshes, for although apparently occupying the same geographic position and growing under similar conditions of environment, yet we can divide them into salt marsh species, those that are adapted to a saline soil with from 1–4 per cent. of sodium chloride, and those less well adapted to a saline soil, but which are to be classed among the plants found in fresh-water swamps. Occasionally, as the list shows, we will meet with such non-saline plants in a typic saline environment. This is to be explained as in the cases of *Vallisneria spiralis, Hibiscus moscheutos, Phragmites communis*, and *Peltandra virginica* by their adaptation to more saline conditions. Again there are fresh-water marsh species found on salt marshes, but their presence is to be explained by the fact revealed by the hydrometer, that while the surface marsh soil may be strongly saline, the subsoil is controlled by fresh water which flows outward from the higher ground under the salt marsh sod. Into the subsoil controlled by fresh water the roots of a number of plants of fresh-water habitat grow, notwithstanding the fact that they are growing in the middle of a salt marsh. Appearances here are deceptive and the peculiar behavior of these plants perplexed me until the hydrometer showed the reason for the presence

---

[9] See preceding table of percentages and specific gravities with which the above figure may be compared.

of such plants on the salt marsh. The first eleven plants of the preceding list may be looked upon as true saline species, while the other plants of the list are those which are typically found under fresh-water conditions of environment. These plants have accommodated themselves to a soil of some salinity as tested by the hydrometer. On the other hand, the degree of accommodation of the typic salt marsh species is indicated. The following show the widest range of accommodation: *Spartina stricta maritima, Spartina patens, Juncus Gerardi,* while *Salicornia herbacea, Distichlis spicata, Limonium carolinianum* show a small range of accommodation. As a result one is justified perhaps in believing that this difference in the degree of accommodation accounts in part[10] for the general and controlling distribution of *Spartina stricta maritima, Spartina patens* and *Juncus Gerardi,* which are most prevailingly present in the salt marshes of the Atlantic coast, while *Salicornia herbacea, Limonium carolinianum,* with less power of accommodation and smaller size, are rarely controlling, but form small associations, or are intermingled with the other salt marsh species. The salt grass *Distichlis spicata,* although it never grows in areas of great extent, yet is usually found where it grows in nearly exclusive association. This power of accommodation seems to be an inherent property of protoplasm and it varies within wide limits for different kinds of plants. The lower plants seem to have a greater power of accommodation, the higher plants a less degree. Professor G. J. Peirce, of Stanford University, has undertaken to study the behavior of some ponds on the flat shore of San Francisco Bay into which salt water is pumped for the manufacture of salt. The water evaporates during the dry season, leaving an accumulation of salt on the bottom and sides of these ponds, and from a minimum specific gravity of 1.06000 in the rainy season the concentration rises in the course of three or four months until the specific gravity reaches 1.22500. A small crustacean (*Artemia*) and the larvæ of some flies are the only animals living in these brines, but there are unicellular plants, bacteria of various sorts, chromogenic and other kinds, *Chlamydomonas*-like

---

[10] The vegetative habits of these plants with powerful rootstocks and methods of seed distribution must also be considered as important factors.

algæ, both green and brown, which are found in various stages of their existence at different times in these ponds.[11]

Sections of Salt Marsh Soil.

A detailed study of the various salt marsh soils along the New Jersey coast was begun coincidently with a study of the salt content of the soil by means of the hydrometer, but these observations have not been carried to completion. A few notes on some of the conditions observed may not be out of place. Taking a sample of the muck soil in the middle of an area of the Manasquan salt marsh covered with *Spartina patens,* we find its total depth to be about 104 cm. From this a block of peat was cut 57 cm. thick. The first 21 cm. at the top was of one color, consisting of 12 cm. of a fibrous root material and 9 cm. of a less strongly fibrous layer. The first 12 cm. represent the remains of the cover plant, for this part gave rise to new plants of *Spartina patens* when the soil was laid flat along the side of the cut. Below these upper fibrous layers followed a lighter brown fibrous layer, 14 cm. thick, and then 7 cm. of a black fiberless layer followed by 16 cm. of a brown fibrous layer where the hollow pipe-stem-like remains of the rootstocks of *Spartina stricta maritima* occur. This section of peat clearly indicates a succession of vegetation types. The marsh deposits began in submerging salt water, because the remains of *Spartina stricta maritima* are found in the lower layers. Then sand and clay material was deposited on which *Spartina patens* began to build up successive layers of peat. This was formerly explained by a change of coast line, but the suggestions of Johnson (see *ante*) that it may indicate a change of tidal level seems to be worthy of consideration in a study of the deposits of peat in the salt marshes of New Jersey, where the coast line is under constant change so as to profoundly influence the height of the tides in the rivers and embayments along the shore.

Economic Considerations.

The salinity of the water, which can be determined by the hydrometer, is the determining factor in the distribution of salt marsh

---

[11] MacDougal, D. T., "Annual Report of the Director," Dept. Bot. Research Carnegie Institution of Washington, 1910, 56.

plants, although the texture of the soil, its aëration and the lines of marsh drainage are influential factors. In the reclaiming of these salt marshes, as has been done so successfully along the Bay of Fundy[12] in Nova Scotia, the hydrometer affords a ready means of determining accurately what amelioration has been secured by ditch drainage. The same method of research can be applied to the study of the alkali soils in many parts of the world, especially in our western states, and the farmer can test the presence or absence of salts and their relative amounts in the soil.

Some years ago Scofield[13] determined the salt-water limits of wild rice, with a view to ascertaining the areas which could be successfully devoted to the cultivation of this valuable but long-neglected food grass. After investigations by means of the electric bridge along Chesapeake Bay and the Potomac River, Scofield assumed that the salt-water limit of wild rice is approximately represented by 0.03 of the normal solution of sodium chloride, while the concentration of the water of Chesapeake Bay is about 0.28 of a normal solution of sodium chloride. So that in establishing cultures of wild rice along the coast streams it is highly important that the concentration of the water covering these areas be determined either by the electric method or by the hydrometer, which is simple and equally applicable. Similarly Fraps[14] determined that 0.3 per cent. of salt is dangerous to the true rice plant where rice farms along the coast are supplied with water pumped from streams occasionally subjected to salt water influences.

The distribution of animals is also profoundly influenced by the salinity of the water. Occasionally extensive oyster beds are ruined by flooding with fresh water, and the oysterman can readily determine the influential density of the water which covers his submerged plantation by means of the hydrometer. Two years ago the following was printed in the Trenton *Evening Times* of Friday, August

---

[12] Harshberger, John W., "The Reclamation and Cultivation of Salt Marshes and Deserts," *Bulletin Geographical Society of Philadelphia,* July, 1907.

[13] Scofield, Carl S., "The Salt Water Limits of Wild Rice," Bull. 72. U. S. Bureau of Plant Industry, 1905.

[14] Traps, G. S., "The Effect of Salt Water on Rice," Texas Agricultural Experiment Station, Bull. 122, June, 1909.

27, 1909, and this excerpt shows the bearing of this study upon the Delaware River fisheries. I quote in full:

> Millions of crabs are moving up the Delaware River from the sea. Their coming is due to the protracted drought, which has reduced the downward strength of the current in the river and caused the saline waters of the Atlantic to reach the harbor of Philadelphia. For the first time in many years the Delaware River is brackish as far as Gloucester, the result of which is that mullet, sea bass and porpoises may be seen every day above Chester. The crabs which are the kind generally caught off the coast are to be found everywhere from the Delaware Breakwater to Philadelphia. For the first time on record, a big catch was made yesterday off the Point House piers, below Greenwich Point in the lower section of the city. Oldmans Creek, Raccoon Creek on the New Jersey side of the river and other tributaries of the river are alive with fish and crabs, and every day fishermen are bringing to market big hauls made in sight of Dock Street market.
>
> Boilers on river steamboats have to be watched carefully, as the salt in the water causes constant foaming and more than ordinary diligence is required by marine engineers to prevent serious results to vessels for which they are responsible.

In the latter case the use of an hydrometer, or salinometer would indicate the dilution at which the foaming in the boilers no longer took place and thus its use in such emergencies of navigation becomes of great importance.

In the following bibiliography not all of the papers cited deal directly with salt marshes, but they treat of the influence of saline solutions in general upon animals and plants. In this list will be found many important papers which represent the most modern expression of opinion upon the accommodation of organisms to varying degrees of saline concentration.

BIBLIOGRAPHY.

Bartlett, H. H.

1909. Submarine Bog at Woods Hole. *Rhodora*, XI.: 221–238, December, 1909.

1911. Botanical Evidence of Coastal Subsidence. *Science*, N. S., XXXIII.: 29-31, January 6, 1911.

Cannon, W. A.

1908. On the Electric Resistance of Solutions of Salt Plants and Solutions of Alkali Soils. *The Plant World*, XI.: 10–14, January, 1908.

Casu, A.

1907. Contribuzione allo studio della flora delle saline di Cagliari Parte III Resistenza fisiologica della flora delle saline all' azione del sale marino. *Annali di Botanica*, V.: 273–354 (1907). Review in *Botanical Gazette*, XLIV.: 234, September, 1907.

Clark, J. F.

On the Toxic Effect of Deleterious Agents on the Germination and Development of certain filamentous Fungi. *The Botanical Gazette,* XXVIII.: 289–327; 278–404 with extensive bibliography.

Coast Advertiser, The.

1910. Closing of Shark River Inlet is Ruining the Oyster Beds, Belmar, N. J., Friday, July 1, 1910.

Copeland, Edwin Bingham.

1897. The Relation of Nutrient Salts to Turgor. *The Botanical Gazette,* XXIV.: 399–416, December, 1897.

Dandeno, James B.

1901. The Application of Normal Solutions to Biological Problems. *The Botanical Gazette,* XXXII.: 229–237, with bibliography. (Reply by Louis Kahlenberg, *Bot. Gaz.,* XXXII.: 437–439, December, 1901.)

Davis, R. O. E., and Bryan, H.

1910. The Electrical Bridge for the Determination of Soluble Salts in Soils. Bull. 61, U. S. Bureau of Soils, 1910.

Dittmar, William.

1884. Report on Researches into the Composition of Ocean Water collected by H. M. S. Challenger during the Years 1873–1876. Challenger Report, Physics and Chemistry, I. (1884): 25.

Drabble, Eric, and Lake, Hilda.

The Osmotic Strength of Cell-sap in Plants growing under Different Conditions. *The New Phytologist,* IV.: 189.

1907. The Relation between Osmotic Strength of Cell-sap in Plants and their Physical Environment. *Bio-Chemical Journal,* II. (1907).

Duggar, B. M.

The Relation of Certain Marine Algae to Various Salt Solutions. *Transactions Academy of Science of St. Louis,* XVI.: 473–489.

Fraps, G. S.

1909. The Effect of Salt Water on Rice. Bull. 122, Texas Agricultural Experiment Station, June, 1909.

Ganong, W. F.

1903. The Vegetation of the Bay of Fundy Salt and Diked Marshes; an Ecological Study. *The Botanical Gazette,* XXXVI.: September, November, 1903.

Harshberger, J. W.

1907. The Reclamation and Cultivation of Salt Marshes and Deserts. *Bulletin Geographical Society of Philadelphia,* July, 1907.

1909. The Vegetation of the Salt Marshes and of the Salt and Fresh Water Ponds of Northern Coastal New Jersey. *Proceedings Academy Natural Sciences of Philadelphia,* 1909: 373–400, with 6 figures.

Heald, F. D.

On the Toxic Effect of Dilute Solutions of Acids and Salts upon Plants

Hill, T. G.

Observations on the Osmotic Properties of the Root Hairs of Certain Salt Marsh Plants. *The New Phytologist,* VII.: 133–142 (four tables and text figures, 21–24).

1909. The Bouche d'Erquy in 1908. *The New Phytologist.* VIII.: 97–103, March, 1909.

Jensen, G. H.

1907. Toxic Limits and Stimulation Effects of some Salts and Poisons on Wheat. *The Botanical Gazette,* XLIII.: 11–44, January, 1907, with 3 pages of bibliography.

Johnson, D. W.

1910. The Supposed Recent Subsidence of the Massachusetts and New Jersey Coasts. *Science,* N. S., XXXII.: 721–723, November 18, 1910.

1911. Botanical Evidence of Coastal Subsidence. *Science,* N. S., XXXIII.: 300–302, February 24, 1911.

Kahlenberg, L.

1906. On the Nature of the Process of Osmosis and Osmotic Pressure with Observations concerning Dialysis. *Journ. Phys. Chem.,* X. (1906): 141–209, published in *Transactions Wisconsin Academy,* XV. (1906): 209–272. (Review in *Bot. Gaz.,* XLII.: 72, July, 1906.)

— with Austin.

1900. Toxic Action of Various Substances on Seedlings. *Journal Phys. Chemistry,* IV. (1900): 533–537; 553–569. (Review in *Bot. Gaz.,* XXX.: 358, November, 1900.)

— and True, Rodney H.

On the Toxic Effect of Dilute Solutions of Acids and Salts upon Plants. *The Botanical Gazette,* XXII.: 81–124.

Krönig, B., and Paul, T.

1897. Die Chemischen Grundlagen der Lehre von der Giftwirkung und Disenfektion. *Zeits. Hyg. Inf. Krankh.,* XXV. (1897): 59.

Landolt-Börnstein.

1905. Table for Converting Specific Gravity of Salt Solution into Percent Sodium Chloride. Physikalisch-Chemische Tabellen, 1905: 322.

Lillie, R.

1901. On the Differences in the Effects of various Salt Solutions on Ciliary and Muscular Movements in Arenicola Larva. *American Journal of Physiology,* V. (1901): 55–85.

1909. On the Connection between Stimulation and Changes in the Permeability of Plasma Membranes of the Irritable Elements. *Science,* N. S., XXX.: 245–249, August 20, 1909.

Lipman, J. G.

1906. Reports of the Soil Chemist and Bacteriologist. Reports New Jersey Experiment Station, 1906, 1907.

Loeb, J.

1900. Ueber die Bedeutung der Ca- und K-Ionen für die Herzthätigkeit. *Pflüger's Archiv,* LXXX. (1900) : 229–332.

1900. On ion-proteid Compounds, etc., I. *Amer. Journ. Physiol.,* III. (1900) : 327–338.

1900. On the Different Effects of Ions, etc. *American Journal of Physiology,* III. (1900), 383–396.

1902. Studies on the Physiological Effects of the Valency, etc., of Ions, I. *American Journal of Physiology,* VI. (1902) : 411, 433.

Ueber die relative Giftigkeit von destillirtem Wasser, Zuckerlösungen, etc. *Pflüger's Archiv,* 97 : 394–409.

1905. Studies in General Physiology, II. (1905), 572, 584, 715.

1906. The Stimulating and Inhibiting Effects of Mg and Ca upon the Rhythmical Contraction of a Jellyfish (Polyorchis). *Journal of Biological Chemistry,* I. (1906) : 427–436.

Loew, Oscar.

Notes on Balanced Solutions. *The Botanical Gazette,* XLVI. : 302.

1903. The Physiological Rôle of Mineral Nutrients in Plants. Bull. 45, U. S. Bureau Plant Industry, 1903.

Magowan, Florence N.

1908. The Toxic Effect of Certain Common Salts of the Soil on Plants. *The Botanical Gazette,* XLV. (1908) : 45–49.

Mayer, Alfred G.

1907. The Cause of Rhythmical Pulsation in Scyphomedusæ. Proceedings Seventh International Zoological Congress, Boston, 1907.

1909. The Relation between Ciliary and Muscular Movements. *Proceedings of the Society of Experimental Biology and Medicine,* VII. (1909) : 19–20.

1909. On the Use of Magnesium in Stupefying Marine Animals. *Biological Bulletin,* XVII. : 341, October, 1909.

Meltzer, S. J., and Auer, J.

1908. The Antagonistic Action of Calcium upon the Inhibitory Effect of Magnesium. *American Journal of Physiology,* XXI. (1908) : 403.

Olsson-Seffer, Pehr.

Relation of Soil and Vegetation on Sandy Sea Shores. *The Botanical Gazette,* XLVII. : 85–126.

Osterhout, W. J. V.

1906. The Resistance of Certain Marine Algae to Changes in Osmotic Pressure and Temperature. Publications of the University of California, II. : 1906, No. 8.

1906-7. On the Importance of Physiologically Balanced Solutions for Plants. *The Botanical Gazette,* XLII. (1906) : 127–134; XLIV. (1907) : 259–272.

Osterhout, W. J. V.

1906. Extreme Toxicity of Sodium Chloride and its Prevention by other Salts. *Journal of Biological Chemistry* (1906) : 363–369.

1900. Die Schutzwirkung des Natriums für Pflanzen. *Jahrb. Wiss. Bot.*, XLVI. (1900): 121–136, figs. 3.

1909. On the Similarity in the Behavior of Sodium and Potassium. *The Botanical Gazette,* XLVIII. (1909): 98–104.

Oswald, W.

1905. Versuche über die Giftigkeit des Seewassers für Süsswassertiere. *Pflüger's Archiv,* CVI. (1905): 568–598, pls. 2–7.

Scofield, Carl S.

1905. The Salt Water Limits of Wild Rice. Bull. 72, U. S. Bureau of Plant Industry, 1905.

Smith, John B.

1902. The Salt Marsh Mosquito. Special Bull. T, Agricultural Experimental Station, N. J., July 8, 1902.

1907. The New Jersey Salt Marsh and its Improvement. Bull. 207, N. J. Agricultural Experiment Station, November 14, 1907.

Stevens, F. L.

1908. The Effect of Aqueous Solutions upon the Germination of Fungous Spores. *The Botanical Gazette,* XXVI.: 377–406, December, 1908.

Transeau, Edgar N.

1908. The Relation of Plant Societies to Evaporation. *The Botanical Gazette,* XLV.: 217–231, April, 1908.

True, Rodney H.

1898. The Physiological Action of Certain Plasmolyzing Agents. *The Botanical Gazette,* XXVI.: 407–416, December, 1898.

— and Oglevee, C. S.

1905. The Effect of the Presence of Insoluble Substances on the Toxic Action of Poisons. *The Botanical Gazette,* XXXIX.: 1–21, June, 1905.

Wahl, Robert, and Henius, Max.

1902. Comparative Table of Beaumé Degrees and Specific Gravity according to Bourgougnon. American Handy Book of the Brewing, Malting and Auxiliary Trades (second edition), 1902: 1156.

Warming, Eug.

1897. Halofyt-Studier. Mem. de l'Acad. Roy. Sci. et des Lettres de Danemark. Copenhagen 6me Ser. Sect., t. VIII., No. 4, 1897.

1908. Dansk Plantevaekst. I., Strand vegetation. 8vo, pp. vi + 325, figs. 154, Copenhagen and Christiania, 1906. (Review in *Bot. Gaz.*, XLV.: 55–56, January, 1908.)

West, G. S.

1904. The British Fresh-water Algæ. 1904: 55.

Willis, Clifford.

1911. Alkali Soils. Bull. 126, South Dakota Agricultural Experiment Station, April, 1911.

EXPLANATION OF PLATES.

Plate XX.

Fig. A. Typic salt marsh near Avalon, N. J., showing prominent growth of salt marsh grass, *Spartina stricta maritima,* fringing open thoroughfare and low sand dunes covered with red cedar, *Juniperus virginiana,* in the distance.

Fig. B. Salt marsh near Avalon, N. J., intersected by tortuous channels at head of a bay blending with the deciduous forest in the center and left.

Plate XXI.

Salt marsh at Somers Point, N. J., with open channel blending with an association, or strip of switch grass, *Panicum virgatum,* which fronts a forest growth of red cedar, *Juniperus virginiana,* holly, *Ilex opaca,* and pitch pine, *Pinus rigida.*

FIG. A

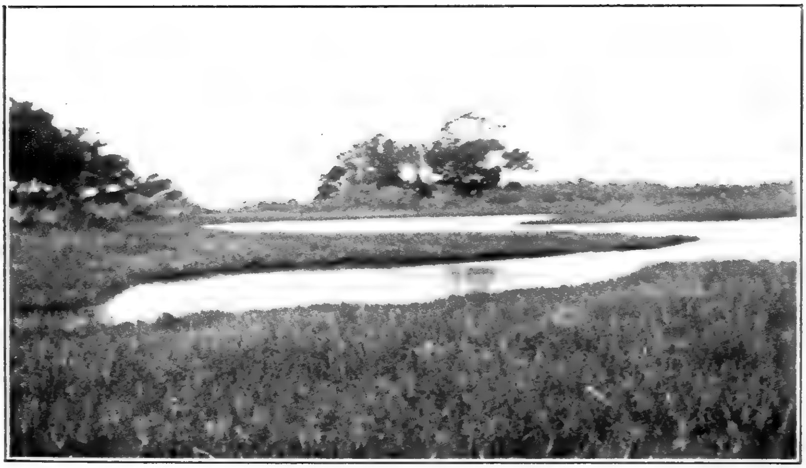


FIG. B

Salt Marshes near Avalon, N. J.

Salt Marsh at Somers Point, N. J.

THE COST OF LIVING IN THE TWELFTH CENTURY.

By DANA C. MUNRO.

(*Read April 20, 1911.*)

As yet it is impossible to make any statement of the average cost of living in the twelfth century in any country of Europe. Much material is accessible in the Pipe Rolls and similar accounts, in the charters and other legal documents, of which so many thousands have been preserved; but no one has attempted a careful statistical study for this period. Thorold Rogers began his work on the prices in England with the year 1259; Curschmann collected some items for Germany during the years 1190–1225; Lamprecht gathered some data on prices for France in the eleventh century; and there are some other partial statements. Whether it will be possible to make an accurate estimate can only be ascertained after minute and extended examination of the accessible material.

But it is possible to gather some examples which are illuminating. In 1181 the former mistress of Henry II., and the mother of Geoffrey, was receiving an annual pension of 20 marks or 13 pounds 6s. 8d. In the same year the "Archbishop of Norway," who was then visiting in England, was allowed by the king 10s. a day for the expenses of himself and suite. The same amount was allowed in 1180 to the Abbot of Glastonbury. Evidently 10s. a day was considered sufficient for the expenses of a high church official and his attendants; probably the pension of 20 marks, or a little over 8d. a day, was sufficient for the expenses of a lady and her servant. This is rendered more probable by the fact that Richard the Lion-hearted, when he hired vessels for his crusade, had to pay only 2d. a day to sailors and 4d. a day to the captains. In 1201 the French ambassadors made a treaty with Venice, by which the latter agreed to carry the crusaders across the sea and furnish them with provisions for a year on the payments of 2 marks for each man and 4 marks for each horse.[1]

The prices current at the time throw some light upon the above: in Lincolnshire, in 1181, a goose cost a penny; a sheep, 4d.; an ox, 3s.; a farm horse, 5s.; a pig, 1s.; scarlet cloth, 6s. 8d. an ell; fine green cloth, 3s.; gray, 1s. 8d.; blankets, 3s. an ell. Thus, if Geoffrey's mother had expended her pension in buying live stock, she could have bought 25 horses, 25 oxen, 25 pigs, 25 sheep, and 100 geese; or if she had preferred, she could have bought 50 yards of scarlet cloth, say, enough for four or five dresses in the fashion of the day. The difference in cost between the necessities and the luxuries is very noticeable.

While it is impossible to state the exact cost of living, it is certain that this cost was increasing rapidly for the upper classes, and probably for the middle classes. The rise was due to a variety of causes, and it would be easy to make out a long list, including war, famine and pestilence; but two appear to have been especially important. First, there was a change in the standard of living. Acquaintance with the east through the crusades led to a desire for the luxuries which were produced at Constantinople and in Asia. Before the first expeditions to the Holy Land spices had been used only to a slight extent in the west of Europe. At the capture of Cæsarea, in 1101, the Genoese received over 16,000 pounds of pepper as a portion of their booty. This, and other spices, soon came into general use and were imported into western Europe in great quantities. The references in the literature of the day point conclusively to the widespread use of spices and their great popularity.

The costly fabrics of the East were also in great demand, and the heroines of the poems are frequently described as clad in the stuffs made in Constantinople, or farther eastward. No lady was considered well-dressed by the poet unless she had garments imported from the East. Oriental rugs became so fashionable that a manufactory for them was established in Paris. Glassware, sugar,

---

[1] De Wailly estimates a mark as equivalent to 52 francs at the present day: that is, two marks would be equivalent, roughly, to 104 francs, or $20. Of course this is entirely misleading, as it would be impossible to furnish transportation and food for a year for $20 per individual.

dye-stuffs, and other oriental products were coveted and secured as far as possible.

Life as a whole became more luxurious. In Germany four meals a day supplanted the three of an earlier period; and the ideal hero was a mighty trencher-man. According to the Pseudo-Turpin, Charles the Great ate "a whole quarter of a lamb, two fowls, a goose, or a large portion of pork; a peacock, a crane, or a whole hare" at a meal. Luxury in dress, at least among the middle classes, was not confined wholly to the oriental products. Fashion began its despotic sway for Germany and other parts of western Europe in the twelfth century, and those who could not afford the Byzantine stuffs might in their domestic weaves imitate the prevailing styles of long trains and full sleeves almost sweeping the ground. Shoes for both men and women changed in style almost every year; sometimes the toes were long and pointed, extending up toward the knees; at other times, short and broad. Other items of extravagance might be mentioned, such as the enormous head-dresses, wigs and other false hair; but enough has been indicated.

Another great source of expenditure was building. The monarchs spent large sums on their castles and residence halls, and the nobles and citizens followed their lead. Palaces, cathedrals, fortresses, country houses, town halls, hospitals and other edifices were going up in all the leading centers. The cost of building was greatly increased by the general substitution of stone for wood, and by the frequent use of lead for the roofs. Great quantities of this metal were exported from England to various places in France, and even to other parts of Europe.

The second cause of the rise in the cost of living was the increase in the amount of money available. Western Europe was just changing from *Natural-* to *Geldwirtschaft.* The author of the "Dialogus de Scaccario," who wrote about the beginning of the last quarter of the twelfth century, says that he had been told of the former custom by which all payments to the treasury were made in kind, and that he had seen a man who had witnessed the bringing in of the provisions from the various parts of the country. In fact, in the reign of Henry I. of England the sheriffs obtained their receipts for so many fowls, eggs, ducks, hogs, oxen, etc., or so much beer, wool, corn or other grain. But this practice had not wholly gone out under Henry II., in spite of the statement of the author of the "Dialogus." In the Pipe Roll of 1181–82, for instance, there is the record of the payment by Cheshire of forty cows in addition to their money dues. On the whole, however, all through western Europe payments in money were superseding payments in kind, and this was due mainly to the increase in the amount of the circulating medium.

Large numbers of coins were brought home from the East. In the Scandinavian lands it is said that more than 25,000 Arabic coins have been dug up in recent times. In the literature of the twelfth century, Arabian gold is very frequently referred to and is contrasted with the lighter-colored gold of the West. At the capture of Cæsarea in 1101 (when the pepper was obtained) the Genoese secured over 400,000 *solidi* of Poitou, and they received only one third of the booty. The crusaders were always keen for gold. Whenever they won a victory they sought anxiously for the precious metals; frequently they cut open the bodies of the slain enemies, because they believed the latter had swallowed their coins; sometimes they made great heaps of the bodies and burned them in order to obtain the gold which had been secreted. Many similar facts might be cited which would illustrate the enrichment of the West by the coins brought in from the East.

Far more important, probably, was the coinage and use of the precious metals which had previously been hoarded, especially in ornaments and works of art. Until about the close of the eleventh century, there had been comparatively little occasion for a large stock of ready money, but when the crusaders made their preparations for their long expeditions they needed large sums of money, both for their equipment and for their journey. Even the participants in the so-called Peasants' Crusade took enough money with them to pay all the expenses for several months, when they marched under the leadership of Walter the Penniless and Peter the Hermit. Because of the demand for coins, the mints of the West were very active in the twelfth century. Under Henry I. of England, 94 minters were busy. In 1125 all the 94 were called up for punishment on the ground that they had debased the coinage, and each one had his right hand struck off. Under Henry II. there was a great amount of coining, of which the details may be followed in the Pipe Rolls, as far as they are accessible. In addition, instruments of credit came into use, especially bills of exchange, which greatly increased the amount of capital. The Templars in their house at Paris received deposits, and gave orders upon their house in Jerusalem. In doing this, they were probably imitating the example of the Jews, who had long used such papers; and we find the example of the Templars, or of the Jews, imitated by others, so that, *e. g.,* by 1188 bills of exchange had become very common in Hamburg.

The extravagance of the age is well depicted in the literature. The knightly hero is always lavish in his gifts and entertainments, as well as in his attire. Sumptuous banquets, where the boards literally groaned under the weight of the dishes, were the fashion. Large stone castles were built and richly adorned, and in these the number of attendants increased greatly. The armor became more costly; the legal expenses, from which the nobles were never free, mounted up; but the main source of out-go was the necessity of keeping up the style of living demanded by the fashion of the day. Consequently the knight had to spend much more, and the minstrels sang only of those who were generous. Even the fathers and mothers in their advice urged their sons to give freely and never to be niggardly.

There were great opportunities to acquire wealth. One of the men who improved his chances to the best advantage was Suger. He was of peasant stock and was educated at the Monastery of St. Denis, where he became intimate with the prince who later was known as Louis VI. of France. The intimacy always continued, and after the death of Louis VI., Suger, who was then Abbot of St. Denis, acted as regent of France during the absence of Louis VII. on the crusade. During the time of the king's expedition, Suger paid all the expenses of the kingdom of France out of his own fortune. He had previously restored and beautified the church of St. Denis at his own expense. And he still had enough wealth, so that in the last year of his life he planned to equip and finance a crusade wholly from his own money. Suger was able to acquire this enormous fortune because of his great ability, and because he understood the economic conditions of the time.

The average noble had no genius for acquiring wealth, and his feudal income, which was fixed mainly by custom, appears to have been stationary or even declining. With the establishment of better order and the increase of the royal power, the nobles had lost both their opportunity to plunder and the right of private coinage, which greatly lessened their income. One feature of the Pipe Roll for 1181–1182 is very significant in this connection. About 300 debtors to the king were listed from various parts of England, most of whom had disappeared or were destitute of means, so that these debts could not be collected. Apparently most of the individuals came from the lesser nobility. The only resource for men of this class was to borrow at usury. The usurers formed one of the two classes of wrong-doers against whom the preaching of the twelfth century was especially directed. They were evidently very numerous, and they preyed chiefly upon the nobles. The merchants and the peasants seldom had to resort to the usurers. There were many Christians engaged in this business, but more Jews, and the latter were to suffer severely as the result of the economic conditions. The rate of interest in England when the security was good was 2d. on the pound each week, compounded once in six weeks, or about 52 per cent. a year.[2] Consequently if a knight borrowed 40 pounds, a sum frequently in excess of the annual income of a knight, and was unable to pay the interest, in a year he would owe 60 pounds and 16s.; in two years, over 92 pounds; in three years, over 140 pounds; in five years, over 324 pounds, and the interest then would be over 3 pounds a week. Probably the ill-feeling against the Jews was due very largely to the anger of the borrowers who found themselves hopelessly involved in debt. There is a very decided change in the attitude toward the Jews in the twelfth century, and it is significant that the preparations for the crusades, when ready money was especially needed, were so frequently accompanied by a persecution of the Jews; *e. g.*, in 1096, in 1147, in 1189. Their great

---

[2] Much more was demanded when the security was not good.

wealth is shown by the fact that the Jews of England contributed 60,000 pounds towards the crusade of Henry II., and all others only 70,000. There is no estimate of the number who contributed this 60,000 pounds, but there had been a great increase since the beginning of the reign of Henry II. At that time all Jews who died in England had to be buried in the cemetery near London. At the end of Henry II.'s reign almost every great town had a Jewish cemetery in the suburbs.

The peasants both in town and country gained in prosperity during the twelfth century. The agricultural laborers profited by the opening of more markets for their products. They were sometimes able to hire the demesne land and even to rent the mill or the whole manor, because the lord of the manor was in need of ready money. In France many *villeneuves* were established which offered special privileges in order to attract tenants. Suger's example in emancipating his serfs was followed more and more frequently by the kings and by the lords. In England many individuals escaped to the towns, and if they were able to remain there unmolested for a year and a day, they were free from all possibility of pursuit.

The merchants in the towns profited most. The Lombard cities of Italy gained great wealth by the carrying both of crusaders and of wares. The trade extended widely in western Europe. Fairs were established where the commodities of the whole known world were offered for sale by the merchants from the various countries, who travelled about from place to place. The increase in the dues which the lords received from these fairs bears witness to their prosperity and to the enlarged trade, of which they were the scene.

Gross states that the gild merchant first appeared in England about 1100, and that the craft society first appeared on the continent, as in England, early in the twelfth century. If we connect these statements with Ashley's dictum, "Trade, as an independent occupation, grew up first in the service of luxury," the importance of the change in the standard of living will be apparent. The establishment of uniform weights and measures, and the universality of certain standards of money, such as the Cologne mark, the Venetian ducat, or the bezant also indicate the rapid advance in commerce.

The fabliaux, or "laughable stories told in verse," the especial literature of the merchant class, began about the middle of the twelfth century. In these tales class-consciousness is very evident. They ridiculed the knights and the clergy, while always depicting the latter as wealthy. Some of these fabliaux, which were written for the merchants of the twelfth century, sound curiously modern, as if they might have been told in the nineteenth century in our own western states. They are frequently irreverent, and show an independence of thought which is very noteworthy in this early period. Their attitude toward women is entirely at variance with that of the courtly literature of the age. In fact, the merchants were thinking for themselves, and were no longer willing to be subservient to the nobility and the clergy. They were rapidly becoming important political factors, and were winning recognition from the monarchs. They were vying in comfort and luxury with the nobles, and frequently ineffective sumptuary laws were enacted to restrict these *nouveaux riches.*

As yet too little attention has been paid to this change in the standard of living and its effects. In this paper an attempt has been made to set forth only a few of the facts, merely to indicate the nature and importance of the problem. Every one of the subjects here discussed is susceptible of elaboration, and needs to be worked out in detail for each country of western Europe and each period in the twelfth century. The material is voluminous: as indicated above, the legal documents should be utilized for the definite statements which they contain, and the literature of the age should be laid under contribution for its information as to the character, customs and points of view of the various classes. The chronicles unfortunately will furnish comparatively little, because they generally give only the unusual events; statements about prices drawn from them are frequently of little value, because the figures are given on account of their extreme highness or lowness. This field, as a whole, offers a good opportunity for many monographs, and such work is essential before we can understand the economic history of the century which was most important in the advance of western Europe.

University of Wisconsin,
Madison, Wis.

AN ANCIENT PROTEST AGAINST THE CURSE ON EVE.

BY PAUL HAUPT.

(*Read April 22, 1911.*)

In the Biblical Legend of the Fall of Man, which symbolizes the first connubial intercourse,[1] the Lord pronounces a curse on Eve, saying, I will greatly multiply thy sorrow and thy sighing;[2] in pain thou wilt bear children; nevertheless thy desire is[3] to thy husband and he will rule over thee (Genesis, iii., 16).[4]

The great pessimistic philosopher ARTHUR SCHOPENHAUER says that the story of the Fall of Man contains the only metaphysical truth found in the Old Testament; it is the acme of Judaism, *der Glanzpunkt des Judentums;* but it is an *hors d' œuvre:* the pessimistic tendency of this legend has no echo in the Old Testament which, on the whole, is optimistic, whereas the New Dispensation is pessimistic, at least so far as this world is concerned.[5]

We all know what the *forbidden fruit*[6] in the midst of the Garden[7] of Eden[8] means: he who eats of it loses his childlike innocence; his eyes are opened, just as Adam and Eve perceived that they were naked. Not to know good and evil, that is, what is wholesome and injurious, means to be like a child.[9] In the eighteenth book of the *Odyssey* (v. 228) Telemachus says to his mother Penelope, I am intelligent and know good and evil,[10] I am no longer a child.[11] In the Bible this phrase is used also of the second childhood: Barzillai of Gilead answered David, when the king asked him to follow him to Jerusalem, I am this day fourscore years old and can no longer discern between good and evil, that is, my intellect is impaired by old age, I have become again like a child.

The explanation of the Fall of Man as the first connubial intercourse was given by the celebrated English philosopher THOMAS HOBBES in his *Leviathan* (London, 1651) and it may be traced back to CLEMENT of Alexandria in the second century of our era.[12] But older than this philosophical explanation of original sin[13] is an

PROC. AMER. PHIL. SOC., L. 201 HH, PRINTED SEPT. 6, 1911.

ancient protest against the curse on Eve, which we find in the following chapter of the Book of Genesis, containing the legend of Cain and Abel.

The story of Cain and Abel is an institutional legend.[14] Just as the narrative of Jacob's wrestling at Peniel (Genesis, xxxii., 24–32) explains why the Jews do not eat the great sciatic nerve, so the story of Cain and Abel shows why the Cainites, or Kenites,[15] had the *mark of Cain,*[16] that is, a tattooed tribal mark which warned every man not to slay a member of that tribe. The murder of a Kenite was avenged sevenfold: if a Kenite was killed, the Kenites would slay seven fellow-tribesmen of the slayer. The tribe of Lamech avenged even the slightest scratch by the death of a youth of the tribe to which the assailant belonged. Lamech and Cain represent tribes, not individuals.[17] The Lamechites guarded their tribal honor even more jealously than did the Kenites: if a Kenite was slain, seven fellow-tribesmen of the slayer were slain to avenge his blood; a Lamechite, however, was not avenged sevenfold, but seventy-sevenfold; even a wound inflicted on a Lamechite was punished by the death of a fellow-tribesman of the assailant, and a boy of the hostile tribe had to pay with his life for the slightest scratch received by a Lamechite. Therefore an ancient tribal poet addressed the women of Lamech:

O Adah and Zillah, attend to my voice!
Ye wives of Lamech, give ear to my utterance:
A man, if they hurt us, we slay; a boy, if they scratch us, we kill;
If sevenfold Cain be avenged, then seventy-sevenfold, Lamech![18]

The Kenites were a nomadic tribe in the desert south of Judah.[19] They came to Canaan with the men of Judah from the Palm City, that is, the port of Elath,[20] at the northeastern end of the Red Sea. Moses' father-in-law is said to have been a Kenite.[21] The Kenites were worshipers of JHVH,[22] but their offerings were different from the sacrifices of the sheepmen of Judah,[23] represented in the story of Cain and Abel by *Abel,* that is *herdsman, herder.*[24] Cain brought to JHVH offerings of the fruit of the ground, but Abel brought of the firstlings of his flock and of the fat thereof; and Abel's sacrifice was more acceptable to JHVH than Cain's bloodless offering. The

Kenites may have been a semi-agricultural tribe settled near Elath[25] before they emigrated with the Edomite ancestors of the Jews to Canaan. Afterwards there may have been some religious differences: the Kenites clung to their vegetable offerings,[26] whereas the men of Judah[23] sacrificed lambs. This led to an expulsion of the Kenites from the region of Judah.

The introductory verse, connecting Cain and Abel with Adam and Eve, is a subsequent addition. The name *Cain* is explained there (Genesis, iv., 1) as being connected with the verb *qanâh,* to produce.[27] When Eve bare Cain, she said, I have produced a man as well as JHVH:[28] just as JHVH fashioned me from the rib He took from Adam, so I have produced now a new human being.—Some people think that, when the Lord created Eve, He did not take a rib from Adam, but his backbone. Most of us have all our ribs. At any rate, woman is not a side-issue.

The story of Cain and Abel was originally simply: Abel was a keeper of sheep, and Cain a tiller of the ground. Cain offered vegetable offerings to JHVH, whereas Abel sacrificed the firstlings of his flock. Abel's sacrifices were more acceptable to JHVH. This displeased Cain, and Cain said to Abel, Let us go into the field;[29] and when they were in the field, Cain rose up against his brother Abel, and slew him.

The field was a tribal battle-ground where the Cainites smote the Abelites, but afterwards they were overpowered and expelled from the territory of the sheepmen of Judah.[30]

A later theologian has inserted two verses (Genesis, iv., 6, 7) which are translated in the Authorized Version as follows: And the Lord said unto Cain, Why art thou wroth? and why is thy countenance fallen? If thou doest well, shalt thou not be accepted? and if thou doest not well, sin lieth at the door. *And unto thee shall be his desire, and thou shalt rule over him.* There is no connection between this last clause and the preceding one, and the translation *sin lieth at the door* is impossible.

The Ancient Versions show that the text of this theological interpolation was corrupt at an early period, and the rendering given in the Greek Bible echoes the tradition that the feud between Cain and Abel was due to some ritual differences. The Septuagint renders: Is it not so? If thou offerest rightly, but doest not cut in pieces rightly, thou hast sinned? Be still!—The Syriac Bible has: Behold, if thou doest well, thou receivest; and if thou doest not well, at the door sin croucheth.—We find the same rendering in the Vulgate: *Nonne si bene egeris, recipies; sin autem male, statim in foribus peccatum aderit.*—The Targum paraphrases: If thou doest thy work well, thou wilt be pardoned; but if thou doest not thy work well, for the day of judgment the sin is laid up, ready to take vengeance upon thee, if thou doest not repent; but if thou repentest, thou shalt be forgiven.[31]—All these explanations are untenable.

The original text seems to have been: If thou art good, I shall receive thee graciously; but if thou art a sinner,[32] I shall not accept thy offering.[33] The final clause, *And unto thee shall be his desire, and thou shalt rule over him,* has no connection with the preceding theological interpolation, but is a gloss protesting against the statement in the preceding chapter: *Thy desire shall be to thy husband, and he shall rule over thee.*[34] Genesis, iii., 16, states: Unto the woman He said, I will greatly multiply thy sorrow and thy sighing;[2] in pain thou wilt bear children; nevertheless thy desire is[3] to thy husband, and he will rule over thee.

Some one—possibly a woman,[35] or a man under the influence of a woman, a species of the genus *Homo,* which is common—added to this statement in the margin: *His desire is unto thee, and thou wilt rule over him.*[36] The story of the Fall of Man and the legend of Cain and Abel may have been written in two parallel columns.[37] The glossator, who added the theological interpolation in the legend of Cain and Abel, and the author of the polemical gloss to Genesis, iii., 16 may have written their remarks in the space between the two columns. Afterwards these two marginal glosses crept into the text, the "suffragettic" gloss to Genesis, iii., 16 being appended to the theological interpolation after Genesis, iv., 5.

The word *desire* or *longing* is used also in the Biblical love-songs, commonly known as the Song of Solomon, where the maiden says of her lover:

My dear one's am I; he is mine, too;   for my love he is longing.[38]

The corresponding word in Arabic (*shauq*) means *passionate love.* If man eats his bread in the sweat of his face till he returneth unto the ground, and if women bring forth children born to suffer, it is due to the *forbidden fruit.* Schiller says,[39] the fabric of the world is held together by hunger and by love.[40]

Notes.

[1] See my paper Some Difficult Passages in the Cuneiform Account of the Deluge in the *Journal of the American Oriental Society*, vol. xxxi., fifth page of the article, l. 2. *Cf.* below, n. 13.

[2] Instead of *hêrônêk,* thy conception, or *thy pregnancy,* we must read *hagîgêk,* thy sighing; *cf.* Psalms, v., 2; xxxix., 4. The Greek Bible has **τὸν στεναγμόν σου**. *Hegyônêk* would have a different meaning, and *yĕgônêk* or *çâratêk* could not have been corrupted to ***hêrônêk.***

[3] Not *shall be* or *will be;* see my remarks in the *Journal of the American Oriental Society,* vol. xxv., p. 71, n. 1; vol. xxxi., fourth page, below, of the article cited in n. 1. The last two clauses may represent an observation of the narrator; *cf.* below, n. 36.

[4] The preceding verse, the so-called *protevangelium* or *protogospel,* should be rendered: *I will put enmity between thee and the woman, and between thy seed and her seed; it* (that is, her seed, the human race) *will crush* (lit. tread down, tread under foot, Assyr. *šêpu*) *thy head, and thou wilt snap at its heel.* There will be perpetual warfare between snakes and the human race; all human beings loathe snakes. The Messianic interpretation of this passage is unwarranted. See my Note on the Protevangelium in the *Johns Hopkins University Circulars,* No. 106 (June, 1893), p. 107; *cf.* my remarks in the *Nachrichten* of the Royal Society of Göttingen, April 25, 1883, p. 102; also Gunkel, *Genesis* (1910), p. 20.

[5] See my remarks in the *Journal of Biblical Literature,* vol. xxi., p. 55, l. 8; p. 66, n. 21; Haupt, *Biblische Liebeslieder* (Leipzig, 1907), p. 66.

[6] We use this term now especially of illicit love. In Ceylon the fruit of *Ervatamia dichotoma* is called *forbidden fruit* or *Eve's apple.* The forbidden fruit in the legend of the Fall of Man is, it

may be supposed, the orange-colored berry of the mandrake which is still regarded as an aphrodisiac and supposed to promote conception; see my paper on Jonah's Whale in vol. xlvi. of these *Proceedings* (Philadelphia, 1907), p. 152, n. 4. In Genesis, xxx., 14, the mandrakes are called in Hebrew: *dûda'îm,* that is, love-apples. The fruit of the mandrake is quite round and of the size of a large plum; it resembles a small tomato. The largest berries have a diameter of 1½ in. (nearly 4 cm.). The idea that the forbidden fruit was a fruit from which an intoxicating drink was prepared is untenable; contrast CHEYNE's article in the eleventh edition of the *Encyclopædia Britannica,* vol. i., p. 168^{b}. In the article on *mandrake,* vol. xvii., p. 566^{a}, there are five misprints in the five letters of the Heb. word *dûda'îm;* similarly there are two misprints in the three letters of the Arabic name for Egypt, vol. ix., p. 41^{b}. The new edition is marred by a great many misprints and inaccuracies, not only in Oriental words, but also in the English text.

[7] Garden is often used for *pudendum mulieris;* see HAUPT, *The Book of Micah* (Chicago, 1910), p. 62, n. 9.

[8] Eden means *pleasure, delight;* Heb. *gan-'edn* denotes a *pleasure-ground.* Damascus, the earthly paradise of the Arabs, is called in Amos, i., 5: *Bêt-'edn,* House of Pleasure; see my remarks in PEISER'S *Orientalistische Literaturzeitung,* June, 1907, col. 306. The Greek Bible has for Heb. *gan-'edn* in Genesis, iii., 23, 24: ὁ παράδεισος τῆς τρυφῆς; the Vulgate: *paradisus voluptatis.* The reading *a garden in Eden* in Genesis, ii., 8 seems to be a subsequent modification introduced by some one who connected Heb. *'edn* with the Babylonian *edinu* = Sumerian *edin,* desert; he may have regarded Paradise as an oasis in the desert like Damascus; *cf.* PINCHES' note in the *Proceedings of the Society of Biblical Archæology,* London, June 14, 1911, p. 161. Damascus means *settlement in a well-watered region;* the original form of the name was *Dârmašqî;* see my remarks in the *American Journal of Semitic Languages,* vol. xxvi., p. 26.

[9] See Deuteronomy, i., 39; Isaiah, vii., 16; *cf.* the translation of *Isaiah,* in the Polychrome Bible, p. 11, l. 25; p. 141, n. 16.

[10] To know good and evil has about the same meaning as our phrase *to cut one's eye-teeth.*

[11] See my paper on Midian and Sinai in the *Zeitschrift der Deutschen Morgenländischen Gesellschaft,* vol. lxiii., p. 519, l. 25.

[12] Compare above, note 5.

[13] The serpent symbolizes carnal desire, sexual appetite, concupiscence. This is the original sin which has been transmitted to all descendants of Adam; only the innocents are free from it. COLERIDGE (*Aids to Reflexion,* 1825) held that Adam's fall was a typical experience repeated afresh in every son of Adam. *Mutato nomine, de te fabula narratur;* see HASTINGS' *Dictionary of the Bible,* vol. i., p. 842^b. In the well known Assyrian relief from Nimrûd, representing the fight with the dragon, the penis of the monster is a serpent; see the plate in GEO. SMITH, *The Chaldean Account of Genesis,* edited by SAYCE (London, 1880). The serpent in the story of the Fall of Man is a later addition; in the original form of the legend Eve was the sole seductress; Eve means *serpent* (Heb. ***Ḥawwâh***=Aram. *ḥiwyâ,* snake, Arab. *ḥáyyah*). See n. 29 to my paper cited above, n. 1.

[14] This legend explains the institution of tattooed tribal marks and the institution of blood-revenge (*cf.* nn. 15 and 17). It illustrates also the superiority of nomadic animal sacrifices compared with agricultural bloodless offerings (*cf.* n. 26).

[15] Kenite means *descendant of Kain* or *Cain;* Cain is the eponym ancestor of the Kenites.

[16] See Genesis, iv., 15; *cf.* HAUPT, *The Book of Canticles,* p. 41; *Biblische Liebeslieder,* p. 61.

[17] *Cf.* our Uncle Sam, John Bull, Columbia, Germania, &c. A Bedouin tribe Cain (Qain) dwelt in the desert of Sinai and the neighboring districts about six centuries after Christ; see NÖLDEKE'S article on *Amalek* in the *Encyclopædia Biblica,* col. 130.

[18] See Genesis, iv., 23, 24; *cf.* my paper on Moses' Song of Triumph in the *American Journal of Semitic Languages,* vol. xx., p. 164.

[19] *Cf.* 1 Samuel, xxvii., 10. The Kenites lived with the Amalekites, but they were on friendly terms with the men of Judah, whereas the Amalekites were perpetually at feud with the Judahites, *cf.* 1 Samuel, xv., 6 and Judges, i., 16 (see below, n. 21). In the

Book of Esther, Haman is called an Agagite, that is, a descendant of Agag, the king of the Amalekites, who had been spared by Saul, but was hewn in pieces before Jhvh by Samuel, whereas Mordecai is introduced as a descendant of the first king of Israel; see Haupt, *Purim* (Leipzig, 1906), p. 12, l. 30. The Amalekites were Edomites who had invaded southern Palestine before the Edomite ancestors of the Jews, after their exodus from Egypt, conquered the region afterwards known as Judah (see n. 23). In Numbers, xxiv., 20 Amalek is called the first (that is, oldest) of the nations. The Amalekites, however, had intermarried with other (non-Edomite) tribes; in Genesis, xxxvi., 12, therefore, Amalek is introduced as a son of Esau's first-born, Eliphaz, by a concubine, just as the sons of Jacob's concubines, Bilhah and Zilpah, were tribes with foreign elements; see my paper on Leah and Rachel in the *Zeitschrift für die alttestamentliche Wissenschaft,* vol. xxix., p. 285. The identification of Amalek with the cuneiform Meluha (*Orientalistische Literaturzeitung,* June, 1909) is untenable. According to 1 Chronicles, ii., 55, the Rechabites (*cf.* Jeremiah, xxxv.; 2 Kings, x., 15, 23) were descendants of the Kenites; but this can hardly be correct. The Rechabites resembled the ancient Kenites in that they were ardent worshipers of Jhvh, and that they continued to live in tents after the men of Judah (see n. 23) had settled in Canaan.

[20] See p. 360 of my paper on The Burning Bush and The Origin of Judaism in vol. xlviii. (No. 193) of these *Proceedings* (Philadelphia, 1909) and my paper on Midian and Sinai (cited above, n. 11), p. 506, l. 12; p. 512, ll. 15 and 33; p. 513, l. 2. In Genesis, iv., 17 we read that Cain built a city.

[21] In Judges, iv., 11 the words *mib-bĕnê ḥôbáb Môšêh* are a secondary gloss (or variant) to *miq-Qain,* and *ḥôtén* is a tertiary gloss to *ḥôbáb.* The original text of Judges, i., 16 seems to have been: *wĕ-Qain 'alâh me-'îr hat-tĕmarîm et-Yĕhûdâh midbár 'Arád wai-yélek wai-yéšeb et-'Amaléq,* Cain went up with Judah from the Palm City to the wilderness of Arad, and went and lived with Amalek. The words *bĕnê . . . ḥôtén Môšêh* and *Yĕhûdâh ašér ban-négeb* are glosses. See the translation of *Judges,* in the Polychrome Bible, pp. 8 and 2; also p. 49, n. 15; p. 62, l. 55; *cf.* my

paper on Hobab = father-in-law in the *Orientalistische Literaturzeitung,* April, 1909, col. 164.

[22] For JHVH see p. 355, n. 2 and p. 357 of my paper The Burning Bush, cited above, n. 20.

[23] Judah is the name of the worshipers of JHVH, who were united under the leadership of David about 1000 B. C. David was not an Israelite, but an Edomite. See n. 18 to my paper The Aryan Ancestry of Jesus in *The Open Court,* Chicago, April, 1909; *cf.* p. 358 of my paper The Burning Bush, cited above, n. 20, and my paper on Midian and Sinai (see above, n. 11), p. 506, l. 2; p. 507, l. 36; also ERBT's remarks in *Orientalistische Literaturzeitung,* July, 1911, col. 298, l. 19. For the sheepmen of Judah see p. 284, n. 5 of my paper on Leah and Rachel, cited above, n. 19; *cf.* my paper on the five Assyrian stems *la'u* in the *Journal of the American Oriental Society,* vol. xxxi.

[24] In Syriac, *habbâltâ* (or *hĕbâltâ, ĕbáltâ*) means *herd, drove,* especially of camels; *cf.* Obil, the name of David's keeper of camels, 1 Chronicles, xxvii., 30 (see *Encyclopædia Biblica,* col. 6). *Hebel,* the Heb. form of *Abel,* may be connected with *hôbîl,* to lead. The name of Jabal, *the father of such as dwell in tents and of such as have cattle,* Genesis, iv., 20, may be derived from the same root; *cf.* HASTINGS' *Dictionary of the Bible,* vol. i., p. 5^a. The original form of *Jabal* seems to have been *Jôbîl;* the Greek Bible has **Ιωβελ** (and **ΙΩΒΗΔ** for **ΙΩΒΗΛ**). *Hebel* may be a subsequent modification of *Hôbîl,* due to a popular etymology combining the name with Heb. *hébel* (for *hábil*) breath, transitoriness; see below, n. 27. For *Jôbîl* = *Hôbîl* cf. my remarks on *Ja'îr* = *Me'îr,* p. 513, l. 24 of my paper cited above, n. 11. The name Moses, Heb. *Môšêh,* may have had originally an *'Ain* at the end so that it would be equivalent to Joshua; see *l. c.,* l. 26, and for the vanishing of the final laryngeal, *op. cit.,* p. 522, l. 47; also HAUPT, *The Book of Esther* (Chicago, 1908), p. 74, l. 14.

[25] *Cf.* p. 528, l. 38 of my paper cited above, n. 11.

[26] In Canaan a bloodless offering smacked of Canaanite heathenism; *cf.* the remarks on p. 44 of the translation of *Judges* in the Polychrome Bible. SKINNER says on p. 106 of his new commentary

on *Genesis* (1910): It is quite conceivable that in the early days of the settlement in Canaan the view was maintained among the Hebrews that the animal offerings of their nomadic religion were superior to the vegetable offerings made to the Canaanite Baals.

