Transactions of the Wisconsin Academy of Sciences, Arts and Letters. volume XI 1896/1897

Madison, Wis.: Wisconsin Academy of Sciences, Arts and Letters, 1896/1897

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TRANSACTIONS

OF THE

WISCONSIN ACADEMY

OF

SCIENCES, ARTS, AND LETTERS

VOL. XI

1896–1897

WITH FIFTY PLATES

EDITED BY THE SECRETARY

Published by Authority of Law.

MADISON, WISCONSIN
DEMOCRAT PRINTING COMPANY, STATE PRINTER
1898

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A HISTORY OF THE DANES IN AMERICA.

JOHN H. BILLE.

WITH A MAP — PLATE I.

Of all the nationalities that have come to this country in any considerable number, the Danes are the ones of whom the least is said or known. They have taken but little part in politics, either national, state or local. Their religious organizations and institutions have attracted no attention, and their settlements seem to have been wholly lost sight of, even by the practical politician. It is this peculiar insignificance of the Danes as a factor in the life of this country to which I especially wish to call attention in the following paper. But as the national characteristics, and the ideas and conditions existing in Denmark, are largely responsible for the position of the Danes in America, it is necessary for an understanding of the subject to begin with a discussion of the Danes in Denmark.

The Danes of to-day, in Denmark, though the direct descendants of the redoubtable vikings, possess but few of their stern, warlike characteristics. In fact, it is only through their fondness for the stories recounting the deeds of the ancient gods and heroes that the modern Danes show their mental kinship to the viking.

Seven hundred years of peaceful occupation among the most peaceful of natural surroundings, together with three hundred years of serfdom under which the majority of the people were reduced to the condition of mere beasts of burden, are the main agencies which have made the Danish descendants of the viking a peace-loving, easy-going, good-natured people, with a considerable lack of self-confidence and enterprise. The political events in Denmark during the present century illustrate most strikingly this non-aggressive spirit of the common people. They have received all their social and political liberties from the powers above them without violence and almost without agitation on their part; and when those liberties have been encroached upon they have made but little resistance. The serfdom of the peasant was removed in 1788 through the benevolent efforts of Count Bernsdorf, then an influential member of the king's cabinet. In the year 1849 the king, Frederick VII., voluntarily relinquished his absolute power and gave his people a very liberal constitution; but in the quarrel which has since arisen between the present reactionary king Christian IX. and his ministry on the one hand, and the representatives of the people on the other, regarding the interpretation of this constitution, the people have made concession after concession, till at present they retain only a semblance of the political liberties given them less than half a century ago.

Another marked peculiarity of the Danish character is a love for the ideal, the emotional, and the romantic. This characteristic shows itself in the literature, in the everyday life of the people, and in many of their social institutions. But it is most strikingly exhibited in the remarkable influence exercised by N. F. S. Grundtvig on the social, political, and religious life of the people. And as his influence has extended to this country, and is a prominent factor in the life of the Danes here, it is necessary to discuss his life and work somewhat in detail.

N. F. S. Grundtvig was born in 1783. He was the son of a minister and was himself educated for the church. He was possessed of a many-sided character, and one full of apparent inconsistencies; but he was pre-eminently a poet and a reformer, possessing the romantic temperament of the one and the courage, enthusiasm, and persistence of the other.

The chief end and ambition of his life was to reform the Danish church, which at the time he entered upon his ministry, 1810, was given over to rationalism of the French pattern, or to dead meaningless formalism. He wished to bring back what he called old-fashioned, living Christianity and pure Lutheranism. At first this was not much more than an implicit belief in the Bible, coupled with a pietistic philosophy of life. But in the course of time his belief underwent some remarkable changes. He dropped the idea of the Bible being an infallible guide, asserting that a belief in the Apostles' Creed and the words of the Communion service, coupled with a good Christian life, was all that was necessary for membership in the true Christian church. But in his opinion the living of a Christian life meant an active, sympathetic participation in all the affairs of life. He wished to substitute feeling and activity for doctrinal discussions and formalism, and individual judgment for blind acceptance of a creed. Being intensely patriotic, his love of country became thoroughly identified with his religion. It is impossible, he said, to love God and not love one's fatherland and mother-tongue. He advanced the idea that each nation had a special mission to perform in the world, and had been especially appointed and trained by God to perform that mission. From the traditions and history of the Danes, he inferred that to them was given the mission of reuniting all the Christian churches, to re-establish "peace on earth and good will toward men," the highest and most sacred mission of all. But in order to fulfill their mission, they must be true to their language and traditions; and if they failed in this, God would punish them as he did the Israelites of old when they strayed from the path he had marked out for them.[1]

[1] Grundtvig may be quoted on this subject so as to prove him to be either a broad-minded, liberal patriot and statesman, or a religious enthusiast who wishes to make the nation a mere tool in the hands of God, or a sentimental, bigoted nation-worshipper. His speeches in the constitutional assembly of 1849 on the subjects of suffrage, freedom of religion, title and rank, freedom of speech, police power of the state, provisions for the poor, and compulsory education are instances of the first kind. (See H. Brun's *Life of Grundtvig*, Vol. 1, pp. 330–342.)

"Heligtrekongers-Lyset," written in 1813, when the allied troops threatened an attack on Denmark, shows him as the religious enthusiast. His "Tröste-Brev til Danmark" written after the war of 1864, his speech at the meeting of his friends in 1865, (see pp. 7–13 of proceedings of this meeting), and also his sermon, "Fredsfyrsten og Morderen," show him the bigot and sentimentalist. His friends have made the mistake of accepting every word from him as a self-evident truth, while his enemies are making the still greater mistake of looking at and criticising his weaker and senti-

He himself was indefatigable in his efforts to arouse and strengthen the patriotic sentiment of his countrymen. He translated into plain modern Danish many of the old Scandinavian myths, stories and ballads, and celebrated both in poetry and prose the deeds and prowess of the old gods and heroes. He addressed himself to the common people, especially to the peasants, for he believed that the upper classes had been so influenced and warped by foreign, especially German, culture and ideas that they had almost lost their Danish character. It was not, however, till 1848–'49 that he began to exert any decided influence on the common people. The war carried on at that time against the rebel duchies, Schleswig and Holstein, and the granting of the constitution, thoroughly aroused the patriotic spirit of the Danes. Grundtvig and his picturesque religion with its poetry, myth, saga, and patriotism, which he still claimed was old-fashioned Lutheranism, pure and simple, gained many adherents. A spirit of religious enthusiasm was aroused. Laymen began to preach and exhort, something hitherto unheard-of. Home missionary societies were organized, and religious meetings of the revival type were the order of the day. But the most important feature of this agitation was the establishment of so-called peasant high schools. From the very beginning of his career Grundtvig had been strongly opposed to the schools of his day, with their "learning by rote of dead and useless facts." He advocated the establishment of schools, the chief functions of which should be to inculcate religious and patriotic sentiment and give instruction in the practical affairs of life. He first tried to interest the government in his ideal. Failing in this, his friends raised sufficient money to enable him to carry out his plan independently, and in 1856 the first peasant high school was established in Denmark proper. Since then the number of these schools has steadily increased till at the present time they number about seventy, with an annual attendance of between three and four thousand students. This means a

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mental utterances,—things which he has said or written under great emotional pressure. His work, "Kirke-Spejl," a series of church historical lectures given in 1863, undoubtedly gives the fairest representation of his views on the subject of nationality and religion.

great deal in a country with an area only one-fourth that of the state of Wisconsin, and a population of only two millions.[1]

These schools have all been built by private enterprise or public subscription, and they are patronized almost exclusively by the rural population. Religion, history, literature, and singing are the main subjects of instruction, and the main aim is to develop the patriotic and religious spirit in the direction indicated by Grundtvig. Their tendency is to lay too much stress on the ideal and too little on the real, to cultivate the emotions rather than intellect. Nevertheless the effect of these schools, as indeed of the whole Grundtvigian agitation, has been to make the common people more patriotic, more appreciative of the higher sentiments, and less submissive to authority of any kind. Pastoral authority has especially suffered. Indeed it has almost entirely disappeared; a fact which partly explains the very

[1] The methods adopted by the high schools are based on the supposition of an ideal instructor dealing with ideal pupils. Nearly all the instruction is given in the form of lectures, or by personal talks with the pupils. This is done on the theory that the living word of the teacher is much more impressive than the dead letter of any book. No qualifications for entering are required; no set lessons are given, no definite amount of work is assigned, and there are no class recitations. The schools recognize no such things as examination, promotion or graduation. No other stimulus is relied upon than the personality of the teacher and the student's love for the work in hand. As might be expected, this method is not conducive to any very intense intellectual activity. In fact, there is such an apparent lack of effort and concentration on the part of the students in these schools that an American schoolmaster, even if he were a Herbartian, would be likely to pronounce the whole procedure a farce. The following is a sample of the work as observed by the writer at the Rodkilde high school on the island of Moen, 1892: A class of about fifty were comfortably seated in a large, pleasant room, each one engaged in some work of knitting or crocheting. They were rattling needles and silently passing judgments upon their work and that of their neighbors; while the teacher was sitting at his desk, delivering a lecture upon the geography of Denmark. In arithmetic these same young ladies were all working at their seats on slates, each one from some different part of the text book. If they succeeded in working the problem in hand to their own satisfaction, they took hold of the next; if unable to work it they went to the teachers, who were sitting at desks at one end of the room. The teacher showed them how to solve the problem and sent them to their seats to work as before.

slight influence which the Danish ministers in this country have on their countrymen. In fact, the whole beautiful religious machinery devised by the state has been put out of gear by this agitation; and the established Lutheran church, or the church of the people, as it is called, though it claims the allegiance of more than ninety-nine per cent. of the Danes, after all is only a name which three different factions are each trying to appropriate to itself. These are the old-fashioned strict doctrinarians, the Grundtvigians, and the Inner Mission society. The first of these three want things to go on in the old, formal way, with religion confined within the church walls and consisting mostly of a strict interpretation of dry theological points by the regularly ordained minister. The Grundtvigians and the Inner Mission people agree in making religion a part of everyday life and every man's concern. But the Grundtvigians are thorough-going optimists. They call themselves the happy Christians, take part in all the pleasures and activities of life with the greatest zest, and concern themselves but little about doctrinal points. The Inner Mission people are thorough-going pietists; they call themselves the holy ones, and profess to despise all worldly pleasures. They insist on absolute belief of total depravity, and literal belief in the Bible.[1] And in spite

[1] The Inner Mission society was established in 1854. It was the outgrowth of the Grundtvigian agitation, and the early leaders, who were all laymen, were adherents of Grundtvig's, but with pietistic tendencies. In 1861 Vilhelm Beck, a minister of the established church, was elected president of the society, which, at that time, had but little influence and no regular working force. But under his leadership it has become the most powerful agency in the country for stimulating and maintaining religious interest. According to the report of the society for 1895 it owned eighty-seven mission-houses, insured at $101,500. Its income for the year was $27,395, nearly all gifts. It employed ninety-six regular missionaries, and counted as its supporters about two hundred of the ministers of the established church and a large number of the teachers of the public schools; 16,000 public religious meetings had been held during the year. It must be remembered that all this is carried on aside from the regular work of the established church, to which all the Inner Mission people profess to belong. The missionaries are working somewhat according to old apostolic methods. They are sent out two by two, and go from house to house exhorting, preaching, and selling religious tracts. When a community has

of the fact that the two factions have a common origin, they are irreconcilably opposed to each other; and the antagonism between them is becoming more marked every year, furnishing any amount of material for quarrels within church circles, both in Denmark and among the Danes in this country. Indeed, the ideas held by the Grundtvigians and Inner Mission society have had a decisive influence on the destiny of the Danes in America as a separate nationality. No other questions, save those of an industrial nature, can lay any such claim to the attention of the Danish public as do these. Politically the Danes are all at sea. There is no strong party with any definite policy, and the sentiment in favor of larger political liberty has become dormant among the common people through the long losing struggle they have carried on against the government. The sentiment of patriotism and national pride too is waning, except among the Grundtvigians, and a feeling of national helplessness is becoming dominant. "We are a small people, capable only of small things" has come to be almost a national motto.[1]

To summarize: The Danes of to-day are a good-natured, easy-going people, somewhat lacking in self-confidence and enterprise, and possessing no strong national ambition and no national institution which can lay claim to their undivided homage; this leaves them without any strong bond of union when removed from the mother country. Though as a nation they have a fair proportion of hard-fisted, matter-of-fact individuals, they are nevertheless largely influenced by sentiment and ideals.

In dealing with the emigrant, however, a new factor enters in, for emigration is a sifting process, and the emigrant differs in many respects from the people of his class who remain at home, and he therefore cannot be judged by the general national characteristics. He is more enterprising, more of a matter-of-

been thoroughly canvassed by the missionaries, public meetings are held at which some of the abler speakers are present. Then Sunday schools for children are organized, or religious clubs for the older people, through which the agitation is continued. The effect aimed at is identical with that of revivalists in this country, though the success attained in Denmark is more lasting.

[1] The disastrous war of 1864 with the Prussians and Austrians has done much to depress the national spirit.

fact man. At any rate his love of personal advantage is liable to be greater than his love of country, home and friends, for he is willing to part with them to better his fortune. He does not as a rule leave his native land because he suffers actual want there, but most usually because he feels unable to maintain what he considers a proper standard of life; and it is only in cases where emigration is prompted by religious or political persecution that he is liable to be a man of as much patriotic sentiment as those who stay at home.[1] The record of the Danes in America furnishes a most striking illustration of this theory; indeed it is impossible to otherwise explain their peculiar indifference toward all that might connect them with the land of their birth.

THE DANES IN AMERICA.

The emigration from Denmark has been more recent and the number of emigrants smaller than from the other Scandinavian countries.[2]

	Norwegians.	Swedes.	Danes.
1860	43,995	18,625	9,962
1870	114,243	97,332	30,098
1880	181,724	194,337	64,196
1890	322,665	478,041	132,543

The fact that emigration from Denmark began so late and never assumed any considerable proportions would naturally

[1] An extended inquiry among my own countrymen who have emigrated, and among those in the same circumstances in Denmark, bears out this theory. In answer to my question to the former, "Why did you emigrate?" the invariable answer was, "I did not want to be a common laborer in my own country," or "I did not care to live such a life of drudgery and poverty as my parents lived; I can't do worse in America, and I may do better;" while my question to the latter, "Why do you not emigrate?" was answered as follows: "I can't bear the thought of leaving home with the chance of never coming back again," "I can't get any pleasure out of life in any other place," or "I would like to go, but when I think of all the dangers and troubles of it I feel I might as well stay at home, and take what little comfort I can get out of life here."

[2] The cause of the smaller emigration from Denmark than from Norway and Sweden is undoubtedly due mainly to the better economic conditions

tend to make the social and religious organizations of the Danes smaller and weaker than those of the Norwegians and Swedes. But this fact does not account for the difference existing, especially between the Danes and Norwegians, in the matter of forming settlements, supporting churches and schools, and general social and political co-operation, — a difference so striking that it must of necessity unsettle the present belief in the similarity of character of these nationalities.

The Norwegians, according to their number, show a stronger tendency to concentrate in large settlements on account of preference for their own countrymen, than any other European nationality, while the Danes go almost to the other extreme in this matter. The table below is an attempt at showing in figures the correctness of this statement. In the second column the highest percentage in any one state is given, because state lines, though not always physical barriers, nevertheless act as a check to close co-operation, especially in a political way. Besides, in the minds of the people in Europe, the state stands for a compact piece of territory of a limited extent, and with this notion is naturally associated the idea of easy and close communication among those living within the state. For these reasons, the immigrants who concentrate largely in one state show thereby a desire for remaining in touch with their own nationality.

The numbers in the third column, indicating the percentage in settlements of more than five hundred, are obtained by adding the numbers of persons of a given nationality in counties where five hundred or more of this nationality are found, and

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existing in the former country. In fact, want is a thing almost wholly unknown in Denmark. The condition of the common people has been improving rapidly and almost constantly during the present century. At the beginning of the century the land was nearly all in the hands of the nobility, while at present only one-seventh of it is in their possession, the rest of it being in the hands of the peasants, who constitute the bulk of the population. (H. Weitemeyer, *Denmark*, p. 100.) Besides this, the improved methods of cultivation have increased the productive power of the country nearly ten-fold. No such decided change in property-holding or in producing power has taken place in Norway or Sweden, while the population has been increasing as rapidly in these countries as in Denmark.

finding what per cent. this sum is of the whole number of persons of that nationality in the United States. The number five hundred is taken, because in counties containing a lesser number of persons of a given nationality, as a rule, no settlement will be found sufficiently large to maintain in a vigorous condition the social and religious life of the mother country, hence a nation with a large percentage in this column shows proof of a desire to concentrate on a basis of nationality.

The percentages in column four for contiguous territory are based on the fact that where more than five hundred of a given nationality are found in adjoining counties they form in many respects one settlement, because they are able to co-operate in the maintaining of churches and schools, and other relations of a social nature which they can only have with their own countrymen. Therefore a high percentage in this column also shows a desire for concentration on the basis of nationality.