[27] Cain may be connected with the Ethiopic *taqánya* which means *to till the ground;* cf. the Pachomian rules in Dillmann's Ethiopic chrestomathy, p. 60, l. 4. *Taqánya* means also *to worship God;* cf. Arab. *qánata* (*qunût*) and Lat. *colere*. Stems *tertiæ y* and *mediæ y* often interchange; *cf.* Ethiopic *qânáya,* to sing, and Arab. *qáinah,* songstress, Heb. *qînâh,* elegy. For Ethiopic *qĕnûy,* servant, we have in Arabic: *qain,* plur. *qiyân.* In Arabic, *qain* means also *smith, metal-worker,* Syr. *qainâyâ.* Some scholars, therefore, believe that the Kenites were a tribe of wandering smiths. Sayce says (in Hastings' *Dictionary of the Bible,* vol. ii., p. 834^b) that the Kenites resembled the gipsies of modern Europe as well as the traveling tinkers or blacksmiths of the Middle Ages. Skinner states (on p. 113 of his commentary on Genesis) that there are some low-caste tribes among the Arabs, who live partly by hunting, partly by coarse smith-work and other gipsy labor in the Arab encampments; they are forbidden to be cattle-keepers and are excluded from intermarriage with the regular Bedouins, though on friendly terms with them; they are the only tribes of the Arabian desert that are free to travel where they will, ranging practically over the whole peninsula from Syria to Yemen.

The legend of Cain and Abel may have connected the name *Cain* with the allied stem *qinnê,* to be jealous, envious, passionate, just as the name *Abel* (see n. 24) was combined with *häbl* (for *hábil*) breath, transitoriness. The saying of Ecclesiastes, *Vanity of vanities* (that is, How utterly transitory is everything!) is in Hebrew *hăbêl hăbalîm;* see Haupt, *Koheleth* (Leipzig, 1905), p. 1; *Ecclesiastes* (Baltimore, 1905), p. 34, n. 2.

[28] Lit. *with* Jhvh. Also we use *with* in the sense of *like, analogously to.* Shakespeare says, *As if with Circe she would change my shape. Cf.* the Critical Notes on the Heb. text of Genesis, in the Polychrome Bible, p. 118. My interpretation of this difficult passage has been adopted by Cheyne, *Encyclopædia Biblica,*

col. 619, n. 3: *I have created a man even as Yahweh;* but we must not substitute *lĕ-‘ummát.* Nor can we read *îš ôt Yahwêh,* the man of the mark (*cf.* above, n. 14) of JHVH, or *îš et‘awwêh,* a man whom I desire. The prediction of the serpent that Eve and her husband would be like God, if they ate of the forbidden fruit, implied that they would be able to create new human beings, and this would make the race of Adam immortal. *Cf.* the fourth page, below, of my paper cited in n. 1.

[29] This clause is preserved in the Samaritan Pentateuch and in the Ancient Versions. The Vulgate has *Egrediamur foras.*

[30] *Cf.* my explanation of the story of Judah and Tamar in n. 26 to my paper cited above, n. 11.

[31] *Cf.* G. J. SPURRELL, *Notes on the Text of the Book of Genesis* (Oxford, 1896), p. 2.

[32] Contrast *the blood of righteous Abel* in Matt. xxiii., 35; see also Hebrews, xi., 4; 1 John, iii., 12.

[33] We must read: *Hâlô, im têṭîb, essâ panêka; wĕ-'im ḥôṭê attâ, lô eqqáḥ qorbânéka.* In the received text *ḥôṭê attâ* is mispointed and misplaced: it appears as *ḥaṭṭât* between *lap-pétaḥ* and *rôbéç* which are corrupted from *lô eqqáḥ qorbânká.* The Greek Bible read *lĕ-nattéḥ* instead of *lap-pétaḥ,* and *rĕbáç* for *rôbéç.* The reading of the received text, *im lô têṭîb,* if thou doest not well, is a later substitution for the original *im ḥôṭê attâ,* if thou art a sinner. We might read also *lô erçêh minḥatéka,* but this could not have been corrupted to *lap-pétaḥ rôbéç.* In *lô eqqáḥ qorbânká* one of the Alephs in *lô eqqáḥ* was omitted; *q* of *qorbânká* dropped out after the final *ḥ* of *eqqáḥ,* and *n* was omitted after the *b* of *qorbânká;* the letters for *n* and *b* are similar in Hebrew; for *q* = *ḥ* see Crit. Notes on *Kings,* in the Polychrome Bible, p. 187, l. 20. For *eqqáḥ qorbânká* cf. Psalm vi., 10: *Yahwêh iqqáḥ tĕpillatî,* JHVH will receive my prayer, and Assyr. *teléqî têmêqšu* and *leqât unnêni,* &c. (see DELITZSCH's *Assyr. Handwörterbuch,* p. 384^{b}, d). GUNKEL's reconstruction of the text (in *Die Schriften des Alten Testaments übersetzt von* GRESSMANN, GUNKEL, &c., part 5, Göttingen, 1910, p. 69) does not commend itself.

[34] *Cf.* Ephesians, v., 22; Colossians, iii., 18; Titus, ii., 5; 1 Peter, iii., 1.

[35] Like Deborah, Esther, Judith, &c.

[36] *Cf.* the observation of the narrator (see n. 3) in Genesis, ii., 24: *Therefore a man leaves his parents and clings to his wife.* The rendering *shall leave* (Matt., xix., 5; Mark, x., 7) is incorrect; it is not a prophecy, nor is it an old saying dating from remote times when the husband went to the tent of the wife and joined her clan, although it is noteworthy that Eve, not Adam, names the child in Genesis, iv., 1 (*cf.* above, n. 28). We may compare the line in the Biblical love-songs (Canticles, viii., 7) where the poet says of Love:

If one should resign for it all his possessions,
could any man therefore contemn him?

This means, from the Oriental point of view: If a man should sacrifice all his possessions to buy a beautiful girl; see HAUPT, *Biblische Liebeslieder,* p. 111. THOMAS DIXON, JR., says in his novel *The Leopard's Spots* of Simon Legree: They say he used to haunt the New Orleans slave-markets when he was young and owned his Red River farm, occasionally spending his last dollar to buy a handsome negro girl who took his fancy.

[37] *Cf.* the remarks in n. ** to my paper Isaiah's Parable of the Vineyard in the *American Journal of Semitic Languages,* vol. xix., p. 194.

[38] See HAUPT, *The Book of Canticles,* p. 5; *Biblische Liebeslieder,* p. 4.

[39] SCHILLER says in the last stanza of his poem *Die Weltweisen:*

Doch weil, was ein Professor spricht,
Nicht gleich zu allen dringet,
Es übt Natur die Mutterpflicht
Und sorgt, dass nie die Kette bricht
Und dass der Reif nie springet.
Einstweilen, bis den Bau der Welt
Philosophie zusammenhält,
Erhält sie das Getriebe
Durch Hunger und durch Liebe.

[40] As a striking illustration of the manner in which some of our leading newspapers occasionally mislead their readers, I will subjoin here the "report" of my paper, which appeared in *The Press,*

Philadelphia, April 23, 1911, under the caption *Education and Race Suicide:* "Declaring that race suicide is due to an increase in intelligence, and theorizing that the human emotions become fewer as human beings become better educated, Dr. PAUL HAUPT, professor of Semitic languages at Johns Hopkins University, spoke at the session yesterday morning. Contrary to the hope of many members of the Society, Dr. HAUPT advanced none of his religious opinions in the course of his address. He spoke upon 'An Ancient Protest against the Curse on Eve' and confined himself wholly to observations on race suicide."—The abstract which I had placed at the disposal of the press was printed in the Philadelphia *Ledger,* the *North American,* &c., April 23, 1911.

PROCEEDINGS
OF THE
AMERICAN PHILOSOPHICAL SOCIETY
HELD AT PHILADELPHIA
FOR PROMOTING USEFUL KNOWLEDGE

VOL. L   OCTOBER–DECEMBER, 1911   NO. 202

THE FORMATION OF COAL BEDS. II.*

BY JOHN J. STEVENSON.

SOME ELEMENTARY PROBLEMS.

(Read November 3, 1911.)

It is necessary, first of all, to consider some matters to which reference is made by every one who has endeavored to explain the formation of coal beds. Too many seem to have been content with acceptance of current statements respecting the apparently commonplace phenomena and too few have thought essential a careful study of work done in recent years. The indefinite and often contradictory assertions contained in discussions, published within the last decade, compelled the writer to study the available literature and, as far as possible, to make examination of the phenomena in place. This study has led him to reject some of his cherished beliefs while it has confirmed others. At the same time, it has increased his respect for the problem, which he has undertaken to solve. The topics to be considered in this portion of the work are:

The effect of floods upon a cover of vegetation,
The phenomena of peat deposits,
The buried forests.

---

* Part I appeared in these *Proceedings*, Vol. L., pp. 1–116.

Each of these topics will be considered only in its relation to the main problem.

THE EFFECT OF FLOODS UPON A COVER OF VEGETATION.

A torrent dashing through a narrow gorge is the poet's symbol of resistless force; a great river in flood, bearing on its surface houses, trees and other floating materials in prodigious quantity, seems possessed of almost illimitable power for destruction. These conditions, so familiar to all, have led to the conception that, in the eroding and transporting power of streams in flood, one can find explanation for the origin not only of sandstone and other inorganic deposits but also for that of coal and lignite beds interstratified with them. So much importance has been assigned to this explanation by several authors, that the phenomena must be considered in detail.

The Work of Torrents.—The torrent in full flood is an interesting spectacle but its importance in this connection is confined chiefly to its bearing on the origin of inorganic sediments.

Long ago De Luc[1] described deposits made by torrents as resembling a much flattened loaf of sugar and he employed the term "cone" to distinguish them from the talus at foot of cliffs. When a stream ceases the cutting down of its bed, the formation of a cone ends and vegetation takes possession of the surface, even of steep slopes alongside of the stream. Eventually the surface is covered with a thin coat of soil and men settle upon it. Such a cone was seen by De Luc on the right bank of the river Arc, en route from Mount Cenis into Italy. It extends from Aigue-belle to Saint-Jean de Maurienne and the line around its base is nearly three miles. It is high against the rocky wall and the surface is comparatively steep. Its history is the same with that of many others. The stream cuts a channel in the cone; occasionally, during a great flood, the banks are overflowed, but the injury is not enough to drive away the inhabitants. A fall from the walls of the gorge forms a talus against which the stream flows; water finds its way through the sands and

---

[1] J. A. DeLuc, "Lettres physiques et morales sur l'histoire de la terre et de l'homme," Vol. II., 1780, pp. 67–68.

renders the mass almost jelly-like. A winter of heavy snows, followed by an unusually warm spring, leads to abrupt swelling of the water and the soft mass is swept out over the surface of the cone, flowing like a flood of lava. Such were the conditions here. A village, la Chapelle, had been built; in 1752, the torrent washed out a vast mass of rock and débris, which covered everything to a depth of 15 to 20 feet, completely burying the hamlet.

In a broad valley, the effects of the torrent's work are confined to the cone, but conditions are different where the valley is narrow. A few years prior to the disaster at la Chapelle, another cone was formed in the Arc valley between Saint-Andre and Saint-Michel. The river was dammed and a lake was the result. The inhabitants of a drowned hamlet endeavored to make a canal through the dam, but the great fragments foiled them and the river was left to make its own canal. De Luc visited the locality several times. When he last saw it, the river had filled the lake with débris, through which it flowed gently, while above and below it foamed amid masses of rock. De Luc notes with some interest that on the other side of the valley, opposite la Chapelle, a torrent was still at work, building its cone. Each spring saw the surface covered by a flood, bringing down new material. Yet the trees, which had gained place and had sent their roots down amid the rock-fragments, maintained themselves against the rushing waters, laden with rocks and débris, and inhabitants of the region gathered fagots there.

Similar phenomena are familiar to all students of mountainous areas. Dejection cones, some of them enormous, are numerous along the Rhone from Viége to Martigny. The flood additions are distinct, several of the cones being deposited by streams with fall of more than 250 feet per mile. Except where new channels had been cut, the trees growing on the surface of the cones are apparently uninjured, though in some cases they have been bent by blocks of rock, whose advance they had checked. The valley of the Adige between Botzen and Rovereto presents many illustrations of similar type; in the mountain areas of the western United States such conditions are merely commonplace.

McGee's[2] observations in the Sonoran district of Arizona and Mexico are equally instructive, though dealing with a somewhat different type of phenomena. That district is within the arid region and the valleys are sand wastes, with shallow channel ways which are dry during all but, perhaps, five days in each year. The mountains are scarred by barrancas or stream-worn valleys, which end abruptly at the plain. The streams during the greater part of the year are mere threads; but, during thunder gusts or cloudbursts, the old channels are filled and new ones digged, though the flow may last but a few minutes or at the most a few hours. The stream gathers loosened rock masses in the mountains, hurls them down slopes into the barrancas, dashing them to fragments and carrying the débris to the edge of the plain. There the coarser materials are dropped, but the finer stuff is transported beyond as a sheetflood until the water disappears by absorption or evaporation. The inclination of the channel ways is not far from 300 feet per mile in the mountains, decreases to 200 feet at the edge of the plain and to 50 feet at the end of the torrential area, several miles away. The flooding of the plain has, in some cases, a width of ten or more miles.

McGee saw one of the floods in 1894. It came abruptly, a mass of water thick with sand, foaming and loaded with twigs and dead leaves. It advanced at first with "racehorse speed" but the velocity diminished quickly owing to evaporation and the flood died out in irregular lobes. The depth was not more than 18 inches on the lower border, where the width of the muddy flood was about half a mile. The noteworthy feature in this connection is that the mass of slime, moving with so great speed, had no injurious effect upon the clumps of mesquite bushes, scattered here and there over the slope. When the flowing mud reached those clumps, its speed was checked momentarily; its course was diverted and it moved alongside at twice to thrice the ordinary rate. After the flood was over, the most striking observable effect was the accumulation of twigs and branches against the clumps of shrubbery and other obstacles.

Russell's notes on the Yahtse river of Alaska, to be considered

---

[2] W J McGee, "Sheetflood Erosion," *Bull. Geol. Soc. America,* Vol. VIII., 1897, pp. 87–112.

in another connection, are equally in place here. That river, issuing from the Malaspina glacier as a swift flood, 100 feet wide and 15 to 20 feet deep, has invaded a forest and surrounded the trees with sands and gravel to a depth of many feet. That current, rapid enough to carry a great load of very coarse material, was not strong enough to uproot the trees and evidently it could not break off the trunks until decay was well advanced. Russell's photograph shows the conditions distinctly.

Smyth[3] has described conditions in the Adirondack mountains of New York, which are of no little importance in this connection and they will be utilized in the sequel, as the character of the region is very like that imagined for some limnic basins in Europe. Many small lakes exist in that region, varying from a few rods to three or four miles in the longer diameter. They are of post-glacial origin and, in many cases, are surrounded by high hills of metamorphic rock, whence streams with rapid fall flow in comparatively narrow valleys. Big Rock lake is typical. It is a mile and a half long, three fourths of a mile wide and is fed by streams which carry much sediment and by their deposits are changing the outline of the lake. The new area is a level marshy meadow, about a foot above the water, covered with a heavy growth of grass and carrying some small balsams and tamaracks. The lakes show every stage from pond to meadow and one of them has been changed throughout into meadow, through which its stream meanders on the way to Big Rock lake, one mile away. After heavy rains, water flows over the meadows to a depth of a foot or more, leaving a sediment of varying thickness; but the torrential streams feeding the lake, though flowing through gorges, whose steep walls are more or less densely timbered, rarely bring down trees or other vegetation.

Torrents carrying no débris do as little injury to vegetation as to the rocks over which they flow. The writer has recognized this many times in the Rocky and other mountain areas of the western United States. Clear creek in Colorado, formed by the union of streams from Gray, Torrey and other high peaks of the Front range,

---

[3] C. H. Smyth, "Lake Filling in the Adirondack Region," *Amer. Geologist*, Vol. XI., 1893, pp. 85–90.

is subject to abrupt rise in the early summer, when hot days cause rapid melting of the snow on those peaks. The upper streams pass over hard rocks and among huge masses which choke the channels, so that, below the union, the creek, following a rocky, mostly narrow gorge and with rapid fall, carries even in great flood comparatively little sand or silt. A rise of 10 feet within 3 or 4 hours is of frequent occurrence. The low narrow "bottom," though so often overflowed by rapidly moving water, is grassy and bears some shrubs. In some places, where the canyon widens and the stream, under ordinary conditions, flows less rapidly, one finds petty islands of detritus covered by shrubs, some of them more than 15 feet high. Clearly these plants are torrent-proof, they have maintained their place from birth. Similar conditions were observed on many other streams of like character.

A Cover of Vegetation Protects against Erosion.—Within any given district of moderate size, some streams are turbid while others are limpid even in flood time. The water may be limpid or turbid in different portions of the same stream. As the rainfall is the same throughout there must be local causes for the variation.

The process of erosion begins with the impact of a raindrop; but that impact is ineffective if the drop fall on more or less elastic material. Thus it is that a cover of decayed vegetable matter, a coating of humus, protects a slope against the erosive power of rainfall; it protects existing vegetation from removal and it may enable plants to regain hold on spaces bared by fire or other agents, even though the slope be abrupt.

Ashe[4] studied an area which has great variety of soils, as the section extends from the Archean to the Quaternary. Soils from partly metamorphosed sandy shales or from mica schist offer little resistance to erosion; in some cases they cannot nourish a sod but each supports its own type of trees. Denuded of forest, the surface is gashed quickly by rains, but when forested it loses little. The accumulation of litter or humus within the Potomac area is small

---

[4] W. W. Ashe, "Relations of Soils and Forest Cover to Quality and Quantity of Surface Water in the Potomac Basin," *U. S. Geol. Survey, Water Supply and Irrigation Paper,* 192, 1907, pp. 299–335.

because of climatic conditions, but it suffices to protect these soils on all except the steepest slopes. Limestone soils, occupying much of the area, are very apt to "wash" when under cultivation, but where covered with forest even the steepest slopes retain their cover of humus and the run-off water is never turbid. Sandstone soils vary much in resistance, when bared, but where they are protected by a thin cover of humus the waste is insignificant. The water of small streams flowing from forest mountain-sheds is clear and pure. The great resistance offered by humus is apparent from the figures given by Ashe. Pines growing on poor soils, rarely yield more than 2 inches; yet this protects all except the steepest slopes. Chestnut oak and white oak give but 3 inches; they too grow on poor soils, which, when exposed, are torn away rapidly. Other woods give from 5 to 6 inches of litter, which is so absorbent that for several days after a rain one can squeeze water from it as from a sponge. Ashe's observations show that this vegetable litter, in the semi-decomposed condition, is so interwoven that it not only protects the underlying soil but also itself resists removal as does a well-rooted sod. The streams coming from the humus covered area are free from vegetable matter, aside from occasional twigs and, at times, some soluble matters leached from the humus.

The White mountains of New Hampshire illustrate well the incompetence of rainfall to remove living vegetation. The rock in that region is mostly granite and the soil, formed since the glacial period, is very largely humus. The slopes are abrupt and the walls of gorges frequently show more than 50 degrees; but most of the area below timber line has a dense cover of vegetation, largely spruce. Yet rains have always been frequent and many times almost deluge-like. The covering of humus is undisturbed by those rains; even where lumbermen have cut away the forest and left their litter and the humus exposed to the fury of storms, one finds little evidence of removal.

Cloudbursts or extraordinary downpours of rain have occurred many times within this area. C. H. Hitchcock has described the flood in the Flume at Franconia, which washed away the great boulder which had been dropped by the retreating ice and had remained suspended in the Flume. That huge mass has never been found. Yet, aside from a landslide or two, the terrific rainfall left the vegetation on the steep slopes unscarred. In June of 1903, a cloudburst of unusual severity broke on the northern part of the White mountains. The roads were gullied and rendered impassable; bridges, large and small, were swept away throughout the region as the streams were filled beyond the high water mark of spring freshets; sheets of water poured down naked rock surfaces in many portions of the abrupt spaces and landslides of limited extent were produced where the slope was covered with loose material. But this vast flood of water did practically no injury to the forest-covered slopes; even débris left on the mountain side by tree-choppers was almost undisturbed.[5]

But the most noteworthy evidence in this region is found on the areas which have been burned over. When a forest fire destroys the soil near the top of a divide or on a very abrupt slope, the residue is removed quickly by rain and the granite is exposed. But if the organic matter has not been destroyed, the soil resists ordinary rains even on steep slopes. If drenching rains be delayed for a few weeks, the surface gains a cover of fireweed (*Erechtites hieracifolia*) and rain is powerless. This growth is succeeded in the following season by a dense cover of raspberry, fern and other plants, among which a cherry takes root to become the characteristic form in the third season. Birches, maples and poplars are prominent during the next season and within five years the spruces make their appearance. If drenching rains follow quickly after a forest fire, the process of restoration is merely retarded, it is not prevented.

Glenn[6] studied the problem throughout the southern Appalachians, an area of 400 by 150 miles, and his studies were extended to another area farther north, 200 by 50 miles. The examination was continued westward for a long distance down the Tennessee river, so that the investigation embraced every type from the bold

---

[5] Communicated by C. A. Snell of Malden, Mass., who examined the whole area within four days after the disaster occurred.

[6] L. C. Glenn, "Denudation and Erosion in the Southern Appalachian Region," *U. S. Geol. Survey, Professional Paper*, 72, 1911, pp. 15–18, 23, 24, 59, 93, 96, 99.

mountains, cut by canyon-like gorges, to broad river valleys with wide bottoms in which the streams meander. This study concerns also some matters to be considered hereafter, but they are included here for convenience of reference.

Glenn asserts that, in forested areas, erosion is at its minimum, for the soil is protected by the litter from impact of raindrops. As drops move down the slope, they are checked by the litter or are absorbed by it, and the rainfall moves so slowly through the mass that for hours after rainfall, the cover is full of water. Even such gullies as were seen have their bottoms covered with litter and plants, showing that the erosion, by which they have been produced, is very slow. Streams flowing from the forested regions rise gradually during heavy rains and fall to normal more gradually, because the litter retards flow. Such streams, even when highest, are, as a rule, but slightly discolored and that discoloration is caused in great part by macerated fragments of leaves and decaying plants, for they carry little mineral matter in suspension. Some of them remain wholly clear even when swollen to far beyond their normal stage. But removal of the forest brings about an abrupt change. The protective efficiency of even a root-matted soil is evident, for when a tree is uprooted or a road is cut, so as to break the continuity, erosion begins at once. The contrast between forested and denuded areas is so striking that no argument is needed. Grass-covered slopes may be destroyed by breaks made when a cow crosses them after prolonged rainfall, but erosion can be checked by covering the surface with litter, held in place by brush; weeds and bushes spring up quickly. The writer adds his testimony in confirmation of these observations by Glenn, for he has seen many thousands of acres of cleared land, which had been abandoned after a few years of cultivation and which now are covered by a dense growth of hard wood—and this on the steep slopes of the Virginian Appalachians.

Glenn's volume is a commentary on the protective influence of vegetation and on its resistance to erosion. The changes in the rivers since the removal of forests from their headwaters, the increased erosion, the increased destructiveness of floods owing to the greater load of inorganic matter are set forth clearly on almost every page.

This increased load has led the formerly almost limpid streams to aggrade their lower reaches, to convert once fertile bottoms into marshes or to cover them with sand and gravel. This aggrading, in many instances, forced the streams to cut new channels or a network of channels through the plain. But this lateral cutting is prevented now by planting willows, aspens, balm of Gilead and other rapidly-growing plants on the river banks down to the water's edge. The silt-laden flood does little injury to these plants and the plain itself is injured only by drowning of crops when floods come in the growing season. Glenn contrasts conditions in the Coosa and Chattahoochee basins. The former river rises in an area still forested and its waters in flood carry little inorganic matter to cause destruction; but forests have been removed from the headwaters of the latter, floods are more frequent and the accumulation of sand is very great—a condition wholly unknown one hundred years ago.

Rixon[7] gives similar testimony to the ability of humus to protect itself as well as underlying material from erosion. "The litter and underbrush among the alpine timber are very heavy, having accumulated for ages. One class of timber, having reached maturity, decays, dies and falls, only to be supplanted by another growth, which in time follows its predecessor." This is in a region where rainfalls are infrequent but extremely violent.

Tuomey[8] studied the influence of forests on surface run-off. His observations were made on four small catchment areas in southern California, where wet and dry seasons are well-marked. In December, 1899, the rainfall was 18 inches. This was at the close of the long dry season, when litter and soil alike were desiccated and each absorbed a large part of the rainfall. The percentage of run-off is given in the first column:

1.	Forested	3	35
2.	Forested	6	33
3.	Forested	6	43
4.	Non-forested	40	95

---

[7] T. F. Rixon, "Forest Conditions in the Gila River Forest Reservation," *U. S. Geol. Survey, Prof. Paper*, 39, 1905, p. 18.

[8] J. W. Tuomey, "The Relation of Forests to Stream Flow," *Year Book of U. S. Dep't of Agriculture*, 1903, pp. 279–288.

But in January, February and March, when the absorbed moisture in the litter was great, the contrast still remained, as appears from the second column, where the run-off from the forested areas averages only three eighths while that from the non-forested area was nineteen twentieths.

The great dunes of Bermuda have their advance checked by vegetation. A network of vines creeps over the surface and breaks the force of the wind. Clumps of grass take root in the open spaces and, within a brief period, the heavy rains can do little more than to move the sand a few inches to be piled against the obstacles. Vegetation holds its place on the loose materials until, at length, a dense growth of oleander and cedar render the deluge-like rains wholly ineffective. The same condition exists along railroads within the drift covered areas of the United States. Many of the through cuts are in drift gravels, with no trace of consolidation, yet their walls show the steady advance of plants in spite of rain and the steep slope.

The resistance which vegetation offers to erosion is manifest on a grand scale in the tropics, where growth is luxuriant and the rainfall extreme. The writer has had opportunity to examine at close range fully 200 miles of the Venezuelan and Colombian coast, much of Trinidad, about 50 miles of the Jamaican coast, as well as much of the Pacific coast of Central America. There are some localities where the rock is not consolidated and vegetation cannot maintain itself. Such as gains rooting toward the close of the wet season is killed during the dry season and rain finds only the unprotected surface on which to act. But such areas are of limited extent. The slopes along the coast are usually quite steep and the stratified rocks commonly dip at a high angle. Landslides, owing to this structure, are not rare and they leave a scar on the surface which persists for years; but aside from those merely temporary interruptions, vegetation is practically continuous on even the steepest slopes. The Jamaican conditions are especially instructive. Where vegetation was destroyed by fire in some extensive areas, Guinea grass has taken possession of even the steepest slopes, giving great spaces of bright green, which are notable features of the scenery—and this in spite of the excessive rainfall. During November of 1909, the rainfall in the mountains of Jamaica was of unprecedented volume, there being at one locality 120 inches in eight days, while in others there were 20 to 30 inches within one day. Banana plantations, with unprotected soil, were washed down the hills and the plants became projectiles with which the flood destroyed vegetation on the lowland; but the forest remained almost uninjured and the litter covering the surface around the trees was practically undisturbed. Where the land was protected by trees, damage was confined to gullies digged by fallen trunks pushed forward by the water. These gullies widened in soft materials and trees, tumbled into the torrent, were carried to the lowland, where they were deposited, pêle mêle, with mineral matter on the cultivated land. Nowhere in the whole area was there evidence that rainfall did any serious injury to either forests or the forest litter.

Cornet's[9] observations in the Congo region are to the same effect. Where the dry season is prolonged, plants are practically dried by desiccation, so that the first rains do great damage; in such localities, this is so serious that vegetation cannot re-establish itself. But, near the equator where rains are almost constant, the forest quickly reoccupies areas which man has cleared. Even in regions with a long dry season, the bottoms of the valleys, owing to dampness, become forested and that puts an end to the action of the wild waters —it may cause even diversion of streams. Clearing of forests lays the humus open and it is carried off to be spread elsewhere, there to enrich the soil. This actually occurs in many valleys, giving what Dupont has termed *terrenoir;* but in the broad alluvial valleys, where humidity prevails throughout the year, vegetable detritus accumulates on the surface and gives a formation of humus *sur place.*

It matters not where one looks, the conditions are the same. Geikie,[10] familiar with the Highlands of Scotland, where bogs in the heath stage cover great areas, says that the surface of a district pro-

---

[9] J. Cornet, "Les depots superficiels et l'erosion continentale dans le bassin du Congo," *Bull. Soc. Belge de Géologie,* Vol. X., 1897, Mem., pp. 44–116.

[10] A. Geikie, "Textbook of Geology," 3d Ed., London, 1893, p. 475.

tected by a thin layer of turf, is denuded with extreme slowness except along the lines of its watercourses. Indeed, the evidence is wholly clear to every one who has crossed Scotland by way of the Caledonian canal, which utilizes a chain of small lakes, fed by streams rising in the Highlands and descending with rapid fall. The lakes are not turbid, they rarely show blocks or chunks of peat where the streams enter, the only evidence of vegetable matter being coloration of the water by salts of organic acids leached from the peat. The same condition exists elsewhere in Scottish lakes.

Many years ago, Marsh[11] wrote elaborately respecting the protective influence of vegetation and the disastrous consequences following removal of forests. He recognizes that humus can absorb almost twice its weight of water, which it surrenders to the underlying soil and becomes ready to absorb more. Twigs, stems, fallen trunks and the rest oppose the rush of water and break into small streams any larger ones formed by union of petty rivulets. He cites many works, reporting official as well as private studies—all recording the same results.

In the French Department of Lozére, which was among those most seriously injured by the inundation of 1866—caused by rains, not by melting snow—it was remarked everywhere that "grounds covered with wood sustained no damage even on the steepest slopes, while in cleared and cultivated fields the very soil was washed away and the rocks laid bare by the pouring rain." Marsh cites Foster, who describes an area with slope of 45 degrees, which consisted of three sections: one, luxuriantly wooded, with oak and beech from summit to base; a second, completely cleared; a third, cleared in the upper part but retaining a wooded belt for one fourth of the height from the bottom. The surface rose 1,300 to 1,800 feet above the stream flowing at the foot. The first section was wholly unscarred by the rains; the second showed three ravines, each increasing in width from summit to base; while the third, of same superficial extent, had four ravines widening from the summit to the wooded belt, in which they became narrower and soon disappeared. He

---

[11] G. P. Marsh, "The Earth as Modified by Human Action," New York, 1874, pp. 232–238.

refers to his own observations that, in primitive regions, running streams are generally fringed with trees and that even now in forested areas of the United States trees come almost to the water's edge, so that the banks are but slightly abraded by the current. He cites Doni respecting the Sestajone and Lima, two streams rising in the Tuscan Appenines and flowing into the Serchio. In rainy weather the volume of the former is only about half as much as that of the latter and its water limpid; whereas the water of the latter is turbid, muddy. The drainage areas are almost equal, but the Sestajone winds down between banks clad with firs and beeches, while the Lima flows through a cultivated, treeless valley.

The writer had opportunity in 1910 to observe the effect of heavy rainfall on the steep wooded slopes in central France, where the rocks are resistant gneisses and granites—a condition much like that of the White mountains. The rainfall during that summer was not merely in excess, it was extraordinary. The showers came suddenly and often resembled the cloudbursts of mountain areas within the United States. In many parts of the area, the gorges are deep, with walls often exceeding 35 degrees, at times exceeding 45 degrees. Many gorges have densely wooded walls; many others have a somewhat scanty growth, scattered over the rocky slope with plants growing here and there in decomposed material occupying clefts or accumulated behind projecting craggy points. During some showers, the water ran off exposed places not in rills but often in broad continuous sheets and the streams were converted into roaring torrents. More than once, after one of these almost cataclysmic rains, the writer passed through some of the gorges and was surprised to find that, apparently, no injury had been done to vegetation on even the steepest slopes. Tender plants, growing in handfuls of loose material on projections, seemed to be unharmed. The streams were followed for many miles, but they had received only rare stems of trees from undermined banks and the eddies showed no accumulation of plant material. Trees, lining the streams and in many cases growing down to almost the low water line, gave no evidence of having been subjected to the force of a dashing torrent. The conditions differ from those, with which every one is familiar, only in that they are on a larger scale. The almost vertical walls of railroad cuts through hard rock are adorned by small plants growing in clefts or even by trees in similar position. These have grown in spite of rains, which threatened to wash away the little soil on which they depend. But the rains are as powerless against plants in railroad cuts as they are against plants growing in like conditions on the walls of Alpine gorges or of canyons in the Sierra and the Rockies.

River Floods.—The floods of rivers have much in common with those of torrents, for most rivers are more or less torrential in their upper reaches; but there are noteworthy differences, aside from those due to volume. The topographical conditions required for torrents are wholly unlike those amid which great rivers exist. Torrents flow, for the most part, in narrow valleys with here and there some wider portions in which are insignificant floodplains; but rivers usually flow in broader valleys, have less rapid descent and are bordered frequently by extensive floodplains. Rivers entering the Atlantic along the eastern coast of the United States empty in most cases into estuaries, which occupy the drowned lower portion of the valley and conceal the floodplain; but the condition is different in the vast interior basin where many great rivers find discharge through the Mississippi channel. Each important tributary of that stream flows for long distances through broad lowlands, which fuse with those of the Mississippi, extending from above Cairo to the Gulf of Mexico and constantly increasing in width toward the south. The coast and the interior types must be considered separately. Illustrations of river floods will be selected mostly from those of the United States, partly because the conditions seem to be unfamiliar to many, and partly because the topographical relations of the central Mississippi region are much like those supposed by some to have existed during the coal-forming periods.

Rivers of the Atlantic Coast.—Shaler,[12] in describing several northward flowing streams of eastern Massachusetts, says that the floodplain is in direct communication with the present margin of the river, so that a very slight rise sends water over the whole of it.

---

[12] N. S. Shaler, "Fluviatile Swamps of New England," *Amer. Journ. Sci.*, 3d Ser., Vol. XXXIII., 1887, p. 203.

The streams, though draining comparatively small areas, carry an enormous amount of water in flood time. At low water, the river extends for some distance through reedy flats on each side of the flowing stream. The swamps, which are without *Sphagnum,* may be divided into three classes: those, formed in areas so frequently overflowed and so penetrated with water that they cannot afford a site for perennial shrubs, are occupied by rushes in the lower portions and by grasses in the upper; those, occupying a narrow belt in which the grasses give place to various bushy and low growing plants, among which alders are the prevalent forms; then, in some places, a third class, a wide field of swamps, really very wet woods, covered with water not more than twice a year and usually two or three feet above the ordinary inundations. The vegetation is continuous from the lower bench to the wet woods and it is able to resist the flood, though the mass of water is very great and the current very rapid. During flood these streams are almost torrential.

The rivers of Maine tell the same story. The Androscoggin, Kennebec and Penobscot are all liable to sudden floods and the fierce rush of water is reinforced by logs cut for timber. But the banks of those streams are covered with bushes and trees to within a foot and a half of the August stage of water; the flood, though aided by the logs, has not succeeded in tearing out these trees, but the trees have seized the logs, which may be seen for long distances entangled in the bushes. Islands in the Androscoggin have trees 40 feet high, against which the floating timber has lodged.

The Connecticut river, draining a great part of the White mountains as well as of the Massachusetts highlands, flows for nearly 200 miles in a broad valley, rising in terraces. It is subject to great floods, for much of the rugged region around its headwaters has been cleared. The writer has ridden several times for a distance of 150 miles along the banks soon after high floods, which had overflowed the second bottom, 15 to 20 feet above ordinary low water. Loose material, twigs and fallen branches, which had become dry but not decayed, had been removed to be deposited in eddies or on the bottoms. But trees and bushes growing on the lower bottom or on the banks down to within a foot of low water, were not removed.

Many of those are old trees which had withstood floods for more than a century, others were very young; but the age mattered nothing, the sapling resisted as well as did the older tree, provided only that it was rooted in material that would not soften during the flood. One great flood had poured over the second bottom in the late summer when the maize had attained its height. But it did not tear the plants from the soil: pressure against the broad leaves sufficed only to prostrate the plant; none was removed.

At the same time, the effect of the flood was shown by trees on the lower bottom, for those 25 or more feet high, if slender, were bent down stream. Those with broad spreading crowns were affected by pressure at the surface of the current. No doubt, if the flood had been repeated at intervals of two or three days, not a few of those trees would have been overturned; but, once overturned against their neighbors, they would tend to protect the others by increasing the density of the mass and so acting as breakwaters to divide the flow. The flood had no effect where the vegetation was dense, the close growth evidently reducing the current to gentle movement. Croppings of peat bogs, 1 to 3 feet thick, appear at many places in the banks. Such bogs suffer no injury except by undermining; in which case, a floating log occasionally tears off a piece.

The floods of the Passaic in New Jersey and of the Susquehanna have been described in several publications. They are more disastrous than those of the Connecticut, from a pecuniary point of view; but those rivers in flood are no more effective than the Connecticut in the struggle against vegetation.

The Potomac river, though of rather rapid fall, flows in a broad shallow channel, an anomaly due in great degree to the relation between its normal stage and its freshets. The flood of June 1 and 2, 1888, the greatest on record, was described briefly by McGee.[13] The height of water at Washington was no greater than during freshets caused by ice jams, but, above the limit of tidal influence, the volume of water and height of rise exceeded any previously recorded. The

---

[13] W J McGee, Tenth Ann. Rep. U. S. Geol. Survey, 1890, "Administrative Report," pp. 150–152.

discharge was thirty-eight times as great as that during the abnormally wet summer of 1889; five hundred and seventy-nine times that of the average low water discharge; it closely approximated that of the Mississippi in ordinary years and was two fifths of the discharge by that river during the flood of 1858. At Great Falls, the torrent was one third of a mile wide and 150 feet deep. This was a flood of unprecedented extent, such as might not be repeated in centuries. It should afford full opportunity for determining the ability of floods to remove vegetation. As McGee entered into no detail in his administrative report, the request was made that he would give such information as seemed proper. His letter[14] is in complete detail and the following citations are taken from it.

> "The most impressive river flood I ever saw occurred in the Potomac several years ago, when during June a series of rains occurred in such order about the headwaters as to raise the river far above any high stage previously recorded—indeed I inferred from its effect in bending smaller trees in connection with the undisturbed attitude of the older trees that it far exceeded any flood of the preceding 150 years. The discharge was not accurately measured, because the flow was too swift to get a weight into the water, but approximate measurements gave a discharge comparable with that of the Mississippi at ordinary stages. After the water subsided I went over the flooded ground with care; and this is what I found—the bottom being irregular, chiefly wooded, partly in field and pasture; in the woods, trees of less than, say, a foot and a half in diameter, were bent down stream and largely robbed of foliage, and a few were broken off, leaving snags; the higher trees had generally lost branches and most of their foliage (the water having risen forty to sixty feet, or well toward the tops of the highest trees); here and there, especially near the channel, a tree or clump of trees had been uprooted and swept away, though not more than say one or two per cent. of the wood in tree or branch was gone. Here and there in the woods, where the current was concentrated by rocks or large trees, a gully, generally two or three feet deep, as many yards wide and as many rods long, had been cut out; elsewhere, especially where rocks and trees had slackened the local current, there were bars and banks of sand; and generally throughout the woods there was a layer of silt, of course, left chiefly by the subsiding waters overspreading the soil—which usually was unmodified otherwise. From a little field, previously on the bottom, a short distance above Georgetown, the entire crop and the soil to plow-depth or more was removed; and in a sloping and somewhat rocky tract of pasture land, upstream from the field, the sward was irregularly furrowed by gullies ordinarily a few feet deep and as many yards wide—the number being such

---

[14] Of December 6, 1910.

that perhaps a quarter or perhaps a third of the sward was removed. The furrowing in this pasture, by the way, represents the most extensive flood removal of sward that I have ever seen. Now considering the translocation of material generally by the flood, it is clear that despite the favorable conditions due to abundant vegetation and to a higher declivity of the flood than that of the normal stream, the ratio of organic matter moved to the inorganic sediment was trifling. . . . What is true of that flood is, I am convinced, true of river floods generally—while the flooded river generally has its transportative capacity greatly increased, the material transported is chiefly inorganic, so that the resulting sediments are mainly mud, silt or sand, rather than organic accumulations."

The writer rode through much of the area two months after the flood had subsided. The chief evidence of great flood presented by the vegetation consisted of somewhat inclined trees, deposits of débris in branches of trees at a distance above the stream and an occasional furrow in the sod. These furrows were produced when the water in swirling around a projecting rock worked under the sod and, soaking the materials below, burst the cover, so opening the way for making a gully. In the forested portions, the litter seemed to have suffered very little injury beyond, as noted by McGee, receiving a cover of inorganic sediment.

Murphy[15] has described a flood on Willow creek in Morrow county, Oregon, a stream combining the features of a torrent with those of a river. The creek, 30 to 40 feet wide and enclosed in banks 10 to 15 feet high, has a fall of 38 feet per mile, but, unlike most of such streams, it flows through a fertile valley, 500 to 1,500 feet wide. The storm causing the flood of 1903 was brief, a cloudburst, and the flood had passed in less than an hour. The water came down as a mass, 20 to 25 feet high, with a slope in front of about 30 degrees, and it was 500 feet wide. It swept away a great part of a town which was in its path. No details are given respecting the damage done to vegetation, but some incidental remarks make the matter sufficiently clear. Referring to methods of determining the high-water level of floods, he says that trees are the best marks; small trees are often bent over and silt or light drift is deposited on them. When the water pressure is removed, the trees straighten up

---

[15] E. C. Murphy, "Destructive Floods in the United States in 1903," U. S. G. S. Water Sup. and Irr. Paper, 96, 1904, pp. 9–12.

and the drifted material is raised above the high level; but rings of silt left on trees, all on approximately the same level, show the true waterline. In this way he determined the extent of the flood. The houses, made of lumber, were lifted from their foundation and were dashed to pieces against rocks or trees.

Wilkes[16] made use of the same method. In speaking of floods on the Willamette river of Oregon, he says that the sudden rises of the stream are remarkable, the perpendicular height of the flood being at times as much as 30 feet, the limit being marked very distinctly on trees along the banks. In New South Wales "near the source of streams, grass is to be seen attached to the trunks of trees thirty feet above the present level of the water, which must have been lodged there by very great floods." This is a commonplace condition; the writer observed it at the head of Sacramento bay in California almost forty-five years ago. He saw many bunches of drift stuff entangled in branches of trees at 10 to 15 feet above the water level, and he was astonished by the fact that so great a flood had done no injury even to the shrubs growing among the trees.

Rivers in Great Interior Basins.—Excellent descriptions of floods within the Mississippi-Missouri area are given in reports of the United States Weather Bureau, those by Morrill and Frankenfield[17] being the most comprehensive.

Man's skill has brought about great changes in the lowlands of the Mississippi. The fertility of that region from the mouth of the Ohio to the Gulf of Mexico early led to settlements at many places. But the periodic floods of the river rendered agricultural operations precarious and levees were constructed for protection. Eventually the construction of such levees was assumed by the Federal government and they now protect a vast area from overflow. The region, now exposed to devastation under ordinary circumstances, is very small, but, during abnormal floods, the levees sometimes give way and

---

[16] C. Wilkes, "Narrative of the United States Exploring Expedition," 1845, Vol. IV., p. 358; II., p. 269.

[17] P. Morrill, "Floods of the Mississippi River," Rep. Chief of Weather Bureau for 1896–7, Washington, 1897, pp. 371–431. H. C. Frankenfield, "The Floods of the Spring of 1903 in the Mississippi Watershed," Weather Bureau Bull., 1904.

crevasses are formed—at times half a mile wide—through which a stream pours with amazing velocity. The conditions are materially different from those prior to settlement of the region, when the floodwaters spread over an area of 100,000 or more square miles; the energy of the flood stream, when it bursts through a crevasse, is much greater than when there were no levees. This, however, is unimportant, for if the later floods are incompetent to inflict serious injury upon lands protected by vegetable cover, the incompetence must have been more marked when the natural conditions existed.

The protection afforded by levees is shown by constant decrease in extent of the flooded area; the flood of 1887 overflowed almost 30,000 square miles below the mouth of the Ohio; that of 1897 covered somewhat more than 13,000, while the area was reduced in 1903 to somewhat less than 7,000—and in this year the extent would have been much less if the new levees at critical localities had been completed so as to resist the very high water. Rivers carrying much detritus and subject to flood build low levees in their passage through the lowlands. The Mississippi constructed such ridges for long distances, thus preventing return of the floodwater, much of which is ponded in swamps and gradually finds its way to the river farther down. This secondary drainage complicates the problem of reclamation.

The Mississippi floods, unlike those of the Nile, are very complex, for below the mouth of the Ohio the river receives great tributaries from the east and the west, whose floods rarely coincide; while the upper Mississippi, receiving the Missouri and other rivers, has its own periods of flood. The source of floodwaters is in the continental storms, arising in the west or southwest and moving toward the east-northeast. The effects are felt first in the lower Mississippi, which is filled by streams entering from the west; the storm advances to the western ridges of the Appalachian where rise streams forming the Ohio, Cumberland and Tennessee rivers. The heavier rains on the Appalachians pour out chiefly through the Ohio but the other streams contribute a great mass. Important floods in the eastern tributaries occur in the spring months, when heavy rains are reinforced by melting snow. The upper Mississippi is not an important factor in respect of quantity, but its swell, coming later than the others, often prolongs the stage of high water. The western rivers, entering below the mouth of the Ohio, are the Arkansas, Red, Ouachita and Yazoo, all of which descend into lowlands, where they meander for a long distance before reaching the Mississippi. The condition in this drainage area is that of rapidly flowing streams emerging from highlands on an immense area of lowland, most of which, unless protected, is subject to overflow.

Both Frankenfield and Morrill emphasize the gradual rise of floods within the open area. Frankenfield gives the record for 1903. The gauge showed at

	Feet.		Feet.		Feet
Cairo, Jan. 28,	17.5	March 8,	45	March 15,	50.6
Memphis, Feb. 1,	10.8	Feb. 22,	33	Mar. 20,	40.1
Vicksburg, Feb. 4,	21.0	Mar. 3,	45		
New Orleans, Feb. 8,	9.1	Feb. 26,	16	Apr. 6,	20.4

The advance was deliberate, the first wave requiring four days for passage from Cairo (at the mouth of the Ohio) to Memphis and seven days thence to New Orleans. The rise was gradual at Cairo, being a foot and a half daily for 39 days to March 8—which was thought to be remarkably rapid—and much less thereafter to the crest; at Memphis, it was one foot for 21 days and only one fourth of a foot for each of the remaining 28; at Vicksburg, barely nine tenths of a foot during each of the first 27 days; while at New Orleans, the daily rise averaged little more than one fifth of a foot throughout the whole period. The great mass of the water came from the Ohio, but the Red and Ouachita, entering from the west, were abnormally high; at New Orleans, the water was at or above danger line for 85 days.

When one studies the reports of local observers, as given in the publications from which this synopsis is taken, he is surprised by the nature and extent of damage within the flooded areas. Artificial protection is almost unknown along the upper Mississippi (above Cairo) as well as along the Missouri and its tributaries. Floods have free course in the low-lying prairie regions of Illinois, Iowa and Kansas as well as in portions of Missouri, and there one should expect to find record of the greater disaster. Morrill has compared the flood of 1897 with its predecessors as far back as 1858 and he has given details in all parts of the drainage area for that of 1897.

In 1897, the Ohio river was out of its banks everywhere from Pittsburgh to Cairo and the tributary streams, also in high flood, were miles wide for long distances, the "bottom," at times, being covered with 20 feet of water, while the overflow reached into the upper portions of cities along the banks. At the mouth of the river, the lowland was flooded for 4 to 6 weeks and the city of Paducah in Kentucky was flooded for 7 weeks. The river rose 50 to 60 feet along the whole distance of more than 600 miles from Pittsburgh to Cairo. Similar conditions prevailed along the Tennessee river, which for 60 miles was 2 miles wide, reaching to the hills on both sides. In the upper Mississippi region, the river spread from bluff to bluff, 3 miles wide for 147 miles along the Iowa border, and a great area of farming land in that state was inundated. Imperfect levees gave way and along the Illinois river an area of 500 square miles was flooded, making a continuous body of water from the Illinois to the Mississippi. Central Arkansas was submerged for long distances along the Arkansas river; while below Cairo, several levees gave way and the flooded district in that region embraced more than 13,000 square miles.

When one comes to sum up the effect of this disastrous flood, as given by the local observers, he discovers, that as far as the geologist is concerned, they were comparatively insignificant. The damage to manufacturing interests by destruction of machinery and by deposits of mud in mills was very great; the railroads lost much through washing out of embankments, the ruin of bridges and the removal of ties and lumber; but loss to the farming population was only moderate because Weather Bureau warnings led them to transfer movable property to higher land. Small houses, barns, lumber and other loose material were floated off to be used as battering rams against bridges; but, for the most part, farms overflowed by the rapid current were little injured. Where wheat had come up, it was drowned, not removed; where seed had been sown, it rotted; where the flood became sluggish, it left a deposit of sand, which made the land worthless, but elsewhere, as soon as the water withdrew, the farmer immediately set about replanting. The great flood had done little injury, had hardly disturbed the soil of cultivated fields.

Frankenfield tells the same story for the flood of 1903. The sunken area of New Madrid was filled and the water, being more or less ponded, left deposits of sand. In the lower Mississippi area, crevasses permitted great overflow, but there was no injury to farms, aside from drowning of the crops, for which there was ample compensation in the form of a rich alluvial deposit. The Ohio river was more than two miles wide in many places between Cairo and Louisville. Near Evansville, Indiana, 300,000 acres of maize and 30,000 acres of wheat were covered, but the only loss was that of 3,000 acres by drowning. The local observer at Evansville reported that the damage would have been much greater if the water had not remained in constant motion. At Topeka in Kansas, the flood was diverted from the river by obstructions piled against a railroad bridge and the water, loaded with sand, swept over a wide area. Crops were ruined and the nursery fields near Topeka were covered with sand which buried the young trees. These instances are merely illustrations of conditions prevailing throughout the whole area.

The reports contain no reference to the disastrous effects of such floods upon areas covered with forest or otherwise protected by close vegetable growth, which at first glance seemed strange, because wooded areas occupy much of the lowland or bottom regions. But the omission was due not to neglect but to absence of anything to record. Reproductions of photographs given by Frankenfield and Morrill show that trees and even shrubs were undisturbed amid the rush of water and coarse sand. The writer asked the former for information respecting the matter. The reply was

> "During the Mississippi floods no forests are uprooted and no bogs are torn away. A considerable quantity of sand is sometimes carried down and deposited when the velocity of the water decreases, either by contact with obstruction or by reason of decrease in inclination of the floodplain. It is of course conceivable that the mass of water rushing through a crevasse carries away a quantity of vegetable matter and perhaps some trees, but the area would necessarily be limited. The true Mississippi flood moves along very sedately, carrying only the enormous amount of alluvial matter in suspension, but very little indeed of foreign matter. Previous to the era of levee con-

struction, the forests do not appear to have been seriously disturbed by floods."

An observation by McGee[18] is in place here. The Mississippi, as it flows past northeastern Iowa, meanders through a densely wooded floodplain, four or five miles wide, now in one main and half a dozen subordinate streams and yet again in numerous large and small channels. But this plain is flooded each year; according to writers already cited, the river at times covers the whole plain from bluff to bluff as a rapid stream.

Lyell,[19] in referring to the 1844 crevasse near New Orleans, says that the water poured through at the rate of ten miles an hour, inundating the low cultivated lands and sucking in several flat boats, which were carried over "the watery waste" into a dense swamp forest. He mentions that the great Carthage crevasse was open during eight weeks and that nothing was visible above the flood except the tops of cypress trees growing in the swamp.

Humphreys and Abbot[20] state that the bottoms of the Illinois river are two to ten miles wide and raised only a few feet above the usual level of the river. The greatest part of this swampy country is included in the "American bottom." The Kaskaskia flows with crooked course through a heavily wooded alluvial bottom, overflowed eight or ten feet by freshets. These authors emphasize the fact, too often ignored, that lowland areas are usually well soaked by rains preceding the floods and the swampy areas become covered with water, so that when the overflow comes, it finds everything prepared for resistance.

Lyell[21] had the weird experience of descending the Alabama river in time of high flood. At night the passengers were startled by crashing of glass and partial destruction of the steamer's upper

---

[18] W J McGee, "Pleistocene History of Northeastern Iowa," Eleventh Ann. Rep. U. S. Geol. Survey, 1891, p. 204.

[19] C. Lyell, "Second Visit to the United States of North America," London, 1850, Vol. II., p. 169.

[20] A. A. Humphreys and H. L. Abbot, "Report upon the Physics and Hydraulics of the Mississippi River," Reprint, Washington, 1876, pp. 38, 66, 76, 82.

[21] C. Lyell, "Second Visit," etc., Vol. II., pp. 51, 141.

works. The boat had "got among the trees." The river banks are fringed with canes over which deciduous cypresses tower, while farther back is the evergreen pine forest. During floodtime, the actual channel is very narrow, as the branches of the high trees stretch far over the water, so that, when the stream has risen 40 or 50 feet, much skill is required to keep the way between them. At that time, the adjoining swamps and lowlands are inundated far and wide. But this flood does practically no injury to the forest directly in the path of its strongest current or to that farther back where the current is less rapid. Lyell found the same condition on the Mississippi delta, where the flood waters, though laden with silt, have not injured even the willow saplings.

The floods of great rivers in other lands exhibit the same phenomena.

According to Humboldt,[22] the floods of the Orinoco begin soon after the vernal equinox and attain their maximum in July. The water remains at practically the same height until August 25, after which it falls more slowly than it rose. Its bounding region is much like that of the lower Mississippi and the flooded area is as large as England though less than the exposed region along the Mississippi. The delta area is always wet except in some petty elevations, which are dry for brief periods. The surface is completely inundated during several months each year. But it is covered with a dense growth of Mauritius palm in which the inhabitants construct raised platforms, on which they reside.

Wallace[23] has described the broad level area extending to 20 or 30 miles from the main stream of the Amazon and extending for long distances along the main tributaries. This is flooded at every time of high water. It is "covered with a dense forest of lofty trees, whose stems are every year, during six months, from ten to forty feet under water." Much of the flooded area at the mouth of the Amazon is covered with the mirite palms, *Mauritia flexuosa* and *M. vinifera.*

---

[22] A. Humboldt, "Personal Narrative," Bohn Eng. Ed., 1852, Vol. III., p. 8.

[23] A. R. Wallace, "A Narrative of Travels on the Amazon and Rio Negro," London, 1853, pp. 419, 436.

Kuntze[24] sailed along the Lourenço river through the vast wooded swamp occupying three degrees of latitude. The remarkable feature, for him, was the absence of transported vegetable detritus. Rare fragments of the swamp are torn off during high water, but these consist not of detritus but of living plants; and these fragments become stranded elsewhere or go to sea broken into bits. The river water is brownish. Everywhere on the Paraguay as well as on its tropical and subtropical tributaries, one finds the dense forests coming down to the river, which are overflowed during floodtime; yet there is no outgoing organic detritus except fragmentary driftwood from trees, which tumbled in from undermined banks. Kuntze followed all the great streams above the mouth of the Parana.

Livingstone[25] has given admirable illustrations of the resistance offered by vegetation. Many times he encountered the rivers in flood, when water spread far over the plains. The conditions within the area of the Chobe and in that of the Lecambye are of the familiar type. He reached the Leeba river at the beginning of the rainy season. The river is bordered by a plain, at least 20 miles wide, where, at that time, the water was already ankle deep in the shallower parts, while on the Lobale plain it was thigh deep and impassable. This flooding was not due to the river, for that had not overflowed its banks. The condition was the same as that observed prior to the coming of great floods in the Mississippi lowlands. The Lobale plains are too nearly level to permit the rain water to flow off rapidly; while the thick sward, so dense as to conceal the water, prevents furrowing of the surface and formation of rivulets. On approaching the Kasai river, he crossed valleys, half a mile to a mile or more in width, with clear fast-flowing water almost chin deep. One, half a mile wide, was deeper and the men crossed it by seizing the tails of their oxen. The extremely rapid current "soon dashed them against the opposite bank." The middle of the flood was where a rivulet exists during most of the year. Boggy places are extensive

---

[24] O. Kuntze, "Geogenetische Beiträge," Leipzig, 1895, pp. 67, 68.

[25] D. Livingstone, "Missionary Travels and Researches in South Africa," New York, 1858, pp. 191–195, 234, 235, 333, 363, 364, 392.

on both sides of the river, but "even here, though the rapidity of the current was very considerable, the thick sward of grass was 'laid' flat along the sides of the stream and the soil was not abraded so much as to discolor the flood." In his later work,[26] he offers an explanation of the conditions.

> "The shallow valleys, along the sides of which the villages are dotted, have, at certain seasons of the year, rivers flowing through them, which at this time formed only a succession of pools, with boggy and sedgy plains between. When the sun is vertical over any part of the tropics on his way south, the first rains begin to fall and the effect of these, though copious, is usually only to fill the bogs and pools. When on his way north he again crosses the same spot, we have the great rains of the year, and the pools and bogs, being already filled, overflow and produce the great floods which mark the Zambesi, and probably in the same manner cause the inundations of the Nile. The luxuriant vegetation, which the partial desiccation of many of these rivers annually allows to grow, protects these bottoms and banks from abrasion, and hence the comparative clearness of the water in the greater floods."

Darwin and Mrs. Agassiz tell a similar story respecting the Parana and the Amazon; Cameron and Stanley have shown the conditions in the region of Lake Tanganika and the Sudd of the Nile has been described by Baker, Willey and other travellers. Everywhere, the conditions are the same; living vegetation and even humus are practically proof against the action of floods.

The Plant Materials Transported by Rivers.—While it is true that a vegetable cover is an almost complete protection against erosion and that neither rain nor floods have much ability to remove rooted plants or to take off the superficial coat of decayed or decaying plant-stuff, still the fact remains that rivers do carry away great quantities of plant materials in one form or another. The quantity brought down by a single torrent may be insignificant; even that borne by a river of considerable size may not impress an observer as important; but when one reaches the lower Mississippi, draining an area of not less than 1,250,000 square miles, fed by tributaries from the Rockies at the west and the Appalachians at the east, which flow for long distances in broad alluvial plains, he finds a

---

[26] "Narrative of an Expedition to the Zambesi and its Tributaries," New York, 1866, p. 554.

mass which seems to be almost inconceivably great. On some streams he finds or learns of huge log barricades, apparently affording ample confirmation of Ochsenius's barricade theory; along others the river bed is set with "snags," impeding navigation; while along the main stream the casual observer is apt to regard the floating trees and other débris as an almost continuous mass.

It is equally certain that a vast amount of finely divided vegetable matter, derived from chafing of logs and trunks during their voyage as well as from partial decay of the floating plants, is carried by all rivers. It is true that studies of the Mississippi, in flood and in ordinary stages, have shown that the quantity in the silts is utterly insignificant when compared with the inorganic materials, but it suffices, during decay, to give off a notable discharge of gas in the outer area of the delta. The suggestion has been made that vegetable matter, minutely divided, may explain the fertility of the Nile deposits. According to Reclus, cited by Marsh,[27] it has been computed that the Durance river, fed by torrents of great erosive power, carries down annually enough solid matter to cover 272,000 acres with a deposit two fifths of an inch thick, containing more available nitrogen than 110,000 tons of guano and more carbon than could be assimilated by 121,000 acres of woodland in one year. The black waters of the Scottish lakes, of several rivers in Florida, of great rivers like the Congo in Africa, the Negro and others in South America prove that an enormous amount of vegetable material is leached from peaty deposits.

When one considers the mass of transported timber, the content of organic matter removed by solution, and reads the more or less crude estimates of organic stuffs in the detritus carried by rivers, the mind is staggered and he is almost ready to concede that in this transportation there is the process fully competent to bring about the accumulation of coal beds. It is important, then, to ascertain, if possible, what becomes of this material.

The trees and shrubs carried by the rivers were not uprooted by the torrents; they come not from abrupt slopes but from lowlands where meandering streams undermine their banks and the plants

---

[27] G. P. Marsh, "The Earth as Modified by Human Action," p. 245.

tumble in with the rest. Gibbs,[28] who saw the spring flood of the Yukon river in Alaska, relates that

> "During the high stage of water, which lasts for perhaps two or three weeks, great sections of the heavily wooded banks are undermined and swept away. The majestic spruce trees and tamaracks and birches, which covered them, topple over and are swept down by the current along with immense quantities of drift wood from the forest beds. The entire accumulation, amounting to thousands of cords of wood, is discharged into Bering sea, whose restless waves and shifting winds scatter this fuel and pile it on barren shores, hundreds of miles distant."

The conditions along the Mississippi-Missouri and their tributaries are the same; when the weakened banks cave, the forest, with its fallen trunks and litter, finds its way into the water. The masses of drifted wood in the channels of the Mississippi and some of the streams entering that river from the west have been mentioned in nearly all textbooks on geology during the last seventy-five years; but in most instances the descriptions have been incomplete, while in some cases they were sufficiently inaccurate to be misleading.

In the early days, great numbers of waterlogged trees were held back by their roots and were moored in the silt with their usually branchless stems pointing down stream. These were the "snags" which rendered navigation perilous. Fewer of them are encountered now because a very great part of the drainage area is under cultivation, but enough are added annually to necessitate the services of several snag-removing boats along the line of nearly 2,000 miles. Most of the floating stems find their way to the Gulf, but some are stranded on the delta during floods. At one time, however, they were diverted, in chief part, into the Atchafalaya, the first great arm of the river at the head of the delta.

Darby[29] has told us that the vast number of trees brought down by the Mississippi were thrown into this arm, through which they were carried with tremendous speed. The Atchafalaya raft began to form in 1778, when practically the whole drainage area of the

---

[28] G. Gibbs, "The Break-up of the Yukon," *Nat. Geog. Mag.*, Vol. XVII., 1906, pp. 268–272.

[29] W. Darby, "A Geographical Description of the State of Louisiana," 2d Ed., New York, 1817, pp. 131–133.

river had still its virgin forest, there being only a few, insignificant settlements west from the Alleghany mountains. By 1816, the head of the raft was within 27 miles of the Mississippi. Darby examined it in that year and reported that it was 20 miles long, 220 yards wide and perhaps 8 feet deep. As it was not continuous, but showed many open spaces, he was convinced that a length of 10 miles would be nearer the truth, thus giving about 4,000,000 cubic yards of loose material as the total accumulation during almost 40 years, practically the total supply of floated timber from the area of more than 800,000 square miles. He says that "the tales which have been related respecting this phenomenon, its having timber of large size and in many places being compact enough for horses to cross, are entirely void of truth. The raft, from frequent change of position, renders the growth of large timber impossible. Some small willows and other aquatic bushes are frequently seen among the trees but are too often destroyed by the shifting of the mass to attain any considerable size." The channel was opened by the state authorities in 1840 and the raft disappeared.

Details respecting variation of position and duration of material were not given by those who described the Atchafalaya raft. But no such lack of information exists respecting the more celebrated raft of the Red river in Louisiana. That stream, formed by tributaries rising in the higher lands of Texas and Oklahoma, flows for a long distance through a region of yielding materials, which, in many places, is densely forested. According to Veatch,[30] this raft began to form in the fifteenth century and by the beginning of the sixteenth, its head was near the present town of Alexandria, somewhat more than 60 miles from the Mississippi river. It consisted of a series of complex logjams, each filling the channel. These ponded the river, which found a new outlet above the raft, so that this, by additions, gradually moved stream, becoming a great irregular accumulation of logjams and open water about 160 miles long.

---

[30] A. C. Veatch, "Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas," U. S. G. S. Professional Paper, 46, 1906, p. 60.

At the time of the early settlements, the foot of the raft was at Natchitoches, 120 or 130 miles from the Mississippi.

Humphreys and Abbot,[31] writing in 1861, reported that the raft was an enormous accumulation of drift logs, some floating, some sunken. The rotting of the logs at the lower end and fresh accessions at the upper end led to advance up stream at the rate of from one mile and a half to two miles each year, while the retreat at the lower end was about equal to the gain above. At one time, the lower end was at Natchitoches but in 1854 it was at 53 miles above Shreveport, a retreat of about 150 miles. At that time, it was nearly 13 miles long. Above Shreveport to the raft, the river bed was strewn with logs, stumps and other vegetable débris. The river is very shallow, 3 to 4 feet deep at low water, and it was about 220 yards wide at the head of the raft, 405 miles from the Mississippi. Rotting would cause the 13 miles, reported by Humphreys and Abbot, to disappear within seven or eight years.

The notes given by Humphreys and Abbot were from a casual examination by their assistant, the matter lying outside of the scope of their work. The raft was a serious obstruction to navigation, cutting off the region above from communication with the Mississippi. Congress in 1871 ordered a complete survey, which was made by Lieutenant Woodruff, whose report, rendered in 1872, gave the first exact information respecting the actual conditions. Captain Howell,[32] in transmitting the report, remarks that the facts have been misapprehended even by engineers. "The 'great raft' itself dwindles to a mere pigmy in comparison with the popular notion of its extent and composition." Woodruff, in 1871, proved that the raft extended along the river for about seven miles, but that throughout that distance the channel is only partially obstructed. The whole mass of floating raft was but 290 acres and the whole area of "towheads" or raft resting on the bottom was 103 acres. The towheads are formed during freshets by accumulations of logs and drift around a "snag." As the water falls, the pile rests on the bottom and a

---

[31] A. A. Humphreys and H. L. Abbot, "Physics and Hydraulics," etc., 1876, pp. 21–23.

[32] C. W. Howell, 42d Congress, 2d Session, Exec. Doc., 76, p. 1.

rapid deposition of mud takes place around it. The surface left above water produces willows, which, growing rapidly and binding the mass together by their roots, protect it from the washing by subsequent freshets. Woodruff advised removal of the raft, but, to prevent renewal, he recommended that the narrow part of the river, in which the raft was forming, be cleared of the willows lining the banks, which obstructed the passage of large bodies of floating drift. If this were done, the banks, no longer protected by the vegetable growth, would cave readily, the river would be widened and the formations of raft would cease. The removal of the raft was completed in 1872 and Woodruff afterwards gave a full history of the obstruction, to which the reader is referred for other details.[33]

Franklin[34] found much floating timber on the Athabasca river in northwestern Canada. "The river carries away yearly large portions of soil, which increases its breadth and diminishes its depth, rendering the water so muddy that it is hardly drinkable. Whole forests of timber are floated down the stream and choke the channels between the islands at its mouth." It is clear that, on the Athabasca as on the Mississippi, caving banks yield the supply of drifting timber. In the same volume, Richardson[35] describes conditions observed along some rivers and lakes within the region traversed by Franklin's expedition. His statements have been cited by many writers but so far as the present writer has seen, not in full. They are as follows, with omission only of some details which are irrelevant here. Peace river brings much large drift timber into Slave river

> "and as the trees retain their roots, which are often loaded with earth and stones, they readily sink when water-soaked and, accumulating in the eddies, form shoals which ultimately augment into islands. A thicket of small willows covers the new-formed island as soon as it appears above water and their fibrous roots serve to bind the whole firmly together. The trunks of the trees gradually decay until they are converted into a blackish substance

---

[33] E. A. Woodruff, in App. Q, Ann. Rep. Chief of Engineers for 1873, Separate, pp. 45–61.

[34] J. Franklin, "Narrative of a Journey to the Shores of the Polar Sea," London, 1823, pp. 192, 357, 364, 374, 381.

[35] J. Richardson, Ibid., p. 518.

resembling peat, but which still retains more or less of the fibrous structure of the wood, and layers of this often alternate with layers of clay and sand, the whole being penetrated to the depth of four or five yards or more by the long fibrous roots of the willows. A deposition of this kind, with the aid of a little infiltration of bituminous matter, would produce an excellent imitation of coal, with vegetable impressions of the willow roots. The same operation goes on in a much more magnificent scale in the lakes. A shoal of many miles in extent is formed on the south side of Athabasca lake by the drift timber and vegetable débris brought down by the Elk river; and the Slave lake itself must be filled in process of time by the matters daily conveyed into it from Slave river. Vast quantities of drift timber were buried under the sand at the mouth of the river and enormous piles of it are accumulated on the shore of every part of the lake. The waves washing up much disintegrated vegetable matter, fill the interstices of these entangled masses and in process of time a border of spurious peat is formed around the various bays of the lake."

In a later work,[36] referring to the drift timber of Slave river, he describes the trees as "partially denuded of their branches and wholly of their bark." The absence of all-important details in Richardson's account is due to the fact that he was not a geologist, but he was an acute observer, as is evident from the general tenor of his reports. McConnell[37] has supplied many of the details omitted by Richardson. The sandy beaches and islands along the lower reaches of Slave river owe their origin to drift timber, which lodges and soon has the growth of willows noted by that author. But those islands cause currents, which either destroy them or move them down stream. Beds of drift timber alternate with clays and sands on many of the islands and in some instances, constitute a considerable portion of the whole mass. The east end of Big island in Great Slave lake is fringed by a wide margin of drift timber. When the interstices have been filled by gradual deposition of sand and the decay of the wood, a dense growth of willows covers it. The coves of the main shore show the same features in many places. Athabasca and Slave lakes are inland seas, larger than Lake Ontario.

Islands, such as those described by Franklin, are not unusual in

---

[36] J. Richardson, "Arctic Searching Expedition," London, 1851, Vol. I., p. 142.

[37] R. G. McConnell, Ann. Rep. Geol. Survey of Canada, N. S., Vol. IV., 1890, pp. 63, 64, 74 D.

the Mississippi river. Humphreys and Abbot[38] have described the process of formation and destruction:

> "Driftwood is lodged upon a sandbar. Deposition of sediment follows. A willow growth succeeds. In high water, more deposition is caused by the resistance thus presented to the current. In low water, the sand blown by the wind lodges among the bushes. An island thus rises gradually to the level of highwater and sometimes even above it, sustaining a dense growth of cottonwoods, willows, etc. By a similar process the island becomes connected with the mainland, or, by a slight change of direction of the current, the underlying sandbar is washed away, the new made land caves into the river, and the island disappears."

When in the temperates such an island, which in spite of current and flood, had grown and had become coated with trees, disappears through undermining, the vegetation floats away piecemeal; but in the tropics the whole mass is bound together firmly by climbing and other plants, whose roots are interlaced and whose stems embrace the trees; so that, when the underlying loose material has been removed, the entangled vegetable matter floats away to be broken up gradually. Many travellers have referred to floating island of plants and plant material. Humboldt saw them on the Orinoco; Mrs. Agassiz was astonished by their size on the Amazon, where some were like "floating gardens, sometimes half an acre in extent." Kuntze saw patches of moderate size floating down the Parana system. Miss Kingsley[39] relates that during high water, the Congo and Ogowé tear away their banks in the region above brackish water, where there is no network of mangrove to protect them. Along the Ogowé, the banks are of "stout clay" and the blocks hold together, so that they often go sailing out to sea and are seen far from land with shrubs or even trees on them. Not all reach the open water, for many are stranded in the delta region, where they collect débris from the flood water and become matted with floating grasses. Eventually they all go to pieces.

De la Beche[40] cites Tuckey's Expedition to the Zaire (Congo)

---

[38] Humphreys and Abbot, op. cit., pp. 97, 98.

[39] M. W. Kingsley, "West African Studies," 2d Ed., London, 1901, p. 87.

[40] H. T. de la Beche, "The Geological Observer," Philadelphia, 1851, p. 370.

as containing the statement that Professor Smith had seen a floating mass about 120 feet long and probably washed out of the Congo, consisting of reeds resembling *Donax* and a species of *Agrostis,* among which branches of a *Justicia* were still growing. Powers[41] saw a floating island in the Gulf Stream in July of 1892. Its area was estimated at about 9,000 square feet and it carried trees, 30 feet high. It was seen again in September, having travelled more than 1,000 nautical miles. This, first seen in latitude 39° 5′, may have been torn off from the Florida coast. In every case the floating islands are of small extent and their rarity makes them objects of curious interest.

Driftwood.—Great rivers carry immense quantities of trees from the undermined banks. Where the course of the stream is interrupted by extensive lakes, such as Great Slave or Athabasca, much of the floating timber becomes scattered and is cast on the shore to be mingled with the mineral material, which eventually buries it. When the stream is continuous, some of the drift is cast ashore in eddies, more is stranded during flood time on the delta or in shallows at the mouth; but by far the greater part is swept out to sea, there to be battered by the waves or carried by currents to perhaps distant shores. Nordenskiold[42] relates that driftwood in the form of small branches, pieces of roots and whole trees with adhering portions of roots and branches, occurs in such quantity at the bottom of two well-protected coves near Port Dickson, that the seafarer may provide a sufficient stock of fuel without difficulty. The great mass of driftwood carried down by the Yenesei floats out to sea. Some of it is drifted by currents to Nova Zembla, the north coast of Asia, Spitzbergen, perhaps to Greenland. Some of it becomes watersoaked and sinks before reaching those shores. But not all goes to sea, for some sinks in the river bed, upright as though rooted in the sands. A bay off Port Dickson was found barred by a palisade of driftwood.

---

[41] S. Powers, "Floating Islands," *Pop. Sci. Monthly,* Vol. LXXIX., 1911, pp. 303–307.

[42] A. E. Nordenskiold, "The Voyage of the *Vega* around Asia and Europe," New York, 1882, pp. 152–154.

That the amount of driftwood accumulated on shores has been estimated in exaggerated style is amply evident from Brooks's[43] observations. In the north and northwest part of Alaska from Norton bay to the mouth of the Mackenzie river, the shore at one time was abundantly supplied with driftwood. The Eskimos, who have been using this wood for generations, are very economical in the matter of fuel and, until the coming of the white man, the probabilities are that the wood accumulated more rapidly than it was consumed. This driftwood is brought down from the interior by the larger rivers, whose banks are forested. The cutting of wood along the banks of the Yukon has already diminished the contribution to the northern Bering sea. The north Arctic coast, eastward from Point Barrow, which is thinly populated by natives and rarely visited by the white man, has some driftwood, but according to Franklin, the quantity is unimportant along the coast visited by him; the material is brought down by the Mackenzie and is carried eastwardly by a strong current. McClure found driftwood on the northeast coast of Banks land, where it is often at a considerable distance above sea level. Low[44] found that the prevailing winds and the force of the waves have determined the accumulation of driftwood on the shores of Hudson Bay. During great storms, the older, the lighter portions of the mass are thrown to a considerable height above mean tide.

The driftwood deposits on the northern side of Spitzbergen, on Jan Mayen and Iceland are mentioned in most of the current textbooks of geology. Some of them, such as the Suturbrander of Iceland and the deposit on the New Siberia islands are clearly not driftwood, at least not the driftwood under consideration, as they contain fruits and tender portions of plants and belong to the Tertiary. As to the others, of undoubted modern origin, the common conception is simply misconception. The descriptions, in many cases, would lead one to suppose that the mass is closely packed and almost con-

---

[43] A. H. Brooks, "The Coal Resources of Alaska," Twenty-second Ann. Rep. U. S. Geol. Survey, 1902, Part III., p. 570.

[44] A. P. Low, Ann. Rep. Geol. Surv. Canada, N. S., Vol. III., 1889, p. 33 J.

tinuous. Potonié[45] has given reproductions of two photographs, one from Jan Mayen and the other by Nathorst from Amsterdam island. The drift material is scattered irregularly, as one should expect, with here and there a considerable pile. The fragments, some of which are very large, are thoroughly battered—the whole resembling very closely what one sees on the gravel flats of rivers subject to flood.

Crantz[46] was among the first to describe the driftwood deposits of Greenland and adjacent regions, and his statements have been cited again and again, acquiring the increment which usually comes with frequent repetition. In the driftwood on those shores he saw many great trees, which had been torn out by the roots and which, through driving and dashing amid the ice for many years, had been deprived of bark and branches and had been bored by worms. A small part of this débris consisted of willows, alders and birches from bays in southern Greenland; with these were aspens from some more distant region; but the predominant forms are pine and fir with great abundance of a fine grained wood, with few branches, which he took to be larch. With these is a reddish wood of agreeable odor, resembling the Zirbel of the Alps. The grouping shows that the trees came from a fertile but cool or alpine region.

The drift could not have come from the American coast at the southwest as the current is contrary; it must have come with the icy current. It is most plentiful on the coast of Iceland and, on the southwest side of Jan Mayen in N. L. 75°, there are two bays in which there is so much wood, driven in by the ice, that a ship might be loaded with it. He thinks the wood may have come from Siberia, where pine and cedar abound, though it may have come from the west coast of North America by way of Bering strait.

Crantz may be right or wrong in his suggestion respecting the source of the material; that is unimportant. His description shows that the mass, though considerable, is comparatively insignificant. The accumulation on the Jan Mayen bays, instead of being a closely

---

[45] H. Potonié, "Die Entstehung der Steinkohle und der Kaustobiolithe überhaupt," Berlin, Funfte Aufl., 1910, p. 126; *Naturwiss.-Wochinschrift*, Vol. IV., Part 4.

[46] D. Crantz, "The History of Greenland," Eng. Trans., London, 1820, Vol. I., pp. 35–37.

packed deposit, was merely enough to load a Danish merchantman of one hundred years ago—say a vessel of 400 or 500 tons. The description shows also that the wood had floated long; it matters not whether it came by the slow drift from Siberia or Norway to northern Greenland and thence southward, or followed the north coast eastward to Davis strait, it is certain that the voyage was very long and the wood showed the effects. This long continued buoyancy of the wood is equally evident in the Gulf of Mexico, where one finds the Mississippi drift wood stranded on the shores along hundreds of miles.

In all extensive deposits of driftwood, the trees are battered, stripped of leaves, bark and often of branches; they are scattered on the strand or piled in irregular loose heaps, where, exposed to the air, they decay; or if in more favorable conditions, the interstices become filled with sediment, the trees become merely logs in shale or sandstone, even their genus being unrecognizable except by microscopic study of the structure.

The quantity of finely divided organic matter transported by rivers is minute in comparison with that of inorganic. Pourtales[47] examined sediment from samples of Mississippi water collected at Carrollton, Louisiana. The first series, taken in March during a flood from the Red and Ohio rivers, yielded no matter of organic origin aside from some spicules of sponges and rare vegetable fibers. A second series, collected in June, during a Missouri flood giving the most abundant sediment of the year, contained in water from the surface some indistinct vegetable fibers and wood cells, but no remains of vegetables were found in the other samples taken at various depths. A third series, in August, contained a vegetable scale or a leaf of moss; while a fourth series, in October, contained no organic matter. A fifth series, collected in the following January, showed on nearly all the filters minute black bodies which may have been pollen or spores.

But the absolute quantity of organic matter carried out is considerable. The "mud lumps" off the mouth of the Mississippi, are masses of tough clay, occasionally forming islands of several acres,

---

[47] L. F. Pourtales, in Humphreys and Abbot, Appendix 8, p. 651.

which rise 3 to 10 feet above the water and give off much inflammable gas. They were studied by Sidell[48] for the Mississippi survey of 1838 and by Humphreys and Abbot at a later time. Sidell believed that in outflow of the river the finest materials, organic matter and silt, went farthest and, after deposition, were covered with coarser materials. Decomposition of the organic matter generates gas, which lifts the overlying deposits. According to Humphreys and Abbot, the mud lumps are formed on the crests of bars and their activity ceases when the gas is exhausted. In 1858, during operations for removal of obstructions, some mud lumps on the bar of Southwest pass were broken by an explosion of gunpowder. Strong ebullition of gas continued over a wide area for 20 minutes after the explosion and the surface of the bar, in a space, 100 feet diameter, sank, assuming the form of an extinct crater. Hilgard[49] gives as composition of gas from one of the mud lumps, marsh gas, 86.20, carbon dioxide, 9.41, and nitrogen, 4.39, which closely resembles the average composition of gas from swamps. Oxygen is absent.

Very little of the vegetable material is stranded on the banks of rivers, comparatively little is deposited on the deltas. Most of the great accumulations in the Mississippi delta, supposed at one time to be driftwood, have proved to be buried forests in place. Terrace deposits along the Monongahela, in Pennsylvania and West Virginia, contain only here and there a woody fragment in the mass of sand, clay, gravel and blocks of rock. The same is true of terrace deposits generally, away from the lines of abandoned curves. In this connection, Brown's[50] observations along the Amazon are instructive. Long lines of cliffs, now on one side, now on the other, are composed of bright-colored deposits, contrasting with the monotonous clay banks of the river. The elevated plateau of these old river deposits, as well as the alluvial plain, is covered with luxuriant forest. Except a narrow strip along the bank, the whole plain is overflowed

---

[48] Humphreys and Abbot, op. cit., pp. 485, 486; W. H. Sidell, Ibid., Appendix A, p. 499.

[49] E. W. Hilgard, "The Exceptional Nature of the Mississippi Delta," *Science*, N. S., Vol. XXIV., 1906, p. 865.

[50] C. B. Brown, "On the Ancient River Deposit of the Amazon," *Q. J. Geol. Soc.*, Vol. XXXV., 1879, pp. 763–777.

during the periodical floods. The cliff crests are from 10 to 160 feet above the floodmark and sections show white, yellow and red sands with bluish or variegated clay beds. Ten feet of red clay was seen at the top of one section, while in another are white clays resting on bright red clays. The area studied by Brown is about 400 by 1,000 miles. Within this he saw four insignificant exhibitions of vegetable matter in the deposits, which seem to have been laid down in an estuary.

It is evident that very little of the drifted material is deposited anywhere within the river region or immediately beyond; the driftwood deposits on the northern shores, though vast in the aggregate, clearly represent but a small part of the timber brought down by the great northward flowing rivers; the writer has followed the Gulf Stream for more than 3,000 miles but he has rarely seen floating logs; in the central part of the so-called Sargasso sea of the north Atlantic, he saw no floating timber and captains of steamships familiar with that area have assured him that driftwood is of rare occurrence; the Orinoco brings down great numbers of trees which should be caught by the westward current, but the writer, during two voyages between Trinidad and Colon, saw not one. What, then, becomes of the vegetable material carried down by the rivers?

Deep sea soundings in the Atlantic ocean give no answer to the question. Material brought up by the trawl seems to be practically free from vegetable matter. It has been suggested that the constant "creep" at great depths maintains the supply of oxygen, which under the pressure would be greater than at the surface, so that organic matter would be destroyed. Whether or not the explanation be in this suggestion, it is certain that where different conditions of movement and pressure exist, one finds an accumulation of vegetable material on the ocean bottom. The observations by Agassiz[51] in the Gulf of Mexico and the Caribbean as well as in the Pacific off the coast of Mexico are final in respect to this matter. His statement is that

---

[51] A. Agassiz, "Three Cruises of the *Blake*," *Bull. Mus. Comp. Zool.*, Vol. XIV., p. 291; "General Sketch of the Expedition of the *Albatross*, 1901," Vol. XXXIII., p. 12.

> "While dredging to the leeward of the Caribbean islands, we could not fail to notice the large accumulation of vegetable matter and of land *débris* brought up from deep water many miles from the shore. It was not an uncommon thing to find at a depth of over one thousand fathoms, ten or fifteen miles from land, masses of leaves, pieces of bamboo and sugar cane, dead land shells and other land *débris*, undoubtedly blown out to sea by the prevailing trade winds. We frequently found on the surface masses of vegetation, more or less waterlogged and ready to sink."

The violent hurricanes of the Caribbean, as described by Maury, must contribute very largely to the mass of vegetable material. Agassiz found similar conditions at the bottom of the Pacific during the cruise of the Albatross, when he was surprised at the distance to which land-derived material had been carried. Along most of the distance between Acapulco and the Galapagos islands as well as all along the coast from Acapulco northward to within the Gulf of California, there is a very sticky mud covering the bottom and interfering seriously with the work of dredging. His description of conditions between Acapulco and the Galapagos is

> "Nearly everywhere along our second line of exploration, except on face of the Galapagos slope, we trawled along a bottom either muddy or composed of Globigerina ooze, more or less contaminated with terriginous deposits and frequently covered with a great amount of decayed vegetable matter. We scarcely made a trawl which did not bring up a considerable amount of decayed vegetable matter and frequently logs, branches, twigs, seeds, leaves, fruits, much as during our first cruise."

The conditions were similar along the continental coast. The trawl was ordinarily well filled with mud along with the usual supply of decayed vegetable matter. Observations of like character have been made by others elsewhere in the Pacific.

In all probability, a great part of the vegetable matter swept out to sea disappears by oxidation at the surface or in the depths; but in favorable localities another great part is deposited in fragmentary condition with fine muds on the bottom, there eventually to form beds of carbonaceous shale.

Conclusions.—The grouping of facts presented in the preceding pages, proving similarity of conditions in all parts of the world, seems to justify the following conclusions:

1. If torrents carry clear water, they produce little effect on

either the rock over which they flow or the vegetation growing on the floor or on the walls. If they carry sand, clay or even fine gravel, vegetable growth on islands, formed by aggradation, resists the flow and causes increased local deposit without material injury to itself. Even fierce mountain torrents sweeping their load of very coarse materials over a dejection cone do not clear the surface from trees.

2. Water of rainfall has practically no ability to remove a cover of living vegetation, even on steep declivities, except indirectly—as by finding access to unconsolidated material below, which may be rendered semi-fluid, so as to move down as a landslide. The heaviest rainfall barely disturbs the cover of litter in a forest; that material breaks the force of the falling drops, it absorbs much of the water, it obstructs the formation of rivulets and protects itself as well as the underlying soil from erosion. Forests are practically uninjured by the heaviest rainfall; even tiny plants, growing in clefts of rocks are equally undisturbed. Rain does not remove the petty deposit of soil on a projecting point of rock, if a tuft of grass has thrust roots into it.

3. River floods in great lowland areas rise slowly, as is shown by the floods of Mississippi, Amazon, Orinoco, Nile and the rivers of central Africa. In passing through forests, those floods lose speed and become merely a quiet overflow with sluggish movement, so that they disturb neither the living growth nor the decomposed litter on the surface. They move the loose dried twigs and leaves, but even those in great part, are transported only a short distance, unless swept into the stream from the bank. The main current itself cannot uproot trees; it cannot even tear loose a floating tree which has lodged against a sandbar directly in the line of strongest flow; but, unless the sandbar be washed away and the tree be set free, that will remain as a "snag," to become more firmly fixed during each succeeding flood. In most cases, the areas subject to these vast floods are prepared beforehand by heavy rains, whereby the humus cover is soaked and, so to say, cemented to resist the moving water. A dense growth of vegetation forms in the channels of tropical rivers and offers such resistance that even the mightiest

floods are checked as surely as though dammed by a mountain. Logjams are not swept out by the greatest floods, though the accumulation is merely superficial; in spite of floods, they accumulate at the upper end while decaying at the lower. If floating débris enter a lake of moderate size, it finds its way directly to the outlet; but if the lake be large and disturbed by waves, the débris is scattered along the shores. Finely divided organic matter carried out by floods is in minute quantity compared with the mineral matter and it is deposited along with the fine mud.

4. The trees as well as the humus swept out by floods were not uprooted by the running water. Their presence in the current is due to the undermining of banks composed of unconsolidated material, so that trees, humus and the rest fall together into the water to be carried away. The damage thus done is very small—the drift carried by the lower Mississippi being the accumulation from the soft banks of more than 20,000 miles of river, the length of torrential and semi-torrential streams being neglected, as they contribute an insignificant proportion of the mass. The quantity of driftwood in all is unimportant, when one considers the area into which it is swept. Comparatively little lodges on its way down the larger streams and most of that is buried in muds as "towheads" or "snags" or accumulates in rafts to disappear by rotting. A small part is stranded on deltas, far less than has been supposed, for in the Mississippi delta the deposits, supposed to be of driftwood, are now known to be old swamps and forests buried *in situ*. Much finds its way to shores more or less distant where, after having been for long time the plaything of winds and currents, it is cast in battered condition, scattered here in clumps or in individual pieces to decay or to be buried in sands. But the greatest part floats until, in half-rotted condition, after long exposure, it finds its way to the depths of the sea, to litter the bottom in areas, 1,000 to 1,500 fathoms below the surface, where, mingled with remains of marine animals, it will become part of bituminous shales, with here and there a pot of impure coal.

5. The conception that moving water, under any known or recorded conditions, can uproot forests and sweep off peat bogs from

even moderately extensive areas is wholly without basis in fact. One must regard it as originating in medieval descriptions of the devastating force of the Noachic deluge, which became an integral part of religious and romantic literature, so that the conception was accepted as a fundamental truth, needing neither investigation nor proof.

THE PHENOMENA OF PEAT DEPOSITS.

Peat or turf is familiar to those living in the temperate zone. It is an accumulation of vegetable matter undergoing special chemical change because protected from atmospheric oxygen by an excess of moisture. If one examine an old peat bog, he finds the surface covered by plants of various kinds growing on more or less decayed material. This, in its uppermost portion, is brown or yellowish brown, but the tint deepens downward until in the ripe peat it is almost black. At the top, one finds the vegetable structure distinct, but downward that becomes more and more obscure until in the mature peat it cannot be recognized by the unaided eye, and there seems to be only a vegetable mud containing, at times, fragments of slightly changed wood.

Peat-making Plants.—Sphagnum is regarded by many authors as the all-important agent in production of peat; and this supposed condition has been utilized more than once to fortify arguments against the suggestion that coal beds originated from growth *in situ*. The prevalence of this misconception is strange, for evidence to the contrary has been presented in many works during the last century.

Darwin[52] says that in the Chonos archipelago, S. L. 44° to 46°, every piece of level ground is covered with *Astilia pumata* and *Donatia magellanica,* "which by their joint decay compose a thick bed of elastic peat." In Tierra del Fuego, the former is the chief agent. Fresh leaves appear constantly around the growing stem, while the lower ones decay. Tracing a stem downward into the peat, the old leaves can be seen in all stages of decomposition until the whole has become blended into a confused mass. Every plant

---

[52] C. Darwin, "Journal of Researches," New York, 1846, Vol. II., pp. 24–26.

in the Falkland islands becomes converted into peat. He saw no moss peat anywhere in South America. Thomson[53] notes that peat in the Falkland islands is very different from that of northern Europe, cellular plants being almost wanting. It is formed for the most part of roots, matted foliage and stems of *Empetrum rubrum,* a variety of "crowberry" common on Scottish hills; *Myrtus nummularia,* a creeping myrtle; *Caltha appendiculata,* a dwarf species of water marigold; with some sedges and sedge-like plants. The roots, preserved almost unaltered, may be traced downward in the peat for several feet, but finally all structure is obliterated and the whole is reduced to an amorphous structureless mass. Mrs. Brassey's[54] description of accumulated decayed and decaying vegetation at Borja bay in the Magellan region is in place here, as showing the origin of peat from forest material.

> "To penetrate far inland, however, was not so easy, owing to the denseness of the vegetation. Large trees had fallen and rotting where they lay under the influence of the humid atmosphere, had become the birthplace of thousands of other trees, shrubs, mosses and lichens. In fact, in some places, we might be said to be walking on the tops of the trees and first one and then another of the party found his feet slipping through into unknown depths below."

But long prior to Darwin, Al. Brongniart[55] asserted that the presence of *Sphagnum palustre* is not necessary to the formation of peat. One finds on the banks of the Meuse, below Maestricht, some peats containing only leaves of resinous trees. He contents himself with the observation that all are agreed that, for formation of peat, the essential condition is stagnant water, covering the surface constantly and never completely dried up. Lesquereux[56] defined peat as a mass of woody plants whose fermentation and, consequently, decomposition were retarded by the presence and the temperature

---

[53] C. Wyville Thomson, "The Atlantic," New York, 1878, Vol. II., p. 185.

[54] Mrs. Brassey, "Around the World in the Yacht *Sunbeam,*" New York, 1883, p. 128.

[55] Alex. Brongniart, "Traité élémentaire de minéralogie," Paris, 1807, Vol. II., p. 41.

[56] L. Lesquereux, "Quelques recherches sur les marais tourbeux," *Mem. Soc. des Sci. Nat. Neuchatel,* Vol. III., 1845, p. 26.

of water. Vogt,[57] while giving pre-eminence to *Sphagnum*, notes that under favorable circumstances any vegetable substance can be converted into peat, for some peats are formed of grasses and reeds. Heer[58] assigns to mosses only a subordinate part and asserts that peat originates partly from mosses, partly from water-plants, from swamp plants, especially from grasses and sedges, and partly from woody plants. A. Winchell in 1860 and Grand'Eury in 1882 made the conditions equally clear, while Früh[59] showed that *Sphagnum* is a late arrival in accumulation of peat.

Peat in the Tropics.—The belief prevails that peat is not produced in the tropics. Jameson,[60] long ago, asserted that peat is peculiar to cold climates, but not wholly so, for Anderson had received some from Sumatra. It is quite natural to find peaty substances in warm climates for peat at the bottom of a mountain is more decomposed than that at the top; that of southern England more than that of north Scotland; that of France is more coaly than that of England, while no peat is found in the French lowlands except under cover. All of which shows that decomposition increases toward warm climates, until, in the tropics, it is so rapid that masses of peat cannot form.

Früh[61] was unwilling to believe that true peat forms in the tropics. He discusses a great number of reported occurrences in tropical and sub-tropical areas. For him, the observations are incomplete and his conclusions are that, so far as known, there is no important deposit of true autochthonous peat in the lowlands of the tropics; that, within the tropics, formation of peat is in elevated regions, where the climate is that of the temperate zone; that the supposed peat layers, bored through in the alluvium of great trop-

---

[57] C. Vogt, "Lehrbuch der Geologie," 2d Aufl., Braunschweig, 1854, Vol. II., p. 110.

[58] O. Heer, "Die Schieferkohlen von Utznach und Dürnten," Zurich, 1858, pp. 1–4.

[59] J. J. Früh, "Ueber Torf und Dopplerit," Trogen, 1883.

[60] R. Jameson, "An Outline of the Mineralogy of the Shetland Islands, and of the Island of Arran," Edinburgh, 1798, pp. 151–153.

[61] J. J. Früh und C. Schröter, "Die Moore der Schweiz," Bern, 1904, pp. 134–143.

ical streams, are prevailingly allochthonous. In this last his reference is to the record cited by Lyell,[62] of a boring in the Ganges delta, which passed through a deposit, having certainly the characteristics of a peat bed. In view of what has been said on preceding pages respecting the accumulation of drifted vegetable matter and of the fact, that the great deposits in the Mississippi delta, formerly supposed to be of drifted material, are of *in situ* origin, one is justified in saying that the testimony of that and other borings cannot be waived aside lightly by the mere assertion of allochthony. The onus of proof is on the one making the assertion.

It is difficult to understand why the *a priori* reasoning that tropical heat should prevent peat formation is thought so conclusive as to make worthless the testimony, which would be accepted as proving the presence of peat in Michigan or north Germany. The conditions of temperature during summer in much of the United States are decidedly tropical; yet peat accumulates. It is true that vegetable matter exposed to moist air must decay more rapidly where the temperature is constantly high than in the temperates, where the hot period is of brief duration; but that has nothing to do with the matter under consideration, for one is concerned with decay of vegetable matter protected from atmospheric action by a plentiful cover of water. *A priori,* one should expect to find peat accumulating in those tropical regions, where the conditions are such as encourage peat-making in the temperates—with only the difference that, owing to the continuous high temperature, complete decomposition should be more rapid and the bog should have the vegetable mud near the surface. But one is not dependent on *a priori* reasoning.

Harper[63] notes that it is an error to suppose that peat is confined to cold climates, since high temperature does not prevent its formation if humidity and topography favor. Peat is abundant on the very border of the tropics in Florida, where tropical temperature prevails throughout the year. *Sphagnum* does not occur south from

---

[62] C. Lyell, "Principles of Geology," Eleventh Ed., New York, 1872, Vol. I., p. 476.

[63] R. M. Harper, "Preliminary Report on the Peat Deposits of Florida," 3d Ann. Rep. State Survey, 1910, pp. 214, 274, 287, 292.

N. L. 29°, but the peat deposits within southern Florida, as far south as lat. 25° 30′, are of great thickness, one dense cypress swamp showing 20 feet. The Everglades of Florida embrace about 7,000 square miles, which must be regarded as considerable. Even between lat. 30° and 31°, there are thick deposits in which *Sphagnum* is wanting or very rare. Cypress, grasses, fern, myrtle make up most of the vegetation and provide material for peat. The water hyacinth, recently introduced into one of the rivers, is now a peat-maker and, in some localities, the peat is composed almost wholly of this plant.

The temperature conditions in the Bermudas are somewhat less severe in summer than in southern Florida, for the summer heat rarely exceeds 84° F. The southwest wind, blowing off the still warm Gulf Stream, prevents low temperature and the humidity is always high. On the main island there are two great swamps, one of which has at least 50 feet of peat. The climate is such that plants of Carboniferous type could grow well, for the banana thrives while palms and the India rubber tree attain great size.

The literature bearing on tropical swamps is very limited. Those swamps, often of vast extent and covered with dense forest, are regarded, rightly or wrongly, as malarial to the last degree, so that they do not invite close examination on the part of travellers. Yet, even in the limited literature, one finds ample proof that, when the necessary condition of topography and continuous moisture prevail, peat does form.

Wall and Sawkins[64] estimate the swamp area of Trinidad at six per cent. The long dry season is not favorable to the accumulation of peaty materials; yet the Nariva swamp, drained by streams flowing 12 to 15 feet below the general level, has a black soil which after desiccation at 300° F. still yielded 35 per cent. of organic matter. Hartt[65] found peat in the state of São Salvador, Brazil, S. L. 10°. He states distinctly that he found peat. "A quarter of a mile south

---

[64] G. P. Wall and J. G. Sawkins, "Geology of Trinidad," London, 1860, pp. 62, 63.

[65] C. F. Hartt, "Geology and Physical Geology of Brazil," Boston, 1870, pp. 365, 509.

of the Imbuçahí is such a grass-covered area, and here excavations by the side of the railroad show that a bed of peat has accumulated, which is two feet thick in some places." It is difficult to understand on what grounds a recent writer feels justified in asserting that this is probably bituminous shale. Hartt knew peat and he knew bituminous shale when he saw them. On the authority of the engineer who constructed the railroad in São Paulo, Hartt states that near Tumanduathy the land spreads out between the hills, level as a lake and about two miles wide, covered with deep layers of black soil "fibrous and woody like peat." The railroad was built over the surface of this bog, but no effort was made to determine the thickness of the deposit.

Mrs. Agassiz, cited in another connection, gives evidence respecting present conditions in Brazil. Kuntze[66] has described the forested swamps on the divide between the Amazon and the Paraguay. High water makes ponds on the broad alluvial plain, in which *Pontederia* and other plants settle. The ponds become filled with silt and humus and a swamp flora, rich in palms, takes possession of the surface. The Lourenço or Cuyaba river, rising in the low divide, unites with the Paraguay at about S. L. 18°. This river, for about three degrees of latitude, flows through the vast wooded Guatos swamp, which Kuntze thinks is, at least in part, a floating bog. He gives no estimate of thickness, but his brief statement leaves no doubt that the mass is very great. The material is true peat, for in another part of his work he speaks of the fragments of peat occasionally torn off from the mass. The invasion of streams by grasses is rapid and complete throughout this region. Kuntze notes this. Morong,[67] in speaking of his attempt to reach the head of Pilcomayo river in S. L. 22°, says that his progress was stopped in a lagoon, 400 miles from the Paraguay river, by a dense growth of grasses and weeds, one species of the former attaining the height of 5 meters.

The great accumulations in the lowlands of Nicaragua and Costa Rica have been mentioned by several authors and the writer knows

[66] O. Kuntze, "Geogenetische Beiträge," Leipzig, 1895, pp. 5, 67, 70.

[67] T. Morong, *Ann. N. Y. Acad. Sci.*, Vol. VII., 1892, pp. 45, 260.

that great swamps with notable depth of vegetable mud abound on the isthmus of Panama.

Livingstone, Cameron and others, already cited, have given abundant evidence that peaty accumulations are numerous and extensive in the wet regions of interior Africa. Lugard,[68] in describing the region near Albert Edward lake, refers to interminable river swamps and bottomless quagmires, choked with papyrus, which abound in Uganda and Ungoro and cease below about half a degree south from the equator. Miss Kingsley[69] says that she encountered three types of bog in west Africa. The broad deep bog was the least difficult, as it makes a break in the forest, and the sun's heat bakes a crust over it, on which one may go—if he go quickly; the shallow, knee- or waist-deep bog is little more difficult as one can wade through it; but the deep narrow bog, so shaded that the sun cannot form a crust over it, is the most abundant and the most difficult. "These required great care and took up a great deal of time. Whichever of us happened to be at the head of his party, when we struck one of these, used to go down into the black, batter-like ooze and try to find a ford, going on into it until the slime was up to the chin."

Chevalier[70] has described an interesting type of peat formation observed in an extended area between the Gulf of Guinea and the sources of the Niger, N. L. 5° to 9°. This great region has many granitic peaks rising to 1,200 or 1,400 meters, but in great part it is a peneplain, 200 to 400 meters above sea level. The southern portion is covered with a dense forest but the northern portion is a savannah with only scattered trees and shrubs. The whole region would be naked rock, were it not for the rôle played by a sedge, *Eriospora pilosa* Benth., which at times covers the rocks to the exclusion of all other forms. It attaches itself to granite and gneiss; the seeds germinate in minute fissures and the roots spread in clusters between thin plates of the rock, altered or decomposed by atmospheric action. When the thin plate of rock has been worn away

---

[68] F. D. Lugard, *Scottish Geog. Mag.*, Vol. VIII., 1892, pp. 636–639.

[69] M. W. Kingsley, "Travels on the Western Coast of Equatorial Africa," *Scott. Geog. Mag.*, Vol. XII., 1896, pp. 119–120.

[70] A. Chevalier, "Les tourbières de rocher de l'Afrique tropicale," *C. R.*, Vol. 149, 1909, pp. 134–136.

by water, heat or the activity of the plant, this is ready to resist the rains and winds, for its adhesion is complete on the steepest slopes.

After spreading for sometime, the *Eriospora* lifts its rhizomas into the air and sets off branches, each terminated by a bouquet of grass-like leaves, and each year, before the rains, abundant rosettes of leaves and flowering twigs are developed at the end of these rhizomas. At the beginning of the dry season, these leaves wither and soon afterward they are consumed by fires lighted by men or perhaps by lightning; only the bases of the leaves remain; blackened, half-carbonized, this coat thickens around the rhizoma. The growth of the *Eriospora* tufts is apparently very slow, but, as they may live for several centuries, they attain notable dimensions. On the border of the virgin forest, some were seen more than a meter high and half a meter thick at the base. The stem divides midway into vertical branches, themselves dividing, the last division having a diameter of 2 to 3 centimeters.

The tufts are not always in contact, there being at times an interval of even 50 meters, but in these intervals on gentle slopes, one finds a fibrous network, very humic, constituting a veritable bed of peat, 5 to 30 centimeters thick. This peat is formed not only of roots and rhizomas, but also of young colonies of *Eriospora,* killed soon after origin by fire or by lack of light. True mosses appear at high altitudes. On the humid flank of Mount Momry, Chevalier found a *Sphagnum* at 850 to 900 meters above sea level. The *Eriospora* peat covers tens of thousands of hectares in French west Africa. The condition described by Chevalier is not wholly unfamiliar in the temperates, where mosses and other plants cover irregular rocky surfaces and form a coating of peat at times several inches thick. This is seen frequently in the southern Appalachians. It is the Rohhumus or Trockentorf of the Germans.

It was reserved for Potonié[71] to present the final evidence. Finding no available literature giving details respecting moorformation in the tropics, he applied to Koordes, botanist of the Dutch expedition across Sumatra in 1891. Koordes informed him that in old

---

[71] H. Potonié, "Die Entstehung der Steinkohle und der Kaustobiolithe überhaupt," 5th Aufl., Berlin, 1910, pp. 152–160.

Javan and Sumatran forests, where hard woods grow, fallen trees, many decades old, lie in great numbers and are still in good condition for export. Termites and fungi are effective agents for destruction of wood in the tropics, but the moisture is almost equally effective in preventing the decay. During the Sumatra expedition, Koordes saw a great, always green Flachmoor, with a 30-meters high mixed forest, extending along the Kampar river at more than 90 kilometers from the coast. As Koordes had made no close study, definitive evidence was wanting to prove that this moor had a true peat floor. But Larive made the necessary sounding at Potonié's request and discovered that the peat in this tropical moor is 9 meters thick.

Examination with the microscope proved the presence of phenogams; spores or pollen; occasional brown threads belonging possibly to fungi; some resin-like bodies, etc. The high content of silica in the ash explains absence of diatoms in the microscopic preparations. Chemically, the material is a true peat and German experts pronounced it a good fuel. The ash in the dry material is 6.39 per cent. while good north German Flachmoor peat has 5 to 7 per cent. The ash of the Sumatran peat contains 74 per cent. of silica.

Koordes estimated the area of the freshwater swamp on the left bank of the Kampar at 80,000 hectares. At both camps within this swamp, the water was stagnant, dark brown and slightly astringent. Walking over the swamp was possible only because roots of trees covered the surface with a dense network. The character of the growth, as shown in Fig. 52 of Potonié's work, is a clear instance of adaptation such as is seen in the *Taxodium* of the southern United States; for the roots are widespread horizontally just below the surface, uniting into "broom-shaped air roots" and "asparagus-shaped pneumatophores." The trees of the forest are mostly evergreens, 25 to 30 meters high and closely set. The underbrush consists, for the most part, of the same species but its growth is slow, owing to the dense shade. The forms are all dicotyledonous and the flora is wholly of inland type. Grasses, sedges and mosses are practically wanting; it is a forest moor. The stagnant pools, poor in phenogams because of the dense shade, are comparatively rich in confervae.

It is sufficiently evident that there is nothing in tropical conditions which would prevent the accumulation of peat. Where there is a long dry season, the vegetable matter is exposed as is that in the ordinary upland forest in the temperate regions. The accumulation of the humus cover advances rapidly for a time but at length the waste by oxidation about balances the additions, so that the thickness does not increase, though the trees shed a greater quantity each year. But in a lowland area where the moisture is great, the chemical changes are modified, the loss is diminished and increased supply brings about increased accumulation. Swamps arise, when from any cause the drainage is impeded. Even along the flow of small springs, peat forms when the water is held back from any cause. On extensive areas, such as the coastal plain on the Atlantic side of the United States or the delta of a river like the Mississippi, where at best the drainage is imperfect, the streams being sluggish and often serpentine, the drainage has been hindered still further by vegetation, the moist area was enlarged and swamps of vast extent originated in post-glacial times. The important condition is the constant supply of water; the drainage must be impeded on the surface and through the bed. In the northern part of the United States probably the greater part of the swamps rest on an impervious bed of glacial clay, an underclay; but it is not necessary that the immediately underlying bed be of normally impervious material, for many large swamps have a floor of fine sand.

Harper[72] penetrated 10 or 12 miles into the Okefinokee swamp of southern Georgia and discovered that the material on which the peat rests is a few feet of Columbia sand overlying the clay, loam or coarse sand of the Grand Gulf formation (Lower Miocene or Upper Oligocene). In some places a "hard pan," colored by vegetable matter and cemented by iron underlies the sand. Sanford[73]

[72] R. M. Harper, "Okefinokee Swamp," *Pop. Sci. Month.*, Vol. LXXIV., 1909, p. 596.

[73] S. Sanford, "Topography and Geology of Southern Florida," 2d Ann. Rep. Geol. Survey of Florida, 1909, p. 193.

reports that the peat of the Everglades in southern Florida rests on sand, rock or marl. Grisebach, cited by Früh, endeavored to explain this apparently anomalous condition for north Germany by the suggestion, that, in very wet years, peat may have been formed in that region even on sands and, being itself practically impermeable, it may have prepared the way for a Hochmoor. Be that as it may, the fact remains that a swamp may begin on an apparently permeable surface; the Everglades are at little above sea level, but Okefinokee is 50 miles from the ocean and 115 feet above mean tide—and its mucky peat contains 85 per cent. of combustible material. In this latter case, one must believe that the underlying sand is not far from an impermeable stratum and that it is saturated with moisture or that by absorption of humic acid the sand itself has been rendered impermeable.

Peat and Peaty Materials.—Russell[74] describes the Alaskan tundra as a swampy, moderately level country having a cover of mosses and lichens with some ferns and many small flowering plants. Below this dense carpet of vegetation is dark humus. Ponds and lakelets abound, surrounded by banks of moss, and occasionally one finds groves of alders and dwarf willows on their borders. The underlying black humus shows few indications of its vegetable origin. It is 2 feet thick at St. Michaels but is 12 feet at a mile farther east. He saw 15 feet on the Yukon and a depth of 150 to 300 feet is assigned to it at the head of Kotzebue sound. The flora of the tundra is essentially cryptogamic, but two species of *Equisetum* flourish with rank luxuriance in great spaces along the Yukon. So vast is this accumulation, in both area and thickness, that Russell ventures to suggest that some coal seams may have had similar origin. If the tundra coast of Alaska should subside, its peat would be covered with sediments and be ready for transformation into lignite or coal. Its associated plants and animals would indicate the climatic conditions, but the overlying sandstone and shale might contain leaves and tree trunks, floated in by rivers from warmer regions.

But where the swamp is forested, especially if the wood resist

---

[74] I. C. Russell, "Notes on the Surface Geology of Alaska," *Bull. Geol. Soc. Amer.*, Vol. I., 1890, pp. 125–128.

rapid decay, the change of that material may advance so slowly that long after the softer parts have been reduced to pulp, the more compact materials may remain almost unchanged. The white cedar logs in the New Jersey swamps are so well preserved in many localities as to be serviceable in manufactures, while the thick peat of many swamps in Florida is without commercial value, because it is crowded with cypress stumps and fallen stems. But decay occurs in the softer woods, so that, as v. Gümbel[75] relates, flattened trunks are found even at a depth of only a meter in loose peat. The flattening was due to rotting, not to pressure.

The newer peat shows distinct felting and Lesquereux[76] states that this condition is marked even when decomposition is far advanced. In peats formed above the original water-plane, the "emerged peats" of that author, the layers are characteristic, one inch thick at the top but decreasing downward to less than one eighth of an inch. While the older or ripe peat shows no trace of organic structure to the unaided eye, the microscope proves that it is composed of fragments of plants embedded in an amorphous material consisting of humic or ulmic acid, or a mixture of those acids and their salts. He observed that, whenever the growth of the peat was checked by dryness or other causes,

> "the upper surface of the peat becomes crusted, hardened and transformed into a thin coating, quite impervious to the entrance of any kind of foreign matter: and it is upon this hard upper crust that the boggy humus forms; or wherever the land becomes resubmerged, a new peat vegetation begins. In which case, such a crust remains as a parting layer between two beds of peat, like the well known clay partings between two coal benches."

v. Gümbel, in the work just cited, asserts that the minute fragments of plants are not only intimately mingled and felted but also, in the denser portions, are bound together and more or less cemented by a humus-like substance, which is soluble in a dilute solution of caustic potash. Peat, treated with this reagent and afterwards dried,

---

[75] C. W. v. Gümbel, "Beiträge zur Kenntniss der Texturverhaltnisse der Mineralkohlen," *Sitz. Berich. d. k. bayer. Akad. d. Wissenschaften. Math-Phys. Kl.*, 1883, p. 126.