The percentages in column five for cities of more than twenty-five thousand inhabitants are given, because a nationality largely represented in these cities may have a high percentage in column three on account of a liking for city life, rather than from any special desire to form settlements for the sake of living with their own people. It is the rural settlement which shows the national preference most strongly; for the formation of large settlements of this kind in a country as extensive as the United States necessitates a strong motive for so doing, and a definite plan. Therefore a nationality with a low percentage in column five, and high percentages in columns two, three and four, shows the strongest tendency to form settlements for the sake of associating with fellow-countrymen. But the emigrants of a nationality which fails in forming rural settlements to any extent, and does not concentrate largely in cities, show the least desire for association with their own people because they do not find such association by accident, as is the case with those nationalities which prefer city life, nor by preconcerted plan, as do those who form large rural settlements. From the table, the Norwegians are thus seen to lead in the matter of forming settlements, while only the French can be said to be in any way less forward in this regard than are the Danes; and these two peoples, therefore, show the lowest concentrating tendency of all the European emigrants to this country.

	I. Total in United States.	II. Highest percentage in one state.	III. Percentage in settlements containing more than 500.	IV. Percentage in contiguous territory.	V. Percentage in cities of more than 25,000.
Norway . .	322,665	31	80	56.6	20.78
Sweden . .	478,041	20.9	79.6	22.2	31.24
Holland . .	81,828	36.07	72.6	31.3	33.54
Poland . .	147,440	19.7	72.2	10.3	57.11
Bohemia .	118,106	22.5	85.4	21.4	48.32
Denmark .	132,543	10.1	47	8.1	23.24
Belgium. .	22,639	20.1	34.7	16.5	22.30
France . .	113,174	18	14.3	14.3	45.69
Wales . . .	100,079	. .	52	25.4	25.80
Scotland .	242,231	. .	56.8	12	41.25

I have omitted the English, Irish, Austrians, Hungarians and Italians because these nationalities have settled in such large numbers in the eastern cities, especially in New York, a fact which would run up their percentage in columns three and four enormously, while it by no means is an indication of the desire or ability of these nationalities to form settlements.

The Germans and Swiss I have omitted because both of these nationalities are made up of elements differing more from each other in language, religion, and race characteristics than do the people of the Scandinavian countries. So if the former should be classed as one nationality then the Scandinavians should also be classed together as one nationality, as has so often been done in national and state census.

The contiguous territory from which the figures in column four are obtained is:—for the Norwegians, the western tier of counties in Wisconsin, with extensions eastward in the north and south; the eastern, southern and western tiers of counties in Minnesota; the northern tier of counties in Iowa; and the eastern in North and South Dakota. It may be said that roughly the eastern, southern and western boundary lines of Minnesota form the center of this settlement. The Swedish settlement extends through the northern peninsula of Michigan, along the northern tiers of counties in Wisconsin, and directly across the state of Minnesota at about the latitude of St. Paul. This settlement is not nearly as compact as the Norwegian.

The Hollanders have established their largest settlement in the southwestern part of the southern peninsula of Michigan. The Polanders and Bohemians have their largest settlements in the city of Chicago. The Belgian settlement is located about Green Bay, Wisconsin. France and Scotland have their settlements in and about the city of New York. The Welsh settlement includes the following counties in Pennsylvania: Carbon, Lackawanna, Luzerne, Northampton, and Schuylkill.

This tendency of the Norwegians to concentrate, and of the Danes to scatter, is not of recent origin; for ever since the Norwegians have commenced to emigrate in any considerable numbers they have been as closely or even more closely concentrated than they are at present; while the Danes have been more widely scattered than they are now, as will be seen from the following tables:

Norwegians.[1]— *Greatest number in four states.*

	1850.	1860.	1870.	1880.	1890.
Total in United States	12,778	43,995	114,243	181,729	322,665
Illinois	2,500	4,891	11,880	16,970	30,339
Wisconsin[2] . . .	8,000	21,442	40,046	49,349	65,666
Minnesota . . .	. . .	8,425	35,940	62,521	101,199
Iowa	. . .	5,688	17,554	21,586	27,078

Danes.— *Greatest number in four states.*

	1860.	1870.		1880.		1890.
Total in U. S.	9,962	. . . . .	30,098	. . . . .	64,196	132,543
New York .	1,196	Illinois . .	3,711	Illinois . .	6,029	12,044
Wisconsin .	1,150	Wisconsin .	5,212	Wisconsin.	8,797	13,885
Utah. . .	1,824	Iowa . . .	2,827	Iowa . .	6,901	15,519
California .	1,328	Utah . . .	4,957	Utah . .	6,071	14,133

[1] As the Norwegians were not given separately by counties in U. S. census before 1890, it is impossible to obtain any definite statistics on this point until 1890.

[2] O. M. Nelson, *History of Scandinavians in America*, p. 134.

From the above tables it will be seen that the Norwegians concentrated from the beginning in the four adjacent states, Illinois, Wisconsin, Minnesota and Iowa; while the Danes were scattered across the whole width of the continent. From the parochial reports of the Norwegian church in America it appears that their settlements were about as large and compact in the fifties and early sixties as they are now; while as late as 1870 there were only five cities and six counties in the United States in which five hundred or more Danes could be found. These were: New York; Chicago and Rock Island, Illinois; Racine and Waupaca, Wisconsin; and Winnebago county, Wisconsin; Douglas county, Nebraska; and four counties in Utah where they had been massed by the Mormon church.

From this it is plain that the present concentration of the Norwegians is not due to accident, nor to the fact that they have been longer in this country than the Danes; nor is it because the conditions in the four states, Illinois, Wisconsin, Minnesota and Iowa, are more congenial to the Norwegians than to the Danes. The opposite might seem to be the the case, for the climate, productions, and occupations in these states are more like those existing in Denmark than in Norway.

There can be only one possible explanation of this difference between the Danes and Norwegians,—that the Danes who emigrate have less love of their native land and its institutions, less national pride, than the Norwegians, and therefore less desire to concentrate.

That such is the case is shown not only in the settlements of the two nationalities, but also in the manner each has supported the church of the mother country.

The first Norwegian church society in America was organized about 1850, when there were only a little more than 12,000 Norwegians in this country; and before this time several local congregations had been organized with their own ministers and churches.

The first Danish church society was organized in 1872, when there were more than 30,000 Danes in the United States; and before this time there was not a single purely Danish congregation with a Danish minister. It is true that some of the Danes had at this time associated themselves with Norwegian and Swedish churches; but though no statistics can be had on this point, it is quite safe to say that not more than five per cent. of the Danes in this country were in this way associated with the Lutheran church.

The following table of percentages of the Norwegians and Danes in America who belonged to the church of the mother country, 1860–90, shows more clearly still the difference existing between them on this point:

	Norwegians.	Danes.
1860	30.2	. . .
1870	34.1	. . .
1880	53.2	6.3
1890	58.9	10.1

In connection with this it must be borne in mind that there have always been some Danes within the Norwegian church; but if these should all return to the Danish church it would not decrease the Norwegian by more than two per cent., nor increase the Danish by more than five per cent.

That the Danish church society should be small would naturally be expected from the fact that the settlements were insignificant and much scattered; but this certainly can not be assigned as a reason for the indifference which the people actually within the church have shown towards it and the institutions it has fostered. On this point the difference between the Norwegians and Danes is as striking as that shown by the percentages of settlements and church members.

The Norwegian ministers, especially in the beginning, had almost autocratic control over their congregations; while the Danish ministers, with very few exceptions, had to submit meekly to whatever terms their congregations saw fit to impose upon them. The only power they possessed was the power of advice, and they had to use that with considerable discretion in order to keep their positions.[1]

[1] But few of them have kept their positions for any length of time. The majority do not average more than five years in a place, and they usually leave because of some misunderstanding with their congregations.

When the Norwegian ministers have gotten into a theological dispute, of which they have had many, their parishioners have invariably taken up the quarrel; and that they were in earnest about it is shown from the fact that they were, as a rule, willing to split up their congregations and go to the expense of building a separate church and of employing a separate minister. But among the Danes there is only one case on record of this kind, and in that case one of the factions was under the leadership of a Norwegian minister.[1]

The Norwegians have as a rule had more than twice as many parochial school teachers as they have had ministers and in the majority of their congregations parochial school has been held during some part of the year. In this line the Danes have done practically nothing.

But it is in the matter of contributions for educational purposes that the difference between the Norwegians and Danes is apparent. During the five years, 1860–65, the Norwegians contributed for the erection of the Decorah college as much as three dollars per communicant. Several times since then they have equaled or exceeded this contribution; and at present there are in connection with the Norwegian church sixteen colleges and academies, one of which, that at Decorah, Iowa, ranks with any of the American colleges in the West for the thoroughness of its course and the scholarship of its graduates. In 1892, these schools were attended by 2,160 students, nearly all of Norwegian parentage; and in all the schools great stress was laid on the teaching of the English language and other English branches.

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[1] This congregation is located in Montcalm county, Michigan. It might be argued that the Danish congregations do not split up because they are too small to maintain two separate churches. This is undoubtedly true in some cases, but the Montcalm congregation separated during the '70's, when it was no larger in its entirety than some of the factions created by the split of 1893 between the Grundtvigians and Inner Mission people.

During the summer of 1894 while visiting the Danish settlements in Polk county, Wisconsin, and Montcalm county, Michigan, I took special pains to find out the sentiment of the laymen on this quarrel, and the majority expressed themselves in favor of peace. In fact, none of them were clear as to what the quarrel was about. Several times my inquiries were answered in this manner: "We are ashamed of our ministers for quarreling, as they ought to know better."

During no consecutive five years up to 1894 had the Danes succeeded in raising as much as fifty cents per communicant for educational purposes; and the educational results attained by them are even more insignificant than the contributions.[1]

There can be no doubt that this lukewarmness among the members of the Danish church in America is in a large measure due to the factional quarrels in the church in Denmark. The immigrants in this country who are of a religious turn of mind still find it difficult to agree on any settled church policy, because they belong to different factions; and besides this, they have all been thoroughly weaned from any reverence for pastoral authority by the agitation carried on by the Grundtvigians and Inner Mission people in Denmark. Each man considers himself an authority on doctrine and church policy, and gives but little heed to the opinions and wishes of the minister, unless these coincide with his own. But in order to get a fair appreciation of the causes and effects of this failure of the Danish church in America it is necessary to give a somewhat detailed history of this institution. Indeed, the history of the Danes in this country, as a distinct nationality, is most intimately associated with the history of the church; for, in spite of its weakness and its failure to gain the support of the Danes, its policy has had a very decided influence on the social, religious, and educational conditions of the Danish settlements.

THE DANISH CHURCH IN AMERICA.

The first step toward the formation of a Danish church in America was taken by the organization of a society in Denmark, 1869, for the purpose of doing missionary work among the Danes in America. This society was composed almost entirely of Grundtvigians. Its work consisted mainly in selecting and training ministers for Danish congregations in America, and in acting as an advisory council to such ministers and congregations.

In October, 1872, three representatives of this society, A. Dan, N. Thomsen, R. Andersen, together with several Danish

[1] This subject will be treated more in detail under the head of the educational efforts of the Danish church in America.

laymen, met in Neenah, Wisconsin, and organized the Danish Mission Society, the name of which was later changed to the Danish Lutheran Church in America. This society adopted a confession of faith of a decided Grundtvigian trend, but declared its intention to work in the manner of the Inner Mission society in Denmark, and to remain in close connection with the mother church.

Arrangements were made for the publication of a paper, *Kirkelig Samler*, "for Christian and popular education and edification." Much stress was laid on the fact that the society did not intend in any way to oppose other Lutheran church organizations. In spite of this, trouble arose immediately between the Danish Mission society and the Norwegian church societies previously established. The trouble was due mainly to a competition between the two factions, for the Danish church members. It was but natural that the Danish society should desire to get all the Danes within its fold, and it was just as natural that the Norwegians should be anxious to keep all the members they already had. But the point at issue was the Grundtvigian doctrine, which the Norwegian societies had previously declared rank heresy. The struggle was a long and bitter one, with the usual and mutual accusations of heresy, lying and treachery. The outcome of it all was that the Danes succeeded in getting the larger number of the Danish congregations already established. But many of these had become much divided in sentiment during the struggle, and there were but few places where the Danish ministers received unqualified support. The Norwegian ministers had succeeded in arousing a suspicion among the Danish laity that the Grundtvigian doctrine was unsound and dangerous, a suspicion which was one of the causes that later brought about the split of the Danish church into the two factions, the Grundtvigian and the Inner Mission.

In spite of this quarrel the Danish church seemed to prosper in the beginning. Already in 1873 it counted 1,020 paying members, 1,600 communicants and five ministers. In 1877 it had 1,934 paying members, 3,533 communicants and 17 ministers. But the situation was not as favorable as these figures seem to indicate, for this rapid growth was largely due to the acquisition of congregations previously in charge of Norwegian ministers. And in most congregations there was an active minority opposed to the new order of things; while even among the ministers themselves considerable difference of opinion existed on the points of doctrine, and church policy. The Grundtvigians, however, were decidedly in the majority, and wholly determined the church policy, which was directed chiefly towards the maintenance of Danish language and sentiment, and the peculiar religious ideas of Grundtvig. The first step in this direction was to make the church in America a part of the Danish national church. At the annual church meeting of 1873 the following resolution was unanimously adopted: "We, the Danish ministers and congregations, hereby declare ourselves to be a branch of the Danish National Church, a missionary department established by that church in America." That this union was also considered seriously in Denmark, is shown from the fact that two graduates from the theological department of the University of Copenhagen, I. A. Heiberg and H. Rosenstand, on receiving calls from congregations in this country, were ordained by one of the bishops of the Danish church, and appointed by the king as regular ministers in that church.[1] There were, however, but few men qualified for holding the ministerial office in the church in Denmark, who could be persuaded to go to America; the small salary, the uncertainty of tenure of office, and the minister's lack of social prestige, all acted as checks in this direction. In order to supply ministers for this new field, a department was established at the Askov High School, a school of the Grundtvigian type, located in the south part of Jutland, for the preparation of ministers to American congregations. It was thought a great advantage to have the ministers trained in Denmark, as they would then be in the closest possible touch with the mother church and all that was Danish, and thus be better prepared to preach the doctrines of that church, and re-enforce

[1] This union was further recognized by the Danish government, by an annual appropriation of $840, made for the first time in 1884, for the training of ministers for the American branch of the Danish church. This money was at first expended in Denmark, but since 1887 it has been sent to this country, and expended here in aid of poor theological students.

the waning Danish spirit in America. Nearly all of these men had the merest rudiments of an education when beginning their work at Askov, most of them being farmers, mechanics, and common laborers, of a pious bent of mind. The course usually extended over but two years, and was limited almost wholly to theological studies. As might be expected, the men thus trained, on arriving in America were almost wholly ignorant of the language and conditions here, in fact, ignorant of nearly everything excepting a few theological arguments and church ceremonies. Even to-day not half a dozen of the sixty or more ministers of this church can converse fluently in English, to say nothing about preaching a sermon in that language. As a rule, they know nothing and care nothing about the social and political conditions here. As far as matters of this world are concerned, they are in truth blind leaders of the blind, or rather of the half-seeing, for many of their parishioners are much better posted on what goes on around them than are the ministers. Their methods of carrying on the business of the church are proof positive of their entire lack of all training and sense for practical affairs of life. They labored from 1878 till 1894, on a church constitution, without producing anything but dissension among themselves. In the matter of incorporation they succeeded no better, for though they worked nearly fifteen years on this problem the society was never properly incorporated, and none of them seemed to know how to proceed in the matter, or why they failed. Yet they all seemed anxious to comply with the law. Their parochial reports are very defective, and during some years were entirely omitted. In these reports no attention is paid to the educational work, nor is any regular account given of receipts and expenditures of money.[1] In annual meetings they seldom had any order either in business or debate. They would often discuss a subject for hours, and drop it without voting upon it. Four or five speakers might follow each

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[1] No complete and comprehensive report of the receipts and expenditures of the churches has ever been published. In this the Danish differ greatly from the Norwegian churches, which, with exception of the Haugians, have always published very elaborate statistics of all the activities of the church each year.

other, each one talking on a different subject, and paying no attention to the remarks of the previous speaker. It was seldom that any definite plan was adopted for doing the business of the society, and when a plan or regulation was finally adopted it was seldom followed out in action. There is even a case on record where it was voted, seventeen to six, to discontinue a certain discussion. The discussion was still carried on for an hour or more, without any break other than was necessary to take the vote to discontinue.[1] In spite of all this chaos a number of projects, besides the union with the mother church, have been set on foot for carrying out the Grundtvigian pet idea of creating a little Denmark in the United States. The most important of these are: (1) The establishment of Grundtvigian high schools and parochial schools. (2) The planting of colonies. (3) The organization of a society for the maintenance of Danish sentiment and language.

THE HIGH SCHOOL.