[76] L. Lesquereux, 2d Geol. Surv. of Pennsylvania, Ann. Rep. for 1885, p. 118.

frequently falls to powder. v. Gümbel found also, in many peats, deep black coaly parts of plants as small fibers, a form which he terms Torffaserkohle and regards as a thoroughly characteristic type.

Peat always contains much water, often 95 per cent., when freshly removed; but a great part of this evaporates on exposure, there remaining in the air-dried material from 10 to 30 per cent., the denser peat retaining the larger quantity. When first taken out, it is plastic but after thorough drying the plasticity is lost. Peat is very porous; v. Gümbel subjected *Sphagnum* peat to a vertical pressure of 6,000 atmospheres and reduced 100 centimeters to 17.7. The compressed material was apparently homogeneous, the streak was lustrous and lamination was distinct on the fractured surface. The reduction was due wholly to compression, obliteration of the pores, for, when moistened with water, the mass swelled to practically the original bulk. This condition, however, may not be constant. The writer has some briquetted peat, made under great pressure and moderate temperature, which has no tendency to swell when moistened. It has lost all plasticity and in sixteen years it has shown no change on the brilliant surface at each end.

Peat, then, consists, aside from introduced sand, clay or calcareous materials, of more or less changed plant tissues, whose organic texture is still recognizable, and of an enclosing substance derived from complete decomposition of plant tissues, which is originally soluble in water but which, on drying or perhaps on oxidation, becomes insoluble.

Fuel peat has from 1 to 25 per cent. of ash. The purest peats contain less mineral matter than is found in the plants whence they are derived; while on the other hand a peat deposit may pass from pure peat into carbonaceous mud and thence into muds almost wholly without trace of carbon. Mills and Rowan[77] have given ultimate analyses of surface and dense peats from two localities in Ireland, which represent the extremes of high grade fuel.

In each case, the ash is excluded in calculating the other constituents. The same authors give twenty-seven analyses of the ash found in

---

[77] E. J. Mills and F. J. Rowan, "Chemical Technology," Philadelphia, 1889, pp. 15–20.

different fuel peats from Ireland, which show, as one should expect, extreme variations, due to local conditions. Potash and soda are in small proportion, varying from 0.146 to 1.667 of potash and from 0.446 to 2.883 of soda, the greater quantity being in the dense peat. Phosphoric acid is present in all but rarely exceeds 2 per cent., whereas sulphuric acid varies from 10 to 44 per cent. Hydrochloric acid is present in small proportion, but approximately that required by the soda. Lime and magnesia are always present, in some cases the former makes up nearly one half of the ash and in others the latter is one sixth. Ferric oxide varies from 6 to 30 per cent. Silica occurs as sand or as soluble silica and alumina is always present, though at times in small quantity. The ash in the samples analyzed varies from 1.120 to 7.898.

	C.	H.	O.	N.	Ash.
1. Surface, Phillipstown	58.69	6.97	32.88	1.41	1.99
2. Surface, Wood of Allen ..	59.92	6.61	32.20	1.25	2.74
3. Dense, Phillipstown	60.47	6.09	32.54	0.88	3.30
4. Dense, Wood of Allen	61.02	5.77	32.40	0.80	7.89

The content of alkalies rarely exceeds 4 per cent. of the ash in New Jersey peats and ordinarily it is less than one and a half per cent.; but calcium carbonate and sulphate are always present in notable quantity, making up from 20 to 30 per cent. of the ash.[78]

Julien[79] has given a synopsis of the available information respecting the proximate composition of peat. The various organic constituents seem to be of rather indefinite character and their study is attended with serious difficulty. Julien cites an analysis from Hermann, giving composition of a peat obtained near Moscow:

Muck-carbon, nitrolin, plant remains	77.8
Humic acid	17.0
Humus extract	4.0
Ammonia	0.25
Crenic acids	Trace
Ash	1.25

---

[78] W. E. McCourt, "A Report on the Peat Deposits of Northern New Jersey," Ann. Rep. Geol. Surv. of New Jersey for 1905, p. 227.

[79] A. A. Julien, "On the Geological Action of the Humus Acids," *Proc. A. A. A. S. for 1879,* pp. 314–324, 329, 331, 353.

But in peat from another locality, the process of change was different:

Muck-carbon, etc.	80.0
Apocrenic acids	17.0
Crenic acids	1.0
Ash	2.0

Julien notes the difference in ash between peat and the plants whence it is derived. *Sphagnum* has from 3 to 4 per cent. and the peat varies from 1 to 25 per cent. Vohl found only 1.25 per cent. of ash in a Hochmoor or *Sphagnum* peat. In the ash of living plants he found 20 per cent. of alkalies and 42 per cent. of silica, but only 3 to 4 per cent. of each in the peat or in the soil. On the other hand, there was concentration of alumina, ferric oxide and calcium carbonate as well as of phosphoric and sulphuric acids. Pyrite occasionally abounds in peat and its decomposition gives a basic ferric sulphate to the bog iron ores.

Nitrogen is always present in peat, sometimes as much as 3 per cent. Many suggestions have been made to explain its occurrence; but Julien thinks that most probably it has been derived from animals living in the peat or in the soil. The vast number of insect cases found in peat bogs is well known and Scudder has proved that insects were very abundant in the coal period. The nitrogen content is due very largely to the exuviæ of insects, and its frequent concentration in the lower layers of bogs may be due to the survival of those exuviæ as chitin.

In the humus one finds as inert substances, nitrolin (rotten wood) and humin, which is black and forms the chief constituent of humus; but it is so mingled with nitrolin that its exact composition cannot be determined. Mulder studied humus and humic acid from the black peat of the Haarlem sea; he obtained ulmic acid from rotten wood as well as from the light brown Frisian peat. The formulas of the several acids obtained seemed to be

Humic acid	$C_{20}H_{12}O_6$
Geic acid	$C_{20}H_{12}O_7$
Ulmic acid	$C_{20}H_{14}O_6$

Stern, however, thought humic and ulmic acids isomeric, with the formula $C_{24}H_{18}O_9$, while Ditmer thought them the same thing, the latter being produced by drying the former.

Humic acid is a colloid and is not absorbed by plants, though its oxidized product, crenic acid, seems to be taken up. Humic acid is very slightly soluble in water at 6° C.; if dried at 120° C. it is much less soluble and if completely dried at a high temperature it is insoluble. Its alkaline salts are readily soluble but those with alkaline earths and metallic oxides are insoluble or nearly so in water, though readily in aqueous alkaline solutions. Calcium humate dissolves in 3,125 parts of water and ferric humate in 5,000 parts, but these form soluble double salts with ammonia. Ulmic and humic acids are rarely free except in bogs. A noteworthy property of humic acid is that, as a colloid, it renders sand impermeable to water.

These feeble acids yield others upon oxidation. Humic gives crenic, which is present in all waters, in rotten wood, in peat and in cultivated soil. Julien has found it, as well as its oxidized product, apocrenic, in American peat. Crenic acid, pale yellow and transparent, is readily soluble in water; in drying, it becomes opaque and blackens when exposed to the light. Alkaline crenates are very soluble but the calcareous salts are only slightly soluble. Those of iron and aluminium are insoluble, but, according to Bischoff, the iron salt is soluble in ammonia, so that it may be dissolved in the presence of decaying nitrogenous substances. The apocrenates have same distribution as the crenates but they are less soluble. These organic acids bleach clays and have solvent effect on silica; the most efficient being the brown or ulmic constituents.

Liebig,[80] writing soon after Mulder published the results of his investigations, stated that a solution of caustic potash blackens in contact with vegetable mould. Dilute sulphuric acid precipitates from the solution a light, flocculent brown or black substance which absorbs oxygen rapidly. After drying it is not soluble in water. Cold water dissolves only one ten-thousandth of its weight from vegetable mould and the dissolved material is chiefly salts; but boiling water extracts several substances, yellow or yellow-brown. On

---

[80] J. Liebig, "Chemistry in its Application to Agriculture and Physiology," Philadelphia, 1843, pp. 112, 113.

exposure, the solution becomes darker and a flocculent deposit is produced. If the yellowish solution be evaporated to dryness and the residue be heated to redness, this becomes black and, when treated with water, yields potassium carbonate. Evidently, boiling water extracts a substance which owes its solubility to alkaline salts contained in plants. Leibig says, on authority of Sprengel, that humic acid becomes insoluble when dried in air or when frozen in moist condition.

Hunt[81] has remarked that organic matters in solution acting on insoluble peroxide of iron form the protoxide, which is soluble in carbonic acid and in excess of the organic (acid) matter. In this way, great quantities of iron may be removed and white clay or sandstone may be produced. The iron salts become oxidized and go down as hydrated peroxide. Manganese deposits are formed in similar fashion. He is inclined to believe that hydrated alumina may originate in the same way. Organic matter dissolved by surface waters reduces sulphates to sulphides and these, decomposed in turn by carbonic acid, yield alkaline and earthy carbonates as well as hydrogen sulphide.

One finds in bogs some types of peat to which the descriptions thus far given do not apply. Examined in detail, these in some cases suggest original differences due to mode of accumulation or to character of material, while in others they appear to be due to secondary processes.

Long ago, Caspary described the Lebertorf obtained at Purpesseln, near Gumbinnen in east Prussia. This material was studied very carefully by v. Gümbel,[82] his specimens being from the type locality. The deposit is 5 feet thick and at 10 feet below the surface. When damp, it is liver-brown in color and dense, but when dry it divides into paper-like laminæ. Under the microscope it proves to be composed of very fragmentary parts of plants within a felt-like, flocky mass, in which are insects, recognizable grass and moss, scattered black wood cells, many spores and an immense quan-

---

[81] T. Sterry Hunt, "Chemical and Geological Essays." Boston, 1875, pp. 97–99.

[82] C. W. v. Gümbel, *op. cit.*, pp. 131, 132, 133.

tity of pollen. Two specimens from other localities agree in that the cross-section shows a comparatively dense mass of boghead-like material, deep brown in color. One contains well preserved remains of leaves and other organs and the other contains some freshwater mollusks. The granular, felt-like mass, treated with reagents, breaks up and then one sees fragments of woody material, seeds, mosses, and above all pollen grains, several thousands to the cubic millimeter. This substance bears remarkable resemblance to cannel.

Blattertorf, so named from its foliated structure, is closely allied to Lebertorf. v. Gümbel has described a specimen from the kurishen lowland south from Nidden. This mass, in extraordinarily thin laminæ, is composed of numerous bright lamellae alternating with dull layers, recalling by their luster, pitch and glance coals. The bright material comes from ribs and the harder parts of plants, the grass leaves, which compose the chief mass. Along with those are bits of moss, bast fibers, etc., in the felt-like mass, as well as an astonishing number of pollen granules.

The results of Früh's[83] studies were published in the same year with those of v. Gümbel. His conclusions respecting the composition of Lebertorf differ somewhat from those reached by v. Gümbel. One rarely finds in ordinary peat any remains of freshwater algæ. But Früh finds that those algæ do not decompose so readily as one might imagine; yet in the ordinary peat they are only rare and accessory constituents, never occurring in such quantity as to be important elements. At the same time there are types of which they are essential constituents.

The Lebertorf, found in ponds within Prussia, as the basis of the Rasenmoor at Purpesseln and as basis of a Hochmoor at Gumbinnen, is a liver-brown gelatinous mass. That from Jakobau, in west Prussia, consists chiefly of algæ, there being more than 60 species of Chroococcaceæ, Hydrodicteæ and Diatomaceæ, with which are found indefinite remains of mosses along with pollen of *Pinus* and *Corylus*. The Torfschiefer of E. Geinitz from Gustrow has a very similar composition. The typical Lebertorf from Purpesseln has recognizable colonies of Macrocystis, while that from Niederwyl

---

[83] J. J. Früh, "Ueber Torf und Dopplerit," Trogen, 1883, p. 20.

in Thurgau shows algæ as the chief constituents, with pollen and chitin remains, all felted and embedded in a gelatin-like mass. These Lebertorfs originated in quiet waters or on damp soil, through continuous deposition of gelatinous algæ.

Lebertorf is the same with Faulschlamm or Sapropel of Potonié,[84] an accumulation of stagnant water organisms, animals as well as plants, a formation characteristic of pools in swamps. The freshwater algæ multiply with such rapidity that eventually a great mass may be deposited. Potonié says that there are lakes in south Germany so filled with Sapropel that they cannot be navigated. Caspary, cited by Früh, conceives that there is no peat-filled lake, on whose bottom this material does not exist. He found it about 9 meters thick at one locality. Früh has given a synopsis in his later work of studies by the students of northern Europe which show the wide distribution of this material. But Lebertorf or Sapropel, so closely resembling cannel in appearance, is not the mass of peat; it is wholly local, originating in open ponds or lakes. The gelatinous algæ are of comparatively rare occurrence in true peat, which owes its origin to plants of wholly different type.

The substance, known as Dopplerite, was described by Haidinger in 1851 and was studied in great detail by v. Gümbel in 1858. Its similarity, in some respects, to coal led the latter author to give it the name of Torfpechkohle. It occurs at many localities, so many that it may be regarded as a normal constituent of peat. The first reference to material of this type in America is in a paper by Fairchild,[85] who obtained some from a bog at Scranton, Pennsylvania. It is described as bright, resembling a firm but brittle jelly and as occurring in branching masses through the ripe or older peat. In drying, it shrinks more than the peat and the color changes from yellowish brown to almost black, finally becoming brown. In structure it resembles coal.

Julien,[86] discussing Fairchild's communication, asserted that the physical features of the substance, as described, are those of apo-

---

[84] H. Potonié, "Die Entstehung," etc., p. 20.

[85] H. L. Fairchild, *Trans. N. Y. Acad. Sci.*, Vol. I., 1881, p. 73.

[86] A. A. Julien, *Trans. N. Y. Acad. Sci.*, Vol. I., 1881, pp. 75, 76.

crenic, humic and other organic acids. He was inclined to believe that this material had been produced by the leaching out of soluble salts of organic acids, in part crenates, from the upper part of the bog and their concentration in the denser portions below, where they filled cavities in the peat. The rapid change in color is not the trifling change due to drying, but is a characteristic reaction of crenic acid, due to oxidation and to partial change into apocrenic acid—a feature observed in the acid and in its salts, both in nature and in the laboratory.

Lewis[87] described the material with more detail. It occurred in swamp muck underlying 8 to 10 feet of peat. Near the bottom and confined wholly to the muck, are irregular veins filled with a black jelly-like elastic substance, in quantity varying from mere stains to streaks, two or three inches wide. When first taken out it is jelly-like, with conchoidal fracture, but on exposure it becomes tougher and more elastic. Under the glass it is brownish red and nearly homogeneous. It is tasteless and odorless, burning slowly and without flame, when fresh. It is insoluble in water, alcohol and ether but is dissolved by caustic potash. Completely dried, it is brittle and coal-like, resembling jet; it burns with a clear yellow flame and no longer softens in water. In composition, it differs from the typical dopplerite in that it contains little more than half as much carbon and very much more oxygen.

Kaufmann, cited by Lewis, regarded dopplerite as a mixture of humus acids and believed that the portion of peat, soluble in caustic potash, is identical with dopplerite. Compact peat contains minute black particles of dopplerite. Peat is merely a mixture of partly decomposed plants with dopplerite, the latter being a homogeneous peat in which all organisms have been decomposed. Kaufmann found that the proportion of material soluble in caustic potash increases with age, a recent peat giving from 25 to 30 per cent., while an old compact peat gave 77 per cent. But in coals, the proportion decreases, from a diluvial brown coal, with 77 per cent., to anthracite in which no portion is soluble. His conception is that, in the forma-

---

[87] H. C. Lewis, "On a New Substance Resembling Dopplerite, from a Peat Bog at Scranton," *Proc. Amer. Phil. Soc.*, Vol. XX., 1881, p. 112.

tion of coal from peat, the first step is the formation of dopplerite and the second is a gradual transformation of the latter into a material less soluble in alkalies and richer in carbon. The peculiarities of the Scranton mineral, its low percentage of carbon and its mode of combustion led Lewis to suggest that it may represent an earlier stage in transformation than that of dopplerite.

v. Gümbel,[88] in giving the results of his later studies, described dopplerite as a yellow brown homogeneous mass without trace of organic structure and enclosing only separated parts of plants. It burns with a sooty flame, thus differing from the Scranton mineral which burns with a clear flame. It dissolves in acid with effervescence; the calcareous matter seems to be combined chemically with the humus-like material. He is inclined to see in dopplerite a substance originating in mere segregation from plant material as the silica of flints is separated from limestone. He looks upon dopplerite as possessing great importance, since in most peats, one finds cementing substances which, optically, physically and chemically, resemble it closely.

Früh,[89] in his earlier work, already cited, gives an elaborate discussion and reaches conclusions differing very much in some respects from those just given. He asserts that dopplerite exhibits the wholesale formation of ulmin compounds and gives detailed description of its physical and chemical properties to prove that it belongs to the ulmin group. Owing to the large proportion of calcium, he thinks the material pre-eminently a Rasenmoor deposit. On wholly fresh profiles of Rasenmoor at Gonten, Schwantenau and Rothenthurm, he saw in the red-brown peat, brown flakes, one centimeter to one decimeter, so mottling the mass that he termed this type Marmortorf. Very frequently the flakes are associated with a fragment of root or twig, along which water would flow. At Rothenthurm he found the dopplerite first along a root. These brown flocks are always rich in water; the Rasenmoor is always rich in water, a condition which favors homogeneous ulminification of the

---

[88] v. Gümbel, *op. cit.*, pp. 129, 130.

[89] J. J. Früh, *op. cit.*, pp. 64, 68, 69–72.

peat. The brown flocks are sources of dopplerite. There is no sharp separation between dopplerite and the surrounding peat—there is always a passage zone, an intermingling of peat and dopplerite.

The mode of occurrence is variable. In many places, he saw veinlets, one to two meters long and one to five centimeters wide; here and there a vein spreads out from a root—one passed over a thin sandstone and was prolonged horizontally for several meters as a little bed, at most two centimeters thick. At the same place, he observed some wedge-shaped veinlets penetrating the glacial drift to a depth of 3 to 4 centimeters, where it filled cracks in the clay, binding the fragments into a breccia. There were no plant remains in the clay, so that the fine gelatinous dopplerite must have been deposited in already existing cavities. The presence of abundant water being essential to the ulminification, the mineral is found especially in the lower part of the peat. As every plant can become ulminified, dopplerite may occur in any moor, where the temperature and moisture are in proper relation. He has found the mineral derived from *Sphagnum* at the contact between Rasenmoor and Hochmoor, where the water-rich condition existed.

Kaufmann believed that with the point of a knife he separated particles of dopplerite from good peat; Früh did this with Marmortorf, but he thinks that even the best Rasenmoortorfs are not usually so far advanced as that. The microscope detects little flakes produced by the flowing together of very tender ulmin material, if the peat be ripe; but one cannot determine whether these are ulmic or humic acid—the quantity is too small. At the same time, he maintains that it is an error to identify with dopplerite the caustic potash extract from peat, as Kaufmann and Muhlberg have done, for potash combines with ulmic and humic acid alike. Dopplerite is a higher member of the ulmin group.

Kinahan[90] often observed that, when peat was taken out on the hills near Dingle bay, little streams of tar, which had filled tubes made by decay of roots, oozed and trickled out from the newly made

---

[90] G. H. Kinahan, Geol. Surv. of Ireland, Explan. of sheets 182, 183, 190, 1861, p. 33.

surfaces. This is clearly the younger stage of dopplerite referred to by Früh.

The Schieferkohle, studied in detail by both v. Gümbel and Früh, is a Quaternary deposit observed at several places in Switzerland. It will be described on a succeeding page. v. Gümbel's[91] type specimens come from Morschwyl, but he studied also specimens from other localities. The mass is partly loose, like peat, partly dense, like pitch coal, containing remains of conifers, birches, etc. It is undeniably peat-like in the less dense portions, where one can recognize mosses and grasses as the predominating constituents. The denser portions are changed by caustic potash into an opaque mass. The microscope shows great quantity of deep brown shell-like splinters of an amorphous textureless substance, which acts as dopplerite. In many parts of plants, the same dark brown material fills the cell spaces. He thinks it not doubtful that the denser condition of this portion of the coal comes from richer accumulation of the amorphous filling material, which he terms Carbohumin. This Schieferkohle contains vast numbers of pine cones, not deformed, and of flattened pieces of wood. In many of the latter, he found an inner woody zone, composed of a soft yellow substance, like rotten wood, while the bark zone had been changed into a shining pitch coal.

Früh,[92] after studying Schieferkohle from many localities, confirmed the view of Heer, Kaufmann and others that the deposits agree with peat in microscopic character. They are peats more strongly ulminified. He often found the interior of rootlets apparently little changed, but after a few minutes exposure, they began to change and at length became brown like the Marmortorf. With regard to the wood fragments, he thinks that the outer portion was ulminified early, perhaps before the bog was covered with drift, whereas the inner portion was merely peated. At the same time he does not recognize dopplerite in the Schieferkohle.

It is sufficiently evident that the difference between Früh and the other observers is merely respecting nomenclature. There is agreement on all matters which concern the questions at issue here.

---

[91] v. Gümbel, *op. cit.*, pp. 136, 137.

[92] J. J. Früh, *op. cit.*, pp. 83, 84.

This is placed beyond doubt in his later work,[93] where he modifies the broad statements made in his earlier work and shows that the difference is formal rather than real. He says that dopplerite originates, as does the peat, out of a varying mass of colloid substances, free humus acids, salts of humus acids, inorganic substances and some nitrogen. So one may regard dopplerite as an ulmate, a humate, a crenate or a mixture of them all, with in addition some inorganic salts. The essential point is that, during the process of peat-making, a greater or less portion of the vegetable material is brought into a condition admitting of flowage, so that it may remain distributed throughout the mass or may be collected into cavities. When the pores of the peat are filled, farther drainage is possible only to a limited degree and the material will find its way to the tissues, becoming the Carbohumin of v. Gümbel. To this absorption of Carbohumin is due the different effect of pressure upon peat and brown coal; in peat the porosity is very great, in brown coal it is small.

Variations in structure or appearance of the peat have been observed in recent bogs, which are as notable as those found in the Schieferkohle. Griffith[94] in describing the Irish peat bogs, said that bases of the bogs consist of clay covered with a layer of peat, which is composed of rushes and flags. Above this is another bed of peat, closely resembling cannel coal, with conchoidal fracture and hard enough to be worked into snuffboxes. It yields 25 per cent. of ash and much oxide of iron. This, in turn, is covered with black peat containing twigs and branches of fir or pine, oak, yew and hazel, only the bark remaining. Where whole trees were found, the roots had disappeared.

Lesquereux[95] relates that on the border of the valley of the Locle, a considerable mass of marl covers a bed of peat, which has become converted into lignite, hard, fragile and with brilliant fracture. The thickness on the border is barely 3 inches. Farther downward toward the bottom of the valley, the marl is only 4 feet

---

[93] J. J. Früh, in "Die Moore der Schweiz," 1904, pp. 164, 165, 166, 167.

[94] Griffith, cited by S. S. Haldeman in Introduction to 2d Ed. of R. C. Taylor's "Statistics of Coal," Philadelphia, 1855, p. 166.

[95] L. Lesquereux, "Quelques recherches sur les marais tourbeux," Neuchatel, 1845, p. 95.

thick and the underlying peat, though showing some change, still retains its peaty character and is a passage from the lignite of the border to the peat now worked in the open valley. One is left to conclude that the deposit is continuous from the border to the uncovered peat.

The Characteristics of Peat Accumulations.—Swamp or marsh accumulations of vegetable matter consist essentially of remains of land plants, including the many water-loving types. Locally, as in the Lebertorfs or Sapropels, one finds freshwater algæ and remains of mollusks, while in many swamp peats the exuviæ of insects abound, often associated with land mollusks. Some of the older books refer to marine peat. Macculloch[96] mentioned a peat found in Scotland, which was composed of *Zostera marina,* and several authors have cited this as a marine peat. But *Zostera* is the ordinary "eel-grass" of estuaries and is a land plant able to endure salt water. Al. Brongniart,[97] under the title "Tourbe marine," states that De Candolle saw in the dunes of Holland some peats which burn well and are composed of seaweeds, notably of *Fucus digitatus.* He, himself, had seen, opposite the rock of Calvados, some extensive beds of brown material, soft and spongy, which had all the external appearance of peat, but it could be burned only with difficulty. That seaweeds may accumulate on a strand, there to form a considerable deposit, is placed beyond doubt by Potonié's description of such an accumulation on Heligoland, of which he gives a photograph. But such deposits are wholly local and possess no importance. Muck,[98] in the first edition of his work, referred to the occurrence, at several places along the North sea, of peat evidently marine in origin. Samples of the material were sent by him to Früh, who submitted them to microscopic analysis. One consisted almost wholly of decaying seaweed; when dried, it burned with small flame and foul odor, but it showed no characteristic of peat. Another, a brown substance washed up on the shore at Blankenberghe, contained no

---

[96] J. Macculloch, "A System of Geology," London, 1831, Vol. II., p. 339.

[97] Al. Brongniart, "Traité élémentaire de minéralogie." Paris, 1807. Vol. II., pp. 41, 46.

[98] F. Muck, "Die Chemie der Steinkohle," 2te Aufl., 1891, p. 164, footnote.

trace of algæ, but consisted wholly of fragments from land plants. The same is true of a specimen from the Dollart. After examining samples from all localities of alleged marine peat, Früh felt himself justified in the positive assertion that thus far no marine peat has been discovered.

The classification of peaty deposits has received much attention from many authors. The literature in America is somewhat limited, as, until very recent years, peat seemed likely to remain indefinitely without economic importance. Among the earliest attempts at classification is that by Shaler,[99] whose grouping was much in detail. He divided the forms into marine marshes and freshwater swamps; the former including grass marshes and mangrove marshes, growing above tide, as well as mud banks and eel-grass marshes, growing below mean tide; the latter including river, lake and upland swamps, each with two subdivisions. The grass marshes are along the coast where salt water bathes the roots of the plants, while freshwater swamps are above tide. Davis,[100] in discussing the freshwater deposits of Michigan, employed the terms bog, marsh and swamp; a bog is an area of wet, porous land, whose soil is mostly decayed or decaying vegetable matter, loosely consolidated and containing so much water as to tremble when one walks on it; the vegetation varies, but usually consists of mosses, sedges or grasses, or a combination of them along with shrubs and even small trees; a marsh does not shake readily when one walks over it, though it may be very soft and wet; the vegetation is mostly grass-like, though shrubs may be present in thickets; a swamp soil is firm, but wet, even to flooding at times, and bears trees and shrubby plants as the most important part of the vegetation. This grouping is not absolute, for the types may all be found in a single basin, the passage from one to the other being very gradual.

In Europe, where peat is of great economic importance, many students have expended great ingenuity in efforts to classify the

---

[99] N. S. Shaler, "General Account of Freshwater Morasses of the United States," Tenth Ann. Rep. U. S. Geol. Survey, 1890, pp. 261 et seq.

[100] C. A. Davis, "Peat," Ann. Rep. Geol. Survey of Mich., 1907, pp. 108, 109.

deposits, which are, practically all of them, freshwater, marine marshes being unimportant economically. Lesquereux, in 1845, recognized two general types of bogs, which he termed supraaquatic or emerged and infraaquatic or submerged, the former being above the waterline and the other at or below it. The prevailing classification in Germany recognizes the Hochmoor, equivalent to the Heathermoors of Scotland, and, in great part, to the supraaquatic of Lesquereux; the Wiesenmoor, Grünlandsmoor, Niedermoor, or Rasenmoor, equivalent to the bogmeadows of other lands; and the Waldmoor or forested bog. These are the Lyngmose, Svampmose, Hoermose; the Kjaermose, Engmose; and the Skovmose of the Danish authors. A similar division is that of Hochmoor, Flachmoor and Zwischenmoor, these being the terms employed by Potonié and some recent authors.

Potonié[101] has described a great moor in east Prussia on the delta of the Memel and Nemonien rivers, which shows the relations of the several types. Going eastward from the shore, one finds first the mud, which on the border is held by water lilies and other plants, referred to as "landmakers" because they are outposts. Higher plants, especially canes, occupy water areas, behind which there develops a meadow Flachmoor of sedges, where frequent floodings prevent growth of trees. Beyond that, foresting begins, and one reaches a moor of black alder, several kilometers broad. The surface is occupied by swamp plants, such as *Iris, Sium,* sedges, which endure well the periodical floodings of this zone. If the area were one of gradual subsidence, equal to the accumulation, the condition would continue for a long period. The surface rises gently and one comes to another flora, accustomed to somewhat drier soil, with alders, hops and nettles. Thus far, one has followed the Flachmoor or Niedermoor; but at a little distance beyond, swamp birches are seen among the alders. The latter soon disappear and the birch zone is reached, beyond which is a zone of forest with *Pinus sylvestris* and *Picea excelsa.* These form the Zwischenmoor or Waldmoor.

In this passage zone, the peat has risen so high that the surface is dry; the forest is here, but as one advances the trees become

---

[101] H. Potonié, "Die Entstehung," etc., pp. 35–40.

smaller because increasing accumulation of peat deprives them of their nutriment. Even exceptionally high floods cannot bring dissolved nutriment to them and they are dependent on rain, dew and dust. At length, the trees are displaced by *Sphagnum,* able to store away dew and rain, to remain moist on even a dry bed, to keep the area wet though it may be several meters above the water level. So one, in going eastward, is still on wet land. This is the Hochmoor, swelling as an hour glass—whence its name. But there is a still higher stage. On the Hochmoor, one's foot sinks deeply into the sphagnum-peat as he advances. At length a pond is reached; the rain collects in pools or small lakes, whence it flows to moisten the surrounding area. Plants thrive here because the changing water gives them nutriment. Reeds and sedges are seen and even *Pinus sylvestris* is present, though much smaller than on the borders of the Flachmoor. This great bog rests on a sandy deposit, with which are mingled the vegetable muds of the kurischen Haff.

As the problem of formation of coal beds is world-wide in scope, the essential features of those beds being practically the same in all lands, the study of peat accumulations must be as broad as possible, if the conclusions are to possess any worth for or against any theory. In the pages to follow, the results of studies by observers in many regions will be presented in detail. This may involve some repetition, but that will serve only to emphasize the importance of certain conditions, which have been overlooked or ignored in some contributions to the discussion.

Peat Deposits in the United States of America.—Marine marshes exist in extensive areas along the Atlantic coast from Maine to Florida, a region believed by nearly all observers to be subsiding. North from Florida, the tidal marshes are grass-meadows, ordinarily treeless. They are covered with grasses, reeds or coarse sedges and the upper surface is near the level of high water. Cook[102] has described those of New Jersey, which are typical of the whole coast from Georgia northward. Alongside of streams crossing the marshes there is a narrow ridge of dry land, but within a few yards one

[102] G. H. Cook, "Geology of New Jersey," 1868, pp. 24, 231, 233, 238, 300, 347–350, 361.

reaches the permanently wet area. Immediately below its sod, is mud or soft earth, which varies greatly in composition. Near the creeks, it is usually fine clayey mud with embedded roots, the whole evidently transported material; at a little distance, it is black earth or muck, formed in a swamp; while at a greater distance one finds only a mass of fibrous roots and vegetable matter with no admixture of earth or mud. The last two are of *in situ* origin. The "meadows" along the Passaic and Hackensack rivers, emptying into New York harbor, show an extreme thickness of 32 feet of "mud" resting on 8 feet of blue clay, while farther up the stream are great marshes resting on fine sandy material. One sees on the surface of these meadows great numbers of white cedar stumps and the mud is crowded with remains of cedar timber.

The condition is due to encroachment by the sea, whereby the treeless marshes advance inland and overrun the white cedar swamps along the streams; one finds at many places the old cedar forest buried in the tidal marsh, while the cedar swamp still exists at a little way beyond. The salt water kills the freshwater grasses and the trees on the border. In many places trees flourished 80 years ago, where one finds now only salt marsh muck. The white cedar is a very durable wood; trunks of trees killed by the salt water are still standing in localities where several feet of muck have accumulated around them.

Lyell[103] observed the effects of this encroachment in Georgia. In coming down to the coast, he found the trees becoming dwarfed and at length disappearing to be replaced by reeds; but in the marshes he saw the stumps and stools of cypress, still retaining the erect position in which they had grown. He quotes Bartram, who stated that when planters, along the coast of the Carolinas, Georgia and Florida, as well as westward to the Mississippi, bank in the grassy tidal marshes for cultivation, they "cannot sink their drains above three or four feet below the surface, before they come to strata of cypress stumps and other trees, as close together as they now grow in the swamps."

---

[103] C. Lyell, "Second Visit to the United States of North America," London, 1850, Vol. I., pp. 334–336.

When one reaches southern Florida, he finds a different type of tidal marsh. Northward, grasses and rushes are the plants which advance the land seaward, but at the south the mangrove is the agent. That plant abounds on coasts in tropical America and is found northward in Florida to lat. 30°, though it is not abundant above lat. 26°. The eccentric mode of growth exhibited by the special type under consideration, long ago attracted the attention of botanists. Bancroft[104] says that it rises from several strong woody roots which emerge from the ground for two or three yards before they unite at the trunk. Tough woody shoots, about three inches in circumference, descend from the trunk to take root and, as the tree increases in size, the shoots increase in number. These by their strength compensate for the looseness of the soil. The tree grows in a low, wet soil by the side of running water.

The Florida mangrove flourishes only in contact with salt water, being stunted by brackish water. Vaughan[105] describes it as attaining the height of 10 to 20 feet and as growing in water or so near it that the soil is saturated. The long seeds take root in water not more than one foot deep, leaves being put forth as soon as the surface is reached. Besides the tufty roots given off at the base, there are others originating at higher levels from the stem, which grow downwards and embed themselves in the soil. Shaler says that these can descend through 8 feet of water in order to take root. Each becomes a new tree to be multiplied in similar manner. Thus a tree may advance 20 or more feet in a century, the advance being checked only when the water is too deep or the waves prevent rooting. These growths, as described by Shaler and Vaughan, form dense thickets, a fringe, which is made denser by litter from the trees; so that débris from the land eventually fills up the space behind and the trees are killed. But, in the interval, a new fringe has been formed. In the moist area behind the growth, freshwater types displace the saltwater forms and a swamp results. Shaler

---

[104] E. Bancroft, "An Essay on the Natural History of Guiana in South America," London, 1779, pp. 76–79.

[105] T. W. Vaughan, "Geologic Work of Mangroves in Southern Florida," *Smithson. Misc. Coll. Quart. Issue,* Vol. V., 1910, pp. 461–464

conceives that the Everglades of southern Florida, with an area of about 7,000 square miles, owe their origin to outward advance of mangroves on shallows of the coast.

The freshwater swamps of the Atlantic and Gulf coasts are, for the most part, sharply distinct from the tidal marshes, even where the latter have encroached. Cook[106] has shown the relation in New Jersey by a section extending from Dennisville to Delaware bay, a distance of about one mile. The cedar[107] swamp begins at the edge of the low upland and gradually deepens to 15 feet. Like most of the cedar swamps in New Jersey, it has been cleared, but clusters of young trees up to 100 years old remain here and there on the surface, which is only a few feet above high tide. The cedar grows densely but slowly. Old stumps show more than 1,000 annual rings, but those near the bark are as thin as paper and the stumps rarely exceed 3 feet diameter, though some have been seen which were 7 feet. The swamp soil is black, peaty, 13 feet thick at Dennisville and, when dry, burns. It shows no admixture of foreign material and contains only 3.35 per cent. of ash, the water in the dried peat being from 12 to 16 per cent. It is very loose and porous, always full of water; the roots of the trees run through it in every direction near the surface, but do not penetrate to the solid ground. Where the peat cover is thin, the roots do pass through to the underlying soil, but, in that case, the wood is inferior and it cannot be utilized in manufactures.

Trunks of trees are buried at all depths and are so numerous that one has difficulty in thrusting a sounding rod to the bottom. Some had been blown over when rotten; others were merely uprooted. Some, blown down, lived for a considerable time afterward. The prostrated trunks lie in all directions and the conditions are precisely the same as those now seen on the surface of the swamp. Large stumps have been found, which grew over logs, now enveloped by

---

[106] G. H. Cook, *op. cit.*, pp. 301, 302, 355, 356, 360, 361, 484.

[107] The cypress or white cedar of New Jersey is *Chamæcyparis thyoides*, which is found in swamps from New Hampshire to Florida and westward to the Mississippi. The bald cypress is *Taxodium distichum*, a form surviving from the middle Tertiary, which extends from southern Delaware along the coast to Texas and up the Mississippi to southern Illinois.

their roots, and at the bottom are found worthless logs of cedar belonging to trees which were rooted in the solid ground below.

Shaler[108] has given a general description of the Dismal Swamp, an area of about 500 square miles, at only a few feet above tide level. It was much larger, but a great part has been reclaimed by draining. The peaty deposit rests on Pliocene sands, of which 10 to 14 feet are exposed on the border; but this is not wholly certain as the bottom has been reached at only one place within the swamp. C. A. Davis has stated recently that the peat is at least 15 feet thick and of good quality. On the western border is Drummond lake, 6 feet deep and somewhat more than 2 miles wide. Shaler says that, here and there within the swamp, one comes to drained areas of considerable size, one of which, embracing about 2 square miles, has long yielded fine crops of maize. He notes that *Sphagnum* has a very small place in this swamp and that it is an unimportant factor everywhere south from the Potomac and Ohio rivers, where the greater heat and decreased rainfall prevent its luxuriant growth. The most important peat-making plants in the region south from those rivers are canes, a grape, the bald cypress and the juniper with, in some localities, the dwarf palmetto—among these, he assigns the chief place to the common cane.

The greater part of the Dismal Swamp is under water during most of the time, but there are elevations rising not more than 3 feet above the general level; yet the drainage due to this slight elevation suffices for growth of pines belonging to the common southern species. In the main area, water-covered, one finds three trees, *Taxodium distichum,* the bald cypress; *Juniperus virginiana,* the juniper; and *Nyssa sylvatica,* the black gum. The juniper occupies spots usually somewhat desiccated during the dry season, but the others, being provided with special appliances, live where their roots are covered with water during even the growing season. The forest is very dense and passage through it is rendered difficult by projecting knees of cypress and the arched roots of Nyssa, while everywhere is a profusion of other plants. The surface is covered with a litter

---

[108] N. S. Shaler, Tenth Ann. Rep. U. S. Geol. Survey, pp. 293, 313, 321, Pl. 8, 9, 10, Fig. 29.

of fallen trunks, twigs and leaves. Shaler's plates from photographs taken in this forested swamp show the conditions thoroughly.

Shaler[109] has described the peculiar modification of structure characterizing the bald cypress. This is the greatest of the conifers east from the Rocky mountains and it is the most stately of all the trees on the eastern half of the continent. On dry ground or where there is no water during the summer half of the year, it shows no peculiarities; but where it lives in swamps, flooded during the growing season, the roots give off excrescences which project above the water, their height depending on the depth of water. These "knees" are subcylindrical and are crowned by a cabbage-shaped expansion of bark, rough without and often hollow within. Whenever these knees become permanently submerged during the growing season, the tree dies; as was proved in the New Madrid area, where, during the 1811 to 1813 earthquakes, the land sank permanently. In Reelfoot lake, within Kentucky and Tennessee, thousands of these long cypress boles still stand in the shallow waters, though 70 years have passed since the slight submergence of their knees. The effect of drowning is shown on a plate in the work previously cited. Many dead stems of cypress rise above the surface of Drummond lake, which is only a few feet deep. Lesquereux thought that these were once part of a floating forest.

Okefinokee swamp in southern Georgia is not wholly a forested swamp. It is larger than Dismal Swamp and more difficult to study. Harper[110] succeeded in penetrating it to a distance, all told of about 18 miles. Here and there are islands, raised a little above the swamp level, at times not more than 2 feet, often less. On those the slash pine and the black gum grow, while all around are sphagnous bogs in which are slash pine, as well as swamp cypress, with sedges, ferns, sundews, and pitcher plants. Pines are wanting where the muck is more than 4 feet deep, but the cypress grows densely until the depth exceeds 6 feet. Where that depth is exceeded, no trees are found

---

[109] N. S. Shaler, "The American Swamp Cypress," *Science*, O. S., Vol. II., 1883, pp. 38–40.

[110] R. M. Harper, "Okefinokee Swamp," *Pop. Sci. Monthly*, Vol. LXXIV., 1909, pp. 596–613.

and the surface is a "prairie." This type has an area of 100 square miles in the western part of the swamp, covered everywhere by water in wet weather, so that one may go in any direction in a canoe. Canes, pickerel weed and water lilies abound but *Sphagnum* is absent, as in this latitude it can grow only in shaded places. Stumps of cypress are abundant and the peat is about 10 feet thick. The Florida swamps, described by Harper and others in the official reports, show all types from the open marsh to the forested swamp. The cypress swamps of the Lake region have grass marshes near the water, which are separated from the dense cypress growth by a narrow belt of small willows. The peat in these deposits is worth little commercially, as it is crowded with logs and woody roots. The great Everglades area belongs to the stagnant water type.

The cypress swamps of the Gulf coast are like those of the Atlantic coast. Lyell[111] relates that, in excavating for the foundations of the New Orleans Gas Works, the contractor soon discovered that he had to deal not with soil but with buried timber; the diggers were replaced by expert axemen. The cypress and other trees were "superimposed one upon the other, in an upright position, with their roots as they grew." The State Surveyor reported that in digging the great canal from Lake Ponchartrain, a cypress swamp was cut, which had filled gradually, "for there were three tiers of stumps in the 9 feet, some of them very old, ranged one above the other; and some of the stumps must have rotted away to the level of the ground in the swamp before the upper ones grew over them."

Conditions in the cypress swamps are the same throughout, whether the prevailing tree be bald cypress or white cedar. The peat is formed by accumulation of litter in the dense forest and, for the most part, the swamps are due to impeded drainage on an almost level surface. The trees are rooted in the swamp material, which at times is of great thickness, more than 150 feet of muck, carrying cypress trees on its surface, being reported from Florida. Such trees find ample nutriment in peat containing less than 4 per cent. of mineral matter and they do not send their roots down to the solid ground. One sees growing amid such conditions not merely shrubs

---

[111] C. Lyell, "Second Visit," etc., Vol. II., pp. 136, 137.

but also majestic trees, such as cypress and gum, which, as well as the less imposing juniper, yield wood of great importance to the artificer.

The inland swamps of the northern states differ in many ways from the coastal swamps. They occur along river borders or in lakelet areas of the drift-covered region. In great part, the former are "wet woods" covered more or less deeply with water during several months of each year, but they show considerable stretches of true swamp. The swamps and marshes of the drift region are less extensive, but they afford better opportunity for studies bearing on the mode of accumulation. They have been investigated by C. A. Davis, H. Ries, N. S. Shaler and others, but the most comprehensive and most recent description is by Davis.

Davis[112] notes that very few highly organized plants can grow wholly submerged in water, and those are mostly endogens; 10 feet of depth seems to be the limit, although *Potamogeton* has been found rooted in 23 feet; other types, low forms such as *Chara* and the floating algæ are indifferent. Some plants, burweeds, arrowheads, reed grass, pickerel weed and water lilies can grow when partially submerged; while some land plants, shrubs and trees can endure long exposure to water about the roots. The surface growth on swamps is important. Elm and black ash swamps are of common occurrence and have, besides those plants, tamarack, spruce, willows, alders, with various heaths and mosses. They do not always show much peat, but what there is is well decomposed and is apt to contain much mineral matter. The greatest thickness of peat in these swamps is reported to be 10 feet. Tamarack (*Larix laricina*) and white cedar (*Chamæcyparis thyoides*) indicate the presence of peat, the latter growing densely on the surface of a deposit, 20 feet thick. Spruces (*Picea mariana* and *P. brevifolia*) also grow on thick peat; willows, poplar and alders grow on the thickest peat and in wet places; but the mosses, *Hypnum* and *Sphagnum,* grow only in advanced swamps.

---

[112] C. A. Davis, "Peat, Essays on its Origin, Uses and Distribution in Michigan," Rep. Mich. Geol. Survey for 1906, pp. 121–125, 128–134, 136–141, 153, 154, 157–159, 160–166, 203, 204, 208, 213, 269, 275, 279, 291.

Peat deposits fill depressions but, in some cases, are formed on almost level areas. Depressions more than 25 feet deep may be filled by algæ, by floating species of seed-bearing plants, by sedimentation, by plant growth from the sides or by a combination of these processes. A frequent succession is Chara-marl, on which rests a peaty soil in which plants take root; the land marsh moves out and tamarack advances on the deeper peat of the shore. As the water becomes shallower, each shore type moves out and is succeeded by the type behind—the water growing warmer and more aërated. Formation of peat on a flat space is much under the same conditions as those on the surface of a filled depression. When the drainage is poor, liverworts or some mosses take possession; if not too wet, rushes, sedges and grasses appear. Accumulation makes the place wetter and only the hardier plants remain. Sedges are the chief peat-producers under these conditions.

The process of filling a depression is often very complicated. In southern Michigan, the early stages are shown in many lakes, which are surrounded by zones of aquatic plants. More or less detritus, organic and inorganic, finds its way into the lake. Where the process is more advanced one can trace the whole succession.

The lowest deposit is formed of *Chara* and floating algæ. This is succeeded in the shallower water by the *Potamogeton* zone and that by the water lilies. Just beyond this one comes to the floating mat of sedges, extending on the water surface to a considerable distance from the shore and buoyant enough to support a considerable weight. The earlier stages may provide soil for rooting of the sedges at the shore line, but the mat itself is wholly unsupported for a considerable distance and is often 18 inches thick. Finely divided material from the undersurface of the mat increases toward the shore, where it becomes dense and the mat is no longer floating. Thus is built the solid peat, structureless, decomposed and nearly black. The surface rises gradually after grounding of the mat and, at each level, new plants appear. Shrubs and *Sphagnum* advance to be overcome in turn by tamarack and spruce, which in their turn are overcome by the marginal flora from behind. Tamarack accompanied by ferns grows far out on the bog.

The final stage is where the sedge mat closes over the surface and the underlying peat has become firm. Sedge is usually the chief factor in the later stages of lake destruction. At times, the mat is pressed down by the weight of trees growing on it. In one case it was found 6 feet thick, resting on semi-fluid peat. A section at one locality showed

		Feet.	Inches.
1.	Sphagnous peat	0	6
2.	Moss peat and shrubs	2	0
3.	Moss peat	0	3
4.	Coarse brown peat, stumps and roots	2	6
5.	Remains of shrubs	0	2
6.	Dark peat rich in sedge remains	2	0

It was impossible to determine the condition farther down as the peat was very wet, but sedges were recognized. Similar conditions were observed in other sections. These all show that the trees were rooted in the mat of pure vegetable material, even when it reposed on the water surface and that, while the trees were growing, the accumulation of peat was continuous.

After the mat has been grounded, *Hypnum* hastens outward from the shore, associated occasionally with some *Sphagnum*. When the surface rises 2 inches above the water level, ferns appear and they are followed by *Sphagnum*, which persists even when the surface is flooded. It is much hardier than *Hypnum* and, for that reason, it has been regarded as chief factor in the production of peat. But it is often absent, having been found in less than 30 per cent. of the localities examined by Davis. The first tree is the tamarack, which grows densely on the level of shrubs, but isolated trees are scattered over the open bog.

Chara-marl occurs frequently in southern Michigan but it was not seen anywhere in the northern portion of the state, where the general succession differs somewhat from that already given. The Chara-stage is wanting; pond weeds, pond lilies and rushes are of irregular occurrence and the sedge-zone is all important. Owing, probably, to absence of fragments belonging to the higher plants, the work of freshwater algæ is more apparent than in the southern peninsula. Algal lake, now covering only a few acres, is surrounded by a great wooded swamp, extending northeastward to a large lake and coming down almost to the water at the north end of Algal lake. The swamp loosestrife (*Decodon verticillatus*) forms the marginal zone. The bottom of the lake is covered with soft flocculent ooze, composed of unicellular algæ with diatoms as well as pollen from conifers. Davis conceived that peat of this type would be like cannel and he thinks that freshwater algæ may have been more abundant in Carboniferous times, when all types of plant life were lower than now. A similar material was found in a mature bog, where the section is

		Feet.
1.	Coarse peat, with stumps, roots and fallen stems	5
2.	Brown peat, good texture, quite plastic	5
3.	Soft, light-colored peat, like that at Algal lake	4

These are the only localities in the United States whence this type of peat has been reported. Ehrenberg, Früh and Potonié have described the felt or Meteorpapier, as Ehrenberg termed it, which remains on swamps after floodwaters have been drained off. Potonié calls it Sapropel carpet, and he has given a photograph showing the material covering land plants of a swamp. But the phenomenon is of by no means rare occurrence in the eastern part of the United States. Davis has communicated by letter that he saw it in 1910 near St. Augustine in Florida, where the water of a swamp had been lowered; the felt was conspicuous on the tussocks, etc. In the Everglades of the same state, he found the felt about the grass and sedge stems in the level swamps. Here and there it contained a considerable quantity of calcareous matter, due perhaps to activities of Cyaphanaceæ present in the algal association. The same type of felt-like development is seen during springtime in marshes of the northern states, where the water drains off slowly. *Spirogyra* and other filamentous algæ sometimes cover the temporary ponds and are left as a felt-like cover when the water has been withdrawn. This felt breaks into small pieces as it dries and is added to the peat. The writer has observed it in very small patches on the New Jersey marshes; he has seen patches more than 10 feet square at many places in Rhode Island and Massachusetts. But in every case, the quantity is insignificant as compared with the mass of other vegetable material and this algal contribution must be wholly unimportant. At the same time, one can conceive of conditions which could render it important.

Shaler expressed the prevailing opinion when he asserted that the presence of moisture determines the distribution of plant life in swamp areas. Advance of swamp destroys the forest. He had seen many places on the coast of Maine as well as in northern Michigan and Wisconsin, where invasion by *Sphagnum* made the surface so wet that even the most water-loving trees of those regions could not maintain themselves. Davis, in his work on Michigan peats, has discussed the causes leading to the succession of vegetation in swampy areas. The shrubs growing at the water level are drought plants, though living where water is abundant; their leaves are linear or even scale-like; the cuticle is dense and the leaves are protected by a waxy or at times resinous coating—all contrived to prevent too rapid evaporation. The explanation of the condition is complex, but it depends mostly on the difficulty with which moisture can be extracted from peat. Once thoroughly air-dried, peat is almost impervious to water, so that plants growing on peat or a peaty soil suffer more from drought than those on other soils. Even when wet, it has little water for plants growing on it. A noteworthy fact in this connection is that some plants, growing near water level in southern Michigan, are found growing only on dry soils in northern Michigan. They find their drought-resisting ability equally essential in both regions. The distribution of these plants is explained by the fact that they have fleshy fruits, which birds eat during their southward migration and the seeds are scattered over moist areas. While the plants must be able to resist drought, they must be able to endure excess of moisture in some localities. Davis saw *Betula pumilla* and some willows living in places where their roots had been covered with one foot of water for several years.

The conditions of advance described by Davis are familiar in other states. They exist even on high swamp areas, as appears from Bradley's[112a] notes on the disappearance of meadows which were used as camping places in the Sierra Nevada. Fifteen years ago, these were open and covered with abundant grass. Originally, they were ponds or lakes which became filled with peat, on which grass thrived. As the material became less wet, tamarack seeds, blown in from the border, took root, but the young shoots were killed by the frequent fires. Since protection against fire has become complete throughout the region, the tamarack has advanced so as to occupy much of the surface, while pines are encroaching, which eventually will crowd out the tamarack and will occupy the whole area. The trees are rooted in the peat.

Bates[113] has shown that swamp conditions and luxuriant growth of trees are not incompatible. In describing the forests of Para, he says that one swampy area was covered with trees more than 100 feet high, all of second growth. In another swamp, the air was marked by a mouldy odor, the trees were lofty and the surface was carpeted with lycopodiums. Farther down in this area, where the ground was more swampy, wild bananas, great palms and exogens grew luxuriantly and were covered with creepers and parasites; while the surface was encumbered with rotting trunks, branches, leaves, and the whole was reeking with moisture. Kuntze, already cited, states that the tropical swamps are densely wooded. Observations by other authors will be referred to in another connection.

Peat Deposits in Europe.—The importance of peat as fuel in Europe has led to thorough investigation of that material from every conceivable standpoint. The literature is so extensive and, in great part, so excellent that one, compelled by limits of space, finds himself embarrassed in selection of authors as well as of matter.

Lesquereux[114] long ago proved that *Sphagnum* is not the important factor in peat-making; he recalled attention to Ad. Brongniart's

---

[112a] H. C. Bradley, "The Passing of Our Mountain Meadows," *Sierra Club Bull.*, Vol. VIII., 1911, pp. 39–42.

[113] H. W. Bates, "The Naturalist on the River Amazons," London, 1863. Vol. I., pp. 44, 47, 50, 51.

[114] L. Lesquereux, "Quelques recherches sur les marais tourbeux," pp. 32, 111, 121, 137; 2d Geol. Surv. Penn., Rep. for 1885, pp. 107–121.

observation that evaporation from that moss is proportionately less than from other plants; and he showed that growth of the moss is checked by freezing and that the plant cannot live in deep shade or under forest trees such as oaks, pines or beeches. He seems to be the first to note that marls covering peat bogs contain impressions of plants.

Lesquereux's conception of the mode of filling depressions from the sides differs somewhat in detail from that given for the United States. Shallow ponds are invaded by vegetation, which forms a mould in which water plants take root. The basin is filled by their decay, the surface becomes humus in which plants of other types grow, giving meadows or forests. The filling is rapid in the early stages. Pools of quiet water are invaded by confervæ, mingled with infusoria, microscopic plants and small shells, which by decay cover the bottom. At times, 6 to 10 inches of this deposit may accumulate in a year. When the water is deep, the same result is reached by another process—the prolonged growth of certain floating mosses, especially of some species of *Sphagnum*. Those, pushing out from the sides, form a thin cover, in which grasses, sedges and other water-loving plants grow. Eventually, this becomes compact enough to bear the weight of trees, even of dense forest; until, becoming too heavy, it either breaks or is pressed slowly to the bottom and covered with water. This, he asserts, is no hypothesis but the statement of actual fact.