This subject comes to the front for the first time at the annual meeting at Chicago, 1876. Though no definite action was taken in the matter, the discussion brought out very decided differences of opinion in regard to what ought to be done. Both sides were agreed that something ought to be done by the church to educate the young, and that the main object should be to make good Lutherans; but the Grundtvigians maintained that this could be done, as far as the Danes were concerned, only through the Danish language and by appealing to the Danish sentiment and memories,— while the opposition insisted that the old ballads played no part in the scheme of salvation, and that as a matter of fact the children born in this country had no Danish memories and sentiments;[2] but this latter was the opinion of only two men, N. Thomsen and Lilleso, and had at the time no influence in deciding the course to be pursued. After considerable more discussion and delay it was finally decided, at the annual meeting of 1878, this time without opposition, to establish a Grundtvigian high school. It was supposed

[1] *Kirkelig Samler*, 1884, p. 497.
[2] *Id.*, 1876, p. 296.

that the necessary money could be raised by gifts, principally from the Danes in America, and each minister present at the meeting undertook the task of soliciting money from his congregation for the purpose. The Danish settlement at Elk Horn, Shelby county, Iowa, was chosen as the place of location; and Olav Kirkeberg, a Norwegian, but one of the ministers of the Danish church and a staunch Grundtvigian, undertook the task of building and conducting the school. No better man could be found for the purpose, for Kirkeberg had the courage of his convictions and unlimited faith in the success of his undertaking. These, in fact, according to his own statements, were nearly the only resources at his command when he began putting up the building which he estimated would cost two thousand dollars. On June 8, 1878, he wrote: "I have bought stones, for the foundation of the school; that took all the cash I had. In a couple of weeks the carpenters are coming; then I shall need five hundred dollars for lumber, while I am not sure of more than two hundred. Though the outlook is not very encouraging, I feel hopeful in the matter; because I am convinced this work will be a benefit to man and an honor to God, and therefore it must prosper."[1] Though continually embarrassed financially he still had the building completed by November, 1878, the time originally set for opening the school. The work as previously announced consisted of studies in general history, with special reference to the three Scandinavian countries; a review in Scandinavian mythology; lectures on the most important epochs in the history of the Christian church; history of literature, with the readings from the works of the best Scandinavian authors; studies in the mother tongue (Danish), including composition; English, including reading, practice in letter-writing, and business forms; science, including physiology, physics, and chemistry; geography; singing; and United States history.[2] All the instruction, excepting lectures on United States history and geography and the study of the English language, was conducted in Danish. The whole programme was to be carried out in the course of five months, with students coming directly

[1] *Kirkelig Samler*, 1878, p. 237.
[2] *Ibid.*, 1878, p. 320.

from the farm and the workshop, having had little previous intellectual training. This latter fact, however, would not necessarily interfere much with the progress of the work, for most of the instruction was given in the form of lectures, requiring but little response or individual effort on the part of the student. It was a sort of five months University Extension course minus the University professors.

The faculty consisted of three men, Olav Kirkeberg, Christian Östergaard, and Mr. Crouse. Kirkeberg and Östergaard had received the greater part of their education at Grundtvigian schools in Denmark, the latter coming directly from Denmark to his work at Elk Horn. Mr. Crouse was an American with some knowledge of law, and was engaged at a regular salary of thirty-five dollars a month. His work consisted in lecturing on United States history and constitution, and giving instruction in English composition, reading, and business forms.

That everything was done to foster the Danish ideas and sentiments, and little attention was paid to the language and history of this country, is plainly shown in Kirkeberg's report of the first year's work. He says: "We found that some of our students had come mainly for the purpose of acquiring a knowledge of the English branches, but most of them failed to get the full benefit of Mr. Crouse's instruction because of their lack of knowledge of the English language. Besides, it was as though the mother-tongue, and the subjects taught therein, won the hearts more and more, and the preference which some at first gave to the English branches gradually disappeared. That young men can thus be touched by things considered most essential by the high schools both in Denmark and Norway, indicates that the cause for which we are working in this country will prosper." [1] On this point, however, he was mistaken, for his enthusiasm and that of his fellow Grundtvigians was not shared by the rest of the Danes in America, and no effort on their part could arouse such enthusiasm. Neither money nor pupils were forthcoming for the support of the school. By January 1, 1879, only eleven hundred four dollars [2] had been col-

[1] *Kirkelig Samler*, 1879, p. 217.

[2] *Ibid.*, 1879, p. 60.

lected for the building and support of the high school. The school was at that time under a debt of seven hundred fifty dollars, and had reached the limit of its credit, and was still far from being well equipped. When the school opened November 1, 1878, only nine of the sixteen students expected were on hand, and the total attendance during the five months' course was only nineteen. The money received in board and tuition, fourteen dollars per month for each student, scarcely sufficed to pay running expenses, to say nothing about the salaries of Kirkeberg and Östergaard.

During the next year the contribution ceased altogether; the debt increased to a thousand dollars; while there was no increase in attendance. In 1880, Kirkeberg, after having expended a good deal of money on the school, reached the limit of his credit and that of the school, and was obliged to abandon the enterprise, broken in health, but still hoping and praying for its success, which he considered of the utmost importance to the welfare of the Danes in this country. The school now became the sole property of the Danish church society, and managed to struggle on with several changes of administration and ownership, as a Grundtvigian high school, till 1890. During all this time the attendance had not averaged forty students a year. It had never received any regular money support from the church, and on the whole its existence had been a most precarious one. Strangely enough, the failure of this school, situated as it is in the midst of the largest Danish settlement in the United States, did not deter the Grundtvigians from establishing similar schools in places much less favorable. In the course of the next ten years four more such schools were established, one in Ashland, Michigan, 1883; one in Polk county, Wisconsin; one in Nysted, Nebraska; and one in Lincoln county, Minnesota, 1888.

The school in Polk county failed immediately for lack of support; while the others have always been considerably embarrassed financially, and the attendance at any one of them has not averaged thirty pupils a year. The total contribution by Danish laymen in America towards the building and maintenance of these schools up to 1894, aside from actual tuition, paid during the whole time does not amount to $10,000. Considering that at the time of the establishment of the Elk Horn high school there were at least sixty thousand Danes in America, and that in 1890 there were a hundred thirty-two thousand, the support which they have given the high schools is exceedingly small. The influence which the high schools have exerted on the Danes in America is still smaller. It is safe to say that not one of a thousand of the persons in the United States of Danish parentage, has attended one of these schools; and that the average time of attendance has not been more than four months. This being the case, the influence exerted by these schools on those who have attended, as well as on those who have not attended, must be almost infinitesimal. Moreover, there is no prospect that this influence will increase in the future, because they are not the kind of schools favored by the Danes here, and all the efforts of the Grundtvigian ministers can not make them so. The case of the Elk Horn school seems to prove this most conclusively. Since 1890, when it was reorganized so as to give prominence to the English branches, the attendance has more than tripled. In 1893–94, it had an enrollment of one hundred seventy-eight,[1] while all the other schools run on the Grundtvigian plan had no increase whatever, their total enrollment for the year amounting to only seventy-six; this, in spite of the fact that the Grundtvigian ministers, who were still largely in the majority, strongly opposed the Elk Horn school and favored the others.

THE PAROCHIAL SCHOOL.

To keep the children within the fold of the Danish Lutheran Church was the desire common to all the Danish ministers. But here, as in the case of the high schools, the Grundtvigian idea that this could be done only by maintaining the Danish spirit, language and tradition was still the dominant one. Indeed it was commonly asserted by them that it was next to impossible for a Dane to be a good Christian and renounce either his language or his allegiance to his mother country. They found it difficult, however, to convince their parishioners of the necessity and utility of their scheme of education, which consisted in an attempt to supplant the common school with a Danish parochial school,

[1] Catalogue of Elk Horn College for 1893–94.

in which the Danish language, history and traditions should be taught in connection with Lutheran doctrines, as interpreted by Grundtvig, while the English branches were to be relegated to the position of incidental studies. The common arguments used in favor of this plan were, that since the public school did not give religious instruction, it omitted one of the most essential objects of education; besides, in the public school most of the teachers were either "infidels" or "sectarians" who were prone to poison the children's mental food with doubts and false doctrine. Furthermore, the discipline and the whole moral atmosphere of the public school destroyed the innocence and sweetness of childhood, and the reverence for parental authority. Several plans for obtaining men and means for these schools were brought forward. One of the earliest and most feasible of all was to make the high school something of a teachers' seminary, and then organize a society whose aim should be to agitate the question among the people and raise the necessary funds. This plan failed, partly because few students stayed at the high school long enough to qualify themselves for the work of teaching, but mostly because the people in general refused to give it any substantial support. The society which was to prepare the way lived only one year, 1879–80, having accomplished nothing beyond the collecting of about one hundred and fifty dollars. When disbanded, it was admitted by its founders to be a failure. Another plan proposed was to get control of the public school in districts where Danes were in the majority, engage a Danish teacher qualified to teach both public and parochial schools, and give him a good salary for teaching the public school, so he could afford to teach the parochial school at a small salary, during the vacation of the former, which was to be as long as the law would allow. This plan, like the first one, came to nothing. No Danes could be found qualified to do the work required; and the high schools, which might have done something along this line, neglected to adapt themselves to the work. Besides this, there were but few districts in which the Danes were in the majority, and in these districts they were usually unable to agree on any scheme of education. In fact, nothing whatever of a practical nature has been done along the line of parochial schools; and the results attained by these schools are correspondingly insignificant. Though there are no definite statistics on this point, it is safe to say that not more than six parochial schools established by this church can lay any claim to permanency, and that less than one thousand Danish children in this country have attended these schools long enough to become biased along the line of Grundtvigian thought.

This failure of the high schools and parochial schools is probably in part due to a lack of system and of agreement among the ministers; but its main cause is found in the almost total indifference of the Danes, at large, toward these schools. Had there been on an average three thousand Danes in hearty sympathy with the cause, they would and could have given a more substantial support both in money and men than has been given. This indifference is not due to any lack of agitation on the subject. The Grundtvigian ministers have had a fair opportunity to reach a large number of their countrymen. They have been located for years in the most populous Danish settlements; they have had the majority in every church conference; and have held almost uninterrupted control of the organ of the church, *Kirkelig Samler*, besides receiving the unqualified support of the Danish society for American missions and of the secular Danish-American newspaper, *Dannevirke.* There have never been lacking enthusiasts among them who have used every means at their command to propagate their particular views; while the opposition, within the church at least, did not become active before 1887, and then only as a small minority.

THE COLONIZATION SCHEME.

This scheme was adopted for the purpose of gathering the Danes into a few large settlements, which was thought to be one of the most effective means of strengthening the church and maintaining the Danish language and sentiment. The first settlement was established in Lincoln county, Minnesota. Here the church secured an option on 35,000 acres of land from a land company. The company agreed to sell this land to Danes only during the first three years. The first year the land was to be sold at an average price of seven dollars per acre, and no greater advance than fifty cents per acre should be made during each of the following years. Besides this the company promised to donate 320 acres for the support of churches and high schools when one hundred actual settlers had been secured. For these privileges the church promised to use its influence in securing settlers. This settlement, in spite of considerable bickering and quarreling between the land agent, the church and the settlers, was fairly successful. The one hundred settlers were secured within a year, and at present the settlement contains about a thousand Danes who are maintaining a high school, a parochial school and a church. It is a settlement apparently as Grundtvigian and Danish as any existing in the United States. An attempt was made in 1888 to establish a settlement in Logan county, in the extreme western part of Kansas. On the invitation of the Union Pacific Railroad company the land committee of the church went out and inspected the land during the month of May. They were completely captivated with the fertility of the soil and the salubrity of the climate. They secured an option on four townships of land, to be sold to Danes at from four to six dollars an acre. They then proceeded to extol the advantages of the place, laying special stress on the fiction that the rainfall, which at present was quite sufficient, would still farther increase as the land was brought under cultivation. This, however, proved a mistaken theory, and the colony dried up in its infancy, while the reputation of the ministers as practical farmers and colonizers was badly damaged. This was the last attempt on the part of the church as an organization to form settlements. The idea however has not been abandoned, but has been taken up by the Dansk Folkesamfund (the society of the Danish people). This society has located two more settlements, one in Clark county, Wisconsin, and another in Wharton county, Texas. As yet these settlements are both in their infancy; like the settlement in Kansas, they are the cause of much newspaper correspondence of a decidedly unfriendly character, in which disappointed land agents are taking a prominent part, making it appear that the land selected is worthless and that the land committee was very incompetent if not positively dishonest; and these opinions are being duly noticed and emphasized by opponents of the Dansk Folkesamfund. It is doubtful indeed if these attempts at settlement have done as much to unite the Danes as the ill feeling created thereby has done to separate them.

THE DANSK FOLKESAMFUND.

This society was established in 1887, under the auspices of a number of ministers and laymen of Grundtvigian tendencies.

The aim of this society is set forth in its constitution in the following language: "We establish this society in the belief that there is a need for an organization which will unite all the Danes in America who desire to maintain the Danish character and wish to aid in the labor of increasing our spiritual inheritance and making it fruitful, not alone for our own benefit or for that of our fatherland, but also for the benefit of the land to which we are now united by the strongest of ties. . . . . When we Danes in America wish to perpetuate in America what is Danish, it is partly because of the inborn love we have for all the things that belong to our fatherland; but it is also because we are convinced that by so doing we are advancing the best interest of the land to which we now belong. When it is admitted that the meeting of people from all nations, on American soil, there to communicate with one another in the English language, is an historic event of first importance, it is mainly because the various nationalities thereby secure an opportunity to communicate to one another the results of their best thoughts and labors. In order that such an interchange may take place it is necessary that each nationality maintain its own language and remain in intimate association with the mother country, for only in this way is it capable of transmitting its possessions to others. We believe the Danish nation has a spiritual inheritance not wholly without value to humanity in general, and we wish to contribute our share toward human advancement."

To advance the interests of humanity in general, then, is the chief end of this society, and to keep in touch with the language and life of Denmark the chief condition necessary for reaching this aim.

But in trying to fulfill the condition the aim seems to be lost sight of; nothing whatever is done to master the English language or become acquainted with American institutions, while every effort is made to maintain all that is Danish and foster exclusion from life in this country. Two branches of this society have been established, one in this country and one in Denmark. The conditions for membership are that a person should be of Danish parentage and not opposed to the Lutheran church. The work of the society so far has consisted (1) in establishing local societies, the members of which hold regular meetings for the discussion of subjects relating to Denmark and whatever is Danish; (2) in founding a library of Danish books to be loaned on the payment of a small fee to any one capable of reading the Danish language; (3) in publishing a paper, *Kors og Stjærne* (Cross and Stars), devoted to an interchange of thought between the members in Denmark and America; (4) in establishing settlements for Danes in America; (5) in directing Danish immigrants to these or other Danish settlements; (6) in sending Danish lecturers of some prominence to Danish settlements; (7) in organizing excursions to Denmark of Danes in this country, especially of American birth, for the purpose of initiating them in the life there and strengthening their love for whatever is Danish. There has also been a general attempt on the part of this society to support the high schools, parochial schools and churches; but the efforts along these lines have not produced any noticeable results, except in the case of the churches; and here it was far from accomplishing what was intended, for this society and its methods of working immediately aroused a storm of opposition from the ministers of Inner Mission proclivities. They claimed it was merely a scheme on the part of the Grundtvigians to create a party in every congregation in favor of their ideas, and thus to drive out all the ministers who did not agree with them. It was almost the only subject discussed at the annual meeting of 1887, and the discussion was so bitter that the ministers themselves seem to have been ashamed of it; for instead of having the proceedings published in *Kirkelig Samler*, a special pamphlet was issued for the purpose, something which has not been done before or since. No conclusion in the matter was reached, however, in this meeting, and the only result of all the discussion was to strengthen the suspicion and ill-feeling already existing; and from that time on there was not a semblance of harmony in the Danish church in America.

The members of the Inner Mission society now began an active crusade against all the plans of the Grundtvigians. Doctrinal differences were emphasized more and more, and the general indifference to the Grundtvigian scheme of education was changed to active opposition.

Rev. P. Vig is the principal exponent of the policy of the Inner Mission faction, while Rev. F. L. Grundtvig,[1] son of the great Danish reformer, is the exponent and leader of the Grundtvigians. The controversy was opened by P. Vig in an article written by him for *Kirkelig Samler* of June 17, 1888, in which he sets forth his ideas on the subject of education as follows: "There are many whose greatest desire it is that the language which is their mother-tongue shall also be the mother-tongue of their children, but feel, nevertheless, compelled to admit that this desire cannot be realized. And we should indeed serve ourselves and our children poorly by doing all in our power to

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[1] F. L. Grundtvig, the acknowledged leader of the Grundtvigians in America, is the youngest son of the great Danish reformer, N. F. S. Grundtvig. He came to America in 1881, after having taken his degree at the University of Copenhagen. In 1883 he accepted the pastorate of a small Danish congregation in Clinton, Iowa, which position he has held ever since. He first made himself prominent by a violent attack on secret societies in general and on Dansk Brodersamfund in particular; this was a secret society of the most innocent kind, established for social purposes and mutual aid, and without any political or religious aims whatever. The attack was based wholly on the fact that it was a secret society, and that in its ritual the name of God was used and prayers were offered in a manner which Grundtvig considered blasphemous. The outcome of this attack was a quarrel between the church and Brodersamfundet (the Brotherhood), in which as usual the church was the loser. From the beginning of his ministerial career Grundtvig has been an ardent supporter of the high schools and of all means for maintaining what was Danish. He was a prominent member of the first land committee, and one of the leaders in the organization of Dansk Folkesamfund, and soon became its actual leader and mouthpiece. He is a voluminous writer of both poetry and prose, but as yet he has produced nothing of any special merit. Most of his

prevent them from becoming Americanized; for the maintaining of the Danish tongue is as far from being the greatest blessing as the getting of the English is the greatest curse. Even if the Danish language is lost to our posterity, they might still retain all that is good and true in the Danish character; for just as a man can take his material inheritance into a foreign country, so he can take his spiritual inheritance into a foreign tongue. We older people must remember that we can hardly imagine ourselves in our children's places. They have a fatherland which is not ours. In a measure it is impossible for them to be Danes; for they lack the Danish environments, and in a measure the Danish tongue must always be a foreign tongue to them. To keep the children born in this country from coming in contact with its language and life is a violation of nature which will at last revenge itself."

This sentiment was promptly attacked by F. L. Grundtvig and other Grundtvigians. They did not, however, stop at this, but made the subject a personal one, thereby arousing a personal animosity which did much to intensify the subsequent quarrel.

The Grundtvigians continued to push their high schools,

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poems are decidedly prosy, a large share of them being argumentative, written to prove his own theories, or to disprove those of his opponent. He is very prone to the use of sarcasm and bitter personal attacks; though he sometimes apologizes for his harsh expressions, he usually repeats the offense when the next opportunity offers itself, and through this unfortunate trait of character he has made more enemies than through the advocacy of his peculiar religious and social theories.

But whatever may be the faults of his character and theories, it cannot be denied that he is honest, fearless, and unselfish in his labors for the cause he considers right. He has never in all his labors in this country considered his own advantage in the matter of money or position. He might have stayed in Denmark and been sure of an easy, paying position; and he might have gone back in 1894, as pastor of the Marble Church in Copenhagen, one of the most honorable clerical positions in Denmark, and one in which he could have been at perfect liberty to preach just what he believed. But he has chosen to stay with his American congregation on a salary scarcely sufficient to support him, with a record of defeat behind him and almost certain failure before him; and that, too, though he considers himself as an exile here, and feels at home nowhere but in Denmark.

while in 1890 the Inner Mission Society found an expression of their ideas in the reorganization of the Elk Horn high school on the American plan; and that this change was approved by the laity is seen from the substantial increase in the attendance at this school already referred to.[1] This did not tend to allay the ill feeling already existing. The Grundtvigians considered the change at Elk Horn as an act of treachery, for now the school for which they had worked so hard and from which they had hoped so much had been taken out of their hands and made a fortress of the enemy, and that too by a man whom they at one time had counted as one of their own. Meanwhile another cause of dissension had arisen. The instructors of the theological school in Polk county, Wisconsin, Th. Helvig and P. Vig, had become entangled in a violent doctrinal quarrel which spread to the rest of the ministers, and it seemed as though the society was hopelessly divided; but at an extra meeting held at Waupaca, Wisconsin, 1891, a truce was patched up. It was agreed that Grundtvig should use his influence in disbanding Dansk Folkesamfund, that the Elk Horn school should be used as a theological seminary, and that Vig and Helvig should return to their posts as theological instructors. But Dansk Folkesamfund refused to disband; the people at Elk Horn did not wish to see their school changed; and Vig resigned his position on the plea that he could not conscientiously work together with Helvig, and again the quarrel was on, more bitter than ever. Finally in 1893 the Inner Mission ministers seceded and formed a separate society. But this separation was one of ministers mostly; the congregations are as yet woefully mixed, and there seems but little hope of getting them divided on a basis of Grundtvigians and Inner Mission, for though there are enough of each faction in every congregation to make it uncomfortable for the other, there are not enough or they are not sufficiently enthusiastic to form separate congregations with permanent ministers and churches, at least no such congregations have yet been found.

One of the immediate effects of this controversy has been to stimulate somewhat the languid interest of the laymen in church

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[1] *Ante*, p. 24.

affairs; but in the main it is a ministers' quarrel and the conservative common-sense members of their congregations look upon it with decided disapproval, while the large majority are not interested enough to find out what the quarrel is about or to range themselves on either side. There is a possibility that the split will in the end make the Danish church somewhat more efficient than it has been so far; for hereafter the Inner Mission faction will have an opportunity to pursue its somewhat aggressive systematic policy without interference by the Grundtvigians, which will be a great advantage in carrying out its plans. Besides, this faction will undoubtedly in the course of a few years have formed a firm alliance with the Danish Church Association, a society organized in 1884 by six Danish ministers and their congregations, which up to that time had belonged to the Norwegian-Danish Conference. In 1890 this society had a membership of 3,493, and church property amounting to $44,775. They have established a school at Blair, Nebraska, and this as well as all the church work of the association is conducted on the same plan and in the same spirit that prevail in the Norwegian church societies. But the fact that only 3,493 out of the 132,543 Danes in America in 1890 belonged to this society, shows that it cannot be very popular with the majority. The two societies when united will not at the utmost contain more than 10,000 members. These, however, will be likely to work together more harmoniously and more earnestly than the Grundtvigians and Inner Mission people, and may succeed in maintaining some quite efficient schools and a few united congregations.

As far as the Grundtvigians are concerned, their past seems to prove conclusively that there is no future for them in this country. They will get but little support from the old settlements; they are unable to establish new ones from the Danes already in this country. Neither can they hope much from an immigration from Denmark, for in the first place such an immigration is not liable to be very extensive in the near future, because the social and economic conditions in Denmark are and promise to be fairly good; besides this, the Grundtvigians will be, as they have been, the last ones to emigrate, for they are more attached to their native land than are their opponents. It is this very fact which accounts largely for the striking indifference with which Grundtvigianism is regarded by the Danes in America, while in Denmark it receives their strongest support. Yet in spite of the present weakness and past failures of the Grundtvigians in this country, they have, nevertheless, exerted a decided influence on the Danes here, especially on those who have congregated in settlements. But this influence has been mostly of a negative character. For, though they could not be persuaded to support the Grundtvigian schools, they were quite easily persuaded from making any special effort to get an English education. The fact that the minister was suspicious of the common school was quite a strong argument in the eye of the thrifty parent for keeping his boy at home to help on the farm instead of sending him to school, and on the whole from taking any special interest in the public school beyond that of keeping the expense of its maintenance as low as possible. The result to-day of this policy shows itself in a condition bordering very closely on illiteracy among a great number of young people who have grown up in the Danish settlements. They have failed to get a fair command of either the Danish or English language, because, as a rule, there was no parochial school to give the necessary instruction in Danish, and they did not avail themselves sufficiently of the advantages offered by the American schools to gain a mastery of the English. But the policy of slighting the English branches in the Grundtvigian high schools has had a more tangible, and if possible, a more detrimental influence on the life of the Danes in America. It has alienated the young Danish immigrants from the church and left them to shift for themselves in the acquiring of an English education, which usually meant a failure on their part to get such an education. They did not care and could not be made to care for the education offered them by the Grundtvigian high schools. Thus they were left out of touch with the church along a line on which it had the greatest opportunity for helping them and extending its influence over them. They could find no American school adapted to their needs, and though most of them were ambitious to master the English language they were usually discouraged in their first attempts and gave it up altogether. It is a rare thing to find in a Danish settlement a man who can carry on the ordinary business transactions in the English language. In fact such a man is sometimes king among his countrymen. They are absolutely dependent upon him in their intercourse with the world where the reading and writing of the English language is required. He may run their political caucuses, their township and school affairs to suit himself, and this in spite of the fact that he is not acceptable to a majority of the voters, for they have no other choice. If it is a rare thing to find a man in a Danish settlement who can do business in the English language, it is a still rarer thing to find one qualified to teach a district school. Even in districts exclusively Danish, a Dane is seldom employed as teacher.[1] A superstition exists in some settlements that a Dane is incapable of acquiring the accomplishments necessary to teach a country school; and that, if through unusual mental endowment and industry any one should actually succeed in this, then the "Yankee county superintendent" would nevertheless deny him a certificate on account of his nationality.

It is, however, not fair to lay the whole blame for this state of things on the Grundtvigian ministers; because there exists among the Danes, especially in this country, a very marked tendency to self-depreciation, a lack of confidence in themselves individually and in their countrymen generally, for which the Grundtvigian ministers are not responsible. But these ministers were the natural leaders of their people, the only ones who had an opportunity. There was need of such leadership, too, for the great mass of Danes who have emigrated belong to the laboring classes, who have had little or no training in the management of educational affairs. They could not, though they had a fair idea of what they wanted, take the initiative in the matter themselves. And if the Grundtvigian ministers, instead of trying to force their own ideas through, had met the desire of their people for an English education, they could have built up a system of schools which would have given them a hold on the most enterprising and

[1] Since the Elk Horn school began to prepare its students for the work of teaching, this state of affairs is somewhat modified.

ambitious young Danes, thus securing them as a support for their church, at the same time giving them a training which would have made them more useful to themselves and the society in which they have chosen to live. While the net result of the educational efforts of the Grundtvigians so far consists in the securing of a few enthusiasts and sentimentalists who by their very system of education have been unfitted for taking any active part in affairs in this country, for they have taken a narrow, one-sided view of Grundtvig's teaching, accepting the emotional side and completely rejecting the practical. Yet, in justice to them, it must be admitted that their main fault consists in adopting a mistaken ideal and espousing a hopeless cause. Their intentions were of a wholly philanthropic and disinterested nature. Many of them have made great sacrifices both in money and social position in order to carry out their ideas; and it is after all to be regretted that they did not adopt some more practical means for carrying out their ideas among the American people at large, for they are full of a spirit none too common among us here. They could have done a great work, if, together with some good practical English instruction, they could have transmitted to the Danes, at large, in this country, a touch of their own idealism. There is need of something to tone down the all-absorbing materialism to which the immigrant is by nature predisposed, and which is so strongly re-enforced by the environment in this country. Though the Grundtvigians are in a measure to blame for the social and religious failures of the Danes in this country, they are not the sole nor the main cause of this failure,—no matter what church or educational policy had been pursued, it would not have had the power to make even a fairly united nationality of the Danes. They have shown conclusively that they have had but little desire to establish any society or church modeled on the society and church existing in Denmark. Their object in coming to this country was to better their material condition. They left Denmark at a time when the spirit of national pride was at a low ebb, when all the political hopes and aspirations of the nation had been disappointed, and when the church was hopelessly divided against itself. There was nothing in their native land they could look to with special pride, no one thing on which they could unite as a basis of their common nationality. The question naturally arises, would it have been better for the Danes individually if like the Norwegians they had formed compact settlements and a strong church; would such a condition have been more favorable for the development of good men and good citizens than the present scattered and disorganized condition?

It is frequently alleged that settlements, churches and parochial schools, as established by the foreigners in this country, form the chief evils of immigration, by perpetuating conditions which produce a heterogeneous population with aims and interests antagonistic to republican institutions and a stable state of society. This belief, however, is undoubtedly an erroneous one, arising out of a misconception of the real needs of our foreign population. These settlements, churches and schools, instead of being a menace to our state, form one of the main safeguards of this country against the dangers accompanying the large influx of people of various nationalities. A large number of the immigrants are young people, and, as far as character is concerned, are still in the formative stage. Nearly all of them come from quiet, staid communities where they have a recognized standing and the pleasure of social intercourse with their equals, and where they are now and then touched by the elevating influences exercised by the church, the school or some other social institution whose work and sentiment they can understand and appreciate. Their social circle holds them responsible for their conduct, stimulating their desire for respectability, thus constituting one of the most potent checks to the vicious impulses that at times are liable to dominate the conduct of people left entirely to themselves. It is this function of stimulating the good and checking the evil, so necessary for the development and maintenance of decent character and good citizenship, which the settlement and church of the foreigner performs, a function which no other institution in this country could perform, yet one of invaluable service to the country as well as to the immigrant. There is no situation much more hopeless and demoralizing than that of the ordinary immigrant, unacquainted with the English language and totally isolated from some staid, sober society of his countrymen, in which the conditions of his native land are in a measure maintained, and where his social standing is dependent on good conduct. In the first place, if he is isolated from such a community he is obliged to play the part of a mute for almost a year after his arrival, save only for such conversation as he can carry on in his native language with the horses and cows about him, and except for such oaths and other strong expressions in the English language as readily fix themselves in the memory of the foreigner, and for the repetition of which there seem to be so many urgent occasions for both native and foreigner. Then again, there is the depressing effect of his social position among the natives. He is made to feel most keenly that he is a being of a lower order, a sort of beast of burden, tolerated only on account of his burden-bearing capacities. He is excluded from all social gatherings of a respectable character, either on account of language or nationality. He is sometimes made the object of pity, but more often of ridicule. As a rule there is only one place, the saloon, where he is received on terms of social equality, and where something is done to make him feel at home and at his ease. It is a rare thing indeed that the young foreigner who cuts loose from the settlement and church of his countrymen, comes under the better influences of American society. He is more often affected by the influences already mentioned plus that exercised by a number of boon companions, who like himself are isolated from all that is elevating, either foreign or American. The character of citizen formed under such conditions is without question far more dangerous to this country than that evolved in the most isolated "priest-ridden" foreign settlement, where at least the sentiment "I am my brother's keeper" is still alive and active. In fact, it is from contemplating the effect of the process of Americanization described above that the foreign clergyman finds one of his chief reasons for excluding his flock from American influence. Being unacquainted with American conditions and out of sympathy with them, to begin with, and both from preference and education of an uninvestigative turn of mind, he reasons from the facts immediately about him; and, seeing only the evil effects of American influence, he fails to realize the fact that it might be used for good. That the minister might advance the cause of his church, and increase the happiness and usefulness of his countrymen, by helping them to choose the good and avoid the evil in American society, is very far from being comprehended by those who dominate the policy of the church. The average clergyman is, however, no more "ignorant and bigoted" in his views than the man who fails to see any good in the efforts of the foreigners to maintain the language, manners and customs of their native land; for such critic does not realize that the tenacious clinging of the foreigners to things which in their childhood they were taught to hold sacred reveals a most valuable characteristic, that it shows a stability of character in the foreigners which makes them much more desirable citizens than they would be if they could throw off all love for and allegiance to their native land and language as easily and with as little regret as they would discard a worn-out coat.

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United States Census Population 1850–90.

APPENDIX.

(The following statistics were obtained from the U. S. census of 1890.)

I.

Contiguous counties in Wisconsin, Minnesota, Iowa and the two Dakotas east of the Dakota river, each county having a population of more than 500 Norwegians.

WISCONSIN.

Ashland	947	Jackson	2,507
Bayfield	1,085	Monroe	837
Douglas	1,058	La Crosse	4,371
Chippewa	1,379	Juneau	518
Burnett	*497*	Vernon	3,387
Polk	1,311	Crawford	801
Barron	2,373	*Grant*	*400*
St. Croix	2,638	Iowa	904
Dunn	3,167	LaFayette	927
Eau Claire	3,897	Green	623
Clark	605	Dane	6,728
Pierce	1,835	Rock	1,632
Pepin and Buffalo	1,232	Walworth	515
Trempealeau	4,118	Racine	949

MINNESOTA.

Duluth (city)	2,389	*Redwood*	*434*
Washington	591	Brown	875
Anoka	1,527	Yellow Medicine	2,384
Ramsey	3,636	Renville	1,980
Hennepin	13,014	Lac-qui-parle	2,641
Rice	1,288	Chippewa	1,995
Goodhue	3,485	Kandiyohi	2,562
Olmsted	820	Meeker	671
Dodge	1,044	*Big Stone*	*466*
Waseca	646	Swift	1,822
Steele	527	Stevens	692
Houston	1,934	Pope	2,623

MINNESOTA — continued.

Fillmore	4,171	Stearns	831
Freeborn	2,600	Grant	1,770
Mower	1,787	Douglas	1,569
Faribault	1,264	Todd	774
Blue Earth	998	Wilkin	641
Jackson	1,232	Otter Tail	5,955
Rock	1,049	Clay	2,700
Watonwan	1,042	Becker	1,527
Cottonwood	785	Norman	3,821
Murray	676	Polk	6,861
Pipestone	*253*	Marshall	1,717
Lincoln	558	Kittson	672
Lyon	988		

IOWA.

Clayton	633	Worth	1,910
Allamakee	1,283	Winnebago	1,871
Winneshiek	3,347	Sioux City	1,758
Mitchell	548		

SOUTH DAKOTA.

Union	612	Minnehaha	2,953
Clay	572	Moody	588
Yankton	1,054	Brookings	1,546
Lincoln	1,324		

NORTH DAKOTA.

Sargent	732	Steele	1,118
Richland	1,837	Griggs	822
Ransom	947	Grand Forks	3,518
Cass	2,428	Nelson	1,098
Barnes	1,150	Ramsey	676
Traill	3,572	Walsh	2,523

II.

Isolated counties in Illinois, Wisconsin, Minnesota, and Iowa, each having a population of more than 500 Norwegians.

ILLINOIS.

Cook	22,365	Grundy	880
De Kalb	580	La Salle	1,718
Kendall	1,099		

WISCONSIN.

Columbia	862	Portage	1,048
Door	962	Shawano	709
Manitowoc	900	Waupaca	1,270
Marinette	867	Winnebago	562
Milwaukee	1,904		

IOWA.

Buena Vista	580	Monona	548
Emmet	533	Woodbury	1,947
Hamilton	1,613	Polk	522
Webster	894	Story	1,824
Wright	529	Marshall	572
Humboldt	1,031		

MINNESOTA — None.

III.

Contiguous counties in Northern Peninsula of Michigan, Wisconsin, and Minnesota, having a Swedish population of more than 500:

MICHIGAN — NORTHERN PENINSULA.

Delta	1,475	Menominee	4,021
Marquette	4,303	Iron	719
Schoolcraft	559	Gogebic	1,769

WISCONSIN.

Florence	500	Burnett	1,541
Marinette	1,407	Polk	1,600
Ashland	1,357	Barron	566
Price	982	St. Croix	694
Bayfield	774	Pierce	1,281
Douglas	1,572	Pepin	739

MINNESOTA.