The lac d'Etaillères, near Fleurir in Switzerland, is open water in an extensive series of peat bogs. Prior to the year 1500, it was the site of a forest; but in that year, according to legend, the forest disappeared and it was replaced by two lakes. The lakes still exist and in quiet water one can see the prostrate trees on the bottom. But a new carpet has already spread over much of the surface, which in turn will become forested and will sink. Thus one may find superimposed beds of decomposing vegetable matter, each consisting of remains of small plants below but of forest remains above. An analogous condition exists in Lake Drummond of the Dismal Swamp, where the bottom consists of a forest cover, once at the top but now under water, while vegetation is encroaching from the sides. It is quite possible that this explanation of the Lake Drummond condition is correct, but that lake is shallow, only 6 feet, and the trees are erect; in the deeper lac d'Etaillères, the trees were prostrated by breaking of the mat. To illustrate the succession in such a case, he gives the section of a bog in Denmark:

		Feet.	Inches.
1.	Fibrous yellow peat with undecomposed mosses	3	8
2.	Oak layer, wood still sound, trunks 2 to 3 ft. diameter.		
3.	Peat, yellowish	6	
4.	Birches, prostrate, *Betula alba*	3	0
5.	Black peat	4	0
6.	Pines, 6 to 10 inches diameter, most of them pointing toward center of the basin, retaining their branches, embedded in a mass of leaves, cones, etc.	8	0
7.	Black compact peat	4	0

and the bottom not reached. This peat was mined for fuel, the works being extensive. The general description by Lesquereux shows that the conditions are not wholly the same in his localities as in many areas within the United States. They suffice to show that *Sphagnum* is a late arrival, though in Switzerland, as in some other portions of Europe it is more important than in this country, where sphagnum-peat rarely exceeds 3 feet.

As illustrating this, one may cite Vogt's[115] description of a Hochmoor at the Ponts of the Canton Neuenburg. This lies between two villages built on limestone benches on opposite sides of a valley. In the middle ages, each village was visible from the other, but that is no longer the case. The bog has raised itself, hill-like, growing most rapidly along the middle line. This mass is *Sphagnum* and its mode of growth shows well the ability of that moss to retain water, so as to thrive at considerably above the water level.

Heer[116] says that life on land began with minute forms and few types. So, in the water, algæ begin the work. Even pure fresh-

---

[115] C. Vogt, "Lehrbuch der Geologie," 2te Aufl., Braunschweig, 1854, Vol. II., p. 110.

[116] O. Heer, "Die Schieferkohlen von Utznach und Dürnten," Zurich, 1858, pp. 1–4.

water, exposed to air and light, is full of minute plants, with boundless capacity for multiplication, forming in vast legions, which sink and form a layer of organic material, the basis of formations composed of higher organisms. These are followed by floating mosses, which, in spite of their small size, soon produce a great mass of organic material. The bladderworts, water milfoils follow and the water lilies spread their leaves over the surface; reeds press out from the shore and sedges of various kinds form a wickerwork of roots, which gradually spread over the whole depression and water is no longer visible. Meanwhile the peat has been growing denser, drawing water from below and keeping the bed moist. In it nestle the milfoils and heaths. The lake closed, woody plants encroach, *Betula* and then *Pinus sylvestris*. But the latter does not grow high, breaking off after attaining a certain height and weight, sinking into the underlying soft material, there to be destroyed and converted into peat as are the shrubby plants. These trees are readily overthrown by the wind and the peat is crowded with the overturned trunks of birch and fir. The harder parts offer prolonged resistance to chemical change and are embedded in a pulp-like mass derived from the softer parts. The conditions in all stages are recognizable in Swiss deposits. The succession may be varied by climatic changes, whereby a Waldmoor may be converted into a Torfmoor and that in turn into a Waldmoor again.

Früh's[117] descriptions of conditions in Switzerland and Germany are much like those given in later years for localities in the United States, though the succession of events may differ somewhat in detail. At the same time, the Hochmoor or *Sphagnum* deposit seems to be built up on the Rasenmoor, composed of *Cyperaceæ, Phragmites* and *Hypnum;* islands of Hochmoor were seen occasionally in a Rasenmoor. Lorentz is cited as having examined 57 moors, of which 31 were Hochmoors developed on Rasenmoors. Früh investigated Hochmoors in Steiermark, the Bavarian highlands and in Switzerland, all of which showed that *Sphagnum* is a late arrival in

---

[117] J. J. Früh, "Ueber Torf und Dopplerit," pp. 5, 7–9, 15, 18, 20.

the peat. In the great Digenmoors of the Bavarian highlands he found

	Meters.
1. Black peat, with *Sphagnum*	1 to 1.2
2. Homogeneous black-brown, compact, plastic peat, with layers of crushed birch stems; a few specimens of *Sphagnum,* but 90 per cent. of the mass consisting of roots of *Cyperaceae*	1 to 1.5
3. Wood layer of conifers	0.4 to 0.6
4 Glacial drift.	

He gives measurements from fourteen localities in Switzerland, only one of which failed to show the succession observed in the section. The exception is a Hochmoor without Rasenmoor foundation and resting directly on a layer of wood remains. One group seems to contradict Sendtner's generalization that Hochmoor accumulates only in localities where the water is not calcareous. This, the "Todte Meer," is a typical living Hochmoor, near Willerszell, bearing on its surface many hummocks nearly equal in height and basal diameter, and bordered by a mountain stream, whose drainage area is in a limestone region. It shows

	Meters.
1. Hochmoor, *Sphagnum*	0.2 to 0.3
2. Felted Rasenmoor, upper part consisting of *Carex* and *Arundo,* with scattered algæ; lower part with *Hypnum*	3
3. Almost pure well-preserved *Hypnum.*	
4. Clay and gravel.	

He finds a simple explanation in the fact that the stream, at high water, does not wet the *Sphagnum.* It may be well to note here that in Michigan, according to Davis, *Sphagnum* is indifferent to the character of the water, the presence of calcium carbonate in no wise affecting its growth.

Früh reports 48 Hochmoors in the Alpine region as originating on Rasenmoors. V. Bemmelen and Staring are cited as having proved the same relations for the provinces of Orenthe, Friesland and Gottingue in Holland. The Rasenmoor does not require hard water, for the vast moors of the Rhine and Maas area are watered by those streams, which contain only 65 and 41 millionths of calcium and magnesium compounds. The relation between Hochmoor and

Rasenmoor is not always apparent as either one may be very thin and the other very thick. In his later, great work on the Swiss moors, Früh has described with much detail all the Swiss deposits and he has offered generalizations which will be considered in another connection.

It had been suggested by some observers that the tree trunks found in the bogs had been drifted into the depressions, but Früh asserts without qualification that they are in place. The condition is wholly normal. A. Geikie,[118] after noting the differences in physical structure as well as in vegetation shown by successive portions of a bog, says that remains of trees are common. Some are embedded in soil underneath the bog; others are in the heart of the peat, proving that the trees lived on the mossy surface and finally were enclosed in the growing peat. This is illustrated by a sketch of a peat-moss in Sutherland. J. Geikie[119] has given much information respecting the Scottish bogs but it will suffice to cite only his later work. The bogs have yielded many species of trees, all of them indigenous. The trees are *in situ,* each rooted in the kind of soil preferred by living examples. There are few acres of lowland bog in which trees have not been found. They occur even in the Hebrides, where trees now are practically unknown. Occasionally, more than one forest bed is present. At Strathcluony, three tiers of Scotch fir were seen, separated by layers of peat. Several tiers were exposed in a railway cutting across the Big Moss; one of standing fir trees with branching roots at 6 feet below the surface, a second at 12 feet and a third at 4 feet lower; so that, counting the surface growth, four different forests have existed there since the bog began.

Aher,[120] in the Bog reports, says that trees in the Irish bogs "have generally 6 or 7 feet of compact peat under their roots, which are found standing as they grew, evidently proving the formation of the peat to have been previous to the growth of the trees." On

---

[118] A. Geikie, "Text-book of Geology," 3d Ed., London, 1893, pp. 478–480.

[119] J. Geikie, "The Great Ice Age," 3d Ed., London, 1895. pp. 286–293, 303.

[120] Cited by S. S. Haldeman, in 2d Ed. of R. C. Taylor's "Statistics of Coal," Philadelphia, 1855, p. 169.

the same page Haldeman notes that it is a remarkable fact, although very common, that successive layers of trees or stumps, in erect position and furnished with their roots, are found at distinctly different levels, at small vertical distance from each other.

Grand' Eury,[121] noting that the plants, active in peat-making, are not the same in all cases, maintains that a distinction must be made between peat, properly so-called, and peat of the *marais*. The former is supraaquatic, covers high plateaus and is formed chiefly by *Sphagnum,* with some other water-loving mosses. Unaccompanied by these, other plants in similar conditions give only soil. Such peat is rarely transformed into a compact *charbon* and it is obscurely stratified. The peat of *marais* is formed on low grounds, along the borders of rivers, lakes or the sea, often in extensive areas. In such places, *Arundo* grows rapidly along with *Scirpus palustris* and reeds as well as with *Hypnum, Nymphæa* and other semi-aquatic plants. This peat may be divided by sandy deposits and at the bottom one finds a muddy peat, almost without structure. It occurs in Holland and on the shores of the Baltic, the marshes being of great extent in both regions. Fossil peat occurs at Utznach in Switzerland.

Still different are the peats of wooded swamps and swampy forests. In depressed areas, where the forests have been killed by swamp plants, the peat, formed of herbaceous plants and prostrate stems, accumulates rapidly. He refers to the wood at Kiögge near Copenhagen, which the Danish naturalists had regarded as due to transport; but Lesquereux had shown that it is in place, the trees having been overturned by the wind—a condition observed in the present forests near by. The mass is composed almost wholly of birch and the upper part consists of empty barks entangled in a mud or half liquid paste, coming from decomposition of the wood.

Grand' Eury examined in the Ural a peat of swamp-forest origin, a mass of herbaceous plants and débris of trees. Stumps rooted in the mass were seen at two horizons in the upper part and others were scattered below. Many stems and branches lie prostrate and,

---

[121] C. Grand' Eury, "Memoire sur la formation de la houille," *Ann. des Mines,* 8me Ser., Tome I., 1882, pp. 197–202.

at the bottom, a considerable portion is formed of barks, wood, leaves and other débris, transported and deposited in the water. Roots can be seen penetrating the gray clay on which the deposit rests. On the borders, the peat has not been changed in position and it is felted and herbaceous. In one part it seems to be composed exclusively of transported plants, there being barks of flattened birches; some laminated portions are formed of humefied epidermis material.

No reasons are given for assigning a great portion of the mass to transported material, the matter being taken apparently as beyond dispute; but one may surmise that the presence of stumps rooted in the peat, the prostrate trunks and the fragmentary condition of the enclosing material may have been for him convincing. Grand' Eury did not believe that trees would grow in peat and the fragmentary condition of plant remains was proof that they had been washed in. The conditions, described by him, are precisely those which are familiar in bogs, for which no conception of transport is admissible.

The Danish swamps were studied by Steenstrup[122] long ago; his grouping resembles that employed by the German students. The most important is the Waldmoor or Skovmose type occupying depressions in Quaternary deposits, often more than 30 feet deep. Where the area was small, the sides were abrupt and the trees growing on them eventually fell into the bog, where they have been preserved. In depressions of great extent, one finds an exterior wooded zone surrounding an interior or central bog zone. The latter resembles the Lyngmose, the heather or Hochmoor stage.

The central area of the Skovmose is very regular. It rests on clay derived from the borders; above which one finds ordinarily one and a half to even four feet of amorphous peat, becoming pulpy in water and containing indeterminable plant remains. The peat is very pure in normal bogs, but layers of calcareous or silicious matter are not unknown. A layer of hypnum-peat rests on the amorphous deposit, 3 to 4 feet thick, containing *Pinus sylvestris*, which grew on the spot, at times forming a forest on the swamp. The trees were

---

[122] Steenstrup, as summarized by Morlot, Trans. in *Ann. Rep. Smithsonian Inst.*, Washington, 1861, pp. 304 et seq.

stunted and grew slowly amid unfavorable conditions, there being 70 annual rings to the inch; yet the trees lived for several centuries. In the larger swamps, two or even three layers of pine stumps are found, *in situ*, with their bases and roots well-preserved. As the surface became higher, and drier, the earlier mosses gave place to others; *Sphagnum* appeared and, at length, heathers. The pines yielded to the birches and those to alders, hazel bushes and *Corylus*. This succession is found only in the central zone; the deposit is too thin on the border.

Weber[123] after prolonged study of peat areas in northern Germany, grouped the peat producing plants into (1) those which form the moor; (2) those which grow on the peat; (3) those which love peat or are bound to it. The best illustrations of the relations of these groups are in moors which began in post-glacial time and have continued until now. As the result of his examination, Weber succeeded in determining the stages in development of the bog and in determining the part played by the several groups of plants. He presented a classification which has been accepted by many of the later students. This will be given in detail as applied to the Scandinavian deposits.

Somewhat earlier, Blytt[124] had discovered that in western Norway the typical succession is

		Feet.
1.	Sphagnous peat, about	5
2.	Forest bed, chiefly of Scotch fir.	
3.	Peat more compressed than that of No. 1, about	5
4.	Forest bed with oak stumps and myriads of hazel nuts.	
5.	Glacial deposits.	

But in eastern Norway, there are four peat layers alternating with three forest beds. In Denmark he finds equally distinct evidence for successive wet and dry periods. In summing up the conditions observed in Norway, Sweden and Denmark, he finds record of the following climatic changes:

---

[123] C. A. Weber, "Aufbau und Vegetation der Moore Norddeutschlands," *Engler. Bot. Jahrb.*, Vol. 40, 1908, *Beiblät.*, No. 90, pp. 19–34.

[124] Blytt, cited by J. Geikie, "Great Ice Age," p. 495.

1. Arctic freshwater beds, containing *Salix polaris. S. reticulata, Betula nana,* etc. A semi-continental climate.

2. Sub-glacial stage, with *Betula odorata, Populus tremula, Salix,* etc. The moors were wet, the climate humid; equivalent to the Danish "birch or aspen period."

3. Sub-Arctic stage, drier, many bogs became dry and were overspread by forest growth; Scotch fir (*Pinus sylvestris*) makes its first appearance.

4. Infra-boreal stage, climate again humid; the flora of Denmark is still of true northern type; *Pinus sylvestris* the common tree.

5. Boreal stage, climate drier and forests overspread the bogs, forming a root bed; *Corylus* and oak abundant.

6. Atlantic stage, climate mild and humid: *Quercus sessiflora* abundant in Denmark and southern Sweden; this is the Danish "oak period."

7. Sub-boreal stage, drier than the last: many peat bogs dried up and became forested.

8. Sub-Atlantic stage, bogs again wet and the youngest peat layer was formed; this is the Danish "beech or alder period."

9. Present stage, the bogs are drying and are becoming forested.

Stages 1 to 4 are wanting in the low level bogs of the Scandinavian coast as that region was still submerged.

The peat deposits of Sweden have been studied by H. and L. von Post, Andersson, Sernander and others, and those of Finland by Andersson. It suffices for the present to present only the salient facts as recorded by L. von Post,[125] reference to the work of some others being deferred to a later portion of this work. Von Post's studies were made in the province of Narke, southern Sweden. His grouping is essentially the same as that offered by Weber but he gives details, necessary to the present discussion, not noted by other students. He finds the following types of deposits:

Limnische. I. 1. Allochthonous mineral deposits made in open water: here are clay, with diatoms, poor in plankton, and clay-gyttja, which is clay with much plankton and diatoms. 2. Allochthonous organic sediments, including (*a*) plankton-gyttja, in open, comparatively deep water, gray to green, more or less elastic, composed of plankton, algae abounding; (*b*) detritus-gyttja, in comparatively shallow water, from *Potamogeton* and *Nymphæa*, red-brown to yellow-black, granular, mostly plant débris with some plankton; (*c*) Schwemmtorf, composed of plant detritus; (*d*) Ufertorf, like the last and formed very near the line of low water. It contains lenses of Lake and of Swamp peat.

---

[125] L. von Post, "Stratigraphische Studien über einige Torfmoore in Narke," *Geol. Foren. Forhandl.*, Bd. 31, 1909, pp. 633–640, 644, 647.

II. Autochthonous organic deposits. The Lake peat including (*a*) *Phragmites* peat, clear yellow, composed of fibrous roots with reeds and some gyttja; (*b*) *Equisetum* peat, like the last in structure, but the color is coal black.

Telmatische. I. Swamp or Niedermoor peats, including (*a*) Magnocaricetum peat, consisting of sedges with *Amblystegium* as accessory, yellow to yellow-brown; (*b*) *Amblystegium* peat, consisting of stems and leaves of that plant with some sedge constituents; (*c*) Bruchpeat, red to black, amorphous humefied peat detritus, *in situ*, with identifiable roots of sedges.

II. Hochmoor peats, (*a*) Cuspidatum peat, bright colored *Sphagnum cuspidatum* and other water-loving mosses, with remains of *Scheuchzeria, Carex* and *Eriophorum.*

Semi-Terrestrische. I. (*b*) Vaginatum peat, *Sphagnum* with *Eriophorum vaginatum* roots and stalks, these often making up one half of the mass, humefied and dark colored; (*c*) *Sphagnum* peat in lenses with *Cladina* remains between clear brown layers of *Sphagnum* with *Eriophorum.*

II. Forest peat, (*a*) Alder forest peat, red-black, amorphous, consists of *in situ* deposited detritus of an alder swamp forest. Remains of alder are recognizable; *Cenococcum geophilum* abundant.

Terrestrische. (*b*) Birch forest peat, like the last, but commonly dark colored, deposited in a birch swamp forest; (*c*) Forest peat, rich in *Eriophorum* and *Sphagnum,* as a rule, dark colored, almost always with stumps and other remains of Scotch fir; (*d*) Forest mould, dark, composed of wood detritus and grains of humus, with stumps.

All of these types from Lake peat down are autochthonous. The upper limit of the basin or limnic deposits is at the normal line of low water; the shore or telmatic deposits are in the space covered at high water, while the terrestrial are on forested areas, rarely covered with water. The alder swamp is the passage zone to the terrestrial. Von Post confirms Blytt's conclusions respecting the alternation of dry and humid periods, and shows how, during the less humid times, forests invaded the peat deposits and in some cases covered the surface of pure peat with a dense growth. He presents sections from a number of localities. One from the Åsta moor shows

A. *Sphagnum* peat, 85 centimeters, with, at 80 centimeters, a mass of fir stumps rooted in the peat and with coaly matter between the stumps.

B. Strongly humefied cuspidatum peat, 10 centimeters.

C. Sedge peat, 30 centimeters, has much *Sphagnum* above.

D. Alder and birch swamp forest peat, with small stumps of alder, birch willow and a great quantity of *Cenococcum geophilum,* 15 centimeters.

E. Shore peat, like transported peat, 25 centimeters, roots of *Carex, Equisetum* and *Phragmites.*

F. Plankton-gyttja, 40 cm. with remains of infloated *Phragmites, Equisetum,* etc., some pollen of *Picea* in upper portion.

G. Clay, 50 cm. rich in saltwater diatoms.

As interpreted by Von Post, one has here at the bottom, a deposit of plankton material or Sapropel. It was invaded by the shore peat, on which a forest of birch and alder grew for a short time amid unfavorable conditions, as the swamp was overflowed at times; this condition became more marked and a sedge swamp followed, in which *Sphagnum* gradually gained control. Still later, for a short period, during which accumulation of peat continued unchecked, the moor was covered with a dense growth of firs; but as the moisture increased, the non-water-loving elements disappeared and a *Calluna-Eriophorum* moor occupied the area. Sections in Skarby lake complex show the same general features as those observed elsewhere in this region. Though there are differences in detail, the story is practically the same throughout. The open water deposits, gyttjas rich in plankton material, form the lowest stratum resting on clay or sand; on this is the shore peat, which gradually passed across the basin. Then came the time of decreasing moisture; alders advanced on the peat surface, now subject to only occasional overflows; they were succeeded by birches, which were rooted in the alder peat; and finally came the great forests of Scotch fir growing in the birch and alder peat, to be succeeded by *Sphagnum*-Hochmoor peat in the moist Sub-Atlantic stage. Peat-making was continuous in the forests and each type of forest peat has its own group of minor plants.

Buried Peat Deposits.—Some authors have contended that peat deposits on the land are not likely to be preserved because, exposed to air, they must be affected by atmospheric conditions and eventually must waste away. Under such conditions, it is certain that only such accumulations of vegetable material as are deposited in water-filled basins would be preserved. But the supposed conditions are purely hypothetical and are not in accord with those existing in nature. Indeed, one looking at a peat deposit, many feet thick, would have difficulty in conceiving how there could be uniformity of conditions for a period long enough to permit wastage of so great a mass, almost impermeable to water after having become thoroughly air-dried. But *a priori* reasoning is unnecessary; for, as Lesquereux recognized long ago, burial of peat bogs is part of the normal sequence of events.

Dawson[126] has described an early Quaternary bog which he saw in Nova Scotia. It underlies 20 feet of bowlder clay and pressure has made the peat almost as hard as coal, though it is tougher and more earthy than good coal. When rubbed or scratched with a knife, it becomes glossy; it burns with considerable flame and approaches the brown coals or poorer varieties of bituminous coal. It contains many roots and branches of trees apparently related to spruce.

Areas of peat buried under glacial drift are numerous in the New England states as well as in New Jersey and some of them will be mentioned in a succeeding section. Newberry,[127] many years ago, collected all the observations then available for states west from the Alleghany mountains. In Montgomery county of Ohio, E. Orton found a bed of peat, 15 to 20 feet thick, the surface covered with *Sphagnum*, grasses and sedges. It contains coniferous wood with bones of elephant, mastodon and teeth of giant beaver; and it underlies 90 feet of gravel and sand. At many places in Highland county of the same state, wells have reached a stratum of vegetable matter and, at Cleveland, a "carbonaceous stratum" has been found at 20 feet below the surface. A similar condition exists at Lawrenceburg, Indiana, as well as at many places along the Ohio; and J. Collett reported that, throughout southwestern Indiana, there is an ancient soil, 2 to 20 feet thick, with peat, muck, rooted stumps, branches and leaves, at 60 to 120 feet below the surface. This deposit is known locally as "Noah's cattle yards." The same condition is reported from a portion of Illinois. The great forest bed of Iowa, discovered by McGee at a later time, is in part a buried bog. Leverett, Taylor, and Goldthwait have described autochthonous peat bogs buried under glacial drift at many localities within the Mississippi area.

---

[126] J. W. Dawson, "Acadian Geology," 2d Ed., London, 1868, p. 63.

[127] J. S. Newberry, "Surface Geology of Ohio," Geol. Survey of Ohio, 1874, Vol. II., pp. 30–32.

In America, observations as recorded are very few and, for the most part, they are merely incidental, as until very recently the geological importance of peat was not recognized; but in Europe the case is very different; one finds there such a wealth of illustration as to cause surprise that any student should entertain doubts respecting preservation of peat deposits by burial under sediments. A few citations must suffice.

J. Geikie[128] says that peat bogs often pass below the sea. In the harbor of Aberdeen, trunks of oak are brought up and at a little distance away, peat was seen below the sea level covered with 10 to 12 feet of sand. This bed, enclosing trees, is known to extend for some distance into the bay. In the Carse lands, the river Tay has cut down to a peat bog, now forming the river bed and underlying about 17 feet of alluvial material, which near the top contains cockles, mussels and other marine forms. This extensive peat deposit of the wide Carse area rests in part on alluvial sands and in part on marine clays. The peat is highly compressed and splits readily into laminæ, on whose surfaces are small seeds and wing cases of insects. As a rule, but not always, it is marked off sharply from the overlying clay and silt. That it represents an old land surface is certain but it is equally clear that, in great part, the vegetable débris on top was drifted in from localities higher up in the valley, for the upper part of the peat contains, at times, layers of silt and twigs, while branches as well as trunks are scattered through the lower 3 or 4 feet of the overlying silt. The conditions are the same in Carse lands on both sides of Scotland and they exist in the Hebrides.

Prevost and Reade[120] have described a peat bed covered by a thick deposit of sediments. The exposed portion is a dark-brown peaty mass, containing large and small branches, roots and rootlets, the latter passing into the underclay. Some large boles and an occasional stump were seen on the upper surface. The authors note as a remarkable fact, that this bed resists erosive action by the river

---

[128] J. Geikie, "The Great Ice Age," 1895, pp. 290–293.

[129] E. W. Prevost and T. M. Reade. "The Peat and Forest Bed at Westbury-on-Severn," *Proc. Cotteswold Nat. Club,* Vol. XIV., 1901.

as well as by the more energetic bore, so that it projects as a promontory. Strahan[130] measured the section exposed during excavations for docks on Barry island. The succession is

1. Blown sand, *Scrobicularia* clay, sand, shingle, with strong line of erosion below. 2. Blue silt with many sedges. 3. Upper peat bed, 1 to 2 feet thick. 4. Blue silty clay with many sedges. 5. Second peat bed, thin. 6. Blue silty clay with sedges. 7. Third peat bed, with many logs and stools, roots in place underneath. 8. Blue silty clays with reeds, willow leaves and freshwater shells. 9. Fourth peat bed with large trees and roots in place and numerous land shells. 10. An old soil with roots and land shells. 11. Rock in place, at 35 feet below the Ordnance datum.

Here as in the Carse area of Scotland, the peat underlies a deposit containing marine shells.

Lesquereux[131] cites a French author, who found at many places in the Department of Nord alternations of peat and sand, the latter containing marine shells. He notes that when the growth of peat is checked by dryness, a crust forms, which is a parting between the old and the new peat. In the valley of the Somme, he found, underlying 8 feet of clay and concretionary limestone, 23 feet, 4 inches of peat in 15 layers, with the partings distinct and the layers differing in character. Alternations of clay, peat and calcareous concretions are not rare.

Geinitz,[132] more than twenty-five years ago, studied the dune-covered bogs near Rostock. At a later period he had opportunity for more detailed examination and his observations are important from several points of view. At the bathing station near Graal, the section shows at the bottom, sand of the Rostock plain, on which rests a one-foot layer of peat, containing stumps of trees which grew on it. The dune formerly covering this deposit has been removed for some distance, exposing the peat, but it still remains at a little way landward. Beyond the dune, one finds a forest of great beeches and oaks, with the peat bed covering the surface between them.

---

[130] A. Strahan, Mem. Geol. Survey, "Geology of the South Wales Coal Field," Part III., 1902, pp. 87–93.

[131] L. Lesquereux, Ann. Rep. 2d Geol. Survey of Penn. for 1885, pp. 116–118.

[132] E. Geinitz, "Nach der Sturmflut," *Aus der Natur,* Vol. IX., 1908, pp. 76–83.

When he looks at the dune surface, he sees, as it were, shrubs rising out of the sand, some short thick stems of beech and oak; but they are not shrubs, they are the still living parts of trees, the same in age and growth as those standing in the open forest. They have been buried by the advancing dune. A mighty storm flood, tearing away the sea wall and removing part of the dune, will expose vertical trees standing in the sands as in the Coal Measures sandstones. At present, one sees advancing masses of sand burying the trees, which grow on low-lying moors. At another locality, storms, during recent years, have exposed an older peat deposit, underlying the sands of the Rostock plain. The outcrop extends hundreds of meters along the shore and shows that the peat is a moss peat, which bore a forest of Scotch fir. There, as also near Graal, the waves have torn off fragments of the peat and have worn them down into elliptical form similar to that of the beach pebbles. Barrois[133] has referred to similar origin of peat pebbles on the shore of the British channel, where some neolithic deposits of peat are exposed to the waves. The fragments of peat are rolled, rounded and eventually transformed into true ellipsoidal pebbles.

Lorie,[134] in his fifth contribution to the surface geology of Holland has gathered together all the available information respecting the buried recent peat deposits of that region.

In all probability the Zuyder Zee was filled with peat prior to the catastrophe of the middle ages, but the only vestige is on the island of Schalkland, where one finds 5 to 7 meters of peat covered with a meter or more of marine clay. The same condition exists on the river Y near Amsterdam and in the province of Zeeland as well as in the west part of North Brabant in Belgium. The peat bed near Oudenbosch, in the latter province, is 0.75 meter thick and underlies 0.65 meter of sediment. It is readily traceable from that village across Zeeland into western Flanders of Belgium, and thence to the coast at Ostend in Belgium and Dunkerque in France, a dis-

---

[133] C. Barrois, "Observations sur les galets de cannel-coal du terrain houiller de Bruay," *Ann. Soc. Geol. du Nord.*, Vol. XXXVII., 1908, p. 7.

[134] J. Lorie, "Les dunes intérieures, les tourbières basses et les oscillations du sol," *Archives Mus. Teyler,* 2me Ser., Vol. III., 1890, pp. 424–427, 444, Pl. 2.

tance of more than 60 miles. Lorie cites Belpaire père, who says that it is one to 3 or even 4.5 meters thick and that it rests mostly on blue clay, though in some localities on fine sand. It is double near Ostend, where the lower bed is black, compact, with roots of reeds, while the upper bed contains no reeds but has woody fibers, apparently roots of heath plants. The peat and its overlying clay are sometimes continuous under the dunes and shore, as is also the case on the island of Walcheren in Zeeland. Trees, rooted in the subsoil, occur frequently in the peat. Belpaire fils says that the thickness of the peat and that of the overlying clay vary from 1 to 3 meters and that the clay level is never above high tide. On the left bank of the Escaut (Scheldt) as it flows from France across Belgium the peat is almost a meter and a half thick, but the clay, 2 to 3 meters, decreases as it recedes from the river. Lorie says that Rutot found a divided peat near Blankenberghe in Belgium. Reference to Rutot's[135] publication shows that the section is

		Meters.
1.	Shore sand	2.30
2.	Gray sandy clay	0.60
3.	Gray sand, with bed of *Cardium* midway	1.10
4.	Pure peat	2.00
5.	Gray sand, slightly argillaceous	0.40
6.	Sandy clay	0.50
7.	Gray, argillaceous sand	2.50

The peat underlies a marine sand and overlies a sand which is but slightly argillaceous.

In 1852, Harting, as cited by Lorie, discovered hard dry peat at 10 to 12 meters below the surface in Amsterdam. Ghyben followed this eastward toward the Wecht river. For much of the distance, it is covered with marine sand, but at that river it is covered with the main mass of peat, constituting the boundary between the sandy diluvium and the alluvial deposits. In later years it became possible to confirm and to extend the early observations, for many borings have been made along railroad lines within the polder areas of Holland. Lorie has tabulated the records of 124 such borings, showing

[135] A. Rutot, "Le puits artesien de Blankenberghe," *Bull. Soc. Belge de Geol.*, Vol. II., 1888, *Mem.*, p. 261. This author has given equally illustrative records in later memoirs published in this *Bulletin,* Vol. VIII., 1894; Vol. XI., 1897.

the conditions between Enkhuizen, north from Amsterdam, and Dordrecht, south from Rotterdam, as well as in localities east and west from that line. It is unnecessary to give more than a few of these as in any group the same conditions are found. Eighteen borings are reported along the east and west line from Rotterdam to the Hook of Holland. Seven of these follow, the measurements being in meters and the numbers are those of the records:

		85.	87.	88.	89.	90.	92.	102.
1.	Sand and clay	4.5	3.9	3.2	6.0	5.1	2.5	4.5
2.	Peat	0.9	1.4	3.0	1.5	2.6	4.5	3.2
3.	Sand and clay	..	..	..	..	0.5	5.5	2.5
4.	Peat	..	..	..	..	0.3	1.0	0.5
5.	Sand and clay	..	..	..	..	6.0	..	0.1
6.	Peat	..	..	..	..	1.0	..	0.5
7.	Sand and clay	..	..	..	..	..	..	1.5
8.	Peat	..	..	..	..	..	..	1.0
9.	Sand and clay	..	..	..	..	..	..	1.2
10.	Peat	..	..	..	..	..	..	1.0

These exhibit the variations to a depth of 16 meters. The material in each case below the lowest peat bed in the column is sedimentary clay and sand. Peat was found in some localities at 19 meters, but it is never continuous to that depth, being always divided by sediments. The greatest continuous thickness found in any boring is 10 meters. At times the peat is replaced wholly by sediment and one can trace old river courses in which no peat was formed and which now are filled with the transported sediment. The records show the conditions in an area of 70 by 20 miles, throughout which one finds one or more beds of peat covered with a greater or less thickness of sediment. These are autochthonous, and they contain stems of trees rooted in the subsoil. The intervening deposits are often distinctly marine in many parts of Holland; a section by Lorie shows

		Meters.
1.	Peat	3.2
2.	Gray clay, sandy below, calcareous, marine diatoms below, plant remains in upper part	0.8
3.	Argillaceous sand with *Cardium* and *Scrobicularia*	5.9
4.	Black peat	0.5
5.	Tough grayish blue clay	1.1
6.	Black, hardly coherent peat	1.2

The portion of Holland considered in Lorie's tabulated records is not less than 1,500 square miles; a more extensive area in Belgium shows the existence of covered peat deposits and this condition reaches far over into France, for, at Cotentin in Normandy, the peat, 20 meters thick, is covered with 3 meters of marine sand. One has in this region an area, almost as great as that of the Everglades in Florida, in which the existence of buried peat bogs has been proved, some of them having been traced continuously in a great part of the region. How great the total area may be, has not been ascertained, but it is very much greater than that which has been studied in detail.

The change in structure and composition of peat, as the depth increases, has been referred to more than once in the preceding pages. Evidently the older the peat, other things being equal, the more thoroughly the material is disintegrated. If compacted by pressure and the removal of water, it assumes the appearance of brown coal and does not regain plasticity, as appears from the descriptions by Dawson and Lesquereux, to which many others might have been added. It is certain that some constituent, once soluble in water, has become insoluble, as soluble silica, once dried, becomes insoluble. When the deposit, exclusive of enclosed wood, has been reduced to mature peat, one must resort to chemical reagents and to the microscope in order to ascertain the component materials. Those bring to view a structure, a physical composition, which is wholly similar to that which Grand' Eury gives for coal studied after the same method. It is a mass of disintegrated fragments, held together by a fundamental material, much of which was originally flocculent. The older quaternary peats show much variation; that described by Dawson has little which suggests peat to the unaided eye; but there are others which so much resemble the newer peats that, were it not for the presence of extinct mammals and the great thickness of cover, one might hesitate before deciding that they are not of recent origin. There are still others, which in the several layers exhibit great variations, some being of comparatively unchanged peat, while the material in others has lost all of the original macroscopic features.

Among the latter group, the most noteworthy example is the Schieferkohle of Utznach, Dürnten and neighboring localities in Switzerland, which is interesting from the economic as well as the scientific point of view. Having been studied in great detail by several geologists, it will suffice as type. Some have thought that these deposits are post-glacial, in which case, they would possess the greatest possible interest to students seeking to ascertain the mode in which vegetable matter became converted into coal and gathered into beds. But the age remains unsettled; Heim[136] maintains that the Schieferkohle lies between moraines. The section in detail at Wetzikon and Utznach shows drumlines and erratic blocks of the last glaciation resting on fluvio-glacial gravels. The lignite, underlying the latter, 1 to 3 meters thick, rests on bowlder clay of the greatest glaciation. These lignites are autochthonous, full of *Betula alba,* the stems at times vertical and with their roots in the underlying bowlder clay.

Heer[137] in his earlier work discussed the Utznach and Dürnten deposits, but dwelt more in detail on the latter as, at that time, it was the better exposed. The lignite is 12 feet thick, rests on clay and underlies about 30 feet of sand and gravel. It is not continuous vertically, but is divided by 6 clay partings, in all about 2 feet. The lowest bench contains much wood together with cones of *Pinus abies,* which are not found in the upper benches. In each higher bench, one finds at the bottom, whole layers of mosses, felted together and pierced by reeds, while above are stems, lying in all directions, with roots, barks and fragments of wood, all pressed flat. The annual rings are distinct in many stems and in one Heer counted 100. Some coaled stems were seen, which he thinks may have been charred by lightning. The trunks are surrounded as in peat by a black-brown mass, which undoubtedly originated from decay of herbaceous plants, converting them into a pulp-like mass. This succession is repeated in every branch, but, in the topmost, stems are comparatively rare, mosses and reeds predominating.

---

[136] A. Heim in letter of May 23, 1911.

[137] O. Heer, "Die Schieferkohlen von Utznach und Dürnten," Zurich, 1858, pp. 7–11; "The Primeval World of Switzerland," *Eng. Trans.*, London, 1876, Vol. I., pp. 29, 30, 32; Vol. II., pp. 149–155, 157, 161–163.

The plants and the conditions are those of a peat moor. The mosses belong to the peat-forming group; the reeds and sedges are swamp plants to which also belongs the bogbean (*Menyanthes*) of which the seeds are abundant in both the coal and the partings. Spruce is present only in the lowest bench but birch and fir (*Pinus sylvestris*) are in the higher benches. The trees are those of the swamps. The animal remains belong in part to a swamp fauna, there being great abundance of insect wing-cases on surfaces of the peat and clay layers, while with them are shells of freshwater mollusks. The larger animals are mammals. Everything goes to show that this Schieferkohle is a compressed, dried out peat and the older opinion—that it originated from drifted wood—is incorrect.

In his later work, Heer gives additional facts respecting Dürnten and some noteworthy observations concerning other localities. At Dürnten, a wedge of sand and pebbles separates the main mass from a 6-inch layer of peat and stems above. The main portion is horizontal, while the thin layer dips toward the place of union and the sands overlying it have the same dip. At Unterwetzikon the lignite, underlying 12 to 30 feet of stratified sands and gravel, rests on a marl with freshwater shells. At Utznach, there are two beds, 5 and 3 feet, separated by 16 to 20 feet of light colored marly material, and the lignite retains its original horizontal position. At Morschwyl, the lignite is 2 feet thick, with vertical tree stems, the whole marly deposit, including the lignite, being 8 feet thick and underlying 26 feet of detritus. At another locality, the cover is 70 feet and the deposit is 3 feet, with vertical stems, 6 feet high and 3 feet diameter, extending into the marl above. This lignite underlies and overlies marl, the whole mass being about 16 feet thick. Heer gives a list of the plants recognized at the several localities and discusses their relations, showing that the grouping is clearly that observed in peat bogs of northern Europe.

v. Gümbel[138] studied this Schieferkohle from many places in Switzerland and southern Bavaria, his typical locality being Morschwyl. In both the partly loose peat-like and the partly dense pitchcoal-like portions, numerous horizontal-lying fragments of

---

[138] C. W. v. Gümbel, "Beiträge zur Kenntniss," etc., pp. 135–138.

boughs and stems were found, mostly conifers, birches, willows and alders, which in some cases resemble brown coal, in others, pitch coal. The peat-like character of the whole mass, as described by v. Gümbel, recalls the buried bogs of Ohio and Indiana. Treated with caustic potash, the looser portions become a soft, dense felted mass, in which the microscope detects as prevailing constituents, leaves of grasses with mosses. *Sphagnum* is the prevailing form. Fragments of wood are comparatively rare, though needles and twigs of conifers are not wanting. The denser portions need application of Schultze's test, a mixture of potassium chlorate and strong nitric acid, which must be allowed to act for a considerable time in order to separate the plant remains. These are the same as in the looser portions. But in addition are splinters of a deep brown structureless material, behaving as dopplerite. It fills cell-spaces in many plant-fragments; this textureless material is the Carbohumin. The numerous cones embedded in the mass are not deformed.

In passing from the Quaternary to the Tertiary, one finds increased difficulty in recognizing peat bogs; the conditions, observed in the older portions of recent bogs and in those of the Quaternary, are intensified by compression and by removal of the water, which kept in soluble condition the ulmic and humic constituents, while advancing chemical change has converted the whole mass into the mature condition. In fine, the amorphous plastic peat has become amorphous brown coal and only trunks of resistant wood remain to tell the story. Yet in some cases the resemblance is so great that little room remains for doubt. A typical instance is the great Senftenberg Miocene deposit, described by Potonié, to which reference will be made again on a succeeding page. To one familiar with the cypress swamps of the United States, there can be no question respecting the origin of that deposit. Aside from loss in plasticity of the peat, and its conversion into brown coal, the description given by Potonié would apply equally well to the white cedar swamps of New Jersey or to some of the *Taxodium* swamps of the Mississippi, where the peat is equally pure, the mud and silt having been strained out as the water passed through cane brakes.

Heer, in his "Primeval World of Switzerland," says that at

Dürnten, the Schieferkohle rests on a gray-white marl containing *Anodonta, Valvata* and *Pisidium.* That marly clay rests on the Oligocene Molasse, which holds a bed of lignite. The woody limbs are still distinct but the rest of the mass has been changed beyond recognition. Yet one finds traces of marsh plants in the overlying marls, while underlying the lignite is an undoubted lake-marl containing *Unio, Planorbis* and *Lymnæa.*

Conclusions.—In this presentation of the features characterizing peat deposits, some facts appear in notably bold relief.

1. Peat deposits vary in form from lenses to sheets; the former are of petty to considerable extent, fill depressions such as pond or small lake basins; the latter, often of vast extent, originate on approximately level areas, where drainage is imperfect. The bottom and top are apt to be irregular; the latter because of islands or sandy deposits but especially because of streams and shallow ponds; but the form of the bottom depends on that of the surface on which it rests. The thickness may show great variation; a few inches of peat at one locality may be continuous with a deposit, 10 or even 60 feet thick elsewhere. Great deposits are not continuous vertically; partings divide the bed into benches; those partings may be very thin, clay or sandy clay with much woody matter, merely desiccated peat wasted by exposure during a dry period, or they may be sediments, varying from films of clay to beds of sand, gravel or clay, loose or consolidated. Peat deposits, especially those of great horizontal extent, often bifurcate and, at times, the "splits" reunite. The underlying material may be clay or sand—usually clay or marl for the lens-shaped deposits, but very often sand or sandy clay for sheet deposits extending over great areas. Sand with slight admixture of clay becomes practically impermeable by absorption of humic acid.

2. Peat deposits are recognized by macroscopic features as far back as the middle Tertiary. Some of Post-glacial age and several thousands of miles in extent are buried under 3 to 30 feet of sediment; some Quaternary deposits underlie 30 to 120 feet of transported inorganic matter and the overlying deposits vary from fine

clay with plant impressions to fine or coarse sandstone, conglomerate or even breccia.

3. Many vast moors, such as those of the Netherlands and North Germany as well as great and small moors in the United States and elsewhere, are at only a few feet above tide. A very slight depression suffices to bring the surface below that level and to introduce marine conditions. In lowland areas, thousands of square miles in extent, one finds a marine deposit, with characteristic fossils, immediately overlying peat, which is sometimes continuous with a still living moor above high tide. In such areas, one finds occasionally a marine deposit, clay or sand, immediately underlying the peat. The overlying or the underlying material or both of them may be distinctly calcareous.

4. The passage from peat to the overlying deposit may be abrupt or it may be gradual through alternations of peat and sediment.

5. The channel ways of streams crossing the moors are traceable in borings after the moors have been covered with sediment; they contain little or no peat.

6. The peat deposit is not always homogeneous. Sapropel, organic mud, is the foundation in a great proportion of lake deposits in Europe and in some within the United States; it is probably absent at bottom of great sheet deposits; but it may occur as lenses in any part of the section, marking the sites of shallow ponds. Sapropel is an unimportant constituent of true peat, which is produced by water-loving land plants, the work of other types being a negligible factor. The several benches of a deposit may differ notably in structure and composition. Peats are laminated even when new, but under compression, the lamination is characteristic and the material has a coal-like appearance.

7. Peat varies greatly in purity. At times, it has less ash than is found in plants whence it is derived, owing to the action of organic acids on silica and other mineral constituents; in most cases it shows notable variations, both vertically and horizontally, that variation depending chiefly on extent of exposure to flooding by muddy waters. Peat often contains a considerable quantity of iron and calcium in combination with carbonic, sulphuric and phosphoric

acids. Alumina and sodium chloride seem to always be present, though the latter is in small proportion.

8. When mature, peat consists of minute fragments of plants, embedded in an amorphous substance, more or less flocculent, the whole cemented by an originally soluble substance, which fills clefts in the peat and at times clefts in the underlying deposit and, in the older peat, penetrates even the cell tissue of plant fragments.

9. In a very great number of peat deposits, one finds erect stems of trees, rooted in the underlying clay or sand. Within extensive areas, the peat mass is crowded with successive generations of trees, which had grown on the peat, their roots not penetrating to the soil below. In the case of the less durable woods, the interior has disappeared and the compressed bark remains; but the prostrated stems of the more durable or resinous woods have resisted decay and they have retained their form; yet in Quaternary peat, the flattening is more or less marked in all. Peat is not good soil for all kinds of plants even when dry, but, even when wet, it is the soil on which several types of majestic trees thrive best; when somewhat less wet, it is the habitat of some other great trees, which flourish, while peat accumulates around their stems.

10. Peat accumulates within the tropics wherever conditions of topography and humidity are favorable.

11. The deposits of true peat are autochthonous.

Buried Forests.

Long ago, erect trees with roots and at times with branches attached, were observed in the Coal Measures. Some geologists were convinced that the existence of these trees was proof that coal beds were formed *in situ*. The force of this argument seems to be recognized by some of those who favor the doctrine of origin by transport, for, in later years, every reported discovery of trees or forest buried *in situ* has been met with incredulity or worse. The writer does not share in the opinion that the presence of trees buried *in loco natali* is of serious import as an argument, directly, either for or against any hypothesis respecting the mode of coal bed formation; but, in this, he apparently differs from so many geologists, that it may be well to supplement the references to buried swamps by some notes upon buried forests.

Russell's[139] description of conditions on the Yahtse river of Alaska relates that the stream, issuing as a swift current from beneath the glacier, has invaded a forest at the east and has surrounded the trees with sand and gravel to a depth of many feet. Some of the dead trunks, still retaining their branches, project above the mass, but the greater part of them have been broken off and buried in the deposit. Other streams, east from the Yahtse, have invaded forests, as is indicated by dead trees standing along their borders. Where the deposit is deepest, the trees have already disappeared and the forest has been replaced with sand flats. The decaying trunks are broken off by the wind and are buried in prostrate position. This deposit, consolidated, would resemble closely a Coal Measures conglomerate.

The submerged forest on the Columbia river of Oregon was observed first by Lewis and Clark and it was examined almost 30 years afterwards by Wilkes; but Newberry[140] was the first to study it in detail. He found the river bordered at intervals on each side by the erect but partially decayed stumps of trees, which project in considerable numbers above the surface of the water. These stumps belong to the Douglas spruce, which still covers the mountain slopes. The dam at the Cascades is a conglomerate, penetrated by threads of silica, often filling cavities with agate and chalcedony. It contains many trunks of trees, some of them merely carbonized, others silicified, while still others show both conditions. These trunks have a microscopic structure closely resembling that of the Douglas spruce. The writer may add that similar conditions exist in the buried forest near Salem on the Willamette river in the same state.

Along the whole Atlantic coast from Nova Scotia to Florida, one finds sunken forests now buried under peat or sediments. Dawson described one seen on the coast of Nova Scotia at 25 to 30 feet below high tide, where the stumps were rooted in material, having

---

[139] I. C. Russell, "Second Expedition to Mount St. Elias," Thirteenth Ann. Rep. U. S. Geol. Survey, 1893. Pt. I., p. 14, Pl. XII.

[140] J. S. Newberry, Pacific Railroad Explorations, Vol. VI., 1856, "Geological Report," p. 56.

all the characteristics of a forest soil, and were scattered irregularly as in an open wood. E. Hitchcock asserted that buried forests are numerous along the coast of Massachusetts; cedar, oak, maple and beech trees are found in the harbor of Nantucket, some erect, others prostrate and all of them surrounded by an imperfect peat. This forest is buried under 4 feet of sand. Cook[141] has described many buried forests in New Jersey, the most interesting being those now concealed under the tidal marshes. At one locality, a ditch was digged to drain some large tidal ponds; it exposed nothing but mud and grass roots; the outrush of water at ebb tide widened this narrow drain to 70 feet and scoured the bottom, which proved to be thickly set with pine, white cedar and gum stumps, standing upright and giving every indication that they were where they had grown.

Tuomey[142] has described an area of tidal marsh, which is covered with live-oak trees, some standing, but most of them prostrate. These are certainly not where they grew and it is equally evident that they have not been transported. Originally, this mud flat, now littered with shells of oysters and mussels, was covered with sand hills, of which some remain. During storms, waves broke over the peninsula, washed away the sand hills and left the trees, some of which remain standing because supported by their broad roots. At another locality, a great white cedar swamp shows living trees, but, toward the river, the trees are dead and the continuation of the mass under the river shows stumps in place. Encroachment of salt water killed the dense undergrowth of the swamp—decomposition of the exposed peat advanced and the trees broke off at the "air line." He refers to many places where the saltwater invasion and subsequent change in the swamp material caused destruction of the white cedar or cypress forest; sediment covered the stumps and another growth followed.

Agassiz,[143] observed a submerged forest at the mouth of the Igurapi Grande, which clearly belongs to the recent epoch.

---

[141] G. H. Cook, "Geology of New Jersey," 1868, pp. 350, 352, 354, 355, 360.

[142] M. Tuomey, "Report on the Geology of South Carolina," Columbia, 1848, pp. 194–200.

[143] L. Agassiz, in "A Journey to Brazil," Boston, 1868, pp. 434, 435.

"Evidently this forest grew on one of those marshy lands constantly inundated, for between the stumps is accumulated the loose felt-like peat characteristic of such grounds and containing about as much mud as vegetable matter. Such a marshy forest, with the stumps of the trees still standing erect on the peat, has been laid bare on both sides of the Igurapi Grande by the encroachments of the ocean. That this is the work of the sea is undeniable, for all the little depressions and indentations of the peat are filled with sea sand and a ridge of tidal sand divides it from the forest still standing beyond. Nor is this all. At Vigia, immediately opposite to Souré, on the continental side of the Para river, just where it meets the sea, we have the counterpart of this submerged forest. Another peat bog, with the stumps of innumerable trees standing in it and encroached upon in the same way by tidal sand, is exposed here also."

Forests buried during the recent epoch are such familiar and commonplace features that further reference to them is unnecessary.

Forest beds of Quaternary age have been reported by observers in many parts of the world. Reference has been made already to the great forest bed of southwestern Indiana, buried under 60 to 120 feet of later glacial material. McGee[144] has described a forest bed, which divides the glacial deposits in northeastern Iowa. It was much disturbed during a later advance of the ice. Accumulations of logs, stems, grasses and peaty soils occur at many horizons in both the upper and the lower till, but they are in largest volume and least disturbed condition at the junction of the two drift sheets. The distribution is related to that of the upper till. Where the glaciation was most energetic, the deposit is absent; where less energetic, it is present but broken up badly; toward the eastern part of the area, the disturbance decreases and the deposit is found in normal condition with everything *in situ*. There one finds the peaty soil with stumps and roots all evidently in place.

Quaternary forest beds are many in Europe. It suffices to quote from J. Geikie,[145] who has described the condition in Great Britain.

"The broad facts then are these: at a depth from the surface, varying from 20 to 60 or 70 feet, occurs a layer of peaty matter enclosing and covering forest trees, the stools of which are often rooted in an ancient soil. Above this buried land surface appear lacustrine, or estuarine or, as

---

[144] W J McGee, "The Pleistocene History of Northeastern Iowa." Eleventh Ann. Rep. U. S. Geol. Survey, 1891, Pt. I., pp. 199–577. Citations from pp. 486–496.

[145] J. Geikie, "The Great Ice Age," 3d Ed., p. 405.

the case may be, marine deposits. Next comes a second forest layer, overlaid by similar accumulations. It is the second forest bed, which is so frequently exposed upon the present fore shores."

In succeeding pages this author gives detailed evidence respecting the stratigraphic relations of forest beds at the different localities.

Passing from the Quaternary to the Tertiary, one finds less frequent notices of buried forests, owing, of course, to lack of exposures. Lyell,[146] after describing the buried cypress swamps of the Mississippi delta, mentions the Tertiary deposits at Port Hudson, which had been seen by Bartram and, at a later date, described by Carpenter. Bartram observed that the erect cypress stumps seemed to be rotted off at 2 or 3 feet above the spread of the roots and that their trunks, limbs, etc., lie in all directions about them. When Lyell visited the locality, the water was too high to permit study of the lowest part of the section and he gave Carpenter's statements respecting it. At the bottom of the bluff, is a buried cypress swamp, containing sticks, leaves and fruits in horizontal laminæ, with filmy layers of clay interposed. With these are great numbers of erect stumps of the large cypress, sending roots into the clay below. At 12 feet higher is a second deposit, 4 feet thick, consisting of logs and branches, half converted into lignite, along with erect stumps. Above this are more than 50 feet of clays, containing two layers of vegetable matter.

Hilgard[147] gives some details respecting what is evidently the lower Port Hudson bed as seen between that place and Fontania. The section in the bluff is

		Feet.
1.	Yellow loam	8 to 10
2.	White and yellow hardpan	18
3.	Orange and yellow sand	8 to 15
4.	Greenish or bluish clay	7
5.	White silt or hardpan	18
6.	Green clay with calcareous and ferruginous concretions, sticks and leaf impresions	30
7.	Brown muck or blue clay with cypress stumps	3 to 4

---

[146] C. Lyell, "A Second Visit to the United States," etc., Vol. II., pp. 134, 178, 179, 180, 192, 272, 273.

[147] E. W. Hilgard, "On the Geology of Lower Louisiana," Smithson. Contrib. No. 248, 1872, pp. 5–7, 9, 11.

"These stumps evidently represent three or four successive generations, growing at higher levels as the surface of the swamp was raised by deposition." Some of them are large and the wood is so hard that it is difficult to detach a piece with the hatchet. No. 5, in some places, is a river alluvium and at times resembles a sandbar. It frequently contains great quantities of driftwood.

The cypress stumps in No. 7 are well preserved and hard, but the driftwood in No. 5 is soft and spongy. When water-soaked and resting on the ground it is visibly flattened by its own weight; one stroke with the hatchet will sever a trunk, 20 inches or more in diameter. But if this soaked material be exposed to continuous sunshine, it not only loses water but also contracts into hard shining lignite, with conchoidal fracture and exhibiting to the eye scarcely a trace of the original structure. A trunk, 6 or 8 inches in diameter, when thus dried, forms a contorted coal layer not more than half an inch thick. The exposed portion of a trunk may be transformed in this way, while the portion, remaining embedded, retains the original features. These changes are very like those seen in the lignite at Putznach as described by Bischof; there is evidently a change from soluble to insoluble in some constituent of the trunk. Hilgard[148] had traced the deposit underlying the Orange sands through a great area in southern Mississippi and the features seem to be the same throughout. It "cannot be better described than as the soil of a cypress swamp, with its muck, fallen trunks, stumps, roots and knees. Of these there are evidently several generations, separated by more clayey layers of muck."

Eldridge[149] mentions a deposit of Eocene lignite in Alaska containing 10 to 15 beds varying in thickness from 6 inches to 6 feet. The ash is from 1.85 to 10.68 per cent. The lignite of these beds resembles a mass of carbonized wood. Stumps, 1 to 2 feet in diameter, are common, standing vertical to the bedding. Their appearance as well as the abundance of slivers and other carbonized

---

[148] E. W. Hilgard, "Report on Geology and Agriculture of the State of Mississippi," Jackson, 1860, pp. 152, 153, 155.

[149] G. H. Eldridge, "Reconnaissance in the Sushitna Basin, Alaska," Twentieth Ann. Rep. U. S. Geol. Surv., 1900, Pt. VII., pp. 21–23.

material suggests that these coal beds originated in a mass of decayed swamp vegetation. Locally, portions of the mass have lost the woody structure and resemble the higher grades of lignite, shading into bituminous coal. But, as a whole, this coal is in its youth and Eldridge thinks it doubtful if a younger example of coal can be found—peat excepted.

Darwin[150] saw in Chili a petrified forest in Tertiary rocks. Eleven trunks were silicified and 30 to 40 were converted into coarsely crystallized white calcareous spar. They had been broken off abruptly, the vertical stumps projecting a few feet above the ground. They were from 3 to 5 feet in circumference. "The volcanic sandstone, in which the trees were embedded and from the lower part of which they must have sprung, had accumulated in thick layers around their trunks; and the stone yet retained the impression of their bark."