Duluth (city)	4,102	Blue Earth	822
Carlton	901	Nicollet	1,619
Aitkin	*407*	Renville	968
Crow Wing	570	*McLeod*	*160*
Morrison	623	Kandiyohi	2,752
Benton	*300*	Chippewa	523
Pine	966	Swift	784
Kanabec	827	Sherburne	512
Isanti	2,758	Stearns	511
Chisago	3,955	Pope	677
Anoka	1,032	Grant	878
Washington	3,399	Douglas	2,521
Ramsey	12,212	Otter Tail	2,470
Hennepin	20,167	Becker	731
Wright	2,550	Clay	1,050
Meeker	3,249	*Norman*	*248*
Carver	1,236	Polk	2,241
Dakota	799	Marshall	2,025
Goodhue	3,695	Kittson	1,668
Sibley	1,134		

IV.

Isolated counties in Illinois, Wisconsin, Minnesota, and Iowa having a Swedish population of more than 500:

ILLINOIS.

Cook	45,607	Henry	4,324
Winnebago	6,204	Knox	4,697
De Kalb	1,695	Peoria	623
Kane	3,252	Warren	832
Will	2,140	Mercer	1,322
Ford	1,189	Rock Island (city)	4,661
Bureau	1,807	McLean	624
La Salle	758		

WISCONSIN.

Door	589	Eau Claire	546

IOWA.

Des Moines	1,973	Cherokee	529
Webster	2,014	Woodbury	2,402
Boone	2,385	Crawford	517
Hamilton	549	Montgomery	1,468
Polk	2,107	Page	1,220
Sac	625	Pottawattomie	561
Buena Vista	899	Wapello	961
Pocahontas	524		

MINNESOTA.

Martin	587

V.

Contiguous counties in Iowa and Nebraska, having a Danish population of more than 500:

IOWA.

Audubon	1,067	Shelby	1,347
Pottawattomie	1,922		

NEBRASKA.

Washington	724	Douglas	4,714
Dodge	623		

VI.

Isolated counties in Illinois, Wisconsin, Minnesota, Iowa, and Nebraska having a Danish population of more than 500:

ILLINOIS.

Cook	7,488

WISCONSIN.

Brown	819	Polk	844
Winnebago	1,210	Racine	2,893
Waupaca	962	Kenosha	554

IOWA.

Black Hawk	645	Clinton	951
Buena Vista	512	Woodbury	711

NEBRASKA.

Howard	1,153	Lancaster	505
Kearney	941		

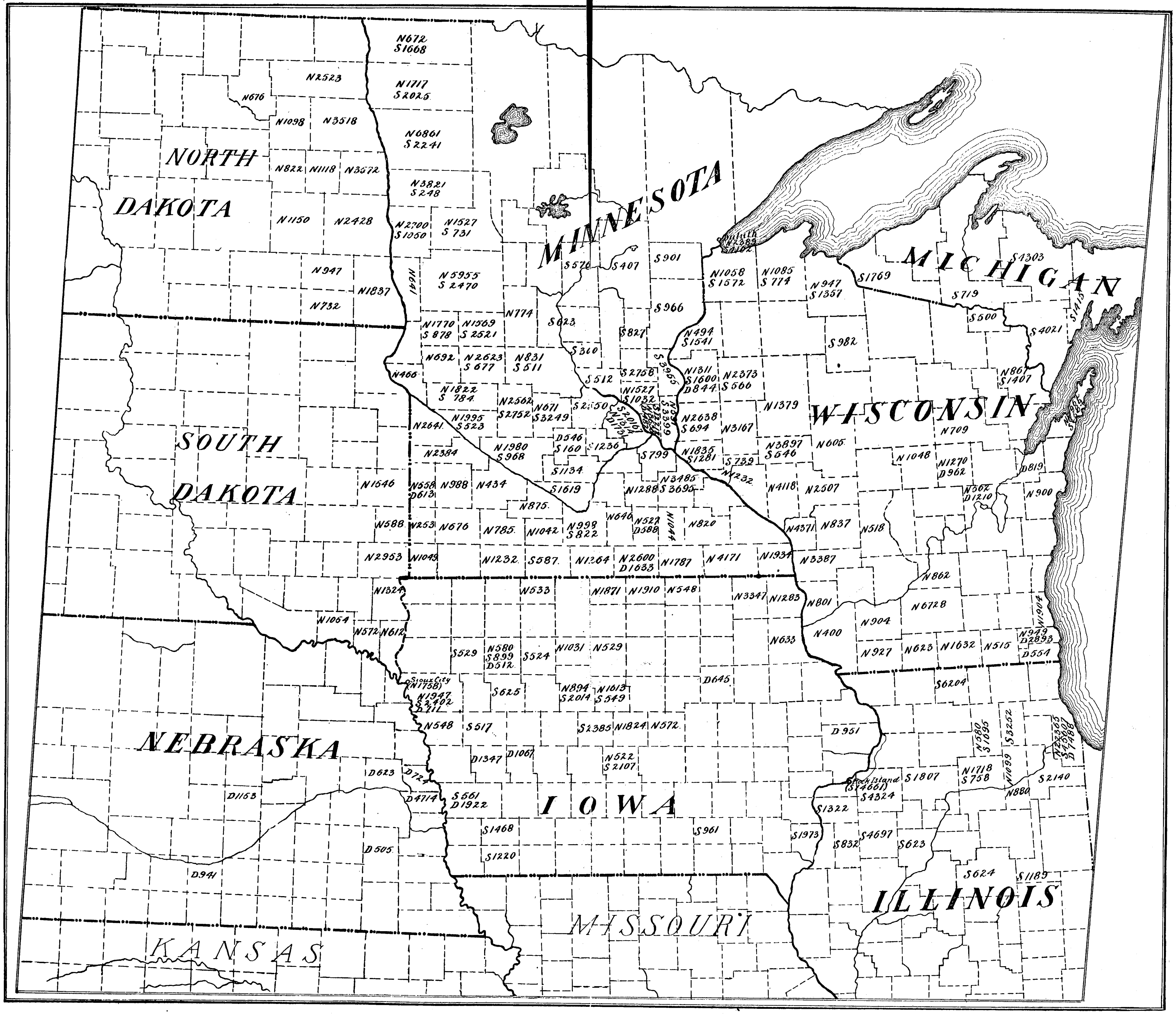
MINNESOTA.

Freeborn	1,633	Lincoln	613
Hennepin	1,731	McLeod	546
Ramsey	1,482	Steele	588

EXPLANATION OF PLATE I.

Map showing the distribution of the Scandinavian population in contiguous areas of Wisconsin, Michigan, Minnesota, Illinois, Iowa, Nebraska, and the two Dakotas east of the Dakota river.

N, Norwegians; *S*, Swedes; *D*, Danes. The figures following indicate the population of each nationality.



BILLE ON DANES IN AMERICA.

THE METHODS OF SCIENCE, AS BEING IN THE DOMAIN OF LOGIC.[1]

J. J. BLAISDELL,

Professor of Philosophy, Beloit College; First Vice President of the Academy.

Sitting as a visitor for several hours in the room of a Christian pastor, and hearing his conversation with several persons of his parish who came to him for advice, he said to me, after their retiring, with something of sadness in his tone, "These people come to me for counsel as their pastor, and little think that I have no pastor, but have to find my way alone." I mistrust that something like this is the feeling of the more thoughtful men of scientific pursuits as they make their way along through the special departments of truth which it is the business of their life to explore and conquer. They find disciples in the study of the one science which occupies them, but when they look up above that, if they are large enough to do so, they have a sense of isolation. The bond that holds together the facts of their particular field is plain, and they have no difficulty in subordinating them into unity under the dominating principle; but the other sciences, save perhaps some intimately related, seem apart, moving in an unrelated orbit, like ships crossing or going on widely parallel lines, pilgrims to different shrines, ships that pass at night, out into a night, from which, for us, we have no sense of their ever being bound to emerge at the same port with us.

The question forces itself upon every thoroughly trained person whether it is so really with the several sciences, whether they are like ships unrelated, at sea, ruled, I do not mean so

[1] **Annual address at the winter meeting of the Academy, Dec. 26, 1895.**

much not by any one several dominant quest which they are severally making, as not by any certain principle of procedure which may constitute of itself a science under whose guidance they all find it comfortable to proceed—somehow a solar force that keeps them all in their orbits, as the pastor I heard, holding together by the law of his master principle the people who came to him to learn the how of living.

It is in the mind of some, perhaps all, when they think deeply on the subject, that there is such an over-guidance for scientific study. It was an earlier habit to call logic queen of the sciences, and though, possibly since the present century began to assert itself, in some directions logic has had put upon it interpretations which would, if they were true, set the matter in doubt, I have thought it might be well to raise the question anew. There is nothing that adds more zest and courage to travel through strange regions than to know the relation of our route to other routes which run along by or cross our own, and the relation of them all to some fixed point. The planets that constitute one system must be interested to know that the splendid orbs which constitute a neighboring one are ordered in their moving by a great central luminary; the mighty and separate systems that inhabit the illimitable sky to-night must be happy, it would seem, that the same gentle touch of gravitation keeps them in their individual integrity and holds them all in placid unity, as a mother keeps her flock in the sweet home of childhood. It does seem as if there were sweet instincts of science, felt by such men as Faraday, which, while we are apt in the ardor of pursuit to neglect them, we do well in moments such as these to let have all the recognition they may find reason for. I shall venture to ask your thought to a few hesitant suggestions regarding logic as having for its domain the methods of scientific procedure, or, as written upon the program of our meeting, "The methods of science as constituting the domain of logic." Logic, the pastor to whom the scientific student comes to learn the methods of his procedure; logic, mistress and law of science.

I need scarcely say that the problem of *science is the transcribing into modes of the mind of the objective facts of the universe of real being.* The child begins the process in making the representative image in its mind of its mother's face bending over it; all the way along, in its multiplying and more comprehensive mental copies it is ever making of the world that smites its senses and its other avenues of apprehension.

> "Shades of his prison house begin to close
> Upon the growing boy.
> . . . .
> "The youth who daily further from the East
> Must travel, still is Nature's priest,

and is getting more of the vision splendid, gathering in more and more of the universe to which he was just now a stranger. To the man, to whom, alas, it ceases to be strange, and therefore seems in its freshness to die away, it only, while it constantly enlarges and is more fully his, though not lost,

> "Fades into the light of common day."

Wonderful procedure of mind in the process of thought, in which, moved by high instinct more than the bee that seeks a lesser sweet, it writes line by line of the splendid macrocosm in corresponding lines of the growing concept of his thought so as to make the microcosm within, exclaiming as he proceeds: "It is mine! There is a world around me; it is splendid; I have found it; I have made it a part of myself; it is mine!"

But there are certain minds, in whom this instinct to appropriate the world of objects asserts itself, who go about this gathering in other than a child's mood. Not moved altogether by the impulses of life's common day as if thinking things are to be known only just whenever and wherever life immediately prompts or enjoys knowing, as the butterfly flits from flower to flower, each for what it contains, they recognize a law of correspondence and orderly distribution. A diviner voice within them seems to be chastening the earlier method and moving them to know the wide domain in its larger, truer and more real form. These we call, by special emphasis, the men of science. The sobering youth of the world has taught them that as the universe is a living growth, and not a dead structure, life has cast it into different departments, each of which, however having common relation with all the rest, may furnish special field of conquest. So they take nature's intimation, and one to one and another to another they go apart in companies to the several fields the divine spirit within them calls to make truer ingathering from for themselves and the age — interpreters for the ownership of future ages of the world's truer being, a priesthood of far more genuine anointing, if they are true to their calling, than youth, though youth in later mood

"Still is nature's priest."

How is it possible that when the universe, whose make seems so orderly as to woo man as a lover to acquaint himself with her nobler beauty and lead him to explore the several departments of a system which gives so many intimations of order, it should not come into his mind, as insight deepens, that there is a vital synthesis of these departments with which he has become acquainted, until at length it breaks upon him that the universe is one universe. Even as when, ascending mountains in boyhood by different paths and encountering different toilsome shoulders on our way, which disclosed the broken volume, the shoulders, from which we looked from one to another and from above and from below, made us know that if further heights were mastered a summit was waiting for us, and underneath it as its blessed domain lay all the kingdoms of the world and the glory of them. And so chiefs in the ministry of science, out on campaign to aid in gathering into the mind's ownership out of the fields of all science the universe as one, have our honor. Ownership, in the mind's store, of the cosmos is the ever-receding but always beckoning goal of dreams of mind, to which the race of mankind, even though only by supernatural redemption fully reaching it while it is our blessedness always to be seeking, is crowding as pilgrims to a common shrine.

1. Inquiring now concerning the relation of logic to this procedure of science, I find *its first office in the insistence it makes that science must ground all its findings in an Ultimate Reason which orders the universe as one.* For after all I have given but a one-sided account of the way in which the conclusion comes to us that amid the multitude of sciences they all find their synthesis in one that comprehends them. Not altogether because by examining the lower structures of the universe we find a converging trend upward do we infer that we

shall find the summit in which all culminate. It is as much in the make of mind to know outright that the field of reality is one whole as it is to know its several territories. It is in all instinct after reality that the universe is one. The mountain top we climb by laborious ascent is not only known to the traveller as the result of his climbing, so that he knows it only when his foot presses its utmost rock. He has lived in the neighborhood of it from boyhood, and has seen its splendors from afar. Mind knows more than it finds out. That the universe is one is not an inference from observation; it is an insight. We may not define to ourselves all the volume of this one so as to infer its content, as some have tried to do, for our eyes are dim. But Plato was right; we know the wholeness by insight, and so all after gettings, when we find them, fall into their place in the organic whole. One sufficient reason, as regulative principle and ground of the whole in every part, is the splendid indigenous revelation of mind, in the light of which the man of science goes to his royal study. That absolute reason — the nous of Plato — supreme, one, answering ultimately all our askings of the reasons why, puts the law upon our science that amid the multiplicity of sciences science must be one, even as there is one reasonable universe. This law, that science must obey that unifying reason — that all thinking must obey it — is the supreme content of the science of logic. Logic is the science of our thought of things as child of the one absolute reason. Only in the liberty of that law is mind satisfied. It gives — and only it gives — science confidence, as having the certainty, in its finding, of that one Reason, splendid fountain of light in which there is no darkness at all, " whose voice is the harmony of the world."

2. *The division of this universe and its distribution into fields as subjects of the several sciences is wholly in the domain of logic.* One is impressed with the apparently opportunistic way in which the various sciences have come into existence one after another; how, for example, astronomy, chemistry, meteorology, physics, psychology, had their origin, and on what account we have now only just so many sciences and no more. One is apt to raise the question how the limit is determined and on what

principle. The more we reflect upon the matter it occurs to us that, while the history of the institution of the sciences has been without much system, logic, holding science under the same law of sufficient reason, really prescribes the bounds of her habitation.

A. *Logic* in her law of sufficient reason *holds science responsible for determinate fields.* The history of the way in which the institution of the sciences has taken place, according as some fact has happened to strike forcibly the attention or made its appeal to curiosity or economical motive, almost suggests that historically the process has had no other direction than that it should go until such time as nothing more might occur to observation suggestive of new fields. Or perhaps we may have set our limit vaguely in the thought that the splendid campaign would be finished only when it should come to be evident that the whole universe had been gone over, and, as with Alexander, we should be obliged to stay our footsteps for the lack of something more to conquer. But it at once occurs to ask whose observation is to determine that the limit of the Ganges has been reached. Science has seemed many times to have reached her outer boundary, in the history of thought, only to take consideration immediately for new advances. One thinks seriously often of what likelihood of further responsibilities for thought still exist for the student. You know there are many sciences besides those which use the senses as their instruments and which therefore are not so palpable. Who shall say that there may not be found more and more fields to conquer, climbing up the steeps of the universe where no discoverer's foot hath been? This universe is very large, larger than our world of matter and our world of mind even. We cannot tell how many more sciences are to be constructed, whatever contracted views we may have of the number possible in the small territory we are at present occupying. And so, if any person, the man of science who knows most has a horizon which makes him humble. But there is one limit prescribed to science, and that is the one of the reason of things, which logic imposes as its directive to thought. Logic says, out of the deep mind, which is the oracle through which the universe reports itself to intelligence: "A system of things is the substance of all being, ordered in the unity of reason, and the student of that system has the limitation of his science in the reason out of which it comes and by which its boundaries are set. We shall go on in glad and tremulous surprise, multiplying our sciences and reviewing their conclusions, disappointing the tears we shed for no more fields of study, but always within, and never in the depth and number of sciences transcending, limits, though hard to find, of a reasonable universe which, while some smile at the mention of it, would seem, if we now had vision of it, radiant with absolute beauty, even the feeble vision of which the great spiritual souls of the world have been ravished with.

B. In the same way logic *prescribes to the sciences the law of their several spheres.* To the majority of minds when asked the reason why the facts of the atomic and molecular movement are grouped together in a specific system of thought called chemistry, the appropriate answer would seem to be, that the facts in question were substantially alike, as being atomic and molecular. We might call this a physical reason. A higher grade of mind would give a physiological reason, in the larger meaning of the word physiology, and say, it was because the facts were alike in being the performing of the same function in the organic structure of the world. But both these answers, mediate in their nature, are only perhaps an unconscious recognition of a sovereign though undemonstrable, because absolute, law which holds the mind in the procedure of reason, furnishing an answer to our question, which is ultimate. Why does the chemist place the movements of the atoms and the movements of the molecules in groups and the modifications of these in groups subordinate, and make them in certain order one department, calling it chemistry? And why in the other view, why, when the student finds a field of facts atomic and molecular, in the living system of the universe, serving identical uses physiologically in the economy, does he put them therefore apart in a hierarchy of concepts and call the world's ownership of them a science? They will tell you: "Because it is a reasonable procedure," intimating thereby that as the universe is in the ground of reason which orders it as one in order of reason, as reason is one, so this same reason imposes on things their identities as law not only of their place in a reasonable system but of our thought of them as having that place in a reasonable system. To think of the facts with which chemistry deals, having in a certain view a communicant identity, as having some other identity and being part of another territory, confounding thus the territories of fact into which the universe is divided, is to think illogically, because logic requires that science think things as they are. It appoints to some one science to make report of a given range of the system and gives its orders that others do their office within that in inferior scope so as to be subordinate, and others still further subordinate, and others still further subordinate, each according to some real natural organic division of the larger field. Another range it assigns to another science. To the great imperial sciences it will be given to occupy co-ordinate service including these lower, and, as these higher must be subordinate to the highest, to that highest and supreme science will belong the prerogative of making the whole universe the field of its study. In this manner each science will be required to occupy its several exact place. Nor will empirical observation have the last word in thus distributing the fields of the various sciences, for this can only be determined by penetrating to the heart of the great system and ascertaining the order and reason in which is all its significance and from which all derives its wonderful form. Behind all empirical determinations the distribution of the sciences will be in subjection to that deeper project. Unexpected sciences come into being subordinating what seems to be supreme, casting down what is lifted up and lifting up what was cast down. Reason thus being ground in which all things have their existence and being the ultimate truth, science, by the insistence of logic, subjects her service to the law of sufficient reason.

3. Logic *gives law to the methods in which science prosecutes its special individual procedures.* We hear much of the methods of science and of the scientific habit of mind, as if there were some directive of mind in its taking possession of its domain which it were well to form the habit of complying with. If I mistake not logic furnishes the ultimate canon for such directive.

A. As every student of the universe understands, *there are certain preliminaries* which have to be gone through with as a preparation for specific scientific work. There is the training of the senses to alertness, so as to have exact apprehension of all things within their range, and the art of arming them for better work, together with the training of those higher powers of mental apprehension which play upon the part of the universe the senses are not related to, and the art of arming them. Still more essential is there the bringing of the sensibilities into full responsiveness, without which it is as impossible to find the real universe or any of its territories, or any of the facts in their real significance in any of these territories, as it is to find the truth of the Apollo Belvidere without any sensibility of courage or moral nobleness or high defiance, or anger at the evil at which he sends his death-delivering arrows. How can one find the real secret of the universe or of any of its parts without sensibility to the love which floods them all; its beauty without a soul to feel its beauty; its pressure of holiness unless his spirit thrills to the moods of its holy administration? Not one thing does the student find in its real character until his soul answers to the soul of all things, as no fiber of the hand can be understood or is other than an unsolvable riddle until the purpose of royal manhood comes to explain it. Then, almost the condition of all is the training of the will for the procedures of science, for I sometimes think that the highest and sublimest examples of trained will are found, not in great statesmen who conduct nations in long critical periods of inertia or passionate turbulence, or in military captains, who hold armies in the vicissitudes of long wars until they have waded by alternate victory and failure through battles of blood and encampments and marches to peace and settled order, but in the silent conflicts of study, where, perhaps in poverty, is no support by the gaze of men and the eclat of parties, nor any stimulation by the thunders of the captains and the bliss of battle.

You will observe that all these preparations for the work of study, which make you men of science what you are — made Faraday what he was — are ordered in inferences logically derived, as regards what they shall be in measure and in form, from the work of science, which in particular you have in like manner concluded from circumstances yourself called upon to do. You did not take upon yourself the harness of preparatory training at haphazard or by mere knack or skill, nor did you blunder into it, nor did nature give it to you save as part of a reasonable procedure. You threw yourselves out on the principles of reason which bottoms all things and all inferential judgment, and were led by loyal logical inference to conclude that, as you were to do a particular work to which you had reasoned as being yours to do, these were the forms of preparation for you to secure, and in the light of that same reason you entered upon them, measured them, shaped them. If logic had not instructed you to say your "Therefore," you had wandered in a wilderness deeper than that the world, alas, would have been in without your science, and never would have found your way. The men of science may be unconscious of the mistress which guides them, though their hand, if they walk truly, is never out of her hand.

B. What we usually call the *distinctive* methods of science are of two classes, which I will call severally the proximate and the ultimate methods, in both of which the true procedure is only fealty to logic.

(a) You know well that it is *the hardest part of scientific work to find the way into the presence of the facts which are the field of your science.* Long and circuitous are the paths by which we enable ourselves to confront them. Take the facts of heredity or of the origin of species. By intermediate processes only do we look such facts in the face. If, for example, you suspect the existence of faculæ across the whole disk of the sun, you put the question to the spectroheliograph, and in the report of the calcium lines H and K you find a witness you can trust in evidence of the fact you have suspicion of. You take the fact of gravitation as operating upon the earth directly as the mass and inversely as the square of the distance, and on the principle of analogy from this you calculate the orbits of a binary star, and on observation you find that the witness you trusted has enabled you to conclude rightly. Professor Langley makes the bolometer his oracle, and is able by the same principle of analogy to detect the presence of variations in the sprectrum which no human eye has ever seen. In another science, amid all the apparent moral confusions which life confronts us with as we follow with the microscope of observation the cases where moral derelictions in character more and more obscure are yet followed by their corresponding sanctions in retributive reckoning, by argument from progressive approach we are confronted with the fact that for every idle word that man shall speak God shall bring him into judgment, and that accordingly not one jot or tittle of the law shall perish. By such methods as these the student of all secondary sciences is obliged to make his way into relation with the facts which he makes the field of his study. Minor premises, which he uses by way of analogy, example, progressive approach, sign, a priori from principle, a posteriori from result, induction from individuals, deductions from generals, he uses as standing ground to reach out into realms beyond his immediate cognizance, as we take the diameter of the sun's orbit as our base line for measuring the distance of the fixed stars and their movements. It is at once seen that in all these methods the principle of procedure is a law of reason which holds conclusion in fixed relation to premises, to transcend which relation we say is unreasonable; without realizing that what we mean is that there exists an absolute reason which all thinking must obey or go off into absurdity and mental chaos. To affirm and formulate this sufficient reason as the law which holds thought in absolute limitations so as to be true, and certain of being true, is however the exact business of the science of logic.

(b) I shall have time only to express briefly my thought as regards *those methods of science which are called ultimate*, which will perhaps by most persons be regarded as being the main ones. That they are the main methods in which science does its actual service in helping mind to become identified with its own universe is to me more than doubtful. It has long seemed to me that, great as have been the mistakes of method in generalization and classification, and fatal, the greater misfortune almost has been in not comprehending the limitation at the point I have already mentioned as set by reason to the very problem of science, which limitation, while it widens magnificently that problem to legitimate boundaries irrespective of all barriers of dogmatism and traditionalism, makes science aware of a final limit of its career within green pastures and by still waters, beyond which is not even the reign of chaos and old night.

1. The first real procedure of mind in its campaign of conquest is *to present to itself in concept the modes of reality which are objective to thought.* First, we will say, through the tracts of the senses by mental signals mind is put upon the knowledge of forms of being which are not modes of self. By the push of wonderful mental instincts, in the same manner, they are grouped according to the inner signals of sensation and defined to the wonderful inner conqueror in the terms of the feeling they occasion. Modes are interpreted as modes of substances, and individual things appear by representation in the field of mind. In the rapid progress of mental history, interpretations of modes are corrected, their groupings are modified, and individuals come to better definition. As the treasure of mind increases and its skill in acquainting itself improves, individual things are combined into larger and complex individuals, which are constructed into completer and fuller complexities and combinations. Now the mind is coming to have rich possessions, persons moving in their places amid the environment of many things, with the landscape around them and the heavens above them, with the sun lighting them by day and the moon by night, and wonder woos it on to enlarge its domain out into the universe of being, like Alexander seeking the empire of the East. Meanwhile, with all this has been coming up into modes of mind through consciousness the transcript of its own being, its individuality, highly endowed with instincts of mastery, with intelligence, sensibility, dominion of will, aspiration, prophecy of conquest, sense of dignity, personality. Other minds start up into the field of view, with combinations of personalities in their organic groupings, in families and nations and the race, and by analogy other populations in other spheres, and lo! mind has now in its vast concept a whole physical universe peopled with inhabitants in their orders. Meanwhile, again, partly as the inference of what it is already in possession of, partly by the vision of high endowment, it is entered into the knowledge of mind that out of the legislation of reason all this is but a procedure in the interest of a beneficent end,

> **Some far-off divine event**
> **To which the whole creation moves.**

The universe is become known to man — a population in the midst of universal nature, charged with moral meaning in government, running its eternal history under the ordering of absolute reason — a living cosmos. Such is science, splendid, glorious, the entering, through long ages only achieved, of intelligence upon its birthright; begun in the instincts of childhood, continued by youth and manhood, entered upon and prosecuted in deeper and more careful mood by men of science, overwatched and guarded by sages, the treasure of mankind, God's lesson to His creatures, as guide of life and motive for convoying them to high destiny.

But if this finding of self is science it is no less manifest that the whole long and difficult procedure is one entirely within the domain of logical principles. You have no guide but reason, for reason only can authenticate the witness of your ordinary observation. You shall therefore be loyal to the exact identities which reason teaches you belong to things, never transcending the lines which separate them and put them apart. You shall treat them as reason bids you treat them. You shall in your thought of all things observe the difference between the contradictories, not calling light darkness and darkness light, but letting your yea be yea and your nay be nay; never constructing your transcript of the earth's crust with the Protozoic beneath the Azoic, of the heavens with the earth as the center of the solar system after the manner of Ptolemy, the invertebrate as ruminant, war as a pastime for nations to play with, sin as a step upward, man a thing of necessitated destiny, the cosmos a harmony without an intelligent author. In doing so you transcend the law that an absolute reason shall be the guarantee of your thinking, save as you have which and in so far as you do not have which, science is guessing, of which law logic is the science and the prophet.

2. I ask your attention to *those methods which science sometimes esteems*, I think mistakenly, *as her consummate achieve-*

ments, the generalizations and classifications of science. In the real structure of the universe, which science makes her field there are no such things as genera or classes. Or rather there is no such communicant identity as to allow us to confound any one thing with any other thing, however in our apprehension of them they are indistinguishable. The lines in the splendid universe, which shut apart individual things and run through their structure to distinguish them, are sharp like the lines which circumscribe and diversify the most delicate engraving, never fall afoul of each other and leave no blur. One grain of sand on the sea shore is absolutely other than any other grain of sand on the sea shore. The solidity of one grain of sand on the sea shore is not the same solidity as the solidity of another grain. The gleam of the butterfly's wing is not the gleam of the dawn. Apart do the individualities of substance and quality in things stand, separate one from the other, no two instances of quality the same, however alike, no two instances of substance the same, however alike. Absolutely solitary are they, however the blood of one circulating purpose runs through them and makes them one glorious living moral and eternal whole. But there are groups and tiers of things in the climbing heights of this one, whose individuals are so indistinguishable to our apprehension that to retain the conception of their separate individualities would only make chaos in our thought again, and the constitution of mind is such that we easily deal with them as having their being respectively in inclusive units. Accordingly out of them we make generalizations of qualities and classifications of things, tier over tier, like Dante's rose of Paradise, flaming hierarchies ot science. But this is only man's weakness. The Infinite Mind sees all things in their individual being as living in the one organic whole. The universe, in His absolute self-consciousness, how resplendent! how absolutely inconceivable in its grandeur, to our weak apprehension! Magnificent is the achievement indeed of the great monarchs of scientific procedure in constructing the pregnant stages of ascending concepts by which man is enabling himself the better to hold the vast portrait he is making. It is only the service rendered by vast breadth of mind to ordinary human weakness, the staff by which the explorer supports himself as he makes his pilgrimage to the mount of vision, the false arch he builds over him lest the infirmity of mind in passing beyond shall be too great to allow his unembarrassed progress.

3. You have always observed, however, that *when one wishes to animate himself* with a view of any portion of the vast domain of the universe in its actual living reality *he puts aside the blur of these genera and classes, by analysis separating them into their individual content and constructing the splendid landscape of being as it is.* In its more deliberate and ordered way this individualizing process wherein things are restored to themselves is the most ultimate procedure of science, in which it takes apart what for the weakness of the time it has provided itself with. The last work it is the high office of science to perform is thus to break itself against the barriers created by its weakness, clearing its eye for the true vision of things as they are and as they lie unfolded in the bosom of Infinite Intelligence. That blessed vision in which all things will be cleared into their true features and the universe will be itself in the eye of rapt intelligence, it is not the destiny of finite mind ever to reach, for the finite cannot overtake the infinite. This is the ideal of science. But it is the blessedness of man to be ever drawing nearer it and enjoying the new and opening sight, the men of catholic science, servants of mankind, leading the way. When the number of the sciences shall be fully made out and the portion of the universe allotted to each shall be well surveyed, with what is now mystery cleared, all in catholic harmony, handing in their several contributions to the one whole, toward which the heart of all is devoted, in that later age of the world, how glad will be the harvest home!

It is needless to say, however, that all this procedure of science in generalization and classification, in determination and individualization, the ever enduring toil of thought, has its orbit in the domain of logic. Its running together of many qualities into one quality pregnant of many instances, its running together of many individuals into one pregnant individual, its shaking apart of one generic quality into its many individual instances and of its one generic individual into its many individuals, each with its several life, the constructing of a universe by blurring of life in order to construct it more conveniently, and the constructing of it more vitally by delivering it from the blur which convenience has allowed, is all along the lines of a sufficient reason on which logic insists as the guarantee of all thought whether divine or human. Put a neutralizing touch on logic as the science of the guarantee which reason furnishes to your processes, and the whole fabric of your science will have no fixedness and tumble into meaningless jargon.

For what now, precisely, is *logic* but *the ordering assertion of those laws out of the domain of reason in virtue of which thinking is reasonable and has any allowance.* Its domain, therefore is all human thought. Starting with simple judgment, the one ultimate form which all thinking sooner or later may be reduced to, and following it through its many variations from the essential type, in concept and reasoning in its various modes and figures, and in all the modes in which it employs elemental energy in transcribing the outer into the inner world, it prescribes to each of them the ultimate condition on which its transcription of things is certain or probable, or has anything to do with reality. It gives law to our simple judgments, prescribing their form and variations and conditions of truthfulness. It compels our notions of things to be clear, distinct and adequate, in order to their perfection. It weighs reasoning in its balances, and insists upon the types to which it must conform or be nugatory. Not one step of science is taken save under her sanction. Science is not irresponsible. The hand of science must be in her hand. Logic is her mistress, all the way up from the feebleness of childhood's thinking to the vision of the seer as he stands in front of the universe in reverent and deliberate awe.

I speak of awe and reverence as the quality of the man of science, for, after all, this law which *logic* proclaims as put by reason upon thought *has its seat in that absolute sphere where all venerableness abides*, a kind of awful government of intelligences which are liable to err. There is one law for the underlying purposes which constitute character, the law of right, to break which is sin. There is another law for the sensibilities, the law of beauty, to be out of conformity with which is ugliness. There is another law of the intellect, the law of truth, to break which is intellectual confusion and the wandering as of the night. This is the imperial legislation of the Absolute Reason in the universe, the ancient and unwritten code, abiding in which is virtue in the will, beautifulness in the sensibilities, truthfulness in science. Under this aboriginal and venerable government over thought we as men of science do our responsible work for our own yearning and that of mankind. It becomes us to be deeply reverent, as have always been the seers of history.

Logic is the science of this fealty of thought to reason. I think of it as a religious science. The teacher of it, the true teacher of it, is one of the prophets, standing in the name of God. The student, constructing his science under the guidance of its teaching, will, if he intelligently apprehend its meaning, go to his service with a deep sense of the sacredness of his calling, with tremulous joy that he is permitted to minister with his hand in the hand of so blessed a leader. *Logic affirms the supremacy of absolute reason, and true science accepts obediently its leadership as of a divine voice.* Under the law of that sacred science of logic, prophet of a higher law, science goes in and out and ministers in sacred things to man.

Beloit, Wis.

RAILROAD POOLS.