The Miocene brown coal deposit at Gr. Raschen near Senftenberg has been referred to on a previous page: Potonié's[151] description is that of a buried forest closely resembling those of New Jersey. It is very similar to the buried cypress swamps and forests of the southern United States, for *Taxodium distichum* is the dominant tree. As in the white cedar and cypress swamps, one finds in this brown coal deposit, 10 meters thick, successive generations of trees. The fuel is mined in open quarry and Potonié's plate shows the erect stumps distributed on the surfaces of several benches as they stood in the old forest, while the walls of the benches exhibit prostrate trunks in the intervening spaces, precisely as one sees them now on the surfaces of the forested swamps in America. These stumps, one third of a meter to nearly 4 meters in diameter, are, like those described by Cook and others, rooted in the peat, now converted into brown coal of excellent quality, as good as that which will come from the Dennisville peat in New Jersey.

There are few recorded observations of buried forests in the Mesozoic rocks; in very great part, those rocks were marine: The

---

[150] C. Darwin, "Journal of Researches," New York, 1846, Vol. II., pp. 85.

[151] H. Potonié, "Ueber Autochthonie von Carbonkohlen-Flotzen und des Senftenberger Braunkholen-Flotzen," *Jahrb. k. preuss. geolog. Landesanstalt.*, 1895, Separate, pp. 19–24.

latest Cretaceous in the United States is mostly of freshwater origin and it contains many coal beds; but there is no positive evidence that buried forests exist. Long ago, the writer saw, in New Mexico, great numbers of stumps and trunks in a sandstone, apparently of this age, and the same deposit has been mentioned by others; but there is no evidence on record to show that the stumps are *in situ*. Lyell was convinced that he saw vertical stems of *Equisetites* in place at a locality in the Triassic field near Richmond, in Virginia, but his observations are not sufficiently in detail to justify one in accepting them as evidence. It has been suggested that slender stems such as those of *Equisetum* or *Calamites* could not stand, while a sandstone accumulated around them; but the suggestion is without basis. The writer has seen slender canes on the Gulf shore of the Mississippi delta, which had been killed many years before by an invasion of salt water; but they were still erect, though sediment had accumulated around them to the thickness of several feet.

The "dirt bed" of the isle of Portland, belonging to the Upper Jurassic, was described long ago by Mantell.[152] The uppermost Oolite stratum is a layer, one foot thick, of very dark friable loam, which seems to have been a bed of vegetable mould. It contains a large proportion of earthy lignite and also, like the modern soil of the island, waterworn pebbles and stones. This is the "dirt bed" of the quarrymen and upon it are branches and stems of conifers and plants allied to *Cycas* and *Zamia*. Many of the trees and plants stand erect as if petrified while growing undisturbed in their native forests. Their roots extend into the "dirt bed" and their trunks into the superincumbent limestone. At the time of Mantell's visit, a large area had been exposed by stripping:

> "Some of the trunks were surrounded by a conical mound of calcareous earth, which had evidently, when in the state of mud, accumulated around the stems and roots. The upright trunks were in general a few feet apart and but 3 or 4 feet high; they were broken or splintered at the top, as if the trees had been snapped or wrenched off at a short distance from the ground. Some were 2 feet in diameter, and the united fragments of the prostrate trunks indicated a total length of between 30 and 40 feet. In many examples, portions of branches remained attached to the stems."

---

[152] G. A. Mantell, "Geological Excursions Around the Isle of Wight," 3d Ed., London, 1854, pp. 287, 288.

Green,[153] visiting the locality some years afterward, remarked that the conditions recall those in interglacial buried forests of Great Britain; for the "brashy" soil, containing the stools of large trees, with here and there prostrate trunks, underlies a limestone carrying estuarine fossils. Other "dirt beds" appear occasionally, showing that the condition was repeated at some localities.

Passing to the Palæozoic, one finds many references to forests and trees buried in place, for excavations and explorations are extensive and the localities, unlike most of those in the Mesozoic, are in regions where scientific observers abound.

Al. Brongniart[154] saw at the mine du Treuil, near Saint-Etienne, a sandy bed, 10 to 13 feet thick, containing "a true fossil forest of monocotyledonous vegetables, resembling bamboo, or a huge *Equisetum,* as it were, petrified in place." These are erect. There were two types of stems; one cylindrical, jointed, striated parallel to their edges and the cavity filled with rock like that which surrounds them. The rarer forms are hollow cylindrical stems, diverging at the lower end "after the manner of a root but without presenting any ramification." Gruner[155] notes the existence of another forest at the same mine, but much lower in the section. The trees are *Syringodendron* and the roots rest on the coal. Brongniart refers to other localities, where vertical stems had been seen, and he cites Charpentier, who explained one rather notable case as due to landslides. Support for this conception was found in the débâcle of Lake Bagne, during which great trees were carried down with the mass and deposited in the original vertical condition position on the plain of Martigny. But Brongniart maintained that such occurrences must be rare, whereas vertical stems are found at many localities. At Treuil, as well as near Saarbruck, one finds not merely a single large trunk but many—a forest of slender stems, which have preserved parallelism among themselves. It is perhaps more difficult to conceive that sandy rock could envelop them after removal without destroying

---

[153] A. H. Green, "Geology," Part I., London, 1882, pp. 252, 253.

[154] Alex. Brongniart, "On Fossil Vegetables Traversing the Beds of the Coal Measures," *Ann. des Mines,* 1821. Trans. by H. de la Beche in "A Collection of Geological Memoirs," 1836, pp. 210, 216.

[155] L. Gruner, "Bassin houiller de la Loire," 1882, p. 226.

them, than to conceive that the deposit was made between them where they grew and were firmly rooted.

The discovery, near Manchester, England, of erect stumps, led several members of the London Geological Society to visit the locality. Hawkshaw[156] in 1839 and 1840 described five erect stumps and he was firmly convinced that they were in the place of growth. Bowman[157] in discussing the same occurrence, asserted that the loss of roots in the Manchester specimens was due to a process of fermentation. He combatted the notion that floated trees would remain erect, maintaining that, when they ceased to float, they would turn over. Several years afterward, Beckett and Sparrow[158] discovered some erect stumps near Wolverhampton, England. Beckett removed the coal attached to one of the trees. The stump was perfectly "bitumenized" but broken off at about 2 inches above the top of the coal, the inner portion being hollowed out to about the level of the coal. The stem was not flattened; it was approximately 4 feet in circumference and the roots spread out in a broad mass. The trunk and roots were covered with one half inch of bark, converted into brighter, more compact coal than that of the interior which was a mixture of coal and shale. The coal bed is about 5 inches thick. A few years later, Jukes[159] visited this locality with Beckett and, in writing about the stumps, he conceded that "they certainly looked as if they had grown there, and perhaps they may have done so, but even so, it by no means settles the question" [of origin of coal beds].

Beckett expressed no opinion respecting the original relations of the forest, but his paper is followed directly by Ick's[160] description, which is more in detail. The surface of the coal had been exposed by stripping in a rudely triangular space of about 2,700 square yards. Upward of 70 stumps were seen on this terrace, some of them more

---

[156] J. Hawkshaw, *Proc. London Geol. Soc.*, Vol. III., pp. 140, 269.

[157] J. E. Bowman, *Ibid.*, pp. 270, 271, 274.

[158] H. Beckett, *Quart. Journ. Geol. Soc.*, Vol. I., 1845, pp. 41, 42.

[159] J. B. Jukes, "The South Staffordshire Coal-field," 2d Ed., 1859, p. 201, footnote.

[160] W. Ick, "A Description of Numerous Fossil Dicotyledonous Trees at Parkfield Colliery near Bilston," *Ibid.*, pp. 43–45.

than 8 feet in circumference, all broken off close to the coal, while the prostrate trunks lie across each other in every direction. These trunks, 15 to 30 feet long, are invariably flattened to the thickness of one or two inches, but the bark is distinct on both sides. The bark is well preserved on the stumps, converted into bright coal, while the interior or woody part is dead looking, with dull luster like cannel. The stumps seldom rise above the surface. In some cases the diverging roots can be followed for nearly a yard, but they cannot be traced into the underlying shale. In some cases, *Calamites* are crowded between the trunks; *Lepidodendron* and *Lepidostrobi* are abundant on the surface, while among them one finds occasional remains of fishes. A noteworthy feature is that there are three coal beds within a vertical space of 12 feet, each of which shows on its surface the remains of an ancient forest—and the same beds are exposed a mile away. Beckett says that the coal, when "broken with the grain," shows faint impressions of *Calamites* and reed-like plants. Ick recognizes that "the position of the trees in each bed of coal seems almost to preclude all doubt of their having grown and perished on the spot where their remains are now found, and the roots are apparently fixed in the coal and shale, which was the original humus in which they grew."

Binney[161] described the great *Sigillaria* stump, discovered at 7 miles east from Manchester and now in the museum of Owens college. The stump is filled with dark-colored fireclay but the roots with a different material. The dark fireclay floor was penetrated to about 3 feet by the stem and roots, the latter being, in part, directed upward.

De la Beche[162] remarks that actual observations of rooted stems are comparatively few because exposures are few. He and W. E. Logan saw many vertical stems in a sandstone at a Welsh colliery. The directly underlying shale contained ferns and leaves of other plants distributed "around in the same manner as leaves and other parts of plants may be dispersed around stems of trees in muddy

---

[161] E. W. Binney, "Description of the Dirkenfield *Sigillaria*," *Quart. Journ. Geol. Soc.*, Vol. II., 1846, p. 390.

[162] H. T. de la Beche, "The Geological Observer," Philadelphia, 1851, pp. 482–485, 497.

places at the present day." The sandstone laminæ, by their arrangement, suggest the washing up of sand around stems in shallow water with small waves. This is shown more clearly at a locality in the Newcastle district, where one can determine the direction whence the current came by position of laminæ marking eddies behind the stems. Prostrate stems, often of same species with the vertical stumps, recall the prostrate trees among stumps in "submarine or sunken forests."

Dawson[163] first visited the South Joggins region in 1852, accompanied by Lyell. Somewhat later, he studied the section in great detail and gave his results in a series of memoirs published by the London Geological Society; but the final discussion appeared in the second edition of his Acadian Geology. Seventy coal horizons, some of them merely "fossil dirt beds," were seen in a vertical section of 4,700 feet and besides these there are many horizons at which rooted stumps were seen. Drifted trunks were observed in the sandstones, but those are neglected here, reference being made only to such remains as were associated with Stigmarian underclays.

Erect stumps were seen in the thin shale roof of Coal 13. In the interval of 38 feet between Coals 16 and 17 are several Stigmarian clays, one of which supports large stumps of *Sigillaria* with plant remains about their foot; the red shale roof of Coal 19 shows an erect *Sigillaria,* while erect *Calamites* stems are present over Coal 21 and a Stigmarian soil at some distance below Coal 22 bears a number of erect *Sigillaria* stumps. Division IV. shows erect stems of *Sigillaria, Lepidodendron* and *Calamites* at 44 horizons in a vertical section of 2,539 feet; several of the underclays, bearing erect stumps, underlie thin coal beds and, in at least one case, Coal 15, the erect stumps are associated with rain marks and footprints, clear evidence of sub-aerial position. At one horizon, the stumps yielded three species of batrachians with land shells and insects; those stumps are rooted in coaly shale forming the roof of a coal bed. "A coaly stump and an irregular layer of mineral charcoal, arising apparently from the decay of similar stumps" were seen in Coal 33*a,* while above that bed in a reddish shale is "a patch of gray sand-

---

[163] J. W. Dawson, "Acadian Geology," 2d Ed., London, 1868, pp. 150–179.

stone, interlaced with *Stigmaria* roots, as if the sand had been prevented from drifting away by a tree or stump." The Millstone Grit, in three divisions and somewhat less than 6,000 feet thick, shows erect *Sigillariæ* in the lower portion, but most of the stems occurring in the sandstones are clearly driftwood.

One must keep in remembrance that Dawson's observations were made on the outcropping face of the beds along the coast; one may only conjecture what might be seen if some of the old soils were stripped as was the coal at Parkfield colliery.

Robb[164] described the rooted stump of *Sigillaria,* seen by him in the roof of a coal mine. The roots cross the slope, which is 11 feet wide; the conditions are shown well in the plate accompanying his report. He observed many *Sigillaria* stumps with their attached roots reaching into the coal seams. He notes one case, where a coal parting contains the roots of an erect tree, "which had apparently forced the layers asunder, 6 or 8 inches, for several feet from the extremities of the roots, beyond which the layers of coal unite again." In another, "where a large upright stem appears rooted in a coal seam, the latter seems to have been actually bent down by the superincumbent weight and, at a little distance, to have resumed its normal attitude."

Gosselet studied[165] the occurrence of erect stems at various levels in a vertical section and discussed their bearing upon the formation of coal beds. At Lens, there are three coal horizons within a vertical distance of 42 meters—Alfred, Leonard and Louise, with thickness respectively of 1.4, 1.6 and 0.6 meter. In the one meter thick shale under the Alfred, overlying an irregular *passée,* he saw two trunks, one resting on the *passée,* with the underlying coal slightly depressed, while, above, it terminates abruptly in a faux-mur, 5 centimeters thick, in direct contact with the coal. No roots could be traced. Five trunks were seen in the Leonard; one evidently had been floated in and a second was too indefinite for determina-

---

[164] C. Robb, Geol. Surv. Canada, Rep. Progress, 1874–5, pp. 196, 203, 204, 235, 237.

[165] J. Gosselet, "Note sur les troncs d'arbres verticaux dans le terrain houiller de Lens," *Ann. Soc. Geol. du Nord.,* Vol. XXIII., 1895, pp. 174, 175, 177–179, 181.

tion. Of the other three, two were implanted in a thin mur-like deposit covering the coal; the roots of one, a *Sigillaria,* spread out in the clay, but the roots of the other could not be traced. The roots of the third, in the coal, could not be recognized as *Stigmaria,* but they extended horizontally as clay masses covered with coal. The roots had been filled with sediment. Eight stems were seen in the Louise. Three rose directly from the underlying shale and crossed the mur, which is 60 centimeters thick; one was cut off abruptly at the coal and the others were broken off just before reaching it. The remaining five are in the roof. One is indefinite, but the others expand at the base and their rootlets are put forth into the shale. These erect trees, throughout, were *in situ;* all were vertical to the bedding. If they had been transported, they would have been inclined in direction of the current. Transported trunks were seen at various horizons but, in the cases described, the trunks were fixed in place by their roots, wherever the roots were seen. This Lens locality is in the great Westphalia-France-Belgium field, a paralic area.

Gosselet refers to conditions in the Banc des Roseaux at Commentry, where trunks are seen arranged in all directions, vertical, inclined, prostrate, and he compares them with those resulting from ravages of a hurricane in the forest of Mormal. There, many of the trees were prostrated; some, held by their roots, were inclined; while a small number remained erect—the conditions bearing remarkable resemblance to those observed at Commentry. His conclusion is that, where one sees the mur rich in rootlets of *Stigmaria,* he may regard it as a soil in which trees spread their roots. If the tree does not rise above the mur, it is because it has been destroyed by carbonization to furnish its elements, in part at least, to the coal bed. When the trunk is cut off sharply at coal or mur, it may be that the deposits were made so slowly that the trunk rotted off at the water-surface. He quotes Fayol as showing that at times one may prove the presence of erect trunks in the coal itself, but usually they are fused with the mass.

In this connection, it is well to recall the fact that Potonié[166]

---

[166] H. Potonié, "Die Entstehung der Steinkohle," etc., 1910, pp. 134–136.

found frequent occurrence of *Stigmaria in situ* at Commentry. One notable discovery was that of a stump, whose roots spread out in an area of 6 meters diameter and retained their minute appendages. According to Renault, the branches extended farther but they could not be followed. Fig. 46, copied from Renault's description, justifies Potonié's remark that, if this be a transported tree, one must believe that it and the fine mud enclosing it had been transported together and deposited in the original position.

Schmitz[167] examined 33 erect stumps exposed in the roof of the Grande Veine of the Liége basin. The coaly crust, sometimes one centimeter thick, and the scars suggest that the plants are *Sigillaria.* The stumps are in a space of 2 by 95 meters, giving for each plant 5.6 square meters, a condition favorable to the belief that they are *in loco natali.* But he found that the trunks are all cut off at the coal bed; most of them show the enlargement belonging near the roots, so that one cannot suppose that the trees extended downward through the coal to the mur. On the other hand, the transition from coal to sterile rock above is barely one centimeter of coaly clay, so that they could not have been rooted in the toit. The laminæ of this faux-toit contain many impressions of twigs of lycopods and *Equisetites.* Four of these pass under the bases of four erect trunks. This led Schmitz to think it impossible that the trunks were *in loco natali;* for if those four were not, there is no reason to suppose that the others were. To explain the condition, one must invoke transport. But, in a later paper to be considered in another connection, he gives the results of a more detailed study, which led him to recognize that the abrupt cutting off at the base was due to slips, which explained the presence of plant impressions under the ends of the free trunks.

Grand' Eury[168] summed up the results of his long study in a memoir presented at the Paris meeting of the Geological Congress,

---

[167] G. Schmitz, "Un banc à troncs-debout aux charbonnages du Grand-Bac," *Bull. Acad. Roy. de Belgique,* 3me Ser., Vol. XXXI., 1896, pp. 261–264.

[168] C. Grand' Eury, "Sur les tiges debout, les souches enracinées, des forêts et sous-sols des végétations fossiles et sur le mode et le mécanisme de formation de couches de houille du bassin de la Loire," *C. R. Cong. Geol. Intern.,* 1900, Vol. I., pp. 523–530.

drawing his illustrations mainly from conditions in the Loire basin. He exhibited twelve charts showing rooted trees and stumps discovered near Saint-Etienne during the preceding decade. Trees and stumps with roots attached were found belonging to *Stigmaria, Syringodendron, Stigmariopsis, Sigillaria, Calamites, Calamodendron, Psaronius, Cordaites* and other forms. In several cases, the leaves still remained attached. The arrangement of the roots depended somewhat on the soil in which they grew. Many times the more yielding soils permitted the roots to grow downward while in clays they tend to spread horizontally. Roots of *Stigmaria*, usually, those of other plants, frequently, are interlaced in such manner as to leave no room for doubting that they are *in loco natali*. The soils of vegetation are distinct, for the roots are woody, herbaceous, or of several kinds, occurring in groups or singly, often interlaced, sometimes spaced but never scattered. They are therefore in place. Where there have been successive generations, the roots of the newer generations sometimes penetrate the stumps of their predecessors and in many cases pierce impressions of plants lying in the shale, through which they pass. The secondary roots of several types are thoroughly distinct at varying levels, while the creeping rhizomas at the base still remain attached to the stem; and one often finds buried at the foot of rooted trees the branches, leaves and fructifications which were detached during their growth.

Grand' Eury's conclusion is that Carboniferous plants were arborescent marsh forms, living as those in the Dismal Swamp, the foot and adventive roots in the water, with the stock and rhizomas creeping on the bottom. They could live either on the area of increasing deposit or in stagnant water. The fossil forests have no continuity; they disappear in all directions, often being reduced to mere groves.

It is unnecessary to give further illustration. One desiring to pursue the matter will find in Goeppert's "Prize Essay" a full statement of all information available at that time for eastern Germany, with full discussion. His studies, in some respects, are as interesting as those by Grand' Eury. Lyell, R. Owen, Lesquereux and Newberry have given examples for the United States.

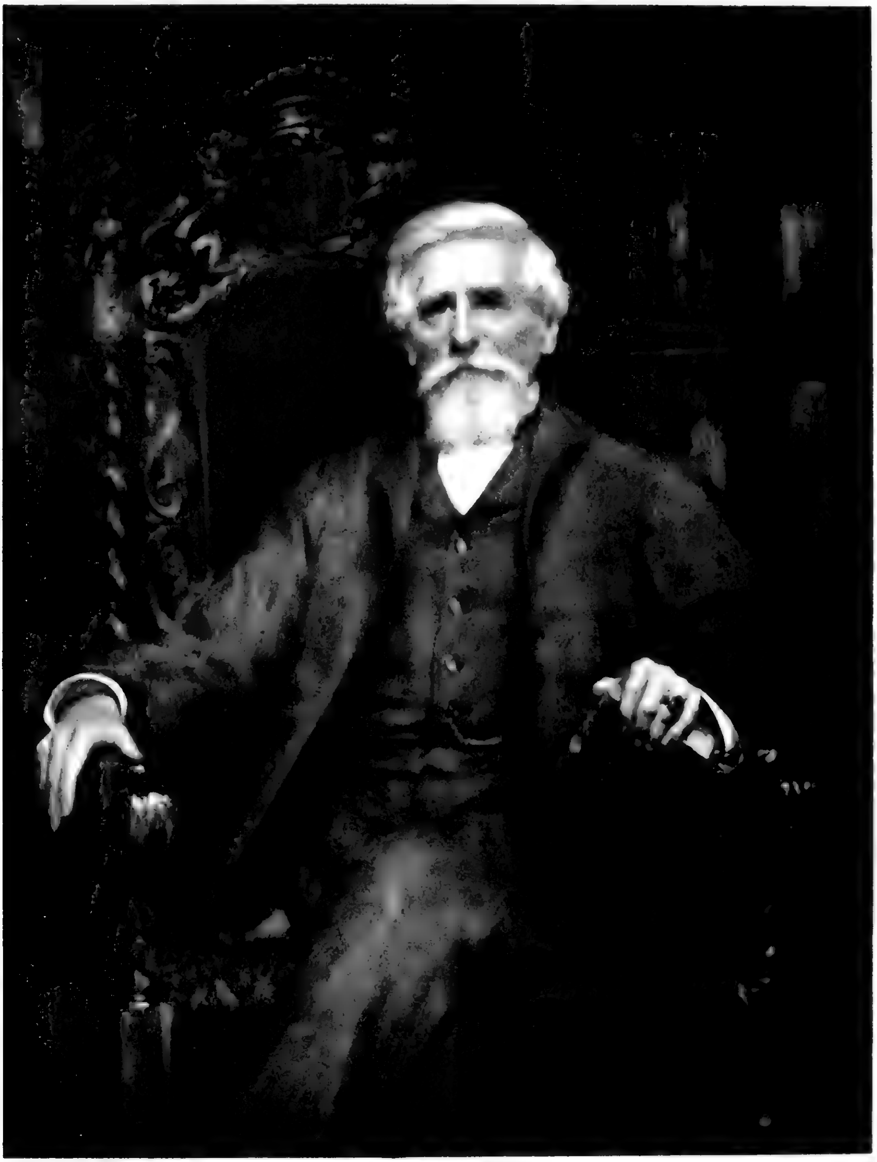
The occurrence of drifted logs and clumps of vegetation is a phenomenon as familiar as that of buried forests; indeed, in the nature of the case, it is more familiar, as coarse rocks are more widely spread than are the coaly deposits. The battered snags of the Missouri-Mississippi and the logs scattered through the delta silts; the similar accumulations in tertiary deposits of the Missouri and Mackenzie; in the London Clay and on the New Siberia islands; the irregular pots of lignite in many places on the continent of Europe; the driftwood in our Newark formation; and the vast abundance of snags, logs and branches in sandstones of the Coal Measures in Europe and America; all bear witness, as do the buried forests, that conditions have undergone no material change since the closing epochs of the Palæozoic. These drifted materials are everywhere distinguishable from plants buried *in situ,* for they have been deprived of all tender parts; of the harder woods in Carboniferous times there are few traces except decorticated stems, casts of the interior, indeterminate forms grouped under *Knorria, Sternbergia* and some other names.

Conclusions.—It is strange that there should be such intense unwillingness to accept evidence in favor of the existence of ancient forests. Reasoning from existing conditions, one would have room for disappointment if such forests were not discovered in the older rocks; yet some authors seem to believe that one is chargeable with overcredulity if he regard buried stumps as rooted in place when they occur in the Coal Measures and his proof is demanded as emphatically as though he had asserted that man's normal position is with his head on the ground and his feet pointing skyward. The abrupt termination of stumps on the coal and the absence of roots are, for some, positive evidence that the trees are not *in loco natali,* though the condition is that which must come about in the cypress swamps of this day; the number of prostrate trunks predominates over that of erect stumps, and this is taken as evidence that all alike were transported; yet every great forested swamp shows that broken and overturned stems fall to be preserved in moist surrounding, while many stumps remain exposed to atmospheric action and, in large part, decay. The very presence of the stump itself is taken to be evidence that it was transported, because one cannot believe that it would resist decay long enough to permit accumulation about it; yet the condition is familiar, for even the slender canes of the Mississippi delta, killed by salt water invasion, remain standing after they have been surrounded by several feet of silt. The filling of stumps by sand or clay is regarded as evidence that the change occurred after complete entombment in the mass of transported material; yet Potonié has shown that stumps on the shores have been found with the decayed interior replaced with sand even into the roots.

Some authors have laid no little emphasis on the Martigny débâcle as showing that landslides may explain those buried forests, whose *in situ* appearance cannot be denied. But aside from the fact that landslides are wholly exceptional and for the most part of limited extent, one may not utilize them as an explanation, unless it be supposed that, during the Carboniferous, landslides could occur amid conditions which would make them impossible now. According to some authors, the great coal areas were level regions; according to others, they were water basins, surrounded by a vast expanse of level area, forested or swampy. Under such circumstances a landslide like that of Martigny or even like that on the lower Adige could affect only the far away border area. But, in any event, the evidence of a landslide would be unmistakable; there would be no room for conjecture. The rock of the slide would be different from that at the same horizon a little distance away; and there would be ample evidence of disturbance in the underlying rocks, produced by downrush upon the water-soaked materials; certainly evidence of the débâcle would not be wanting. But no such evidence has been reported from any locality; on the contrary, where detailed descriptions have been given, one finds that the bedding is undisturbed and the conformability is complete. Equally, the buried trees are not relics of floating islands such as those of the Amazon and Congo, for they are not associated with filled valleys, but stand in and on rock of the type prevailing at the horizon for long distances.

OBITUARY NOTICES OF MEMBERS DECEASED

a*



Henry C. Lea.

HENRY CHARLES LEA.

(*Read January 20, 1911.*)

INTRODUCTORY REMARKS.

By WILLIAM W. KEEN, M.D., LL.D.,

President of the American Philosophical Society.

Members of the American Philosophical Society, Members and Representatives of the Library Company of Philadelphia, of the University of Pennsylvania, of the Academy of Natural Sciences, and of the Historical Society of Pennsylvania, Ladies and Gentlemen:—

In the days of Julius Cæsar and during the wars which followed his assassination, "Triumvirate" was a word very familiar to Roman citizens. But whether applied to the first or the second triumvirate it had a sinister meaning. Our own city, however, for many years has had an illustrious triumvirate of men who have been eminent in literature, science and civic life, Horace Howard Furness, S. Weir Mitchell and Henry Charles Lea. No other American city could boast three names comparable to these.

When one of these three, and such a man as Henry Charles Lea has passed away, it is fitting that his associates and the community at large should halt for an hour in our busy life and pay a tribute to his character and achievements.

The American Philosophical Society, of which he was an honored member, therefore suggested to the four other public institutions named with which Mr. Lea was associated by membership, and which had benefited by his active interest and generous support, that a joint meeting in memory of Mr. Lea should be held. The idea was most cordially received and a speaker representing each of these societies will share in the proceedings of the evening.

In addition to these distinguished local representatives, His Excellency, the Right Hon. James Bryce, the British Ambassador, has come from Washington especially to do honor to the memory of his fellow historian and friend.

Through the generosity of Mr. Lea's family, two portraits, one of Mr. Henry C. Lea, and the other of his father, Mr. Isaac Lea, will be presented to the American Philosophical Society.

As an illustration of the thoroughness with which Mr. Lea prepared for his work, I may cite the following little incident:

While spending the winter of 1907–8 in Rome I saw in an antiquarian bookstore a catalogue of books on Witchcraft, a subject in which I knew Mr. Lea was deeply interested and of which, though he was then eighty-three years old, he contemplated writing a full account. I sent the catalogue to him—a list of seventy or eighty titles—some of them very rare, and offered to aid him in securing any which he might wish to purchase. In reply I received a letter of thanks, but he declined my proffered assistance for the very good reason that he "already had all of them in his library."

I have now the pleasure of introducing Edward P. Cheyney, Professor of European history in the University of Pennsylvania, and a co-worker with Mr. Lea, who will read a memoir on the Life and Works of Mr. Lea.

ON THE LIFE AND WORKS OF HENRY CHARLES LEA.

By EDWARD POTTS CHEYNEY.

It has been so short a time since Mr. Lea was moving among us—to so many of those who are here he is still almost a living presence—that it is well-nigh impossible to view his long life and to estimate his great work as a thing detached from us, completed, a part of the past. Especially may one who through his whole mature life has looked upon Mr. Lea with admiration as a scholar, with gratitude as a kindly adviser, critic and friend, and with constantly increasing appreciation as one of the world's great men, acknowledge the inadequacy of this sketch of his life and list of his achievements. Indeed in this city, in which Mr. Lea's whole life was passed, and in this company to whom his personality and much of his work were familiar, I shall frequently rather be bringing his career to remembrance than giving information concerning it.

Henry Charles Lea was born in Eighth Street above Spruce, Philadelphia, in the year 1825. His boyhood has left a few suggestive reminiscences. He remembered learning the letters of the Greek alphabet as a child of six at the bedside of a mother well-educated and strong in mind, however frail in body—the daughter of Mathew Carey, the sister of Henry C. Carey. The intellectual atmosphere into which he was born and in which he grew up is indicated also by the studies in natural history of his father, Isaac Lea, and by his own training under a private tutor. From this tutor, whose name was Eugenius Nulty, a scholar of an old and rigorous type, and a man of much individuality and force, he received an unusually thorough and effective drill in the ancient languages and other fundamentals. A short stay in 1832 at a school in Paris, where he was the only boy not a native of France, probably had something to do with his easy use of French, both as a spoken and a written language, during his later life. He remembered the French boys bringing to school bullets found in the streets after the Parisian rising that led to the dethronement of Charles X. It was a long memory that covered the history of France from the Bourbons to the thirty-eighth anniversary of the Third Republic.

A more characteristic reminiscence was that of his desire, as a boy of twelve or fourteen, for a copy of Anacreon in the Greek, which was unobtainable because of the necessity, in the shadow of the crisis of 1837, of so rigid an economy as to forbid the expenditure of fifteen cents for the cheapest copy procurable. In a series of visits to the Philadelphia Library he copied the whole of Anacreon, and thus possessed himself of the first of his collection of manuscripts—none the less accurate probably because it was made in the nineteenth and not in the ninth century. The publication in *Silliman's Journal* when he was a boy of thirteen of a paper on "Manganese and its Salts," the result of a period of study in a chemical laboratory, may serve as a reminder that his earliest training was as much in scientific as in classical lines; and also that his mind was of that type that must produce as well as acquire.

By 1843 boyhood was over. At the age of eighteen, a new period opened with his entrance into his father's publishing house, and thus commenced a business career which was to last for thirty-seven years, till his retirement in 1880. As a youth, during the next four years, he worked hard at business in the daytime and equally hard at his studies late at night and early in the morning. Few persons, I think, can look over the files of the magazines of the years from 1843 to 1846 and realize without astonishment that the sixteen or more long articles signed by Henry C. Lea were the work of a young business man of eighteen to twenty-one, regularly occupied during the long working hours of that period. He was fulfilling two apprenticeships at the same time, one to the publishing business, the other to literature.

It is curious to see the conflict of interests in the latter of these fields between science and the humanities. In May, 1843, he published in the *Transactions of the American Philosophical Society* a paper on "Some New Shells from Petersburg, Va.," and in August of the same year in *The Knickerbocker* of New York an article on "Greek Epitaphs and Inscriptions." In September, 1844, in a southern journal is to be found a critical article by him on Leigh

Hunt; two months later in a journal of natural history, a description of "Certain New Species of Marine Shells." But the literary gradually predominated over the scientific. In the *Southern Literary Messenger* of Richmond, Va., in the year 1845 and early in 1846, he published a series of six articles under the general heading "Remarks on Various Late Poets." These are critical studies and appreciations of Miss Barrett, long before she became Mrs. Browning; of Miss Landon, while she was still disguised under the initials L. E. L.; of Tennyson, then publishing his earlier poems; of Eliza Cook, and several others. Interspersed with these in the same and other journals, are reviews and articles with many quotations and translations on "The Greek Symposium and its Materials," "Anacreon," "The Imagination and Fancy of Leigh Hunt," the Latin poet "Festus," and "Ménage," the poet of the French renaissance.

To such activity there is usually but one end, and to Mr. Lea it came in the year 1847, when a very serious breakdown in his health put an end for a while to all efforts except those for its restoration. Recuperation, travel, marriage, hard and well-remunerated mercantile work, rather than study and writing, filled in the remaining years of early manhood.

With improving health and increasing strength began what may be considered a third period, marked by many activities, including a resumption of written work, which had now been laid aside for more than ten years. In the *North American Review* of January, 1859, appeared what was ostensibly a review by Mr. Lea of a volume published by a German historian some years before. But the article was really not so much a review as a scholarly study of two forms of mediæval trial, compurgation and the wager of battle. An article on judicial ordeals appeared six months later, also in the form of a book review. These studies, revised and enlarged and with an additional chapter on torture as a form of trial, were gathered into a volume and issued in 1866 under the title "Superstition and Force." This was Mr. Lea's first book. Others followed on similar subjects. In 1867 appeared "The History of Sacerdotal Celibacy," and in 1869 "Studies in Church History." These works it will be observed are in a totally different field from that of his early literary and scientific writing. His entrance upon it seems to have been by the following route. In the desultory reading of his long period of ill health, he had taken up the French memoir writers and chroniclers. Following the bent of a naturally logical mind he had traced these writers backward in time from Commines to Monstrelet, from Froissart to the Chroniques de St. Denis and Villehardouin, till, in the Middle Ages, he had found himself in a new world, faced and surrounded by the conceptions of mediæval law and the mediæval church. Once having become interested in this body of institutions he was more and more impressed with its significance; he perceived the influence of mediæval jurisprudence and the mediæval church on modern times; and to this phase of the history of civilization he devoted the studies of the remainder of his life.

But Mr. Lea's studies were still only one of his interests. He was deeply moved by the questions raised by the Civil War and took an active part in the work of their solution. His labors in the national cause as well as those in the cause of municipal and civil service reform I must leave to more competent hands for description. I may, however, refer to his characteristic recourse to his pen to reach his objects. During the height of the dispute concerning slavery, when Bishop Hopkins's pamphlet, the "Bible View of Slavery," was issued and widely circulated as a defence of that institution on Biblical grounds, Mr. Lea wrote a parody, the "Bible View of Polygamy," showing that just as good a case might be made out from the Bible for the one institution as the other. Later, as a warning in our treatment of the American Indians, he wrote an article on the "Indian Policy of Spain," and on the outbreak of the Spanish war he published an article in the *Atlantic Monthly* of July, 1908, suggesting the deep-lying causes of the decadence of Spain. When we took up new responsibilities in the Philippines, he published a pamphlet called "The Dead Hand," utilizing the experience of Catholic governments to show the evils of the possession of land by ecclesiastical bodies. These are only a few examples of much more than a score of pamphlets, articles and open letters called forth by public crises in which Mr. Lea took a keen interest and to the solution of which he always felt that history had something to contribute.

His services in connection with the adoption of the first International Copyright Act had the special value that he was both an author and a publisher, and could look on the subject from two points of view. The first of his two long periods of service on the Board of Directors of the Philadelphia Library began early in this period, closing in 1879.

Before passing on to the characteristics of a later period it must be noted that it was during this part of his life that Mr. Lea laid the foundation of his library. So far as I am aware Mr. Lea stands alone among historical scholars in having done his work entirely in his own library, without recourse to any university or public collection; and this library was entirely his own creation. He had no nucleus for it, no aid in constructing it. No one who has ever entered upon the serious study of a new field will fail to estimate at something like its true value the difficulty of finding what materials for its study exist, and of obtaining access to them. In Mr. Lea's subject these difficulties existed in the highest degree. Few bibliographical guides then existed, no older or even contemporary scholar was at hand to give advice; his ideals of thoroughness were so uncompromising, and his desire for knowledge of the actualities of the past was so keen, that the merely obvious sources of information were quite inadequate to his desires. Much that he did was pioneer work, in which equipment must be constantly adjusted to newly discovered needs. Fortunately he had means which enabled him to purchase books freely wherever they might be found, and when the materials needed proved to exist only in a manuscript form, to have special copies of those made for his use. But the purchase price bears no very close relation to the value of a library collected with care, insight, discrimination, years of labor and watchfulness, and above all a constant realization of its character as an instrument adapted to a certain specific end. I may perhaps be pardoned if I say that Mr. Lea's bequest of his library to the University of Pennsylvania instead of either burying it in a great public collection, or allowing it to remain a purely private possession, or scattering it to the four winds, seems to me to place in additional clearness his conception of it as a working collection for purposes of research, to serve others in the future for the use to which he himself put it.

In 1865 Mr. Lea anticipated withdrawing from active business life, but the sudden death of his partner seemed to necessitate his remaining in control, and he continued a publisher for fifteen years more, until 1880, when he retired. This change was coincident with or shortly followed by a second breakdown, which made him almost an invalid for four years from 1880 to 1884. During this time his restlessly active mind could not refrain entirely from production, and he returned, for the moment at least, to the more purely literary interests of his earlier life. He had always been fond of making translations from various languages into English, and in his historical as well as his literary articles he had frequently given reproductions of old poems. He had also written verse from time to time, and occasionally exchanged such productions with at least one other well-known business man in Philadelphia. The war especially had led him to write several poems. Some forty of these, mostly translations from French, German, Italian, Spanish, Latin and Greek, he gathered together and published privately in 1882 under the title "Translations and other Rhymes." Whether from Mr. Lea's temperament, mood or physical condition, these poems look rather to the darker sides of life, its experiences and mysteries; as in his own verses closing

> The riddle who can read?
>   Who guess the reason why?
> We know but this indeed,
>   We are born, we grieve, we die.

With Mr. Lea's return to his usual health in 1884 began a long period, twenty-five years, of vigorous, laborious and yet serene life; old age it could hardly be called, although it carried him from his sixtieth year through his eighty-fourth. The many-sided interests of this period of life and activity, I can scarcely do more than name. A large fortune, watched over assiduously, and with very definite theories as to its investment and use; scarcely less well-marked abstention from certain forms of investment; an unwillingness to serve on responsible boards without performing the labor required by responsibility; discriminating and carefully considered philanthropic and charitable gifts—such were some of his most material interests. He gave quietly, and only after the object had fully commended itself to him. Such giving can hardly be described in detail and must be left in the main to the privacy of purely personal life. A few of the more notable of these benefactions, however, may be mentioned. In 1888 Mr. Lea erected an addition to the Philadelphia Library building, doubling the size of its reading rooms and bookstacks. In 1897 he erected important buildings for the Pennsylvania Epileptic Hospital and Colony Farm at Oakbourne, Pa., and subsequently paid for the erection of still other buildings, added to the endowment of the institution and contributed toward its maintenance. In 1889 he offered to pay for the construction of a building for the study and teaching of hygiene and bacteriology at the University. This building was erected in 1891 and dedicated February, 1892. His library, as is well known, he bequeathed to the University. In addition to these and other substantial gifts to the University Mr. Lea was one of that body of generous subscribers to its general expenses who have enabled it, without the large endowments of the other great Eastern universities, and without the munificent state appropriations of those in the West, to perform a work fully commensurate with theirs. For a number of years he subscribed liberally to this purpose and lightened the burden of the Provost by the kindness and readiness with which he gave.

Immersed in his literary work and devoting many hours a day to it, yet the courteous host of the Wistar parties, the cordial giver of time and advice to any who were preparing to entertain learned bodies in Philadelphia, the participant in all scholarly projects in the field of history, the ready writer of communications to the public journals on all large questions that arose, the persistent walker through Philadelphia streets, he was certainly not a recluse. His face and form were familiar to a large circle of acquaintances and he welcomed callers cordially. Among his more intimate characteristics during his later life may be mentioned his habit of spending some days or weeks each year at the Delaware Water Gap, in the spring when the fruit trees blossomed, and in the fall when the autumn leaves were in their glory. He was always interested in wild flowers, knew them and their haunts in the country and at the shore, where he spent the summer, and he even botanized among the flower stands of the old colored women along Market Street. He was fond of curios and semi-precious stones, attended Philadelphia sales and corresponded with dealers in such objects, and made an extensive collection of Japanese pottery and bronzes. He collected also engravings and books on art.

But it was primarily to the work of the historian that the labors of Mr. Lea were devoted during this long period of his later life; and it was as a scholarly historian that he won eminence and received recognition in full measure. Doctoral degrees from Giessen, Pennsylvania, Harvard and Princeton; fellowships or honorary or associate membership in more than thirty learned societies in Germany, Italy, Russia, England, Scotland and America; medals, congratulatory letters and private correspondence testify to this. He was long a Vice-president of the Historical Society of Pennsylvania. He was urged to serve as President of the American Historical Association soon after its organization, and finally consented in 1903. He could not preside, as its meeting was held that year in New Orleans, and he did not feel that he could make so long a journey from home, but his presidential address on "Ethical Values in History" made a profound impression at the time and was reprinted afterward.

These honors and this recognition were partly for his earlier work on the history of mediæval law, already described, but in the main an acknowledgment of the series of great works which during this period appeared in almost unbroken continuity. In 1888 appeared the "History of the Inquisition of the Middle Ages," in three volumes; two years afterward a volume of "Chapters from the Religious History of Spain Connected with the Inquisition"; two years after this he edited a "Formulary of the Papal Penitentiary"; in 1896 he published his "History of Auricular Confession and Indulgences," in three volumes. Then came a period of ten years in which only one volume, the "Moriscos of Spain," and some pamphlets and magazine articles were published. This long passage of time was due to the fact that he was preparing his largest and most important work, a "History of the Inquisition of Spain," published in four volumes in 1906 and 1907. In 1908 he published a "History of the Inquisition in the Spanish Dependencies," and was at work last year collecting material and making notes for a "History of Witchcraft," when he finally laid down his pen.

The late period of life to which this productivity extended is of much significance. Few historians have died under sixty; much historical writing has been done by men in their seventies; Ranke and Bancroft at ninety, Mommsen at eighty-six, and Mr. Lea at eighty-four are only some of the most conspicuous instances of a considerable number of scholars who with unclouded clearness of mind and unabated vigor of spirit were drawing on their long-accumulated store of knowledge and applying their slowly ripened judgment to the problems of history at more than eighty years of age.

The early part of Mr. Lea's life was contemporaneous with the beginnings of American historical production. The historical works of Irving, "Columbus" and the "Conquest of Granada," were published during Mr. Lea's earliest years. In 1834 appeared the first volume of Bancroft's "History of the United States." In 1837 Prescott began his historical career by the publication of "Ferdinand and Isabella." Parkman's first work, the "Conspiracy of Pontiac," was published in 1851, and the first volume of Motley's "Rise of the Dutch Republic" in 1856, when Mr. Lea was collecting material for his "Superstition and Force."

A marked difference, however, is to be noted between the historical work of these writers and that of Mr. Lea. Each of the five chose as a subject a period of time or a series of events or a group of personalities which possessed some well-defined dramatic character. The almost personal struggle, gigantic in significance, however limited in time and space, fought out in the Netherlands between William of Orange and Philip of Spain, awakened the sympathetic fire and was described by the literary grace of Motley. The romantic adventures of Cortez and Pizarro, and the scarcely less stirring narrative of events in Spain during the same period gave a subject of unexcelled interest to Prescott. Parkman from boyhood was attracted, as he tells us, by the picturesque surroundings and incidents of the struggle for the Northern continent between the Indian, the Frenchman and the Englishman. Bancroft selected the early and heroic period of our own national life, and Irving equally dramatic episodes. In contrast with these Mr. Lea chose a much earlier period of the world's history and a group of subjects during that period of which the elements are less emotional, more intellectual; in which the problem is rather to understand than to depict, rather to explain than to narrate. Whereas their periods were modern, he chose the middle ages; whereas they recounted principally events, he wrote principally on institutions. The mediæval conceptions of law; the organization, ideals, doctrines and practices of the mediæval church; the origin, development, connections and influence of the Inquisition, one of the most characteristic embodiments of the spirit of the mediæval church—such were the great problems he took up for solution. They were narratives, of course, that he wrote, as all history must be narration, but they were narratives not so much of incidents in the life of certain individual men as of incidents in the life of mankind. He was dealing not so much with occurrences—these served as illustrations only—as with the development of principles. In this more difficult and more philosophical conception of history Mr. Lea was a pioneer in America, and his choice was apparently made independently even of such European scholars as had preceded him in it.

Why he made this choice has long been a matter of interest to historical scholars. He himself could probably have told how rather than why he took this attitude toward history. The wind of human interest " bloweth where it listeth " and we seldom know just why we have become so deeply interested in some one particular field of knowledge or endeavor. But it is to be remembered that Mr. Lea's early surroundings and interests were largely in the field of natural science. The analogy between the history of institutions and the study of natural history is very close. There is the same subordination of the individual to the type, the same interest in logical classification, the same greater attention to observation than to exposition. It would seem entirely natural therefore that Mr. Lea, having become interested in the Middle Ages, would wish to understand and elucidate the rules and ideas of mediæval law and organized mediæval religion, rather than merely to narrate the story of external events during that period.

The same early interest in natural history, acting on a certain type of mind and strengthened by a business training, may be the clue to Mr. Lea's adoption of so distinctly scientific a method in his historical work. Scientific method is much the same to whatever department of knowledge it is applied. It is simply the direct method, going as immediately as possible to the phenomena which it is intended to observe; the objective method, treating the phenomena without subjective distortion or personal bias; the comparative method, treating individual examples and occurrences as material for classification and generalization; the rigorous method, using only facts that can be absolutely verified, or when this is impossible discriminating clearly the different degrees of certitude of facts. Allowing for certain difficulties in obtaining and interpreting the material with which the historian has to deal, no biologist, chemist or astronomer has been more true to these canons of scientific method than has Mr. Lea in his historical works.

There is one corollary of this attitude toward history, however, that Mr. Lea was not willing to accept. To most scientific historians it seems no more within their province to express ethical judgments on the men and institutions of the past, or to draw practical lessons for the present from them than it is part of the duty of any other scientific investigators. They deem their work done if they observe, explain, narrate. According to their view it is no more the duty of the historian to draw moral lessons than it is that of the geologist or of the botanist. Mr. Lea did not feel so. In the preface to his "History of the Inquisition of the Middle Ages," written in 1887, he said: "No serious historical work is worth the writing or the reading unless it conveys a moral. . . . I have not paused to moralize, but I have missed my aim if the events narrated are not so presented as to teach their appropriate lesson." His practice already alluded to of bringing his stores of historical knowledge to bear on present day questions in the form of occasional pamphlets or essays indicates the same belief, namely, that it is one of the duties of the historical student to provide moral or practical teaching for the community. Yet I am inclined to believe that the conception of the historian as also a moralist became less pronounced in Mr. Lea's mind as his life went on. In his "History of the Inquisition of Spain" his judgments of the church are less severe than in his earlier work on the "History of the Inquisition of the Middle Ages." His presidential address to the American Historical Association in 1903 was devoted to a vindication of Philip II. of Spain from many of the charges against him, on the ground that men and institutions must be judged by the moral standards of their own time, not ours. He speaks of Motley's condemnation in a certain case as "the language of a partisan and not of an historian," and declares that Lord Acton's famous appeal, "to suffer no man and no cause to escape the undying penalty which history has the power to inflict on wrong," to be based on a mistaken view of the function of history. He points out that "history is not to be written as a Sunday-school tale for children of larger growth." He was more willing, I think, in later than earlier life to tell the story and leave his readers to draw what moral from it they wished. In his own words, "the historian may often feel righteous indignation—or what he conceives to be righteous—but he should strenuously repress it as a luxury to be left to his readers." Yet he did not entirely reject his earlier view, for in December, 1907, only two years before his death he wrote: "I have always sought, even though infinitesimally, to contribute to the betterment of the world, by indicating the consequences of evil and of inconsiderate and misdirected zeal. The search for truth has been stimulated by the desire to diminish the consequences of error."

Yet sincerely as Mr. Lea tried to be impartial in his treatment of the men and institutions of the past, he has been subjected to serious criticism, principally from adherents of the Roman Catholic Church. He has been charged with interpreting mediæval documents unfairly, giving undue credit to doubtful documents because they supported his views, and of allowing his general opposition to Catholicism to draw him into a partisan presentation of his subject. The changes have been rung on these charges in many different keys, but they are all reducible to these three forms, unfair interpretation of the records, prejudiced acceptance of documents, and an anti-Catholic propaganda under the guise of history. Much of this criticism has been made by men of no standing in scholarship and may be safely disregarded as unimportant. On the other hand, such criticism as that of Dr. Blötzer, published in 1890 in the *Historisches*

Jahrbuch of the *Görresgesellschaft,* that of Dr. Baumgarten in his book "Henry Charles Lea's Historical Writings," published in 1900, and the obituary essay of Alphandéry in the *Revue de l'Histoire des Réligions* since Mr. Lea's death, must be given the respect due to serious scholarly opinion. The validity of these criticisms can of course only be tested by scholars in the same field. But one or two general observations may be made concerning them. In so far as the statements refer to the validity or meaning of documents, that is a scholar's question, the kind of question that arises in all fields of investigation, that always must arise, and in which Mr. Lea would have been the first to disclaim for himself infallibility. One of the difficulties of such criticism, however, is shown in a curious slip made by one of Mr. Lea's most learned critics, Professor Baumgarten, of Munich. He endeavors to show at some length that Mr. Lea is mistaken in what he says of the mediæval rules for keeping holy the Sabbath day. But Mr. Lea was speaking not of keeping the Sabbath, the first day of the week, but of the forbidden meeting of witches with the devil, which was known as the "witch Sabbat," and he was absolutely correct in what he said. Professor Baumgarten is learned, but he does not happen to be learned in the history of witchcraft, where this expression belongs. As a further indication of the purely academic character of much of this criticism it may be remarked that a Catholic reviewer of Baumgarten's attack upon Mr. Lea while agreeing with him in this part of his work, proceeds to criticise Baumgarten's own work so severely as quite to take the edge off his harsh judgment of the American scholar.

But such criticisms, whether correct or mistaken, belong in the realm of knowledge, not of motive. In answer to charges of bias, intentional partisanship or unfairness, one can only cite Mr. Lea's own ideals and practices and the weight of opinion of thoughtful readers of his works. In this regard it is to be noted that many Catholic scholars are included among his unquestioning admirers, and all acknowledge the weight of his scholarship. The very latest criticism of an adverse nature closes by speaking of him as *ce bon ouvrier de vérité,* "this good laborer for the truth." Mr. Lea himself would have wished for no better description.

But there is stronger testimony from the Catholic side. On

December 19, 1896, Lord Acton, an English Catholic scholar, who had already expressed in the reviews a high opinion of Mr. Lea's work, wrote to him describing the project of the "Cambridge Modern History," which has now become so well known, and asking him to write a chapter in the first volume to be called "The Eve of the Reformation." In his letter Lord Acton uses the following expressions: "This is the important and most critical and cardinal chapter, which I am anxious to be allowed to place in your hands. . . . It is clear that you are the one indicated and predestined writer, there is no one else. . . . I know of none whom I could go to if you refuse." Mr. Lea replied in letters dated January 7 and March 22, 1897, giving a somewhat reluctant consent, and pointing out that such an article must contain many of the same statements that he had already made in his published works. In reply Lord Acton wrote, April 4, saying: "I sincerely thank you for the honor you do me in giving the aid of your hand and the sanction of your name to our international undertaking. . . . Your last work contains almost all I am asking for, ten times told and full measure running over." After some other intervening letters, the correspondence was resumed in March and April, 1898, when Mr. Lea sent the manuscript of the chapter, which was acknowledged by Lord Acton with renewed thanks, and eventually printed exactly as written. Eight years later, after Lord Acton's death, during a controversy that arose concerning his Catholic orthodoxy, a correspondent in the *Tablet,* a London Catholic journal, denied that Lord Acton had asked Mr. Lea to write this famous chapter. In answer to this Mr. Lea prepared a communication to the same paper giving an outline of the correspondence which I have just described. Before sending this letter, however, he saw an article in the London *Times* of October 30, 1906, by the present Lord Acton, upholding his father's orthodoxy. In a spirit of kindliness, and fearing to make this filial task more difficult, Mr. Lea decided not to send the correction he had prepared, laid it away among his papers, and the facts are now made public for the first time.

Even his severest Catholic critics have restricted their condemnation to a few parts of his work. There is not one of them that fails to bow to the extent, the depth and the minuteness of his knowledge. One speaks of his "welcome collection and exposition of important and universally interesting material for church history, grandiose capacity for labor, the use of inclusive and often obscure sources and works of literature," another of the "long and clear paths he has drawn through the masses of fact he has collected."

The truth is Mr. Lea was a man who keenly resented injustice, was shocked by unnecessary suffering and deplored waste. In ecclesiastical history he found much that seemed to him worthy of condemnation, and he condemned it often in unsparing terms, blaming freely men whose actions he thought wicked, and institutions which he thought conducive to the perpetuation of injustice and the infliction of undeserved suffering. Those, on the other hand, who look on the dominant influences of the middle ages with especial sympathy, or feel called upon to defend the Catholic church from criticism, have deeply resented this condemnation. They feel that Mr. Lea has not given the other and pleasanter side of the story, that he has not pointed out the amelioration of society, the consolation to individuals, the gentler and kindlier services of the mediæval church. Yet in all fairness it is to be remembered that Mr. Lea's studies led him through dark stretches of human history, that the weight of "man's inhumanity to man" must often have pressed heavily upon his spirit, that sympathy with suffering, resentment against injustice, hatred of oppression, and grief over ignorance and prejudice must often have made their appeal rather to the warm emotions of the man than to the cold impartiality of the historian. Which of us could read the sad records of the Inquisition, analyze the motives of men who were a disgrace to the high office of the papacy, describe the work of the visible church through periods from which even the most devout of churchmen turn away sick at heart, and still possess always a judicial calm and a sympathetic spirit? And yet through all his studies Mr. Lea preserved moderate judgment, optimism and belief in the essential goodness of human nature.

Yet it is not the moral judgments expressed in Mr. Lea's writings that have most impressed scholars. It is the mass, solidity and originality of his knowledge, the minuteness of his research, and the extent of his production. The larger works that I have before enumerated amount to seventeen volumes. Several of them have been reissued in successive editions, in each case with revision, eliminations and additions. Many of his pamphlets, articles in journals and other minor works, have involved much original investigation of the same kind as that made for his larger works. The extent of this investigation is indicated by thousands of references to works of the most technical and recondite character, in at least seven languages; to manuscripts belonging to remote periods, published in obscure localities, often by almost unknown authors, and difficult of access. In addition to these printed references are numberless pencilled notes, comments and other evidences of use scattered through the books in his library.

In order to carry out his work as he had planned it, especially his later volumes, it was necessary to make use of records in European depositaries which were still unprinted. The University of Oxford by special resolution ordered that any manuscripts in the Bodleian library needed by Mr. Lea in his work should be sent to America for his use; but in the case of archives this was obviously impossible. He was disinclined to go to Europe, and his means enabled him to make use of another alternative. This was to have copies of these manuscripts made by copyists there and sent over to him. Of course much was thus obtained of which he could make no use, but much was invaluable, and had never before been used by any scholar. Some two hundred bundles of manuscripts are now on his library shelves, all of which have been annotated throughout with his fine handwriting, and marked as having been copied, excerpted from, and otherwise utilized or discarded. Only two years before his death he arranged with M. Salomon Reinach to have a mass of material for his "History of Witchcraft" copied at the Cabinet de MSS. in Paris, and this he was engaged in examining, as it reached him, during the last weeks of his life.

The great volume of Mr. Lea's accomplishment, combined with his practice of having unprinted material copied and sent to him from Europe, has given rise to a strange misconception of his habits of work. One of his critics suggested that Mr. Lea, being a man of wealth, might have secured the services of others; another that his numerous references to obscure sources pointed to his possession of a large body of detailed quotations which could be used by him in constructing his books. A third critic copied and developed these suggestions, till, according to the well-known process of the growth of a legend, it has been stated in a French journal that much of Mr. Lea's work was done for him by assistants, that he kept a card catalogue of quotations and references, and that his work was largely a mosaic made by putting together these materials gathered by others. Nothing could be more absurdly untrue. No scholar ever worked more absolutely independently than he, few ever worked more completely alone. He never employed a secretary or clerk, never dictated a letter. Just as his library was collected according to his own judgment, just as the material for his writing was collected by himself, so his books were written from his own brain and by his own hand in the most literal sense of the word. He never spared himself labor in his writing. When his "History of the Inquisition of Spain" was ready for the press it bade fair to occupy six large volumes. After serious thought Mr. Lea decided that this was too long, and notwithstanding his eighty years of age and a pressing realization of the possibility that death might overtake him with the work of half a lifetime incomplete, he quietly set himself to the task of rewriting the six thousand pages with his own pen in shorter form, and within a year completed his task, reducing it from the six volumes to four. Surely this was a high instance of courage and the simple dignity of the scholar. No haste to appear before the public, no pretense, no boasting, no complaint; simply a sincere and loyal recognition of the claims of scholarship, and a willingness to grapple with all the difficulties of his subject, whatever form they might take.

Those who are familiar with Mr. Lea's methods of work know how he accomplished so much. Day after day, month after month, year after year, he labored constantly, usually six or more hours a day, with intense and concentrated yet alert and interested application. He often expressed his joy in the combat with a student's difficulties, his pleasure in labor, his satisfaction in achievement. Although his health was by no means constantly good, yet for sixty-five years he did not spend the whole of any one day in bed. During many years of his later life he sat down regularly to his desk at two or three o'clock in the afternoon and worked until dinner time.

Then in the evening he began again and worked until eleven. And this occurred seven days in the week.

He began a new subject by copying, translating, tabulating and summarizing his sources, in his own clear handwriting, on sheets of paper, with such comments and cross references as occurred to him in the course of his work. Great stacks of such sheets he took away with him to the seashore in summer, and classified, combined and re-read them there. He made it a practice never to begin to write a book until he had all the material he intended to use in it collected and classified. Thus in some cases he spent literally years in gathering material before he had written a word of his book in its final form; and when he came to write he wrote almost entirely from this highly organized material. Similarly he never sent any part of his work to the printer until the whole book was completed and revised in manuscript form. If this patient, systematic, self-controlled method of work is compared with the restless, hurried, confused and broken way in which most of our production is carried on, it is not hard to solve the riddle of his great accomplishment.

He obtained singularly little help from others. In his early years he had, as has been seen, a first rate general education and good literary training. But when he once entered upon the difficult road of historical investigation, he traveled alone. He overcame its difficulties with native genius but with much tribulation. His search for the bibliography of his subject was a hard one. He learned new languages as he felt the necessity for them. He has himself left a record of his regret "that there were no scholars here to whom he could look for guidance in the paths which he desired to follow," and that "as a solitary student he was obliged to collect around him the necessary material." This detachment from other scholars working in the same line had distinct disadvantages. The editions of the sources which he used were in many cases not the best, or those that gave the most help, and he did not obtain assistance that lay at hand in journals devoted to the investigation of mediæval history and in modern works in allied subjects. On the other hand, this same independence in his work gave a distinction and an individuality to his thought and writing that added immensely to its effectiveness. He saved much time from controversy, and he studied and wrote with a directness that would have been impossible if he had paid more attention to current writings and discussions in his field. He seldom asked or obtained either information or ideas from other scholars. But this arose from no sense of separation, depreciation or jealousy. It was simply the result of his lifelong habits of work. He had chosen his field for himself, tilled it in his own way and reaped its harvest with the labor of his own hands.

He had much pleasant correspondence with prominent European and American scholars. He was always ready to talk freely to his visitors and, so far as he took the time to read recent works, cordially praised many of them. He closed his address as President of the American Historical Association in December, 1903, with the following words of appreciative recognition of the work of younger men: "As one of the last survivors of a past generation, whose career is rapidly nearing its end, in bidding you farewell I may perhaps be permitted to express the gratification with which, during nearly half a century, I have watched the development of historical work among us in the adoption of scientific methods. Year after year I have marked with growing pleasure the evidence of thorough and earnest research on the part of a constantly increasing circle of well-trained scholars, who have no cause to shun comparison with those of the older hemisphere. In such hands the future of the American school of history is safe, and we can look forward with assurance to the honored position which it will assume in the literature of the world."

The deepest impression made by a survey of the career of Mr. Lea as an historian is an overwhelming sense of the impoverishment of the world of scholarship now that he has gone from it. Doubtless the careful, systematic, scientific study of the past will go on; science is continuous and progressive, history will more and more be studied and written as he has studied and written it. Doubtless others will rise up in his place to continue his work. Confidence in the future of historical investigation could not be expressed more strongly than he himself has expressed it in the words I have just quoted. And yet the broad outlook, the massive acquirements, the trained capacity, the patient industry, the indomitable perseverance, the sustained interest, the alert and ardent mind of this great scholar,—how can we spare them from historical research and writing? When shall we again have the clear-eyed layman investigating subjects left too generally by custom to the churchman? Where can we seek for the intellectual courage that will extend its view over so many centuries, and the industry that will prepare itself so thoroughly for the combat with their difficulties? What capacities scattered among many possessors will make up for the combination of powers in one personality? What later travelers along the way of historical study will see so widely, observe so keenly and record so well as this first and greatest of American scientific historians?

THE PRESIDENT:

The next speaker will be our fellow member, the Right Hon. James Bryce, the British Ambassador—a conspicuous representative of the culture of the old world as Mr. Lea was of the culture of the new.

THE RIGHT HONORABLE JAMES BRYCE:

I am asked to speak to you about one of the greatest historians of our time; to do so is for me not only an honor, but also a duty, because I was privileged during many years to enjoy his friendship, first given to me as a friend and pupil of Mr. Goldwin Smith, and because I am probably the only member of the British Academy, a body of which he had been elected some time ago a foreign member, who is now resident in this country.

Of his public life as a citizen and of his character in its various private relations, others here can speak with knowledge fuller than mine; yet I must not forget to dwell upon and gratefully acknowledge the uniform kindness which he showed to us younger men when we approached him, and which witnessed to the genial warmth of his heart. What I have now to say will refer to him as a historical scholar and author.

Anyone asked to say what are the qualities needed for the writing of history might enumerate them as follows: diligence, patience, accuracy, the power of critical discrimination, impartiality, penetration, judgment. All these are qualities which belong to the substance of historical writing. As regards its form, one would particularly specify the power of clear statement and the gift of putting color and life into narration, together with those other attributes which make up what we call "brilliancy of style."

Let us consider Mr. Lea's intellect and the work which it produced with reference to the various attributes I have enumerated, and let us begin with the form of his work and of those things which belong to style and manner.

That which is called literary excellence, *i. e.*, the charms and allurements of style, was never very much in Mr. Lea's mind and was altogether subordinated to a consideration of the matter to be dealt with. Whether it was that he did not think that his talents lay in the purely literary direction or that he did not much care for the graces of composition, reckoning merits of form as trifling compared to merits of substance, he paid comparatively little regard to the adornment of that which he had to say. In this respect he would have satisfied—as indeed he anticipated—the canons of what is now called the scientific treatment of history. But his writing had that which is the greatest merit of style, perfect clearness, both in the statement of facts and in the exposition of his views of the facts. It was always plain, direct, intelligible, and with that he was content. The facts were so interesting to him, and he felt that an exact statement of them ought to be so interesting to all scholars, that he never spent any time on decking them out with any rhetorical embellishments. If his manner may be called level and business-like, it is never dull, because the essential facts are carefully selected, words are not wasted, the matter is so stated as to go straight home to the reader's mind.

Now let us return to those attributes of the historian which relate to the substance of his work.

His industry was above all praise. For fifty years he labored incessantly on his researches, giving to them in earlier days all the time that he could spare from his business and his public duties as a good citizen, and in later days devoting to them practically all his working time. When his health became comparatively weak, he so arranged his life as to reserve all his forces for study and composition. Just so much open air exercise was taken as the interests of health required, and every moment that could be given to the library was given.

Nothing could exceed the care and patience with which he investigated the sources from which he drew his materials. He verified every reference, he neglected no out-of-the-way authority from which information could be obtained. Few recent writers have had their statements so seldom questioned, and rarely indeed was he proved to be in error. He rightly held accuracy to be the first of all the historian's aims and the highest test of the historian's excellence. The splendid library which he accumulated by the labor of many years, fortunately enabled him to have on his own shelves an unusually large number of the books that he required, while his means were sufficiently large to bear the cost of procuring copies of manuscripts preserved in European collections. Neither trouble nor expense was spared in procuring these essential materials. It need hardly be said that whoever travels through unexplored territory, relying upon original sources, many of which have never been properly scrutinized, needs a high measure of critical insight. Whether nature gave Mr. Lea that capacity, or whether he acquired it by long experience, it certainly had reached in him an unusually high development, and this is one of the features of his books which gives them their permanent worth. In accompanying him one feels one's self always on firm ground.

Some of the subjects which he treated at great length, such as his monumental histories of the Inquisition in Southern France and in Spain and his history of clerical celibacy, deal with subjects in which freedom from any bias or prepossession, whether religious or political, is specially needful, and indeed one may say essential in order to secure the confidence of all readers, whether Roman Catholic or Protestant. Mr. Lea was a Protestant by birth and conviction, but he was, as a scholar ought to be, perfectly fair in his treatment of ecclesiastical and religious questions. One may indeed say that scholarship fails to bear one of its best fruits if it fails to make a man impartial in handling ecclesiastical history. His books were never written with any purpose or bias save that of eliciting the facts. To write in such a spirit was far rarer in the days when Mr. Lea began his work than it is in our time. Religious prejudices were so strong and so general among both Protestants and Roman Catholics that it was quite unusual to find a writer in whom you could not discover immediately that he wrote with either a Protestant or a Roman Catholic color. But it may be said of Mr. Lea that he not only never suppressed evidence, but also that he always treated evidence in a purely judicial spirit, endeavoring to give its due weight to every item, whether or not it fell in with any theory that he might have formed or any notions he had entertained. In one of the last conversations I was privileged to have with him he told me that he had been surprised when he investigated the subject to find that the Inquisition, terrible as it was, put to death by no means so many persons as was commonly believed.

When after weighing the evidence and reviewing the facts established, he had to deliver his own judgment upon them, it was sure to be both a cautious and a weighty judgment. To large generalizations he was not very prone, feeling the dangers that lurked in them, and feeling also that if the facts are fully and carefully stated, scholars at least may generally be left to draw their proper conclusions from them. Great historians may be recognized hardly more by the fine quality than by the small quantity of the general theories they propound. It is the untrained men who are alike facile and feeble in their speculations.

One feature of Mr. Lea's judgment deserves to be noted because it is one which, although apparently discarded by some among the most recent school of scientific historians, was placed in the forefront of an historian's merits by a great man whom it is a pleasure to name as a warm admirer of Mr. Lea's work, I mean the late Lord Acton. Mr. Lea was sparing in condemnation, for he had a charitable mind, and he was not copious in moralizing reflections, but he carried a clear and sound moral sense into all his judgments. Cruelty and perfidy and rapacity were hateful to him wherever they were found. Their foulness was not to be palliated by dwelling on the distinction between the standards of one age and another. There are, no doubt, many offences to which we ought to give a greater indulgence when we meet them in past times than we should give them now, but even in the rudest communities these three sins always were sins as they always will be sins, and, as Lord Acton used to say, they ought not to be excused by any differences of time or country.

I may sum up the impression which Mr. Lea's intellectual character and attitude leave upon his readers and left most of all upon those who knew him personally, by saying that he loved truth with a whole-hearted devotion. The love of truth is the compass by which an historian must steer. It is the highest quality in the investigator, whether his subject be human things or external nature. It was his love of truth that made him so diligent and exact and scrupulous in the study of his authorities and in the statement of his results. It is this quality above all that distinguishes men like Hallam and Stubbs, Maitland and Gardiner, and in this country men like Parkman and your latest historian of the United States, Mr. James Ford Rhodes, from the mere littérateur, however brilliant a stylist he may be, who occupies himself with history because it is a subject which lends itself to literary effect. And I may perhaps add that we in England feel doubly grateful to the United States when she gives us an historian who makes to European history contributions of permanent value. In observing the widespread and eager activity with which, in this country, your younger students are devoting themselves to the history of the thirteen colonies and of the United States in all its ramifications, I have sometimes been inclined to wish that more of them occupied themselves with the history of Europe, which, after all, is a part of your own history, because you are yourselves a European people, although settled in another hemisphere. Mr. Lea is a bright example of the services which an American historian, standing outside the strifes and prejudices that still affect the minds of many European writers, can render to branches of history which eminently require calm and dispassionate investigation.

The vision rises before me of our venerable friend as I used to see him sitting in his library, surrounded by books that rose from the floor to the ceiling—rows of precious volumes which he had gathered with such painstaking diligence—happy among them, gentle and serene in aspect, and pursuing his labors in an old age which had left him in full possession of his admirable powers, wise and just, zealous and untiring as ever in the pursuit of truth. He thought nothing of fame. He did not seek for recognition either at home or abroad, and the circle from which he received recognition was the comparatively narrow one of scholars who were able to appreciate what he had done for them. But he has set before us a splendid example of single-minded devotion to the enlargement of knowledge, and has given us a great mass of first rate original work, work which has stood and will stand the test of criticism. This work of his, covering some of the most obscure and difficult branches of research and throwing new light into many a dark corner of the past, will perpetuate his name and win for it a gratitude of many generations of historical scholars.

THE PRESIDENT:

It is a great pleasure not to introduce, but to present to you Dr. Horace Howard Furness, the speaker on behalf of the Library Company of Philadelphia, one of the foremost of Shakespearean scholars, the genial friend not only of Mr. Lea, but of our entire community.

DR. HORACE HOWARD FURNESS:

Mr. President, Fellow Members of the Philosophical Society, Ladies and Gentlemen: Lincoln in his immortal Gettysburg address taught us, I think, the spirit in which to observe commemorative services. The *deeds* that men have done, the *tasks* they have achieved—these endure, and our commemorations are for our own benefit, not for the honor of those whose hands have ceased from their labour. By rehearsing their victories, we are, ourselves, urged forward, and in following their example our truest commemoration is found.

And who would not gladly be a humble follower of such a leader as he whom we have met this evening to commemorate? From mouths of wiser censure than mine you have listened to a review of his manifold talents and activities. A man so various that he seemed to be not one but all good men's epitome. Of Sir Walter Scott, who for twenty-five years performed the arduous and varied duties of Sheriff and Clerk of the Session, it has been said, that an historian of Edinburgh could hardly escape the conviction that during those years there must have been in that city and at the same time, two utterly dissimilar men, both bearing the same name, the one a poet and literary man of commanding genius and the other a great citizen, ever in public and active civic life. Would not an historian of Philadelphia come to the same conclusion and express his conviction that there were here in Philadelphia during the last half century two men both bearing the identical name, Henry Charles Lea? One striving and prominent in the heady fight of politics and reform; and the other a modest, sequestered scholar, leading a cloistered life of historical research.

'Far, far indeed behind his worth come all the praises we can now bestow.'

I cannot analyze his character. His loss to me is too recent and we are all too close to him. My few words cannot but be stammering; if haply they only be coherent.

Whatever may be the qualities demanded in a scholar, and especially in an historian, accuracy in statement stands preëminent. It is the foundation of his work; on it rests the whole superstructure—a taint of suspicion of a scholar's truth is the fly which ruins the apothecary's ointment.

In this accuracy, Mr. Lea ranks among the highest. The sources whence he drew his statements cannot be impugned. They are the very words of the speakers, the very acts of the governments, the very decrees of the church. And of them he urges upon the reader no interpretation drawn from imagination, or tinged by prejudice. He gives the documents themselves, from which the interpretation to be drawn is the bare, unqualified meaning of the very words themselves.

And herein he reveals to us the lofty attribute of pure intelligence; pure intelligence is absolutely cold and impartial. This impersonality elevates his writings to the ruthless dignity of a scroll of fate. Here are your facts. Lament, deplore, extenuate as you will, but deny you cannot.

. Obedient to this high attitude, an historian need not point the moral. Whoso cannot of himself *find* the moral, for him will Clio for ever inscribe her scrolls in vain. We need no elimination of the personal question when we read Lea's general conclusions drawn from a survey of the whole field; and, in less prejudiced and less impartial hands, we all know how vulnerable such general surveys are apt to be.

For an historian to attain, however, an eminence from which he can sweep the horizon, he must be, with a cool head and unclouded brain, omnipresent in the times whereof he writes. There must be not only no point of the horizon, political, ethical, and ecclesiastical, which he has not scanned; but also the manners, the customs, the complex trending of thought, the very form and pressure of the age and body of the time, must be as familiar to him as are those of his own. To accomplish this as thoroughly as Lea accomplished it, demands exhaustive research, wide reading, digesting, collating, analysis, and all held in memory to the point of saturation. In the presence of such an achievement, as we find again and again in Lea's works, we can only stand in mute respect and admiration, tempered with what is akin to awe. To achieve this, difficult as it is, is a duty imposed on every historian; and, recognizing this duty, as "the stern daughter of the voice of God," Lea obeyed it.

John Fiske is said to have observed that "the life of the wisest man is chiefly made up of lost opportunities, defeated hopes, and half finished products."

Is this true of our friend? Ah no! In moments of quiet reflection, when to the sessions of sweet, silent thought he summoned up remembrance of things past, he could not but have been conscious that instead of losing opportunities, he had created them; instead of hopes defeated, he could count hopes triumphant, instead of products half finished, he had rounded full and complete the work of a lifetime wherein no hour was wasted. At such seasons, with his keen insight into human nature, he could not but have been conscious that he had bequeathed to the world a legacy, in comparison wherewith wealth turns to apples of Sodom and the clusters of Gomorrah. Here is a legacy free to all and the more it is used the wider grows its beneficence and value. It thrives by wasting.

Surely, surely, he could have harbored never a doubt as to its permanence. In dreaming over its future, well might he have murmured to himself with haughty truth:

"Et tunc magna mei sub terras ibit imago."

"A man's light," says Jeremy Taylor, "burns awhile and then turns blue and faint, and he goes to converse with spirits; then he hands his taper to another." But where shall we find him who is worthy to accept Lea's taper? Of him, who shall venture to hold it, it will crave wary walking to keep its flame as pure and bright, as when it illumined the pages beneath Lea's own hand;—those pages which will endure, which cannot but endure. Is it exaggeration to paraphrase Dr. Johnson and assert that, "time which is continually washing away the dissoluble fabric of other writers will pass without injury the adamant" of the "History of the Inquisition"?

And now, as a last word, when the image of the friend, admired and respected by us all, and so dear to some of us, rises before me, I would fain in this present circle, close-knit as we are by a common emotion, breathe one low-toned word of sympathy with those from whom as husband and father, it was to him so bitter a pang to part.

Before that sad group we can only stand at a distance with heads bowed and in silence.

"Fear no more the heat of the sun
Nor the furious winter's rages:
Thou thy worldly task hast done
Home art gone and ta'en thy wages."

"The ground that gave him first has him again.
His pleasures here are past, so is his pain."

THE PRESIDENT:

The speaker on behalf of the Historical Society of Pennsylvania was to have been Mr. Joseph G. Rosengarten, of Philadelphia, but serious illness in his family precludes him from being here. He has, therefore, requested Professor Jastrow, of the University of Pennsylvania, to read his remarks.

MR. JOSEPH G. ROSENGARTEN:

The world-wide reputation of Mr. Lea as a historian forms the fitting complement to the affectionate esteem with which his memory is rightly cherished by his fellow citizens of Philadelphia. As a reformer he initiated basic changes in our municipal methods. His services to the United States Government began early in the troubled days of the Civil War, when with a few friends he joined the Union League, and with his pen aroused Union sentiment to thoughtful action in that great crisis. When troops were to be raised he was the most active member of a commission of citizens who administered honestly and efficiently the large sums expended in bounties and in organizing the volunteers. At the end of long years of sharp and often bitter contests with the Federal authorities, Mr. Lea earned the hearty praise of General James B. Fry, the provost-marshal-general, for his honest and capable management of local recruiting in the interest of the United States, the state and the city. His pamphlets and verses formed frequent contributions to the cause, and the Union League may well be proud of the effective help given in this way at a trying time.

Equally characteristic of the man was his action in resigning from the League some years later on account of its refusal to throw its influence on behalf of municipal reform, when Mr. Lea and his associates were waging their war against corruption in local politics and administration. He led the attack on the Public Buildings Commission, and originated the Citizens' Municipal Reform Association to reform the government of the city and secure a better class of representatives in the legislature. It carried on the contest largely with the help of Mr. Lea's vigorous pen. His newspaper articles and pamphlets brought home to the people the need of sweeping changes. Much of what he thus advocated was secured in the new Constitution, and the convention that drafted that instrument drew largely from Mr. Lea's powerful arguments. It was chiefly owing to his well-directed attacks that the Gas Trust fell at last, thus relieving the city of a heavy burthen of corruption. Again, as a member of the Committee of One Hundred, Mr. Lea gave direction to its efforts to secure good city government. What he did in municipal affairs he sought to do in state and national matters. He was a strong and active advocate of civil service reform, and urged the introduction of the merit system of admission to civil service appointments by open examination.

One of his old and earnest associates says that "Mr. Lea was the pioneer in the cause of honest government, and to him above any other man is due the credit of first organizing the reform sentiment in Philadelphia into a body capable of real work."

Later, when he was more deeply engrossed in his splendid literary work, although not in good health, he helped in spirit and in the most substantial way the cause of good government. His deep interest in his native city was maintained till the end of his life. Keenly alive to its honor, he set an example of civic duty that is unfortunately not common in men of his type of mind. He realized better than most of us that good government can only be achieved by the harmonious and hearty coöperation of all classes of the community in civic affairs.

The same industry that had made him as a mere boy a contributor of scientific articles to leading journals, and enabled him to learn from his father's life-long devotion to scientific research, in maturer years made him a welcome contributor to the leading newspapers and periodicals on the topics that appealed to the public, for he was a recognized authority on all public questions that he discussed.

As late as 1897 he drafted for his associates in Philadelphia an admirable appeal to the Senate of the United States for the prompt ratification of the treaty with Great Britain, providing for the arbitration of international questions when not settled by the ordinary process of diplomacy. In it he showed his mastery of large and important issues, and put in clear, crisp, significant sentences the reasons that justified a new departure in the interests of peace.

A complete bibliography of all his contributions on public topics would be a very long one, and would bring home to his fellow-citizens a realizing sense of how useful Mr. Lea was to them, to the community in which he lived, to the state, and to the nation, for all of which he labored with such unselfish zeal.

An interest in public affairs and an ability to discuss them on the highest plane, may have been inherited from his grandfather, Mathew Carey, a man of mark in the early days of the Republic. But the grandson was not only a successful publisher and a man active in affairs, he was also a diligent student, and even during the trying days of the Civil War and in the turmoil of discussion of municipal questions, in the quiet of his own study he was accumulating the material for that succession of his historical works which have made him famous as a historian, foremost in the world in the subjects that he made his own.

Preoccupied as he was, he gave freely of his time and money to charities, public work and educational schemes. For years a director of the Philadelphia Library, he gave it a large reading-room that doubled its usefulness. A trustee of the University, he gave it the laboratory of hygiene, and by his will made it the ultimate owner of his splendid library, a collection of original historical works and material for historical research that will attract earnest students for all time. In his own busy life he always welcomed students to his library, and its treasures were put freely at the disposal of all who shared his own love of truth and the lessons to be learned by a diligent and intelligent use of the real sources of history, the original works and manuscript records gathered by him from foreign archives and repositories.

Without the gift of oratory, or even a fondness or willingness for public speaking, his contributions with his pen during an exceptionally long and active life, formed a solid gain to a sound system of good government, and to a new light on complicated historical questions, all with a lofty spirit, a love of truth, and a zeal to help the world on in its upward progress. Impartial, unpartisan, inspired always and only by an unselfish aim, and without any personal ambition or desire for fame, Mr. Lea was a citizen of whom his native city and country may well be proud.

Honors came to him in the recognition from scholars and learned institutions, and from the leaders of public thought at home and abroad, but unaffected by them except as they furnished him an assurance of the service that his arduous labors had rendered, he retained the same simple truth-loving and truth-seeking spirit from boyhood to the end of his useful and honored life. It is characteristic of the man that oblivious to the steady growth of his fame as a scholar, which was even more rapid abroad than at home, his work continued steadfast and untiring.

His strength and his life ended before he could complete the "History of Witchcraft" in hand at the time of his death. Much original material was collected from various sources, and more came after that active brain was stilled, and that busy pen fallen from his hand. A great amount of notes was made by him with the careful thoroughness so characteristic of his studious preparation before he began work on his final text, which was then subjected to frequent revision before he would publish the result.

The correspondence of Mr. Lea with public men and scholars at home and abroad ought to throw much light on his intellectual growth and development, and on the influence that he exercised during his long and busy life. His singular modesty, his contentment in his own library and in his literary work, his absolute indifference to public honors or recognition, made all the greater his sacrifice of so much strength, and time, and labor, to public service, to duty as a citizen. All the more is it important that there should be a full and complete memorial to him, showing how he was trained in early youth, developed into a busy man of affairs, active in a great national crisis, earnest in advocating much needed reforms, and crowned by the highest authority as a historical author of the foremost rank.

Through all his lifetime of activity there ran a stream of constant and wise philanthropy, a steady giving to all good causes, but only after careful inquiry and investigation, and always without ostentation or publicity. Of his personal traits one cannot but recall his kindly gentle nature, his interest and sympathy in all who worked in the same fields—history, public affairs, scientific research, philanthropic and educational projects. None of those who were thus associated with him would ever have suspected from his modest bearing that Mr. Lea was a great scholar and historian, whose works received the highest encomiums of great scholars and historians at home and abroad. They in turn never heard from him of the manifold public services he had rendered during his busy life. Let us then pay tribute to his many remarkable achievements in all his pursuits.

There are examples of great historians whose memories have been honored by making their libraries accessible to students. Our American universities have many such libraries brought here and made the shrines for the studious worship of successive generations of scholars. Mr. Carnegie made a gift of the library of Lord Acton a special tribute to Lord Morley. Mr. Lea himself provided that his library should in due course come to the University of Pennsylvania. In making this provision Mr. Lea was manifestly actuated by the hope that his collection might be of service to future generations of scholars. Such a collection should indeed become the natural center of the historical work done at the University, whither students might come and find every facility for continuing those researches that made Mr. Lea an example and an encouragement for all who follow his love for the truth. The noblest memorial to a great scholar is to provide for a continuance of his work.

I trust, therefore, that I may be permitted to hope that the priceless collection, so carefully gathered by Mr. Lea during his long life, should be properly housed so as to make it most fully serviceable and that amid worthy surroundings its very presence may serve as an example to which the historians of the generations to come might turn for fresh inspiration.

Henry C. Lea needs no memorial. His achievements constitute his monument, but it is important for our sake and for the sake of the generations to come that his memory be kept alive and that the recollection of his active and useful life and of his many-sided labors be kept before us in a manner worthy of the man, the citizen, the historian in whose honor we have gathered tonight.

THE PRESIDENT:

The portrait of Mr. Henry C. Lea, an admirable copy by Mr. H. H. Breckenridge of Vonnoh's original painting, will be presented to the Society by the representative of the University of Pennsylvania, and of the American Academy of Arts and Sciences of Boston, Dr. S. Weir Mitchell, the third of our distinguished Philadelphia triumvirate, whose own portraits in print rival in felicity those of the artist on canvas.

DR. S. WEIR MITCHELL:

Mr. President and Gentlemen of the Philosophical Society: I have had the honor of being selected by the family and friends of Mr. Henry Charles Lea to present to the Philosophical Society the portrait of our greatest historian. The portrait I thus place in the custody of the society is a copy of the well-known portrait by

Vonnoh, painted eighteen years ago, and is regarded by those who knew Mr. Lea best as an excellent picture of the man as he was. But that responsive face could never be so put on canvas as to recall for me the change from the grave scholarly look of attention to the smile which welcomed a friend to the privilege of a social hour; alas!—here the artist fails us—

> " For Painting mute and motionless
> Steals but a glance of time."

It is not a part of my function to speak at length of the work of my friend, or of his personal character and the qualities which made him both loved and respected. It is probable, however, that no one of those who speak of him this evening has done full justice to a characteristic which he possessed in a degree I have met with in no other man of eminence. The brief contribution I shall here make is a sufficient record of the extraordinary humility of Mr. Lea concerning works which scholars regard as among the classics of his time. I hesitated to speak of it because it involved mention of myself and of a service I was so happy as to render my friend, and through him to the art of the historian.

About the year 1887, when Mr. Lea was half-way through the first volume of his work on the Inquisition, he broke down in health and consulted me. I was able to give him a schedule of life, to which he adhered with extraordinary fidelity, and with the result at last of allowing him to resume the task which he had for a time given up. When the first volume of this great work was completed, he sent it to me with a letter. In it he said that he had held back the printing of the introductory pages of his book for a week, because it was his desire to dedicate to me a work which could not have been carried thus far without the health which my counsels had restored to him. He went on to say that he had felt, however, so much doubt as to the reception of this book by scholars, that he finally resolved not to connect my name with what might possibly be considered a failure.

The letter was perhaps a greater compliment than even the dedication would have been. I think of it with grateful remembrance, and venture to offer it as my contribution to what has been said about one of the most remarkable men with whom I have had the good fortune to be associated in a long life.

THE PRESIDENT:

The portrait of Mr. Isaac Lea, a striking copy of Mr. Uhle's by Mr. Thomas P. Anshutz, of the Academy of the Fine Arts, will be presented by Dr. Samuel G. Dixon, the worthy successor of Mr. Isaac Lea as President of The Academy of Natural Sciences of Philadelphia.

DR. SAMUEL G. DIXON:

Mr. President, Members of the American Philosophical Society, Honored Representatives of our Mother Country, Ladies and Gentlemen: It is my privilege tonight to present to you, on behalf of the family of the late Henry C. Lea, a portrait of Isaac Lea, LL.D., by Uhle, that at last it may rightfully take its place in the series of portraits of distinguished members, which adorn the hall of the Society.

Isaac Lea's work was ended long ago; he rests beneath "the low green tent." It may be fitting on this occasion to recall, if only briefly, his work and services to science.

The honor of membership in this Society has not always an equal significance. In most cases it is bestowed in recognition of large performance in the domain of science or of affairs; but rarely has a man's work been discounted, and a member admitted for what he was expected to perform.

Eighty-two years ago this Society elected to its membership a young man whose actual achievement was then small; but he was destined to become, in his own special line of research, the most eminent of his generation.

This young man was Isaac Lea. His life work was the study of fresh-water mollusks. Born in 1792, of parents belonging to the Society of Friends, whose English ancestors had followed Penn to America, young Lea lost his birthright by serving in a volunteer rifle company towards the end of the War of 1812. About this time he became interested in geology, under the inspiring influence of Professor Vanuxem, whose pioneer work on the geology of New

York was soon to begin. Geological horizons are recognized by their fossil shells, and Lea was thus led to study living mollusks, the better to understand those in the rocks.

The receipt of some fresh-water mussels, sent by Major Long, of the U. S. Engineer Corps, then engaged in deepening the Ohio River, was the occasion of Lea's first paper, which was published in the *Transactions* of this Society for 1827.

Once attracted to this subject Lea found an inexhaustible field for work. The great river systems of a continent marvelously prolific in bivalve mollusks supplied material. Naturalists in all parts of the country sent the species of their localities. His enthusiasm infected others, and from North and South America, India and Australia, material to be worked up poured in. Lea's work on these great collections of fresh-water mollusks form a series of thirteen stately and richly illustrated quarto volumes, part published by this Society, part by the Academy of Natural Sciences. His last paper appeared in 1876.

Every man who sets himself the task of cultivating one plot in the field of intellectual endeavor must needs resist the voices calling him to other tasks, lest in scattering his force, he fail of high achievement. Lea published but little outside of his special work. Several papers dealing with foreign materials included in gems and other crystals, and one notable paper, on the reptilian tracts of the red sandstones of Pennsylvania, were his main digressions.

In whatever direction, however, his researches led him he was sure to pursue them to a successful end. The value placed upon them by his fellow scientists is sufficiently indicated by the positions of honor to which they called him.

I venture upon any estimate of the value of Lea's work with hesitation, since my own studies have been in a field widely diverse. I can but give the verdict of those competent to judge, whom I have consulted. Lea's work was mainly descriptive. It was the pioneer work in his branch of zoölogy, breaking path for those who came after. The march of modern zoölogy could not proceed without such work as his. And it is the honor of this man that his work was well done. While investigations growing out of Lea's work may prove to have what we term "practical" applications, yet in laying the foundation of our knowledge of freshwater bivalves, Lea's aim and achievement were purely intellectual. Of him may be truthfully quoted those noble words of Tyndall: "The true son of science will pursue his inquiries irrespective of practical considerations. He will ever regard the acquisition and expansion of natural knowledge—the unravelling of the complex web of nature by the disciplined intellect of man, as his noblest end—and not as a means to any other end."

THE PRESIDENT:

Dr. Dixon, Dr. Mitchell, Mrs. Henry C. Lea, and other members of Mr. Lea's family, in the name and on behalf of the American Philosophical Society, it gives me great pleasure to accept with sincere thanks these gifts of affection and of a just civic and family pride. They will find in the notable collection already in the ancient hall of the American Philosophical Society the portraits of worthy spirits and warm friends from those of Washington, Franklin, Jefferson and Rittenhouse down to those of Cope, Leidy and Newcomb. There they will ever live, an inspiration to young men of what may be achieved by a long life of faithful unremitting labor, and a reminder to old men of what has been thus splendidly achieved by their predecessors.

OBITUARY NOTICES OF MEMBERS DECEASED

Jacobus Henricus Van't Hoff.

JACOBUS HENRICUS VAN'T HOFF.

(*Read April 22, 1911.*)

It is always pleasant to discuss the work of a truly great man, but the loss of an adored teacher and one of the best of friends, is among the most trying ordeals through which we are called upon to pass.

I shall say relatively little of the life of Van't Hoff, since it was simple and comparatively uneventful; but devote most of my time to his work—work which found chemistry, for the most part, an empirical science, and left it well advanced towards becoming an exact branch of natural science.

Jacobus Henricus Van't Hoff was born in Rotterdam, August 30, 1852, the son of a physician. He died in Berlin, March 1, 1911, and was, therefore, almost exactly fifty-eight and a half years old. He received his early training in the "Realschule" in Rotterdam, and in 1869, at the age of seventeen, went to the Polytechnikum in Delft, completing the three years' course there in two years. At the age of nineteen he went to the University of Leyden and remained there one year. He then repaired to Bonn to work with the distinguished organic chemist, Kekulé, and thence to Paris to come under the influence of Würtz. He then returned to Holland and in 1874, at the age of twenty-two, made the Doctor's degree at Utrecht, his dissertation being in the field of organic chemistry.

Van't Hoff, in 1876, at the age of twenty-four, was appointed privatdozent in physics in the veterinary college in Utrecht. He was called to Amsterdam in 1877 as lecturer in chemistry, and in the following year was appointed professor of chemistry. Van't Hoff held the position of professor of chemistry in the University of Amsterdam until 1896, when he accepted a call to Berlin as professor in the University and a member of the Imperial Academy of Sciences. He lectured once a week on physical chemistry in the University of Berlin, and a research laboratory was provided for him in the suburbs of Berlin by the Imperial Academy of Sciences.

Let us now turn to the work of this very great man.

Van't Hoff's name will always be associated with the following epoch-making discoveries:

The founder of the science of stereochemistry.

The first to apply the law of mass action to chemical reactions in a broad way, and thus to open up the fields of chemical dynamics and equilibrium.

To have pointed out the close relations between solutions and gases, and thus to have placed the whole subject of solutions upon a scientific basis.

Van't Hoff, as we have seen, began his scientific career as a pupil of Mulder in Utrecht, of Kekulé in Bonn, and of Würtz in Paris. During this period he was, therefore, busy primarily with organic chemistry, and let us see the result. At the age of twenty-two, while still a pupil of Mulder in Utrecht, he published in 1874 a short paper of eleven pages in Dutch, which was destined to revolutionize the whole subject of organic chemistry. Organic chemistry, at this time, under the dominating influence of Kekulé was concerned chiefly with the question of constitution, but the constitutional formulæ then in vogue did not even raise the question as to how the atoms within the molecules are distributed in three dimensions in space.

The short paper by Van't Hoff in Dutch had to do with the tremendous, and apparently hopeless problem of the arrangement of the atoms in the molecules in space. The following year (1875) this paper was translated into French, bearing the title "La Chimie dans l'Espace," and two years later into German, with a preface by Wislicenus, "Die Lagerung der atome im Räume." Let us glance briefly at the contents of this paper.

It had been shown by the work of Henri and others that methane, or marsh gas (CH_4), is a symmetrical compound, *i. e.,* all of the four hydrogen atoms bear the same relation to the carbon atom. Van't Hoff pointed out that this fact alone forces us to conclude that methane must be represented in space by the regular tetrahedron; the carbon atom being at the center of the tetrahedron and the four hydrogen atoms at the four solid angles. This is the only geometrical form in three dimensions in space in which a central object is surrounded symmetrically by four things of the same kind. Thus arose the conception of the "tetrahedral carbon atom." Pasteur had been studying the property possessed by certain liquids of rotating the plane of polarization of a beam of polarized light passed through them. He had reached the conclusion that in order that a liquid should have this property—be "optically active"—its molecules must possess some kind of asymmetry. Further than this Pasteur could not go. The solution of the problem of optical activity remained for Van't Hoff.

He examined the constitution of all of the optically active compounds of carbon then known, and found that they all contain at least one carbon atom in combination with four different atoms or groups; and this applies to every optically active compound of carbon known today; and these number more than a thousand. Van't Hoff simply extended his theory of the "tetrahedral carbon atom" to that of the "asymmetric tetrahedral carbon atom" and the problem of optical activity was solved.

This was the beginning of the stereochemistry of carbon, from which the stereochemistry of several other elements is the outgrowth; and it is not an exaggeration to say that the tetrahedral carbon atom has been the guiding thought in organic chemistry for the past thirty years.

Shortly after the appearance of the little paper in Dutch Van't Hoff published his book on organic chemistry "Ansichten über die organische Chemie." In this work he attempted to systematize organic chemistry, and especially to place it upon a quantitative basis. He was impressed with the purely qualitative nature of organic chemistry as exemplified by the Kekulé school. Certain substances were brought together under certain conditions and certain "yields" were obtained. Very little had been done up to that time towards measuring the velocity of reactions, or the conditions under which chemical equilibrium was reached. These were the problems to which Van't Hoff next turned, and the results of his studies in this field constitute his second great contribution to chemical science.

It had long been known that mass or relative quantity of the reacting substances not only conditions the velocities of chemical reactions, but often even the direction or nature of the reaction. The effect of mass on chemical reaction was given simple algebraic expression in 1867 by the Norwegian mathematical physicist Guldberg, and the Norwegian chemist, his son-in-law, Waage; both of the University of Christiania.

It remained here again for Van't Hoff to demonstrate the real importance of the law of mass action. He showed that chemical dynamics in general, and the conditions that obtain when chemical equilibrium is reached, can all be dealt with by the law of mass action. In this work the whole subject of chemical dynamics and equilibrium was reduced to a science, and whatever has been subsequently done in this field has felt the influence of this early work by Van't Hoff.

The results, both theoretical and experimental, obtained by Van't Hoff and his co-workers, were published in the well-known volume "Études de Dynamique chimique" in 1884. In the portion of the work that deals with chemical dynamics, it is shown that the velocity of a reaction is a function of the number of molecules taking part in that reaction; and a method for determining the "order" of a reaction, or the number of molecules taking part in the reaction was worked out. The effect of temperature on reaction velocity was here discussed, and it was pointed out that chemical reactions are, in general, much more complex than we are usually accustomed to regard them; a number of "disturbing" factors coming into play.

The treatment of chemical equilibrium is quite as important as that of chemical kinetics. The new feature here was the systematic application of thermodynamics to such problems. Before this book appeared there was no scientific treatment of the subject of chemical equilibrium. Van't Hoff showed in this volume the importance; indeed, the absolute necessity of a physical and mathematical training for every chemist who wishes to go beneath the purely empirical side of his science.

We come now to the third and greatest contribution of Van't Hoff to chemistry in particular and to science in general, *the relations between solutions and gases.*

The first paper dealing with this subject was published in 1886 in the *Transactions of the Swedish Academy of Sciences*, under the title "The Laws of Chemical Equilibrium in the Dilute Gaseous or Dissolved State of Matter." This, according to Donnan,[1] was quickly followed by two other papers: "A general Property of Dilute Matter" and "Electrical Conditions of Chemical Equilibrium."

The well-known paper in which the relations between solutions and gases were first pointed out was published in the first volume of the *Zeitschrift für physikalische Chemie,* under the title "Die Rolle des osmotischen Druckes in der Analogie zwischen Lösungen und Gasen," and which has been translated into most of the civilized languages of the globe.

It is always interesting to learn how a great mind discovers a great generalization, and in this case we have the account in Van't Hoff's own words. He delivered in 1894 his well-known lecture before the German Chemical Society which led directly to his call to the University of Berlin. From this the following section is quoted:

"Jung wie ich war, wollte ich dann auch die Beziehungen zwischen Constitution und chemischen Eigenschaften kennen lernen. Die Constitutionsformel soll ja doch schliesslich Ausdruck des ganzen chemischen Verhaltens sein.

"So entstanden meine 'Ansichten über die organische Chemie,'[2] die Sie wohl nicht kennen. Es lohnt sich auch kaum. Nur hatten sie für mich den Werth, dass sie eine bestehende Lücke mir sehr scharf zeigten.

"Nehmen wir ein Beispiel!

"Wie bekannt, übt in organischen Verbindungen der Sauerstoff eine beschleunigende Wirkung auf fast sämmtliche Umwandlungen aus: Oxydation bei CH_4 schwerer als bei CH_3OH u. s. w.

"Um jedoch daraus werthvolle Beziehungen zu erhalten, ist genaue Kenntniss der Reactionsgeschwindigkeit Bedürfniss, und so gings zur Reactionsgeschwindigkeit, und es entstanden meine:

"Études de dynamique chimique.

---

[1] *Nature,* **86,** 85.

[2] *Ber. d. chem. Ges.,* **27,** 7, 1899.

"Reactionsgeschwindigkeit zunächst als Hauptzweck. Chemisches Gleichgewicht aber unmittelbar daneben. Wo doch das Gleichgewicht einerseits auf Gleichheit zweier entgegengesetzter Reactionen beruht und andererseits durch sine Verknüpfung mit der Thermodynamik eine feste Stütze gewährt.

"Sie sehen, un mein Zeil zu erreichen, kam ich stets weiter vom Ziel; das kommt öfter vor.

"Und weiter musste ich noch, denn die Gleichgewichtsfrage grenzt unmittelbar an das Affinitätsproblem, und so war ich angelangt bei der sehr einfachen Affinitätserscheinung, zunächst derjenigen, welche als Wasseranziehung sich äussert.

"Schon Mitscherlich hatte sich in seinem Lehrbuch der Chemie[8] die Frage gestellt nach der Grösse der Anziehung, welche das Krystallwasser im Glaubersalz zurückhält. Ein Maass dafür erblickte er in der verminderten Krystallwassertension:

"'Wenn man in die Barometerleere bei 9° Glaubersalz bringt, sinkt das Quecksilber um 2.5 Linien (5.45 mm.) durch Wasserdampfabgabe. Wasser selbst bewirkt dagegen eine Senkung von 4 Linien (8.72 mm.)—die Affinität des Natriumsulfats zu seinem Krystallwasser entspricht also der Differenz 1.5 Linien (3.27 mm.) d. i. etwa 1/16 Pfd. (1/32 kg.) pro Quadratzoll (2.615 qcm.).'

"Dieser Werth, 1/200 Atm., kam mir unerhört klein, hatte ich doch den Eindruck, dass auch die schwächsten chemischen Kräfte sehr gross sind, wie es mir z. B. auch aus Helmholtz' Faraday-Lecture hervorzugehen schien.

"So lag die Frage nahe, ob nicht noch in einfacheren Fällen diese Wasseranziehung in mehr directer Weise zu messen sei, und dann ist wohl die wässrige Lösung die einfachst denkbare, bedeutend einfacher als die Krystallwasserbindung.

"Mit dieser Frage auf den Lippen aus dem Laboratorium kommend, begegnete ich dann meinem Collegen de Vries und seiner Frau; der war gerade mit osmotischen Versuchen beschäftigt und machte mich mit Pfeffer's Bestimmungen bekannt."

Thus was Van't Hoff brought in contact with the measurements of osmotic pressure made by Pfeffer, and "with that insight into

---

[8] 4. Auflage, 565, 1844.

the real meaning of phenomena, and that foresight that enables one to see relations from very meager and imperfect data, which are characteristic of the highest genius. Van't Hoff saw from the few osmotic pressure measurements of Pfeffer the relations between solutions and gases—the laws of gas pressure applied to the osmotic pressure of solutions. In a word, we could deal with solutions as with gases."

This raises the question why is it so important to be able to deal with solutions as with gases? We know more about matter in the gaseous state than in any other state of aggregation. There we can apply the laws of thermodynamics. Van't Hoff applied the laws of thermodynamics to solutions and gave us for the first time a satisfactory thermodynamical theory of dilute solutions.

The question, however, still remains, why is a satisfactory, rigid theory of solutions of such importance? This becomes almost self-evident if we will consider what solutions mean for science in general.

The whole science of chemistry is hardly more than a branch of the science of solutions in the broader science of that term. Solutions are fundamental to nearly all of the biological sciences, experimental botany, zoology, physiology, pharmacology and pathology, and geology is as dependent upon solutions as chemistry.

In the light of these facts it is obvious that the science of solutions is fundamental for natural science in general, and the placing of solutions upon an exact, scientific basis might almost be regarded as the initial step towards rendering chemistry, geology and the biological sciences exact branches of science.

This is what Van't Hoff did in pointing out the relations between solutions and gases. He, however, did not stop here. The laws of gases apply to the osmotic pressures of solutions of nonelectrolytes only, *i. e.,* to solutions of substances which do not conduct the current. These laws do not apply to the osmotic pressures of a single electrolyte, and since all acids, bases and salts are electrolytes the gas laws do not apply to solutions of the most common substances in chemistry. Van't Hoff saw clearly these exceptions to the relations that he had discovered and pointed them out in his great paper above referred to. It is well known that it was to explain these exceptions that Arrhenius proposed the Theory of Electrolytic Dissociation.

We must not gather the impression that these three epoch-making contributions of Van't Hoff to science were the whole of his life-work. Quite the opposite is true. They were only his greatest work.

He made a number of other discoveries which would have rendered any less distinguished man famous. Take his paper on "Solid Solutions" published in volume five of the *Zeitschrift für physikalische Chemie.* Before this paper appeared we hardly ever thought of certain mixtures of solids having the properties of liquid solutions. Van't Hoff showed that such was the case, and thus opened up a new field of research.

After accepting the call to Berlin Van't Hoff took up an elaborate experimental problem—the study of the formation of the salt deposits from desiccated inland seas, such as at Stassfurth. He had previously studied the conditions of formation and decomposition of double salts, especially the conditions of temperature and concentration, and published the results in his "Vörlesungen über Bildung und Spaltung von Doppelsalzen" in 1897. The methods which were developed in this earlier work were applied to this complex geological problem with great success. The results of this investigation carried out from 1896 to 1909, partly with Meyerhoffer and partly with assistants, were published in two volumes, one in 1905 and the other in 1909, under the title "Zur Bildung der ozeanischen Salzablagerungen."

The writer, only a year and a half ago, heard Van't Hoff express the wish that this work might all be published in collected form, but he added that the means were lacking and he never lived to see this desire gratified.

The total number of papers published by Van't Hoff was very small. In addition to the books mentioned above should be added his "Vorlesungen über theoretische und physikalische Chemie," his "Theory of Solutions" and "Acht Vorträge über physikalische Chemie" being the lectures delivered at the University of Chicago in 1901.

A few words in conclusion in reference to Van't Hoff the man. The writer was fortunate enough to have worked in the laboratory of Van't Hoff in Amsterdam in the spring of 1894. His method of work was somewhat as follows: When interested in a problem he would gather together all the data bearing upon it, assign what he considered the proper value to each determination and then as the result of such comparisons draw his conclusions.

There has been a wide diversity of opinion as to whether Van't Hoff was, or was not, a great experimenter. While this is a matter of very little consequence, because there are many to experiment for every Van't Hoff to generalize, this difference in opinion arose I think as follows: Van't Hoff published very few experimental results until he took up the problem of the conditions under which the salt beds were deposited. This naturally led to the conclusion that he had done very little experimental work, while such was not the case. He published very little experimental work not because he did very little, but because of his attitude towards such work. He did not publish results simply for their own sake. If they confirmed or disproved some theory or generalization in which he was interested, they were published, otherwise not. He looked upon experimental results as valuable not in themselves, but just as they bore upon some generalization. During my student days in his laboratory Van't Hoff was working very intently and for long hours, but not a result that he obtained during that period was ever published. Personally, I regard Van't Hoff as a very skillful experimenter, but he looked upon experimental results in a different way from most men.

During the time at least that I was with Van't Hoff in Amsterdam, he impressed me as living under an intense strain. His every motion suggested one keyed to a high pitch. He had wonderful power of concentration, which reminded one of Rowland. In Berlin he seemed to have "let down" as we usually say. He was living on a much lower key, probably due in part to the disease which much too early ended his career.

When I saw him for the last time last summer a year in Berlin, it was obvious that he was losing in the fight against the disease.

Although suffering from shortness of breath, the same personal charm which characterized him in health was still there. He was one of the most simple, modest, honest, unostentatious and unselfish of men.

Van't Hoff enjoyed at least one blessing not given to all great men. He lived to see his work understood, recognized and appreciated. He was a member of most of the learned societies and academies in the world. He was elected a foreign member of the American Philosophical Society in 1904. He was elected a foreign member of the Royal Society in 1897. He received honorary degrees from a large number of the most distinguished universities, including Cambridge, Manchester, Heidelberg and Chicago. The German emperor conferred upon him the order "Pour le Mérite," and Van't Hoff received the first Nobel prize in chemistry in 1901. The University of Berlin at their centenary celebration of 1910 bestowed upon him a gold medal for his scientific researches (Die grosse golden Medallia zur Wissenschaft). According to recent advices the city of Rotterdam will create a Van't Hoff prize, to be awarded, like the Nobel Prize in Chemistry, for the best investigations in the field of chemistry.

A leading Berlin journal thus refers to Van't Hoff: "Ein ganz Grosser ist dieser Tage gestorben, der Chemiker Van't Hoff." This can scarcely be translated into English. We have no words strong enough to convey in good English the exact meaning of "Ein ganz Grosser."

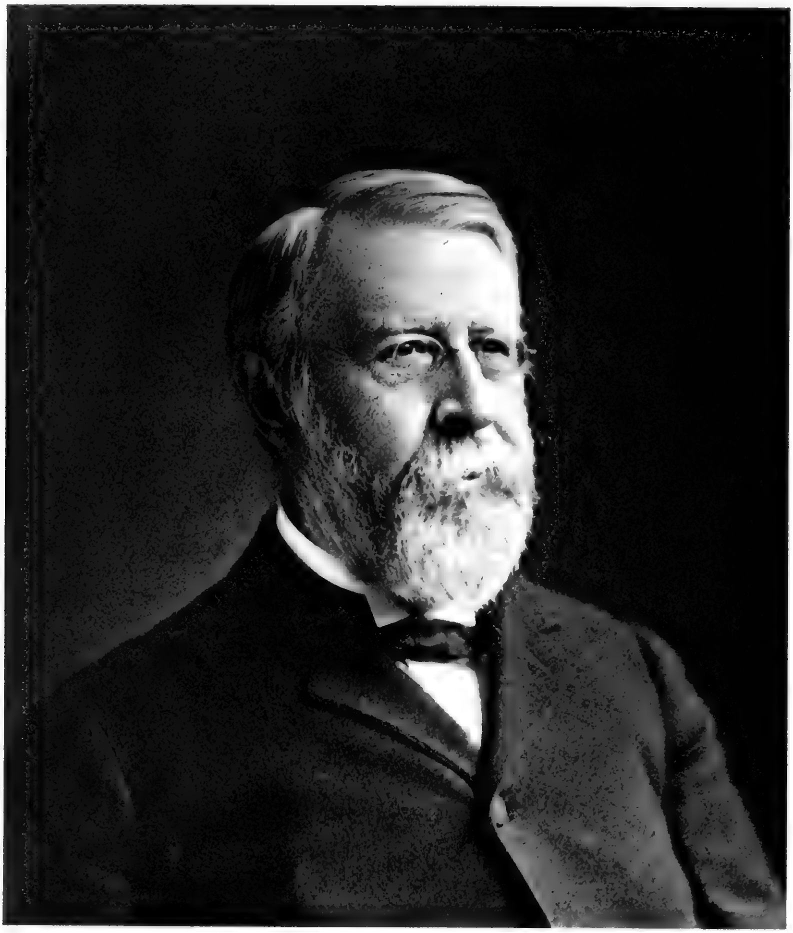
From the same journal I quote: "Van't Hoff hat uns wie ein neuer Kopernikus das Weltzystem Weiter begreiben gelehrt; Van't Hoff, ein geborener Holländer, tätig an der ersten deutschen Universität, gehörte mit seinem Wissen der ganzen Welt."

The accompanying photograph, which was recently sent me by Mrs. Van't Hoff, represents the great man as he appeared shortly before his death.

Thus lived and worked and died not only one of the very greatest men of science of his day, but of all time; a man whose name the history of science will reverence as it does that of Maxwell, Pasteur and Helmholtz.

Harry C. Jones.

Johns Hopkins University,
April 20, 1911.



George F. Barker.

GEORGE FREDERICK BARKER, M.D., Sc.D., LL.D.

(*Read May 5, 1911.*)

When the present writer was asked to prepare a memorial notice of Dr. George F. Barker, he felt some hesitancy, believing that some other and closer friend would be better fitted to undertake it. Still, there had grown to be a strong bond of friendship and sympathy between Dr. Barker and himself, increasing with the flight of years. Both began life as chemists, and both spent their earlier years in teaching that science, while maintaining all along an unbroken interest in its advance. Both were early trained in the mechanical workshop as constructors. Together, through many years, they witnessed, and themselves assisted in, that great extension of electrical science and its applications to the arts and industries, which have so greatly changed the conduct and convenience of modern life. Contemporaries they were, from its very inception. They were fellow delegates to international congresses of electricians, fellow members of several scientific and technical national societies, including the American Philosophical Society.