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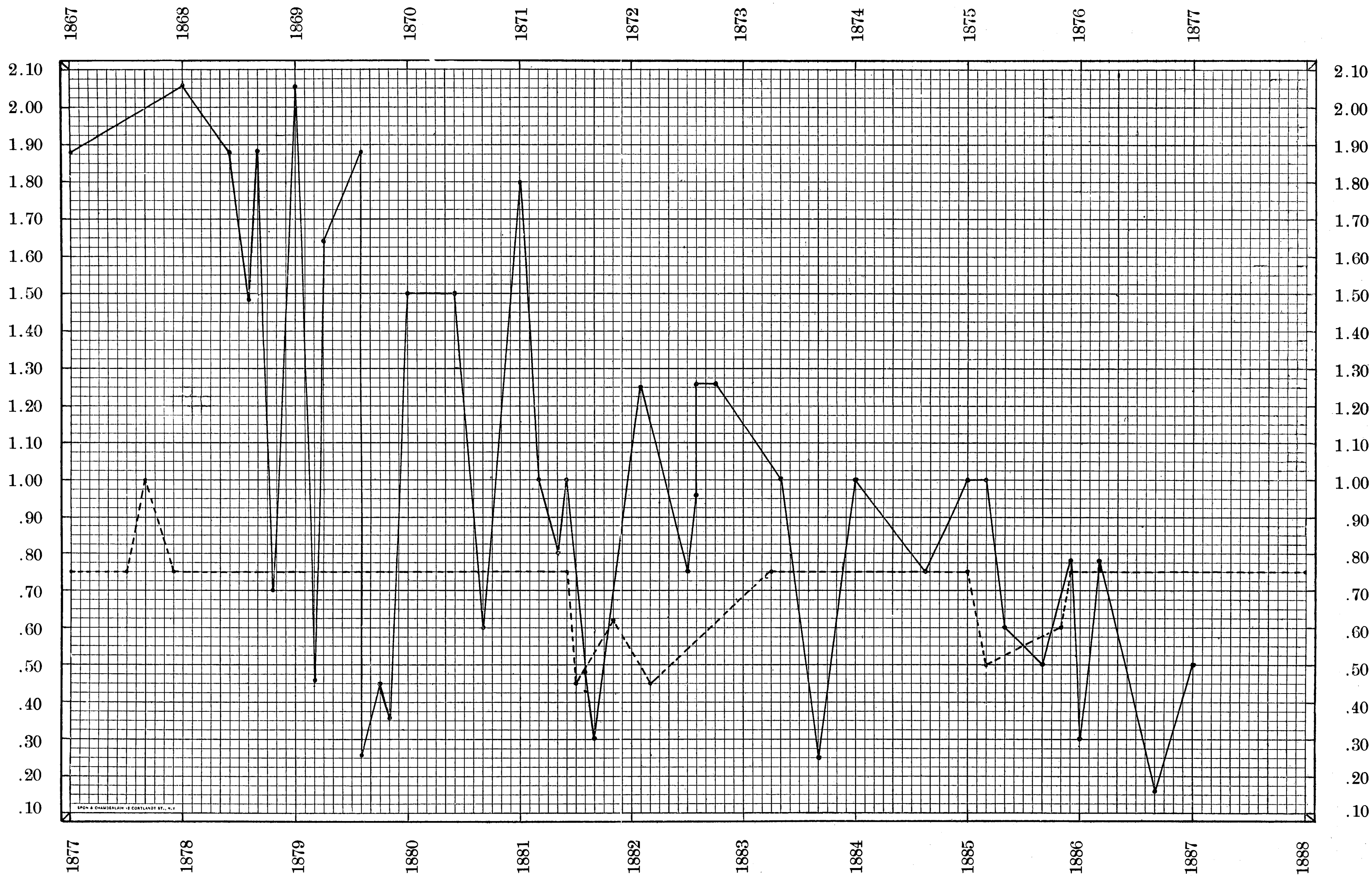
WITH PLATES II AND III.

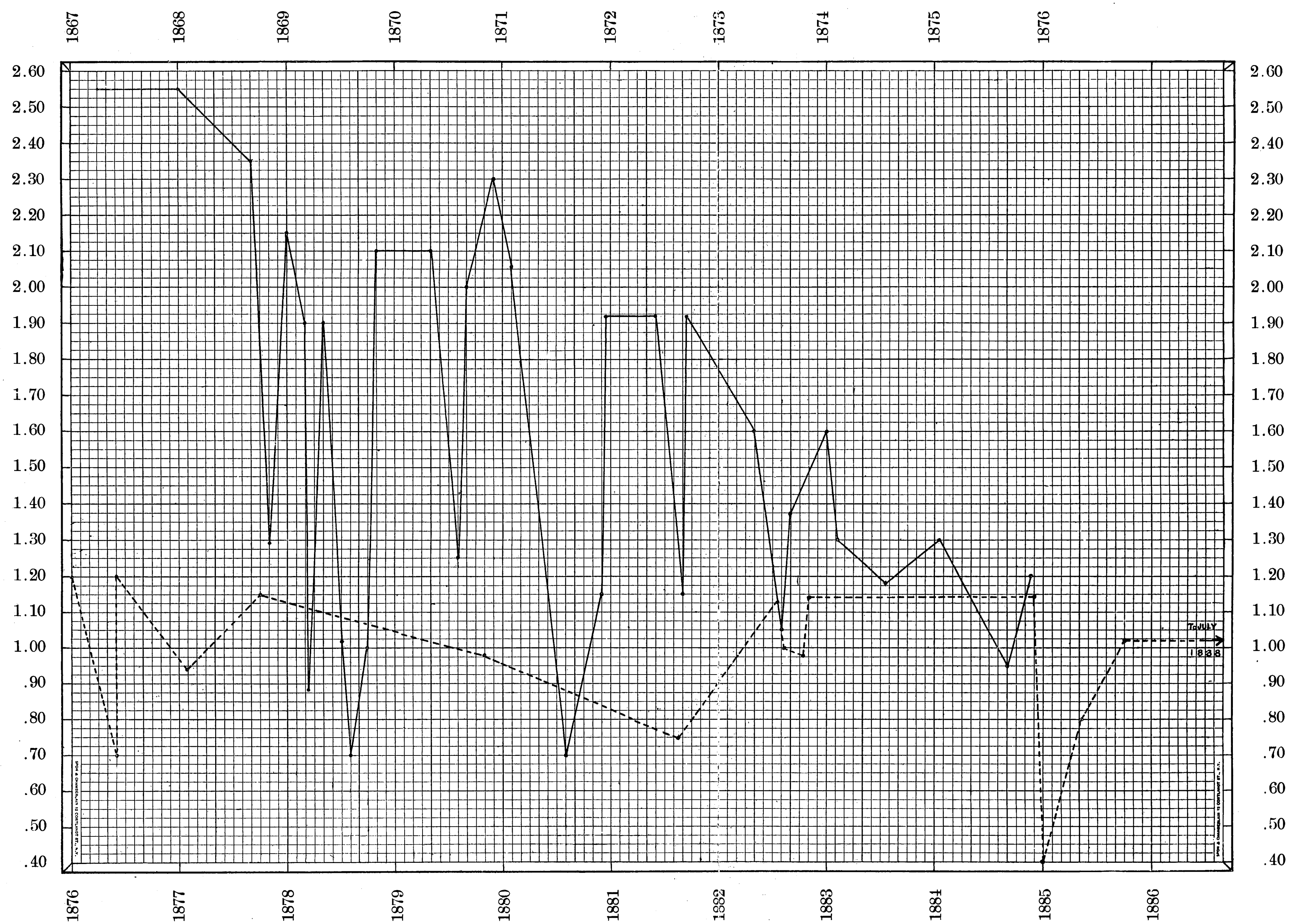
A pool may be roughly defined as an agreement between competing carriers for the apportionment of competitive traffic, or of the receipts therefrom.[1] They may be divided into three gen-

[1] The Century Dictionary gives the following as a definition of a pool: "A combination of the interests of several otherwise competing parties, such as rival transportation lines, in which all take common ground as regards the public, and distribute the profits of the business among themselves equally or according to special agreement. In this sense pooling is a system of reconciling conflicting interests, and of obviating ruinous competition, by which the several competing parties or companies throw their revenue into one common fund, which is then divided or redistributed among the members of the pool on a basis of percentages or proportions previously agreed upon or determined by arbitration." This definition seems to me to possess several palpable defects. In the first place the words "distribute the profits" could strictly be applied only to a "money pool," thus excluding both "traffic" and "territorial" pools, the former of which at least is far more important both in extent and numbers than the "money pools," being almost the only kind known in the United States. Then it is doubtful if the words "all take common ground toward the public" is strictly true, as it probably expresses an ideal rather than a fact, as it is certainly true that under the most perfect pool that has yet been formed, some residual competition, at least in facilities, has been retained. The latter part of the definition is simply an argument for pooling, as is shown by the words "reconciling conflicting interests and of obviating ruinous competition." That it has been so recognized by the pooling advocates is shown in an editorial of the Railroad Gazette for May 25th. 1894, p. 372. See Hudson, Railways and the Republic, pp. 196–7 for definition of pooling and a division into traffic and money pools. Also Hadley, Railroad Transportation, pp. 75-76.



——— Rates on dry goods, New York to Chicago, before pooling; ------ ditto, after pooling. Years at top belong to solid line; those at bottom to broken line.

SIMONS ON RAILROAD POOLS.



——— Rates on dry goods, New York to Memphis, before pooling; ------ ditto, after pooling. Years at top belong to solid line; those at bottom to broken line.

eral classes according to the basis of apportionment, as territorial, traffic and money pools.[2] In the first, each road is assigned a distinct territory from which to draw its traffic, and within which it is secured from all competition. In the second, the traffic is diverted by common agreement to the different roads according to pre-arranged percentages. Then any road carrying more than its assigned percentage is required to divide all profits arising from such traffic among the other roads included in the pool according to the same ratio at which the traffic was to have been divided. In the third form all the competing roads carry at rates fixed by common agreement, and the proceeds are turned into a common fund or "joint purse" which is divided among the roads according to percentages previously agreed upon.

The first of these forms is obviously impossible of application in the United States, owing to the complexity of our railway system. It is found only in a few countries of Continental Europe, particularly France, where the country was partitioned out among a few great railroads during the construction period. The second form is the one which was in vogue in the United States before the passage of the Interstate Commerce Act, although there were also in existence some examples of the last form, or money pool. Since the pool is primarily a rate arrangement, and the rate question is a fundamental one in all discussions of transportation, it is fitting that the pool should be first discussed in its relation to rates.

The fundamental fact to be borne in mind in any discussion of the rate question, is that rates at the present time, and there is no prospect of change so far as I can see, are fixed upon the principle of "what the traffic will bear."[3] When this principle is analyzed it is found to mean simply that the fundamental idea in the fixing of rates shall be the value of the service to the shipper. This principle is then modified in one

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[2] Cohn, Englische Eisenbahnpolitik, vol. i, pp. 329-330, where a different classification is given, founded upon historical development, Also Midgeley, International Review, vol. vi, pp. 503.

[3] Taussig, Contribution to the Theory of Railroad Rates, pp. 17-18. Interstate Commerce Report, 1890, pp. 15-16.

direction by the application by the railroads wherever possible of the principle of the monopoly charge, while on the other hand residual competition is still a powerful factor in the determining of rates at many points. The element of governmental interference is also sometimes made a factor in rate-making, but for the present this influence may be disregarded as not affecting the question under discussion. It must be admitted that the tendency of the pool is to unify the railroad systems, and hence to increase the monopoly element at the expense of the competitive element as a factor in rate-making. And in so far as this is true the influence of the pool must be to raise rates. By the raising of rates must be understood equally the prevention of a decline. A graphic representation is herewith given of the fluctuations in rates according to the statistics gathered by Mr. McCain for the "Aldrich Report," between New York and Chicago (plate II) and between New York and Memphis (plate III) The solid line shows the fluctuations before pooling; the broken line that after pooling.

It will be seen that plate I shows a rapid and continuous fall of rates in the traffic between New York and Chicago in the twelve years between 1865 and 1877. In this year the great "Trunk Line Pool" was formed, which lasted with breaks, as seen upon the chart, until the passage of the Interstate Commerce Act in 1887. It will be seen that taking the whole period into consideration during which the pool was in force there was almost no decline in rates. On examining plate III it will be seen that practically the same phenomenon is exhibited. In the five years previous to the formation of the pool in 1875 (and the same would have been shown by a diagram of the rates for the five preceding years) there is a rapid decline in rates with violent fluctuations. From that time until 1887 there is, as before, but very little decline. This would seem to bear out the conclusions arrived at above, that a pool tends to maintain rates above their normal level. It may be said, however, that any evidence gained either directly or indirectly from the rate sheets of the railroads is by no means conclusive evidence as to the actual rates charged at any time upon the railroads of the United States. However, two things may be said: First, that tariff rates are always as high as any rates charged, and second, they are more closely adhered to during a period of pooling than under unrestricted competition. Now, both of these facts would tend to exaggerate the results that I have arrived at. They would tend to make the rates appear higher under unrestricted competition than they really were, and *vice versa.*

But, as has been so often said, the question of rates is not so much one of high versus low rates as of steady uniform rates opposed to fluctuations and discriminations. And it is just at this point that the advocates of the pooling policy claim their greatest strength. They say that when a pool has once fixed the rates it requires the consent of a large number of roads to change them, and hence when once fixed they tend to be permanent. But the result of this is rather a change in the character of the fluctuations than a disappearance of the evil. The fluctuations, instead of occurring continually and from day to day, occur only at long intervals, but are then much more violent. The pool maintains rates for some time at a fixed point and then there is a long and disastrous rate war. These wars are usually much worse than those that occur under a purely competitive regime, because owing to the result of the pooling policy the roads are in a prosperous condition at its beginning, and then they are animated by a feeling of animosity that is seldom found save at the breaking up of a pool. And finally, in addition to usual incentives for obtaining traffic, there is the added one of a hope of obtaining a better percentage in the pool which all know will be the final outcome of the struggle.

But rates may be changed in other ways than by a direct revision of rate schedules. They may be equally affected, though in a less evident manner, through changes in classification. The influence of the classification upon the height, stability and uniformity of rates is so great that anything affecting it is of paramount importance in any discussion of the rate question.[4]

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[4] Mr. F. B. Thurber, wholesale grocer of New York City, said in his testimony before an investigation of the Interstate Commerce Commission in 1890: "The question of classification goes to the very bottom of the rate-making power. If it be true that he who makes the songs of a country may care but little who makes its laws, it is doubly true that

One of the reforms advocated by all students of transportation is a more nearly uniform freight classification. This the pooling advocates claim the pool will secure. They say that since under a pool the division of freight and fixing of percentages must necessarily be by classes, there will be a constant tendency to bring all freight under one of the regular classes, and then to make these classes uniform throughout the United States. This would accomplish two greatly desired reforms. It would unify classifications, and abolish special rates. But it may be said in answer to these statements that they would at any rate be true only of the traffic pool, while the prevailing sentiment seems to be in favor of a money pool as the most desirable form to be establisned should pooling be allowed by law. Again, the territory covered by the pools would be almost identical with that at present covered by the various traffic associations, and these have almost all the incentives and ability to procure uniform classification that would be possessed by a pool.[5] In fact, so far as the fixing of rates are concerned it is difficult to see in what respect they differ from pools, and indeed the pool is only asked for as means of *maintaining* the rates established by these associations. But the results which they have attained in this matter, although undoubtedly of value, certainly leave much to be desired, when a single railroad (the C. & N. W.) within the territory covered by one of these associations (The Western Traffic) issued 12,500 special tariffs between January 1st, 1893, and September 16th, 1895.[6] Moreover, it would appear that the movement toward uniformity has been more rapid since the passage of the Interstate Commerce Act and the

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if railroad managers have the power to make the classifications, they need care but little for laws prohibiting them from favoring large shippers by means of special rates, rebates, etc" See also "Report of General Conference of Railroad Commissioners," March, 1889, pp. 36-60. Ibid., 1890, pp. 121-134.

[5] See "Extract from Senate Report No. 1394, Second Session, Fifty-second Congress," (McCain Report) p. 405, for list of these associations and territory covered by each, where it will be seen that they are almost identical as to territory with the old pools, which they supplanted.

[6] Ibid., pp. 404-408, where it is shown that the movement toward uniformity has been most rapid in recent years.

prohibition of pooling than it was previous to the passage of that act.[7]

But there is another phase of the railroad question which has perhaps been the cause of more complaint and legislation than all the others combined. I refer to the subject of discrimination in rates. Anything that would remove this evil would be tolerated even though it brought with it many disadvantages. And here again the advocates of pools put in a strong claim for their policy. Says the editor of the Railway Review for September 10th, 1892:

"Those who have made a study of the railway question know that in the development of the railway service no other means than pooling has as yet been discovered which will serve to render operative the design of the act to regulate commerce. In other words, it is only through pooling that discrimination can be removed, and a system of equal rates under similar circumstances universally established."

It is claimed that discriminations are the result of unrestricted competition between railroads; that they are the only means by which the weaker roads can exist under a regime of free competition. The pool, by removing the incentive to struggle for traffic, removes at the same time all incentive to grant rebates, or make discriminations of any kind.

This position would seem to possess great strength as applied to the indiscriminate granting of rebates and special favors to individual shippers which prevailed in the United States at one time.[8] But the character of discriminations has changed within

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[7] Railway Review, April 14th, 1894, p. 212, contains a complaint signed "Manufacturer," which is generally favorable to the Southern Steamship Association, but claims that the territory governed by it is behind all the rest of the United States in the matter of uniform classification. It will be remembered that this territory has been the most thoroughly pooled of any in the United States.