The writer may be pardoned for adding that in scientific tastes, there was many a bond of sympathy between them. The great advances in astro-physics, the researches in chemical physics, the wonderful discoveries in Roentgen rays, and the later epoch-making investigations in radio-activity, aroused in them a like interest. Above all, the friendship that had existed for so many years was of a kind which time could but ripen and increase. Dr. Barker was constant in his attendance on important scientific gatherings, and active in their work, and when a year or so before his death he was compelled to remain away owing to illness, his absence was at once noticed and regretted. His cordial greeting so warmly given and earnestly reciprocated was missed by his friends, who did not then know that the end of a most useful life had almost come, and that they were to see him no more. The writer, since the early seventies when Dr. Barker came to Philadelphia, had enjoyed his friendship and kindly appreciation, and his loss has left a gap never to be closed.

Nevertheless, he survived many of his associates, if only for a short time. In 1891 he headed a committee of five members of the National Academy of Sciences, appointed to report on the Henry Draper Medal, the others besides Dr. Barker being Wolcott Gibbs, Simon Newcomb, and C. A. Young, and Professor A. W. Wright, who is the only one who now survives. It was when Dr. Barker took the chair of physics in the University of Pennsylvania that the writer first had the privilege of his acquaintance. He was then among the faithful attendants upon the meetings of the American Philosophical Society, of which he became a member in 1873 and later, as is well known, served as an officer of the Society, acting as Secretary from 1877 to 1897, and also as Vice-President, between 1899 and 1908.

The record of the scientific work of Dr. Barker is distinguished by remarkable versatility. Moreover, his temper of mind was such that, while giving full worth to research in so-called pure science, he did not lose sight of the practical application of scientific principles as a most important factor in human progress. As a chemist he dealt ably with the purely theoretical side of chemical problems, yet was an eminent and trusted practical chemist. He gave a large fraction of his life's work to abstract physical science, but was ever keenly interested in engineering. Nor did he fail in extending this interest to other branches of science besides those which he had made peculiarly his own. We find him observing transits and solar eclipses, and making and recording observations in astronomy with the same ability and enthusiasm which he manifested in chemistry or physics. Even in his later years we find the same acute interest in his studies and work in Roentgen rays and radio-activity. It was also true that at all times he showed for the work of others a generous appreciation and interest, and when such work commended itself to him he was not slow in assisting towards its proper recognition.

As a friend and associate he was held in the highest personal regard by those who knew him, and his death brought to them a deep sense of irreparable personal loss. His earnest interest in science is attested by the numerous papers which form a partial record of his thought and work, while his fine personal traits remain to those who new him as a memory which will not soon fade.

In the early Philadelphia days Dr. Barker lectured frequently in public to large and appreciative audiences. He spared no pains to interest and instruct those who attended. Was there a new development or discovery in science, he strove to make his auditors appreciate it as he did. His mechanical and practical skill was of great aid in devising and arranging apt and often brilliant experimental illustrations, with which his popular lectures were crowded. It was the writer's privilege as a young man to be present on a number of such occasions at the Academy of Music, and he remembers vividly a lecture on electric lighting in which, as a unique feature, an early Gramme dynamo, secured from abroad by Dr. Barker, was driven by a gas engine, and used to furnish the electrical current. Before that time a large voltaic battery, almost prohibitive from its cumbersomeness and cost, would have been required to produce any semblance of the brilliant effects of the electric arc then shown. This was at a time when there was but little appreciation of the possible great future growth of electric lighting, and about two years before the invention of the incandescent lamp by Edison.

As a natural result, however, we find that Dr. Barker was not only, from the first, in personal touch with Edison in his pioneer work, but was one of those deeply interested in his early incandescent lamp development. More broadly it can be said that throughout his long service to science, Dr. Barker followed with special ardor the rapid and important growth of electrical science which has continued in the intervening years.

When the American Philosophical Society celebrated the 150th anniversary of its foundation, it was he who, under the title of "Electrical Progress Since 1743," studiously reviewed the advance of electrical science due to workers such as Franklin, Faraday, Hare, Henry and others. As another evidence not only of his deep interest in electrical advancement but of the early recognition of his foremost position at the time, he was appointed U. S. Commissioner to the Paris Electrical Exposition held in 1881, and an official delegate to the Electrical Congress then held. This was indeed a famous congress, by which much work of vital interest and importance was either accomplished or initiated, particularly concerning the nomenclature of the several electrical units, and the evaluation of standards; a work which has been continued by the subsequent international chambers of delegates at each of the important Congresses held since that time; the last being that at St. Louis in 1904.

At the Paris Exposition of 1881, which was the first exposition to be devoted to electricity solely, Dr. Barker was also made vice-president of the Jury of Awards, and in recognition of his services received the decoration of Commander de la Legion D'Honneur, an honor accorded to but few Americans. He was also a member of the U. S. Commission at the Electrical Congress held during the Philadelphia Electrical Exhibition of the Franklin Institute in 1884. He served also on the Jury of Awards at the World's Columbian Exposition in 1893.

During his long connection with the University of Pennsylvania, his services were valued very hightly by his associates; he was always helpful in the solution of the problems presented, and brought to bear a ripe judgment so as to decide upon the course to be taken in any case with fairness and calmness. His service to the community was none the less valuable. This was evident in his work while a member of the Board of Public Education, and his counsel in relation to such matters as water supply, illuminating gas and other municipal problems was much esteemed. Dr. Barker was one of the first to point out the fallacies and trickery of the famous Keely motor scheme, and to denounce it in the public prints. This scheme was actively exploited in the late seventies in Philadelphia. Needless is it to say that all the subsequent history of that long-lived fraud, and its final wind-up and exposure upon the death of Keely amply confirmed the entire justice of Dr. Barker's original denunciation of it.

As an author and writer he was, as in other things, most careful and conscientious. His text-book on "Elementary Chemistry" which first appeared in 1870 went through many editions, and was esteemed as embodying the most advanced thought, presented for the first time in our language thoroughly and systematically. No less an authority than Wolcott Gibbs commended the book highly.

Barker's "Physics, Advanced Course" published in 1892 as one of the American Science Series, was likewise an embodiment of the most modern views and met with a hearty reception. The treatment was mainly from the standpoint of energy and interchanges therein, and the ether of space was frankly assumed as the fundamental thing in dealing with all forms of radiation. From his habit of mind it was to be expected that in his scientific papers we should also find the results of the latest investigations. He was particular in giving a comprehensive bibliography of the subject, where it was possible. Thus, the valuable address delivered by him before the Chemical Society at Columbia University in March, 1903, is a model paper. Its subject was "Radio-Activity and Chemistry," and its great historical value will be understood when it is stated that to it is appended a bibliography of no less than ninety titles of papers by the leading investigators.

Some of his earlier papers and addressess assisted to a considerable degree in enforcing the great principles of conservation and correlation of forces, the discussion of which was carried on actively in the period between 1860 and 1880. Before those years the ideas of permanence of energy and the importance of energy interchanges had not received universal recognition or acceptance. It is now generally recognized that the indestructibility of energy is a more necessary postulate than the indestructibility of matter.

Dr. Barker's logical mind did not limit itself to the consideration of physical forces merely. He had taken the degree of doctor of medicine and it was natural that he should be led to consider the relations between the physical and so-called vital forces. We find his views expressed in a paper entitled "The Correlation of Vital and Physical Forces," published in 1875 by Van Nostrand, and also in his address as retiring president of the American Association for the Advancement of Science, at the Boston meeting in 1882. This latter address was entitled "Some Modern Aspects of the Life Question." He identifies vital force or energy as that stored in the complex protoplasm under physical and chemical conditions only; a view which more and more guides the biochemists of today in their researches. The Association address is an excellent example of clear logical scientific thinking. In it Dr. Barker drew ably from his rich fund of knowledge in physics, chemistry, biology, and kindred branches. He claims for science its true position as interpreter of the things which can be known, but points out clearly the limitations of this knowledge.

The writer may be pardoned making a few quotations:

> But the properties of bodies are only the characters by which we differentiate them. Two bodies having the same properties would only be two portions of the same substance. Because life, therefore, is unlike other properties of matter, it by no means follows that it is not a property of matter. No dictum is more absolute in science than the one which predicates properties upon constitution. To say that this property exhibited by protoplasm, marvellous and even unique though it be, is not a natural result of the constitution of matter itself, but is due to an unknown entity, a *tertium quid* which inhabits and controls it, is opposed to all scientific analogy and experience. To the statement of the vitalist that there is no evidence that life is a property of matter, we may reply with emphasis that there is not the slightest proof that it is not.

Again, at the close of the address, speaking of the dependence of all activity on the earth upon solar radiation:

> It is a beautiful conception of science which regards the energy which is manifested on the earth as having its origin in the sun. Pulsating awhile in the ether, the molecules of which fill the intervening space, this motion reaches our earth and communicates its tremor to the molecules of matter. Instantly all starts into life. The winds move, the waters rise and fall, the lightnings flash and the thunders roll, all as subdivisions of this received power.

And further:

> But all this energy is only a transitory possession. As the sunlight gilds the mountain top and then glances off into space, so this energy touches upon and beautifies our earth and then speeds on its way. What other worlds it reaches and vivifies, we may never know. Beyond the veil of the seen, science may not penetrate. But religion, more hopeful, seeks there for the new heavens and the new earth wherein shall be solved the problems of a higher life.

That the taking up of the teaching of physics by Dr. Barker did not prevent a continued interest in chemical studies is shown by his serving as the chairman of the sub-section of chemistry of the American Association in 1876, when he delivered a notable address on "The Molecule and the Atom." In this he points out the importance of considering the energy interchanges in chemical reactions, a matter which up to that time had been more or less neglected. Even as late as 1891, he was honored by being made president of the American Chemical Society, and delivered an address on the "Borderland between Physics and Chemistry," in which he dealt with the necessity for distinguishing the fundamental notion of "mass" from that of "weight." He further showed the rich harvest to be expected in the application of the kinetic theory to solutions, and concluded by a remarkably clear exposition of what was then known of the nature of electric forces in their relation to chemical actions. In these later years, it has indeed been the field of physical chemistry which has yielded an abundant harvest; the advances in it have been of the greatest importance to science. Indeed, the electro-physicist of today has even split the one time ultimate chemical atom into the more fundamental electrons. We must credit Dr. Barker with a keen appreciation of the directions in which further scientific advances were to be made.

None the less clear was his prevision of the future of applied science. In this connection the writer must content himself by quoting from a brief paper read at the Saratoga Meeting of the American Association for the Advancement of Science in 1879. The title of the paper was "On the Conversion of Mechanical energy into Heat by Dynamo Electric Machines." It must be remembered that at the time the paper was read no practical incandescent electric lamp had been made, and industrial electric development had scarcely begun even with the older arc light. The quotation reads:

> ·The amount of heat actually obtainable from dynamo electric machines when worked upon a commercial scale, is a question which in the near future is to become of very considerable commercial importance. That electric distribution, at least in our larger cities, is ultimately to be the source of light supply, is already placed beyond a peradventure. But far more than

> a simple light production is to be expected of this marvellous agent. It must not only light our houses, but it must warm them and must furnish mechanical power to them for a thousand petty operations now either done not at all, or done by manual labor. It must pump the water, raise the elevator, run the sewing machine, turn the spit, perform its part of the laundry service, and perhaps even assist in the cooking.

As before indicated, it was natural that the early work of Edison on the carbon filament lamp should greatly interest Dr. Barker. This lamp was not brought out until 1880, but we find that it was in that year tested as a light source by him, acting in collaboration with Professor Henry A. Rowland. The results were published in the *American Journal of Science*, and in the *Chemical News*. This account of early tests was followed in 1881 by papers dealing with the general subject of electric light photometry and by results of tests. Dr. Barker was chairman of the Sub-commission on Incandescent Lamps at the Paris Electrical Exposition in 1881, the other members being Wm. Crookes, E. Hagenbach, A. Kundt and E. Mascart. There is no need to make any comment on the standing of these men. Their work was in fact pioneer work done at the start of an industry which today has become one of enormous importance. As the Paris Exposition of 1881 was the first to be devoted entirely to electricity and its applications, it possessed a peculiar interest. The International Congress of Electricians held at the same time has been before referred to. Dr. Barker prepared a report on the proceedings of this congress.

As an example of painstaking and exhaustive work in another field, by a committee of which he was the head, may be mentioned the Report of the Committee of the National Academy of Sciences, on Glucose. The investigation was undertaken at the request of the Commissioner of Internal Revenue, as the information was needed as a guide to Congress in legislation concerning the manufacture and sale of glucose sugar. The other members of this committee were W. H. Brewer of Yale, C. F. Chandler of Columbia, Wolcott Gibbs of Harvard, and Ira Remsen of Johns Hopkins. The report covers more than 100 pages and must have represented a great amount of work. The subject is most thoroughly dealt with, and to the report is appended a complete bibliography.

A glance at the list of writings of Dr. Barker will show at once the great range of subjects about which he had informed himself, and upon which he was equipped to accomplish valuable scientific work. His alertness of mind, even a few years before his death, is plainly evident in his later papers on such subjects as radioactivity and intra-atomic energy in 1903, and before that time in his discussion of liquefied air, Roentgen rays, wireless telegraphy, monatomic gases, etc.

From the fact that he survived many of his contemporaries and associates in scientific work, it was natural that it should have fallen to his lot to prepare memoirs to some of these to whom he was most closely drawn. How well the work was done, with what conscientious care as to facts, and in what personal estimation he held these friends, can only be understood by a careful reading of these memoirs. Coupled with tender remembrances, they show a sincere admiration for the accomplishments, the discoveries and researches which he so ably describes. He spared no pains to bring out clearly, and often in detail, the things for which his friend was best known, his scientific methods and results, and throughout all this his keen personal interest and affectionate regard is manifested. This largeness of view and willingness to devote much time and effort to assist in securing that place in science which his friends' work seemed to him to deserve, appears to the writer as quite characteristic, and implies a most generous spirit. Examples of the truth of this will be found in his memoirs of John William Draper, and of his son, Dr. Henry Draper, read before the National Academy of Sciences, one in April, 1886, and the other in April, 1888. The elder Draper died early in 1882, and his son Henry late in the same year.

The splendid achievements of the elder Draper in science and philosophy are well known, and are most ably dealt with in the memoir referred to, while Dr. Barker's close personal relations with Henry Draper gave him excellent opportunities for obtaining the biographical material which he has incorporated in the memoirs. Henry Draper devoted himself to optical and astronomical science, constructing improved instruments and devising new methods. Of him Dr. Barker writes from the standpoint of a warm personal friend telling of a most fruitful career too soon closed; a scientist of the highest type stricken in the midst of his life work, with the brighter promises of his future unfulfilled.

A memoir on the eminent chemist and mineralogist, Dr. F. A. Genth, was read by him before the American Philosophical Society in 1901, and also before the National Academy of Sciences. For the latter society he also prepared an extended memoir of another noted chemist, Matthew Carey Lea; in which is given a careful, critical résumé of Lea's remarkable investigations and discoveries, chiefly in chemistry, optics and photography.

Dr. Barker was born July 14, 1835, at Charlestown, Mass., and attended school there, afterwards going to Berwick and Yarmouth academies in Maine, and to Lawrence Academy in Groton, Mass. When about sixteen he entered as apprentice the establishment of J. M. Wightman in Boston, a maker of philosophical instruments, and remained there five years. This apprentice period must have given a training very valuable to one who was afterward to so freely use scientific apparatus. After taking the degree of Bachelor of Philosophy at the Sheffield Scientific School, where he was also assistant to Professor Silliman, he entered the Harvard Medical School as a student and assistant in chemistry.

From this time his career as a science teacher and lecturer was continued with but little interruption. He received the degree of Doctor of Medicine from the Albany Medical College in 1863, having completed his medical course there while Acting Professor of Chemistry in the school. In 1864 he served as professor of natural sciences in the Western University of Pennsylvania, soon thereafter going to Yale as demonstrator in the medical department, where in 1867 he was appointed Professor of Physiological Chemistry and Toxicology, a chair which he held for six years, when he was appointed Professor of Physics in the University of Pennsylvania. Beginning in 1873 he continued this work as head of the department for twenty-seven years, becoming Professor Emeritus in 1900.

Before coming to Philadelphia he had acted as State Chemist in Connecticut, giving testimony in some noted cases of poisoning. He was also at times engaged as expert in patent cases, concerning electric lighting, telephones, batteries and chemical processes.

It was only to be expected that one so able and active as he was should become the recipient of many honors. Besides those already mentioned, including positions of honor on important commissions and the like, he was given the honorary degree of Doctor of Science by the University of Pennsylvania in 1898, and in the same year, the degree of Doctor of Laws from Allegheny College and also from McGill University. He was elected a member of the National Academy of Sciences in 1876 and later an honorary member of the Royal Institution of Great Britain. He was also a member of scientific societies in France and Germany. He attended many notable educational and scientific meetings as a delegate from societies or from the University which he so long served. He was assistant editor of the *American Journal of Science,* from 1868 to 1900, and contributed for a number of years accounts of the year's progress in physics, to the annual Smithsonian Reports.

Dr. Barker was married in 1861 to Mary M. Treadway, of New Haven, who survives him, and had five children, of whom three daughters are living. He was in his seventy-fifth year when he died in Philadelphia, last May.

Thus closed a life of great and varied service, one devoted to high ideals—a striking example of industry and achievement, a life spent in doing good. Thus ended the career of a lifelong student of science of an exceptional range of accomplishment, an excellent teacher, and a man of noblest aspirations. To those who knew him well there remains the vivid remembrance of his sterling worth and fine personal qualities.

A list of his principal publications and papers is appended.

ELIHU THOMSON.

SWAMPSCOTT, MASS.,
April, 1911.

BIBLIOGRAPHY.

1863. The Forces of Nature. An address delivered before the Chemical Society of Union College, July 22, 1863. Printed separately. Pamphlet 45 pp., Albany, N. Y., 1863.

1864. Account of the Casting of a Gigantic Rodman Gun at Pittsburg. *Am. J. Sci.,* **37,** (2), 296–301.

1864. Report of a Trial for Poisoning by Strychnia. *Am. J. Medical Sciences,* **43,** 399–480.

1866. Principles of Modern Chemistry. Part I. Chemical Philosophy. (With Benjamin Silliman.) 8vo, pp. 100, Theodore Bliss & Co., Philadelphia.

1867. On Silvering upon Glass. *Am. J. Sci.,* **43,** (2), 252.

1867. Formic versus Carbonous Acid. *Am. J. Sci.,* **44,** (2), 263–264.

1867. On Normal and Derived Acids. *Am. J. Sci.,* **44,** (2), 384–398.

1868. Notices of Papers in Physiological Chemistry. On Hoematoidin. On the Coloring Matter of the Yolk of the Egg. On the Chemical Constituents of the Supra-renal Capsules. On the Rational Formula of Urea. *Am. J. Sci.,* **46,** (2), 233–239.

1868–9. Notices of Papers in Physiological Chemistry. On Formation of Sugar in the Liver. *Am. J. Sci.,* **46,** (2), 379–390; **47,** 20–32, 258–270, 373–398; **48,** 49–64.

1870. A Textbook of Elementary Chemistry. Theoretical and Inorganic. Charles C. Chatfield & Co., New Haven, Conn.

1870. Abstract of the Second Series of Prof. Meissner's Researches on Electrized Oxygen. *Am. J. Sci.,* **50,** (2), 213–223.

1870. The Correlation of Vital and Physical Forces. A lecture delivered before the American Institute, New York, December 31, 1869. No. 2 University Series, pp. 36, C. C. Chatfield & Co. New Haven. Canadian Naturalist, **5,** 416–437. Les Mondes, **23,** 113–117, 151–157, 201–208. Half hours with Modern Scientists (Huxley, Barker, Stirling, Cope and Tyndall). Vol. 2, pp. 37–72. C. C. Chatfield, New Haven.

1871. On the Rational Formulas of the Oxides of Chlorine and of Oxides Analogously constituted. *Am. Chemist,* **2,** 1–4.

1871. On Molecular Classification. *Am. Chemist,* **1,** 359–360.

1871. A Textbook of Elementary Chemistry. Theoretical and Inorganic. Fifth edition. Charles C. Chatfield & Co., New Haven, Conn. (Translated into French, Japanese and Arabic.) 12mo, 342 pp.

1872. Acoustic Illustration of the Method by which Stellar Motions are Determined with the Spectroscope. (Account of address by Alfred M. Mayer.) *Am. Chem.,* **2,** 412–413.

1872. The Chemical Testimony in the Sherman Poisoning Case. *Am. Chem.,* **2,** 441–445.

1872. Note on the Spectrum of the Aurora. *Am. J. Sci.,* **2,** (3), 465–466. *Am. Chem.,* **2,** 248–249; *Nature,* **5,** 172–173.

1873. On the Spectrum of the Aurora of October 14, 1872. *Am. J. Sci.,* **5,** (3), 81–84.

1875. A New Vertical Lantern Galvanometer. *Jl. Franklin Inst.*, **69**, 431–437; *Am. J. Sci.*, **10**, (3), 207–212; *Proc. Am. Phil. Soc.*, **14**, 440–445; *Phil. Mag.*, **50**, 434–440. Carl Repertorium **12**, 46–52.

1876. The Molecule and the Atom. (An address to the Chemical Subsection of the American Association for the Advancement of Science at its Buffalo meeting.) Proc. Am. Assn. Ad. Sci., **25**, 85–107.

1876. Chemistry. Johnson's Universal Cyclopedia, Vol. I, pp. 901–906.

1877. Improved Method of Obtaining Metallic Spectra. Read before National Academy of Sciences, April, 1877. Rept. Nat. Acad. Sci. for 1883, p. 47.

1878. Magneto-electricity—III. Johnson's Universal Cyclopedia, Vol. IV, appendix, pp. 1616–1623.

1878. On a new Method of Measuring the Pitch of a Tuning-Fork. Proc. Am. Assn. Ad. Sci., **27**, 118–121.

1878. On the Microphone of Hughes. *Am. J. Sci.*, **16**, (3), 60–63.

1878. On the Results of the Spectroscopic Observation of the Solar Eclipse of July 29, 1878. (A report to Dr. Henry Draper, The Director.) Proc. Am. Assn. Ad. Sci., **27**, 113–118; *Am. J. Sci.*, **17**, (3), 121–125.

1878. On the total Solar Eclipse of July 29, 1878. *Proc. Am. Phil. Soc.*, **18**, 103–114.

1879. On Arago's Experiment showing the Magnetism of a Conductor. Read before National Academy of Sciences, October, 1879. Rept. Nat. Acad. Sci. for 1883, p. 51.

1879. Instructions for Disinfection. (George F. Barker, C. F. Chandler, Henry Draper, Edward G. Janeway, Ira Remsen, S. O. Vander Poel.) The National Board of Health, leaflet, 1879.

1879. On the Conversion of Mechanical Energy into Heat by Dynamo-Electric Machines. Proc. Am. Assn. Ad. Sci., **28**, 160–169.

1879. On a Curious Case of Crystallization of Canada Balsam. Proc. Am. Assn. Ad. Sci., **28**, 169–172.

1879. Note on J. C. Draper's paper "On the Presence of Dark Lines in the Solar Spectrum which correspond closely to the lines of the Spectrum of Oxygen." (A critical review.) *Am. J. Sci.*, **17**, (3), 162–166; *Spettrosc. Ital. Mem.*, **8**, 16–20.

1880. Report on the Manly Telegraph Cable. Pamphlet 8vo, 15 pp., Philadelphia.

1880. On Condensers for Currents of High Potential. Read before National Academy of Sciences, November, 1880. Rept. Nat. Acad. Sci. for 1883, p. 53.

1880. On the Efficiency of Edison's Electric Light (with H. W. Rowland). *Am. J. Sci.*, **19**, (3), 337–339; *Chem. News*, **41**, 200–201.

1880. Report on the Contamination of the Water of the Schuylkill River. Pamphlet, 8vo, 15 pp., Philadelphia, Pa., 1880.

1881. Some Modern Aspects of the Life-Question. Address as retiring President at the Boston meeting of the American Association for the Advancement of Science in 1880. Proc. Am. Assn. Ad. Sci., **29**, 1–30; *Revue scientif.*, **4**, 225–235, 1882.

1881. On the International Congress of Electricians at Paris. *Am. J. Sci.*, **22**, (3), 395–396.

1881. On Electric Light Photometry. Read before National Academy of Sciences. April 1881. Rept. Nat. Acad. Sci. for 1883, p. 53.

1881. On the Condenser Method of Measuring High Tension Currents. Read before National Academy of Sciences, April, 1881. Rept. Nat. Acad. Sci. for 1883, p. 53.

1881. On the Carbon Lamp-fiber in the Thermo balance. Read before National Academy of Sciences, April, 1881. Rept. Nat. Acad. Sci. for 1883, p. 53.

1881. On Incandescent Lights. Read before National Academy of Sciences, April, 1881. Rept. Nat. Acad. Sci. for 1883, p. 53.

1881. Physics (An Account of Recent Progress). Ann. Rept. Smith. Inst. for 1879–80, 235–288.

1881. Chemistry (An Account of Recent Progress). Ann. Rept. Smith. Inst. for 1879–80, pp. 289–297.

1881. On Mascart's Electrometer and Its Use as a Meteorological Instrument. Read before the National Academy of Sciences, November, 1881. Rept. Nat. Acad. Sci. for 1883, p. 54.

1881. An Account of Recent Progress in Physics and Chemistry (For the Years 1879 and 1880). From the Smithsonian Report for 1880. Pamphlet, 8vo, pp. 2 + 63.

1882. On the Results of the Incandescent Lamp Tests at the Paris Exhibition. Read before National Academy of Sciences, April, 1882. Rept. Nat. Acad. Sci for 1883, p. 54.

1882. On an Improved Form of Standard Daniell Cell. Read before National Academy of Sciences, November, 1882. Rept. Nat. Acad. Sci. for 1883, p. 55.

1882. Report of the Sub-Commission on Incandescent Lamps at the International Exhibition of Electricity, Paris, 1881. (George F. Barker, William Crookes, Ed. Hagenbach, A. Kundt, E. Mascart.) Pamphlet, 8vo, 28 pp., New York.

1882. On Secondary Batteries. Proc. Am. Assn. Ad. Sci., **31**, 207–217; *Chem. News*, **47**, 196–199, 1883.

1882. Henry Draper. A minute prepared as Secretary of the American Philosophical Society. *Proc. Am. Phil. Soc.*, **20**, 656–662, December, 1882.

1883. Physics (An Account of Recent Progress). Ann. Rept. Smith. Inst. for 1880–81, pp. 333–379.

1883. Chemistry (An Account of Recent Progress). Ann. Rept. Smith. Inst. for 1880–81, pp. 381–390.

1883. An Account of Progress in Physics and Chemistry in the year 1881. From the Smithsonian Report for 1881. Pamphlet, 8vo, pp. 2 + 58.

1883. The Future of American Science. (Anon.) *Science*, **1**, 1–3.

1883. Henry Draper. A Biographical Notice. *Am. J. Sci.*, **25**, (3), 89–95.

1883. On the Variability of the Law of Definite Proportions. *Am. J. Sci.*, **26**, (3), 63–67.

1883. On the Measurement of Electromotive Force. *Proc. Am. Phil. Soc.*, **21**, 649–655.

1883. Report of Committee on Methylated Spirits. (Ira Remsen, C. F. Chandler, George F. Barker.) Rept. Nat. Acad. Sci. for 1883, pp. 57–63.

1883. Report of Committee on Glucose. (George F. Barker, William H. Brewer, Wolcott Gibbs, Charles F. Chandler, Ira Remsen.) Rept. Nat. Acad. Sci. for 1883, pp. 65–143.

1883. Efficiency of Storage Batteries. Read before National Academy of Sciences, April, 1883. Rept. Nat. Acad. Sci. for 1883, p. 56.

1884. On a Lantern Voltameter. Read before the National Academy of Sciences, April, 1884. Rept. Nat. Acad. Sci. for 1884, p. 6.

1884. On the Fritts Selenium Cell. Read before the National Academy of Sciences, April, 1884. Rept. Nat. Acad. Sci. for 1884, p. 6.

1884. Physics (An Account of Progress in the year 1882). Ann. Rept. Smith. Inst. for 1881–82, pp. 459–508. Separate, 1883. 8vo. pp. 2 + 50.

1884. Report on Glucose (Committee of Nat. Acad. Sci. Geo. F. Barker, Chairman). Govt. Print. Off., Pamphlet, 8vo, 108 pp., Wash.

1884. The British Association at Montreal. *Am. J. Sci.*, **28**, (3), 300–303.

1884. The American Association at Philadelphia. *Am. J. Sci.*, **28**, (3), 303–307.

1884. The National Conference of Electricians at Philadelphia. *Am. J. Sci.*, **28**, (3), 386–390.

1884. Shall the Ammonium Theory be Applied to Alkaloidal Salts? (Symposium.) *Weekly Drug News and Prices Current*, **9**, 705–706.

1885. Physics (An Account of Progress in the Year 1883). Ann. Rept. Smith. Inst. for 1882–83. pp. 571–628. Separate, 1884. 8vo. pp. 2 + 52.

1885. On the Use of Carbon Bisulphide in Prisms. Being an account of Experiments made by the late Dr. Henry Draper of New York. *Am. J. Sci.*, **29**, (3), 269–277.

1885. Report of Committee on Philosophical and Scientific Apparatus. (George J. Brush, Wolcott Gibbs, Samuel H. Scudder, Simon Newcomb, George F. Barker.) Rept. of Nat. Acad. Sci. for 1884, pp. 65–67.

1885. Physics (An Account of Progress in the year 1884). Ann. Rept. Smith. Inst. for 1883–84, pp. 433–489. Separate, 1885. 8vo. pp. 2 + 57

1886. Memoir of John William Draper, 1811–1882. Read before Nat. Acad. of Sci., April, 1886. Biographical Memoirs. Nat. Acad. Sci., **2**, 349–388.

1886. Protection of (Philadelphia) Public Buildings (City Hall) from Lightning. Rept. Commissioners for the Erection of "The Public Buildings," pp. 25–28, Philadelphia, 1886.

1886. Physics (An Account of Progress in the Year 1885). Ann. Rept. Smith. Inst. 1884–85, pp. 577–636. Separate, 1886. 8vo. pp. 2 + 60.

1886. Telephone. Johnson's (revised) Universal Cyclopedia, **7**, 736–737.

1887. On the Henry Draper Memorial Photographs of Stellar Spectra. *Proc. Am. Phil. Soc.*, **24**, 166–171.

1889. Physics in 1886 (An Account of Progress in the Year 1886). Ann. Rept. Smith. Inst. for 1886–87, pp. 327–386. Separate, 1889, 8vo, pp. 60.

1891. On Zinc Storage Batteries. Read before the National Academy of Sciences, November, 1889. Report Nat. Acad. Sci. for 1889, p. 12.

1891. Report of Committee appointed by the National Academy of Sciences on the Henry Draper Medal. (George F. Barker, Wolcott Gibbs, Simon Newcomb, Arthur W. Wright, C. A. Young.) Rept. Nat. Acad. Sci. for 1889, pp. 53–63.

1891. A Textbook of Elementary Chemistry, Theoretical and Inorganic. Revised and Enlarged. 8vo, 348 pp. John P. Morton & Co., Louisville, Ky.

1891. The Borderland between Physics and Chemistry. Address as President of the American Chemical Society. *J. Am. Chem. Soc.*, **13**, 13–29.

1891. The Physiology of Manual Training. An address at the Opening of the Williamson Free School of Mechanical Trades. The Williamson Free School of Mechanical Trades. Pp. 61–69, Philadelphia, 1891.

1891. The Modern View of Energy. Syllabus of a Course of Six Lectures. University Extension Lectures of Am. Soc. for Ex. of Univ. Teaching. Series A, No. 30, pp. 16, 1891.

1892. A Textbook on Physics. Advanced Course. Lg. 8vo, 902 pp. (Ten editions.) American Science Series, Henry Holt & Co., N. Y.

1893. On the Storage of Electrical Energy. *N. Y. Independent*, **45**, 280–281.

1894. Electrical Progress since 1743. A Paper read before the American Philosophical Society on the Occasion of the Celebration of the 150th Anniversary of its Foundation, May 27, 1893. *Proc. Am. Phil. Soc.*, **32**, 104–154.

1895. Memoir of Henry Draper. Read before Nat. Acad. of Sci. April, 1888. Biographical Memoirs Nat. Acad. Sci., **3**, 81–139.

1897. Sketch of Moses Gerrish Farmer. An address before the American Institute of Electrical Engineers at Greenacre, Me., July 20th, 1897. *Trans. Am. Inst. Electrical Engineers*, **14**, 414–417.

1897. The American Philosophical Society. A paper read at the Greenacre Conference, July, 1897. *Electrical Eng.*, **24**, 90.

1898. Liquefied Air. A lecture delivered before the Scientific Association of Johns Hopkins University, March 24, 1898. *Balt. Am.*, March 25.

1898. Address on Alexander Dallas Bache, made on Presentation of Portrait to the Bache Public School of Philadelphia, April 13, 1898. Presentation of the Portrait of Professor Alexander Dallas Bache, pamphlet, pp. 12–17, Philadelphia.

1898. Röntgen Rays. Memoirs by Röntgen, Stokes and J. J. Thomson. Translated and edited by George F. Barker. Sm. 8vo, 82 pp. Scientific Memoir Series. Harper and Brothers, New York.

1898. Liquid Air. A Lecture delivered before the Friends Institute Lyceum, Philadelphia, Pa. Sci. Am. Sup., Sept. 24, pp. 19021–19022, 19036–19037. *The Chautauquan*, **27**, 526–529.

1899. Wireless Telegraphy through Scientific Eyes. *Lippincott's Mag.*, **64**, 301–311.

1899. The Hydrogen Vacua of Dewar. Read before the National Academy of Sciences. Rept. Nat. Acad. Sci. for 1899, p. 13.

1899. Air as a Liquid. *N. Y. Independent,* May 25, pp. 1419–1422.

1901. Memoir of Frederick Augustus Genth. Read before the American Philosophical Society. December 6, 1901. *Proc. Am. Phil. Soc.,* **40** (Obituary Notices), X–XXII.

1901. The Monatomic Gases. Read before the National Academy, November, 1901. Rept. Nat. Acad. Sci. for 1901, p. 16.

1901. On the Newer Forms of Incandescent Electric Lamps. Read before the National Academy, November, 1901. Rept. Nat. Acad. Sci. for 1901, p. 16.

1902. Biographical Memoir of Frederick Augustus Genth, 1820–1893. Read before the National Academy of Sciences, November 12, 1901. Biographical Memoirs Nat. Acad. Sci., Vol. 5, 202–231.

1903. Radioactivity and Chemistry. An address delivered before the Chemical Society of Columbia University, March 19, 1903. *School of Mines Quarterly,* **24,** 267–302.

1903. On the Radioactivity of Thorium Minerals. Read before the National Academy of Sciences, April, 1903. *Am. J. Sci.,* **16,** (4), 161–168.

1903. Intratomic Energy; the Unmeasurable Force of Inanimate Nature. *N. Y. Sun,* p. 6, July 12.

1904. On Radioactivity and Autoluminescence. Read before the National Academy of Sciences, April, 1904. Rept. Nat. Acad. Sci. for 1904, p. 13.

1905. Biographical Memoir of Matthew Carey Lea, 1823–1897. Read before the National Academy of Sciences, April, 1903. Biographical Memoirs Nat. Acad. Sci., Vol. 5, 154–208.

MINUTES.

MINUTES.

Stated Meeting, January 6, 1911.

William W. Keen, M.D., LL.D., President, in the Chair.

The decease was announced of:

Prof. Charles Otis Whitman, at Chicago, on December 6, 1910, æt. 68.

Hon. Joel Cook, at Philadelphia, on December 15, 1910, æt. 68.

M. Georges Bertin, at Paris, on December 22, 1910, æt. 63.

Prof. Charles E. Munroe, of Washington, read a paper on "The Investigation of Explosives at the Pittsburgh Testing Station," which was discussed by Dr. Holland, Mr. d'Invilliers, Dr. Chance, Prof. Keller and Mr. Jayne.

The Judges of the Annual Election of Officers and Councillors held on this day between the hours of two and five in the afternoon reported that the following named persons were elected, according to the Laws, Regulations and Ordinances of the Society, to be the officers for the ensuing year.

President:

William W. Keen.

Vice-Presidents:

William B. Scott, Albert A. Michelson, Edward C. Pickering.

Secretaries:

I. Minis Hays, James W. Holland,
Amos P. Brown, Arthur W. Goodspeed,

Curators:

Charles L. Doolittle, William P. Wilson, Leslie W. Miller.

Treasurer:

Henry La Barre Jayne.

Councillors:

(To serve for three years.)

Henry F. Osborn,	Edward W. Morley,
Joseph G. Rosengarten,	Henry H. Donaldson.

Stated Meeting, February 3, 1911.

William W. Keen, M.D., LL.D., President, in the Chair.

Prof. William B. Scott read a paper on "The Mammals, Past and Present, of the Western Hemisphere," which was discussed by Mr. Willcox and Dr. Jastrow.

Stated Meeting, March 3, 1911.

William W. Keen, M.D., LL.D., President, in the Chair.

An invitation was received from the Royal Frederic University to be represented by a delegate at the Centennial of the founding of the University, to be celebrated at Christiania on September 5 and 6, 1911.

The decease was announced of:

Richard Lewis Ashhurst, at Atlantic City, on January 30, 1911, æt. 72.

Jakob Heinrich Van 't Hoff, at Berlin, on March 2, 1911, æt. 59.

Prof. F. M. Jaeger, of the University of Gröningen, read a paper on "Fluid Crystals and Bi-refringent Liquids," which was discussed by Prof. Learned, Prof. Doolittle and Prof. Goodspeed.

Stated Meeting, April 7, 1911.

William W. Keen, M.D., LL.D., President, in the Chair.

The following invitations were received:

From the Verein für Naturkunde zu Cassel, to be represented at the 75th anniversary of its founding, on April 23, 1911.

From the Société de Roubaix, to be represented at the 30th Congrès National des Sociétés Françaises de Géographie to be opened at Roubaix on July 29, 1911.

The decease was announced of:

Benjamin Chew Tilghman, at Philadelphia, on March 6, 1911, æt. 49.

Heber S. Thompson, at Pottsville, Pa., on March 9, 1911, æt. 70.

Henry Pickering Bowditch, M.D., at Jamaica Plain, Mass., on March 13, 1911, æt. 71.

Samuel Franklin Emmons, at Washington, on March 28, 1911, æt. 70.

Rear-Admiral George W. Melville read a paper on "A Century of Steam Navigation," which was discussed by Mr. Willcox, Prof. Doolittle and Mr. Jayne.

Mr. Joseph Willcox offered some remarks on "Remains of Glyptodon found in Florida," and also on "Teeth of Zeuglodon from Wilmington, N. C."

General Meeting, April 20, 21, and 22, 1911.

Thursday, April 20. Opening Session—2 o'clock.

William W. Keen, M.D., LL.D., President, in the Chair.

The decease was announced of:

Charles A. Oliver, M.D., at Philadelphia, on April 8, 1911, æt. 56.

Henry Pemberton, at Philadelphia, on April 11, 1911, æt. 84.

The following papers were read:

"Notes on Cannon: Fourteenth and Fifteenth Centuries," by Charles E. Dana, Philadelphia; discussed by Dr. Keen.

"Rise in the Cost of Living in the Twelfth Century and its Effects," by Dana C. Munro, Professor of European History, University of Wisconsin.

"Elizabethan Physicians," by Felix E. Schelling, Professor of English Literature, University of Pennsylvania.

"Moreau de St. Méry: One of Our Forgotten Members," by J. G. Rosengarten, Philadelphia; discussed by Prof. Cleveland Abbe and Mr. Sachse.

"The Relations of the United States to International Arbitration," by Hon. Charlemagne Tower, Philadelphia.

"The Early German Immigrant and the Immigration Question of To-day," by M. D. Learned, Professor of German, University of Pennsylvania; discussed by Prof. Henry F. Osborn.

"On the Solution of Linear Differential Equations by Successive Approximations," by Preston A. Lambert, Professor of Mathematics, Lehigh University, Bethlehem.

"Generalizations of the Problem of Several Bodies, its Inversion, and an Introductory Account of Recent Progress in its Solution," by Edgar Odell Lovett, President of the Rice Institute, Houston, Texas.

"On the Totality of the Substitutions on *n* Letters which are Commutative with Every Substitution of a Given Group on the Same Letters," by Geo. A. Miller, Professor of Mathematics, University of Illinois. (Introduced by Prof. C. L. Doolittle.)

"Report on the Second Conference of the International Catalogue of Scientific Literature," by Leonard C. Gunnell, of the Smithsonian Institution (introduced by Dr. Cyrus Adler); discussed by Prof. Henry F. Osborn.

Friday, April 21. Executive Session—10 o'clock.

William W. Keen, M.D., LL.D., President, in the Chair.

Mr. Charles Francis Brush, a recently elected member, signed the Laws and was admitted into the Society.

The Proceedings of the Officers and Council were submitted.

Morning Session—10.05 o'clock.

Edward C. Pickering, LL.D., F.R.S., Vice-President, in the Chair.

The following papers were read:

"Study of the Tertiary Floras of Atlantic and Gulf Coastal Plain," by Edward W. Berry, Associate in Palæontology, Johns Hopkins University (introduced by Dr. J. W. Harshberger); discussed by Prof. Harshberger and Sir John Murray.

"The Desert Group Nolineæ," by William Trelease, Director of the Missouri Botanical Garden, St. Louis.

"The Blueberry and Its Relation to Acid Soils," by Frederick V. Coville, Botanist U. S. Department of Agriculture (introduced by Dr. J. W. Harshberger); discussed by Dr. Harshberger and Dr. W. P. Wilson.

"The New Cosmogony."

"The Extension of the Solar System beyond Neptune and the Connection Existing Between Planets and Comets."

"The Secular Effects of the Increase of the Sun's Mass upon the Mean Motions, Major Axes and Eccentricities of the Orbits of the Planets," by T. J. J. See, U. S. Naval Observatory, Mare Island, Cal.

"Extension of Our Knowledge of the Atmosphere," by A. Lawrence Rotch, Professor of Meteorology, Harvard University (introduced by Prof. W. M. Davis); discussed by Prof. W. M. Davis.

"175 Parabolic Orbits and other Results deduced from over 6200 Meteors," by C. P. Olivier, of Charlottesville, Va. (Introduced by Prof. Cleveland Abbe.)

"The Solar Constants of Radiation," by Charles G. Abbot, Director of the Astrophysical Observatory, Smithsonian Institution, Washington. (Introduced by Dr. Charles D. Walcott.)

"Some Curiosities in the Motions of Asteroids," by Ernest W. Brown, Professor of Mathematics, Yale University.

"Spectroscopic Proof of the Repulsion by the Sun of Gaseous Molecules in the Tail of Halley's Comet," by Percival Lowell, Director of Lowell Observatory, Flagstaff, Ariz.

"Self-Luminous Night Haze," by Edward E. Barnard, Astronomer, Yerkes Observatory, Williams Bay, Wis.

"Some Peculiarities in the Motions of the Stars," by W. W. Campbell, Director of Lick Observatory, Mt. Hamilton, Cal.; discussed by Dr. See, Prof. Pickering and Dr. C. G. Abbot.

Afternoon Session—2 o'clock.

William W. Keen, M.D., LL.D., President, in the Chair.

"Shore and Off-Shore Deposits of Silurian Age in Pennsylvania," by Gilbert Van Ingen Assistant Professor of Geology, Princeton University (introduced by Prof. W. B. Scott); discussed by Prof. W. M. Davis.

"Tertiary Formations of Northwestern Wyoming," by William J. Sinclair, Instructor in Geology, Princeton University. (Introduced by Prof. William B. Scott.)

"On a New Phytosaur from the Triassic of Pennsylvania," by William B. Scott, Professor of Geology and Palæontology, Princeton University.

"Alimentation of Existing Continental Glaciers," by William H. Hobbs, Professor of Geology, University of Michigan, Ann Arbor.

"On the Formation of Coal Beds," by J. J. Stevenson, Emeritus Professor of Geology, University of the City of New York.

"Problems in Petrology," by Joseph P. Iddings, U. S. Geological Survey, Washington. (Introduced by Dr. Keen.)

"Front Range of the Rocky Mountains in Colorado," by William Morris Davis, Professor of Geology, Harvard University, Cambridge.

"Supposed Recent Subsidence of the Atlantic Coast," by Douglas W. Johnson, Assistant Professor of Physiography, Harvard University (introduced by Prof. Wm. Morris Davis); discussed by Dr. See, Mr. Willcox and Prof. H. F. Reid.

"Relation of Isostasy to the Elevation of Mountains," by Harry Fielding Reid, Professor of Geological Physics, Johns Hopkins University; discussed by Prof. Iddings, Prof. W. M. Davis, Dr. See and Prof. Reid.

"The Transpiration of Air Through a Partition of Water."

"Elliptic Interference with Reflecting Gratings," by Carl Barus, Professor of Physics, Brown University, Providence.

"A Phenomenon of Vision."

"On Disruptive Discharges of Electricity through a Flame," by Francis E. Nipher, Professor of Physics, Washington University, St. Louis; discussed by Prof. J. McKeen Cattell.

"The High Voltage Corona in Air," by John B. Whitehead, Professor of Applied Electricity, Johns Hopkins University. (Introduced by Prof. Joseph S. Ames.)

"Nature and Causes of Embryonic Differentiation," by Edwin G. Conklin, Professor of Zoölogy, Princeton University.

"The Origin and Significance of the Primitive Nervous System," by George H. Parker, Professor of Zoölogy, Harvard University. (Introduced by Dr. H. H. Donaldson.)

Evening Session.

Prof. Svante Auguste Arrhenius, of Stockholm, gave an illustrated lecture on

"The Physical Conditions of the Planet Mars."

Saturday April 22. Executive Session—9.30 o'clock.

William W. Keen, M.D., LL.D., President, in the Chair.

Pending nominations for membership were read and the polls were opened. Secretaries Holland and Brown, tellers, subsequently reported that the following nominees had been elected to membership:

Residents of the United States.

George A. Barton, A.M., Ph.D., Bryn Mawr, Pa.
Bertram Borden Boltwood, Ph.D., New Haven, Conn.
Lewis Boss, A.M., LL.D., Albany, N. Y.
John Mason Clarke, Ph.D., LL.D., Albany, N. Y.
W. M. Late Coplin, M.D., Philadelphia.
John Dewey, Ph.D., LL.D., New York City.
Leland Ossian Howard, Ph.D., Washington, D. C.
Joseph P. Iddings, Sc.D. (Yale, 1907), Chicago.

Alba B. Johnson, Rosemont, Pa.

Arthur Amos Noyes, Ph.D., Sc.D., LL.D., Boston.

George Howard Parker, S.D., Cambridge, Mass.

A. Lawrence Rotch, S.B., A.M. (Hon. Harvard), Boston.

Leo S. Rowe, Ph.D., LL.D., Philadelphia.

William T. Sedgwick, Ph.D., Hon. Sc.D. (Yale, 1909), Brookline, Mass.

Augustus Trowbridge, Ph.D. (Berlin), Princeton, N. J.

Foreign Residents.

Svante Auguste Arrhenius, Stockholm.

Jean Baptiste Edouarde Bornet, Paris.

Sir John Murray, K.C.B., F.R.S., LL.D., Sc.D., Edinburgh.

Morning Session—10 o'clock.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

"Taking a Census of the Chemical Industries," by Charles E. Munroe, Professor of Chemistry, George Washington University, Washington.

"Some Recent Results in Connection with the Power of Solutions to Absorb Light," by Harry C. Jones, Professor of Physical Chemistry, Johns Hopkins University.

"The Properties of Salt Solutions in Relation to the Ionic Theory," by Arthur A. Noyes, Professor of Theoretical Chemistry, Massachusetts Institute of Technology (introduced by Dr. James W. Holland); discussed by Prof. Arrhenius.

"The Atomic Weight of Vanadium," by Gustavus Hinrichs, of St. Louis. (Introduced by Prof. Amos P. Brown.)

"Quinazolone Azo Dyestuffs: A new Group of Azo Dyes," by Marston Taylor Bogert, Head of School of Chemistry, Columbia University, New York.

"The Secretion of the Adrenal Glands During Emotional Excitement," by Walter B. Cannon, Professor of Physiology, Harvard University; discussed by Dr. Keen and Prof. Cattell.

"Phylogenetic Association in Relation to the Emotions," by

George Crile, Professor of Clinical Surgery, Western Reserve University, Cleveland; discussed by Dr. Keen.

"On Coagulation of the Blood," by William H. Howell, Professor of Physiology, Johns Hopkins University; discussed by Dr. Keen and Prof. Pickering.

"Abnormal Forms of Life and Their Application," by Alexis Carrel, Associate Member of the Rockefeller Institute for Medical Research, New York; discussed by Dr. Leo Loeb, Prof. Minot and Dr. Keen.

"The Cyclic Changes in the Mammalian Ovary," by Leo Loeb, Director of the Pathological Department, St. Louis Skin and Cancer Hospital.

"The Origin of the Porpoises of the Family Delphinidæ," by F. W. True, Head Curator, Department of Biology, U. S. National Museum, Washington, D. C.

"Helios and Saturn," by Morris Jastrow, Jr., Professor of Semitic Languages, University of Pennsylvania.

"On the Religion of the Sikhs," by Maurice Bloomfield, Professor of Sanskrit and Comparative Philology, Johns Hopkins University.

"An Ancient Protest Against the Curse on Eve," by Paul Haupt, Professor of Shemitic Languages, Johns Hopkins University.

"Theories of Totemism," by E. Washburn Hopkins, Professor of Sanskrit, Yale University.

"The New History," by James H. Robinson, Professor of History, Columbia University, New York (introduced by Prof. Cheyney); discussed by Prof. Bloomfield and Haupt.

"Eggettes: a Conservation of Fuel," by Robert P. Field, of Philadelphia; discussed by Prof. Houston and Dr. See.

Afternoon Session—2 o'clock.

William W. Keen, M.D., LL.D., President, in the Chair.

Prof. Leslie W. Miller, on behalf of the subscribers presented a portrait of Thomas Hopkinson, first President of the American Philosophical Society.

Symposium on Modern Views of Matter and Electricity.

"The Fundamental Principles," by Daniel F. Comstock, Assistant Professor of Theoretical Physics, Massachusetts Institute of Technology. (Introduced by Prof. W. F. Magie.)

"Radioactivity," by Bertram B. Boltwood, Professor of Radio-Chemistry, Yale University.

"Dynamical Effects of Aggregates of Electrons," by Owen W. Richardson, Professor of Physics, Princeton University.

"The Constitution of the Atom," by H. A. Wilson, F.R.S., Professor of Physics, McGill University, Montreal (introduced by Prof. Magie); discussed by Profs. Magie, Webster, Heyl, Arrhenius, Pickering and C. L. Doolittle.

Prof. Bertram B. Boltwood.
Prof. Arthur Amos Noyes.
Prof. George Howard Parker.
Mr. A. Lawrence Rotch.
Prof. Svante A. Arrhenius.
Sir John Murray, K.C.B.

Newly-elected members signed the Laws and were admitted into the Society.

An obituary notice of Prof. Jakob H. van't Hoff was read by Harry C. Jones, Professor of Physical Chemistry, Johns Hopkins University.

Special Meeting, May 2, 1911.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

Prof. George A. Barton.
Dr. W. M. Late Coplin.
Mr. Alba B. Johnson.
Prof. Leo S. Rowe.

Newly-elected members signed the laws and were admitted into the Society.

Stated Meeting, May 5, 1911.

William W. Keen, M.D., LL.D., President, in the Chair.

Letters accepting membership were read from:

George A. Barton, A.M., Ph.D., Bryn Mawr, Pa.
Bertram Borden Boltwood, Ph.D., New Haven, Conn.
John Mason Clarke, Ph.D., LL.D., Albany, N. Y.
W. M. Late Coplin, M.D., Philadelphia.
John Dewey, Ph.D., LL.D., New York City.
Leland Ossian Howard, Ph.D., Washington, D. C.
Joseph P. Iddings, Sc.D. (Yale, 1907), Chicago.
Alba B. Johnson, Rosemont, Pa.
Arthur Amos Noyes, Ph.D., Sc.D., LL.D., Boston.
George Howard Parker, S.D., Cambridge, Mass.
A. Lawrence Rotch, S.B., A.M. (Hon. Harvard), Boston.
Leo S. Rowe, Ph.D., LL.D., Philadelphia.
William T. Sedgwick, Ph.D., Hon. Sc.D. (Yale, 1909), Brookline, Mass.
Augustus Trowbridge, Ph.D. (Berlin), Princeton, N. J.
Svante Auguste Arrhenius, Stockholm.
Sir John Murray, K.C.B., F.R.S., LL.D., Sc.D., Edinburgh.

The following papers were read:

Obituary notice of Prof. George F. Barker, by Prof. Elihu Thomson, of Swampscott, Mass.

"The Lignite Coals of the United States and their Utilization," by Joseph A. Holmes, Director of the Bureau of Mines, Washington.

"William Rush—the First American Sculptor," by Edward H. Coates, Esq. (Introduced by Dr. W. W. Keen.)

Stated Meeting, October 6, 1911.

Charles L. Doolittle, Sc.D., in the Chair.

Letters accepting membership were read from:

Edouarde Bornet, Paris.
Lewis Boss, Albany.

The decease of the following members was announced:

Edouard du Pont, at Cannes, France, on March 31, 1911, æt. 70.

Samuel Hubbard Scudder, at Cambridge, Mass., on May 17, 1911, æt. 74.

G. Johnstone Stoney, at London, Eng., on July 1, 1911, æt. 85.

James Christie, at Atlantic City, on August 24, 1911, æt. 71.

James Andrew March, at Easton, Pa., on September 9, 1911, æt. 86.

Francis Jordan, Jr., at Point Pleasant, N. J., on September 12, 1911, æt. 68.

Pierre Emile Levasseur, at Paris, æt. 82.

Stated Meeting, November 3, 1911.

William W. Keen, M.D., LL.D., President, in the Chair.

The decease of the following members was announced:

A. B. Meyer, at Berlin, æt. 71.

Henry C. McCook, at Devon, Pa., on October 31, 1911, æt. 74.

The following papers were read:

"Factors Affecting Changes in Body-Weight," by Francis G. Benedict.

"Formation of Coal Beds—Some Elementary Problems," by John J. Stevenson.

Stated Meeting, December 1, 1911.

William W. Keen, M.D., LL.D., President, in the Chair.

The decease was announced of:

George F. Dunning, at York Cliffs, Me., on June 26, 1910, æt. 93.

Mr. Arthur L. Day read a paper on "Geophysical Research."

CORRIGENDUM

In Mr. Berry's article on "A Study of the Tertiary Floras of the Atlantic and Gulf Coastal Plain" in No. 199, the sketch maps on pages 306 and 308, by mistake, have been transposed and that on page 308 should have been printed on page 306 and that on page 306 should have been printed on page 308. The legends are correctly numbered, but Fig. 1 has been printed over the legend of Fig. 2 and *vice versa.*

INDEX