[8] There is some dispute, however, as to their effect, even in this case. Says Adelbert Hamilton, in the Chicago Tribune for March 1, 1884: "Unjust discrimination pools have not stopped. Neither do they prevent it. It exists to-day to a far greater extent than ever before, and in bold open defiance of law and justice." This writer is in favor of a legalized pool, under direct control of government.

the last few years. Instead of an indiscriminate granting of rebates to every one who applies, great concerns have been developed in all lines of industry who succeed in obtaining favorable rates to the exclusion of all competitors. In other words, discriminations have become concentrated upon a few great firms, while all others pay the tariff rates. The powerful incentive which this gives to the movement toward concentration of industry is evident. The question then arises as to what will be the effect of the pool upon this new form of discrimination, as to how it will meet this new problem? And at first sight appearances would seem to be strongly against the pool as a remedy in this case. Almost all of the great "dependent monopolies" which constitute so prominent a factor in the industrial life of the country to-day had their origin during the period of pooling. More than this, almost all of them had more or less intimate connection with the pools. Indeed it has been alleged that they depended upon the pools for their existence. The so-called "Cattle Trust" or "Pool" was organized in 1875, and was firmly established with almost complete control of the market in 1879. It was long used as an "evener" (or instrument for the distribution of freight) in the great "Trunk Line Pool" from Chicago to New York.[9] The Anthracite Coal Combination has a similar history. But it is of the Standard Oil Company that the greatest complaint is raised. It has been alleged that without pooling, this great combination could never have been formed.[10]

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[9] See United States Report on Internal Commerce, 1879, pp. 164–177.

[10] See Hudson, Railways and the Republic, pp. 209–10, and chapter entitled "A Commercial Crime."

United States Report on Internal Commerce, 1879, pp. 178–9: "The almost marvelous success of this association (the Standard Oil) has resulted mainly from the fact that its managers have succeeded in securing from many of the trunk railroads of the country special rates of transportation. The power which it has for several years exercised as an "evener" in the coal-oil pool, extending from the oil regions to the sea-board, has enabled it to secure a monopoly of that traffic. The railroad pool controlling the transportation of coal oil to the sea-board now embraces three of the principal trunk lines. . . . In carrying on this apportionment scheme the Standard Oil Company acts as an evener, But the fact remains that all of these combinations have flourished with equal rapidity, and new ones of almost equal magnitude have arisen since the abolition of pooling. This fact causes one to ask what would have been the result had pooling not been in force at the time when these great combinations were forming? It is well recognized that natural causes aided greatly in making the three concerns just named powerful monopolies. These causes had given the concerns under consideration a practical control of the market before the pooling policy was inaugurated to any great extent. The question a once arises as to whether these great firms could not have obtained much greater concessions from a number of warring railroads than from a strong pool. This is what is claimed by the railroad men of the country. They say that no railroad will-

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or, in other words, it agrees to secure to each road the proportion of the traffic agreed upon among themselves in condition of certain special advantages accorded over all other shippers in the matter of rates."

An editorial in the Railroad Gazette, November 1st, 1878, says: "The terms of the contract with the Standard Oil Company have, we believe, never been published. Its chief features are understood to be that the oil company guarantees to divide the whole oil traffic — not its own business simply, but the whole business — in whatever proportions the contracting railroads may direct, in return for which it is guaranteed a large rebate . . . on all shipments of crude oil to refineries, on the shipments of third parties as well as its own. Substantially the whole production of petroleum is to pay the Standard Oil Company 50 cents a barrel for affecting the distribution of business among the carriers, or for doing the work of a pool. . . .

"This plan is identical in principle with the plan by which the live-stock traffic east of Chicago has been distributed most of the time for three years or more. That is, the railroad companies having agreed to divide the traffic in certain proportions, engage leading shippers to bring about the distribution for them and to pay them for this service by giving them an allowance on all the freight shipped." He concludes his article, however, as follows: "Imagine its (the Standard's) power if, in the absence of any control for the distribution of this freight, it had been free to send it by whatever route it pleased from day to day; how it could offer the whole traffic to one if it could make greater reductions on rates; how it could punish any combination to maintain rates alike to all shippers by similar action — a not uncommon policy on the part of shippers who do not command a tithe of the traffic."

ingly grants a rebate or special favor to any individual shipper, but that discriminations are extorted from them by the exigencies of competition. They point to the fact that great concerns like those mentioned have it in their power to ruin any railroad which refuses to grant them favors, and that unless the railroads are allowed to act as a unit in the matter of rates and transmission of freight these discriminations must be granted.[11] Hence they hold that the prohibition of pools has tended to promote trusts.[12] They claim that any organization which it is lawful for the railroads to make at the present time will be unable to meet and overcome the demands of such great concerns as the Standard Oil and the Dressed Beef Combine. An illustration of the weakness of the present railroad combinations under such conditions was exemplified in the recent endeavor by the Western Traffic Association to limit the mileage paid on private cars. This private-car mileage constitutes one of the most dangerous forms of discrimination in vogue at the present time.[13] The most pernicious instances of its effects is seen in the case of the Tank and Refrigerator Car Companies.

[11] United States Report on Transportation Interests of United States and Canada. Testimony of John McNulta, p. 39. Speaking of the dressed beef trade he says: "The four great packing houses, acting in concert, control the markets, and with an advantage in rates can absolutely crush out all competition, and by the further fact that the number of car-loads of dressed beef east from Chicago is greater than the number of car-loads of grain shipped by rail from that city to the seaboard."

[12] Inter Ocean, December, 1893. Report of the testimony before a Senate Committee on Interstate Commerce: "Mr. Depew said that the Interstate Commerce Law had been established to prevent discrimination, but its effect had been to promote trusts, beyond anything that had ever been dreamed of. There were eight roads between New York and Chicago, but for all purposes of the public there was but one. If an iron-clad rule of equal rates under equal conditions of time were established, the New York Central and the Pennsylvania would do eight-tenths of the business. The other roads would go into bankruptcy with all the attendants of bankruptcy. In this way the law preventing pooling was creating trusts. If this law continued in force five years longer Mr. Depew thought there would not be an independent business man in any of the large cities of the United States."

[13] Judge Schoonmaker, in a paper read before the Third Annual Con-

Now no railroad willingly pays these rebates. Says Judge Schoonmaker, of the Interstate Commerce Commission: "The revenues of carriers are seriously impaired by the amount these payments add to the expenses of operation, and it is not uncommon when rates are abnormally low that after the deduction of these payments not even the cost of carriage is left to the road, so that the traffic thus carried is sometimes detrimental to the carrier." [14]

Thus it is seen that this practice is equally undesirable from whatever point it is viewed. But when recently the Western Traffic Association sought to reduce the rate of car mileage from ¾ cents to 6 mills per mile, the Standard Oil and the Dressed Beef Combine were able, by playing one road off against another, to compel the payment of the old rate, and thus defeat the efforts of the railroads to accomplish a very necessary reform. [15]

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vention of Railroad Commissioners, held in Washington, March, 1895, pp. 39–46 of report: "The use by carriers of private cars of shippers instead of their own equipment has developed in the last few years to very large proportions. . . . The principal articles for which they are used are such staples as petroleum and cotton-seed oils, turpentine, live-stock, and dressed meats. . . .

. . . "By an investigation made in 1889 it appeared that on a single line of road between Chicago and an interior eastern point, a distance of 470 miles, refrigerator cars owned by three shipping firms made in nine months, . . . 7,428,406 miles and earned for mileage $72,945.97, . . . or substantially at the rate of $100,000 a year.

"By another investigation, made in 1890, it appeared that private stock cars . . . used upon a line made up of two connecting roads between Chicago and New York, . . . had cost altogether $156,500, and had earned for mileage in two years . . . $205,582.68; that the entire expense to be deducted during that period for car repairs and salaries for their management was $34,050.48 leaving net revenue to the amount of $171,532.20, being an excess of $15,032 above the whole cost of the cars. The cars were therefore paid for and a margin in two years, and thereafter, under the same arrangement, and a corresponding use of the cars, an income of upwards of $100,000 a year was assured on an investment fully repaid, or in effect on no investment whatever."

[14] Report of Third Annual Convention of Railroad Commissioners, pp. 44–45.

[15] Chicago Tribune, November 14th, 1894: "It appears from a communication sent to railroad managers by Chairman Midgeley that the

This occurred, notwithstanding the fact that the Western Traffic Association was backed up by the Central Traffic and Trunk Line Association in its endeavors to secure justice to the railroads and shippers. But, say the pooling advocates, had there been a pool covering this territory with a pre-determined assignment of traffic, there would have been no incentive for the weaker roads to have yielded to the demands of these concerns, and the rate fixed by the association would have been maintained.

But it is doubtful if even this latter form of discrimination marks the final stage in the process of union between common carriers and producing concerns. There is another and a still closer form — that of joint ownership. This, it is claimed by many, will be the last step. That it is at least a possible one is seen by the fact that it has already been taken in the case of many coal mines, grain elevators and cotton compresses,[16] as well as the Union Stock Yards, of Chicago. This union may take either of two forms — that of absolute ownership by the corporation as a corporation, or the same men may hold a controlling interest in both concerns. In the former case I can see no way in which the pool or any other remedy could affect the case, but where, as is so often the case, the subsiduary business is used as a means of defrauding the small stockholders in the railroad by placing rates upon the subsiduary product so low as to yield no returns to the railroad while piling up the product of the outside concern, the influence of the pool would certainly assist the smaller stockholders in maintaining remunerative rates.

Other phases of the question which merit attention, but whose consideration would exceed the limits of this paper, are the relation of pools to railroad laborers, to the stock market, to rail-

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Standard Oil Company and the big packers have been successful in their efforts to get exemption from the 6 mills rate agreement and secure a higher rate for their cars. They did not effect this by legitimate means but they prevailed upon certain weak-backed managers to make long-time contracts with them at ¾ cent per car per mile run with the Union Tank Line Company (Standard Oil), and at 1 cent per mile run with certain packing companies."

[16] See Message of Governor Hogg, of Texas, March 8, 1893.

road construction, and considered as a step toward government ownership.

In conclusion, it must be remembered that in discussing the question of pooling we are discussing an alternative. The traffic must be divided among the lines in some way. The question, then, simply resolves itself into one of whether this division shall be determined by competition or authority. And it must be remembered that the competition which is to accomplish the division is not the same as that governing ordinary industry, but is of the nature which belongs to the so-called natural monopolies. Whether such a force will accomplish as good results as the conscious efforts of those affected is really the question at issue.

Chicago, Ill.

THE ADJUSTMENT OF RAILROAD RATES IN PRUSSIA.

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I.

On April 1, 1895, the Prussian railroad administration was completely reorganized. Previous to that time there had existed two distinct official bodies (ressorts) immediately below the Minister of Public Works, who (then as now) is the executive head of the railroad administration. These bodies were known as Eisenbahndirektionen and Eisenbahnbetriebsämter, respectively, the one having purely administrative functions, and the other having direct charge of the operation of the railroads. Of the former there were eleven and of the latter seventy-five. The functions of both have now been united in the royal state railroad directories,[1] of which twenty have been created. Each directory is composed of a president, appointed by the king, and the requisite number of associates, two of whom may act as substitutes[2] of the president under the direction of the minister.[3] Each directory has administrative control over all the railroads in its circuit.[4] It decides all cases arising out of the action of special and of subordinate branches of the administration; and, representing the central administration, it may acquire rights and assume responsibilities in its behalf. Below and subordinate

[1] Altona, Berlin, Breslau, Bromberg, Cassel, Cologne, Danzig, Elberfeld, Erfurt, Essen, Frankfurt on the Main, Halle, Hannover, Kattowitz Königsberg, Magdeburg, Münster, Posen, St. Johann-Saarbrücken, Stettin.

[2] Ober-Regierungsrath and Ober-Baurath.

[3] Minister of Public Works, unless designated otherwise.

[4] The subordinate administrative organs of the state (Oberpräsident, Regierungspräsident, Landrath, etc.) have certain powers over concessions, police regulations, etc.

to these directories are special administrative organs upon which falls local supervision. The functions of the directories are general, while the functions of the local offices[5] are special. The local offices may be divided into six classes, according to the work they perform, namely, operating, machine, traffic, shop, telegraph and building offices.[6] The chief inspector (Vorstand) of each local office has power to let smaller jobs, to grant leaves of absence, and, together with certain committee members, to control certain kinds of railroad property, impose fines, fix fees, etc.

Private railroads,[7] which before April 1, 1895, had been supervised by a special railroad commission, are now subject to the jurisdiction of the president of a directory[8] and his two chief associates (substitutes). The number of miles[9] supervised by a directory depends upon various conditions, chief among which are the geographical distribution of the railroads and the intensity of the traffic.[10]

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[5] Betriebs-, Maschinen -, Verkehrs-, Werkstätten -, Telegraph -, and Bau - Inspektionen.

[6] Eisenbahn-Verordnungs-Blatt, 1895, pp. 49-68, contains a full account of the duties connected with the various classes of local offices. However, all the important laws and regulations governing Prussian railroads are found in "Vorschriften für die Verwaltung der Preussischen Staatseisenbahnen," Amtliche Ausgabe, Berlin, 1895.

[7] Compare Ministerial Erlass, vom 2. März, 1895.

[8] The following directories are charged (April 1, 1895), with the supervision of private roads: Altona, Berlin, Breslau, Cassel, Cologne, Elberfeld, Erfurt, Essen, Frankfurt, Halle, Hannover, Königsberg, Magdeburg, Münster, St. Johann-Saabrücken, Stettin. As there are twenty directories and only sixteen supervise private roads, it is evident that circuits for private roads are not identical with directorial circuits.

[9] The Berlin directory supervises 587 kilometers, while Halle embraces 1,884 kilometers of state roads. Between these two extremes lie the other circuits. It may be added here that on April 1, 1895, the private roads represented together only 2,200 kilometers (not including 1,945 Anschlussbahnen and 71 kilometers rented to private parties) against 27,060 kilometers of state roads, of which 10,479 kilometers contained two or more tracks.

[10] That is, by the number, size, and speed of trains, which in turn influence the nature of the track, safety appliances, and equipment in general.

All Prussian railroads, then, whether state or private, are subject to the jurisdiction of a carefully graded administrative system — local, intermediate and central — each part of which is organically connected with every other part in such a manner that, without interfering with the ability to act promptly in cases of emergency, every act not only finds its responsible agent, but the central organ can also make its influence felt in the remotest branch of the system, and at the same time not transcend its responsibility to the public. This feature of the Prussian system will be well illustrated by what follows on the question of rates.

II.

But before passing on we must consider the relation of the federal government to railroads, for it also has extensive powers over all the railroads in the empire.[11] All the powers of the federal government over railroads may be grouped under five heads:[12]

1. The right to legistate.
2. The right to grant concessions.
3. The right to control rates.
4. The right to supervise the building, operation, and administration of railroads.
5. The right to employ the railroads for the national defense.

The federal constitution makes it the duty of the government to cause the German railroads to be managed in the interests of the general traffic, as a uniform network.[13] The phrase, "as a uniform network," is an elastic one, and probably would suffice to give the federal government most of the powers it exercises; yet, nine articles[14] of the constitution are either wholly or in

[11] There are also *federal* railroads — those of Elsass-Lothringen — a number of which have been rented to Prussia, and a military road from Berlin to the shooting grounds at Zossen. The system of rates adopted on the federal roads after the Franco-Prussian war exerted considerable influence on the development of systems of rates in Germany.

[12] Eger, Handbuch des Prussischen Eisenbahnrechts.

[13] Reichsverfassung Art. XLII.

[14] These are Articles IV. 8, VIII. 5, and XLI. to XLVII., inclusive.

part devoted to the subject of railroads, embracing matters pertaining to construction, equipment, operation and repair. It expressly declares [15] that the government shall strive to introduce a uniform system of regulations for the operation of all German railroads, and a uniform system of rates; that it shall strive to secure the greatest possible reduction of rates, especially for long hauls of articles supplying the wants of agriculture and of industry, such as coal, coke, wood, ore, stone, salt, pig-iron, fertilizers, etc. In times of distress and famine the emperor, on recommendation of the railroad committee of the Bundesrath [16] may temporarily fix rates for the transportation of the necessaries of life, provided that such reduction shall not reduce rates below those charged on the respective railroads for the transportation of raw material. [17] The constitutional provisions have, of course, been supplemented by ministerial rescripts, royal orders and statutes. But these few sentences sufficiently reflect the relation of the federal government to the railroads of the empire. How this principle of responsibility and control is carried out by the state governments we shall now consider in the case of Prussia.

III.

The great variety and number of shipments and passenger transfers involved in the railroad business makes it impracticable, if not impossible, for each undertaker to make a special contract with each individual applying for railroad service. But even if this were possible, in view of the nature of transportation and the many public and private interests involved, it might become exceedingly prejudicial to these interests to leave the adjustment of rates entirely in the hands of the undertaker, without definite legal responsibilities to the public.

Unfortunately, a considerable number of people still look upon a railroad as a business essentially similar to any other busi-

[15] Article 45.

[16] By Article VIII. 5 the Bundesrath appoints from its numbers a permanent committee on railroads, post and telegraph.

[17] The Emperor has not yet exercised this power.

ness, and, as such, subject to the laws of free competition. Railroad rates, according to this supposition, are determined by the same laws that determine the price of crackers and soap. Legislation (or rather lack of legislation) in accordance with these supposed principles of the industry of transportation by rail has often tended to perpetuate chaotic conditions rather than give an impulse towards uniformity, system and order. Placing railroads into the category of ordinary business enterprises, we have allowed an industrial force, more serviceable than which there is none, to bring at times uncertainty and confusion into the business world, when stability and order should have prevailed. And all because we have refused to recognize the lack of identity between a railroad and a soap factory. Although a number of far-sighted men in our own country — and among them many prominent railroad men — have long recognized this distinction, the American public has been inclined to adhere to the old tradition, and it has, perhaps, too often overlooked the difference between the railroad business and an ordinary industrial enterprise. The element of monopoly in railroading, with its inevitable tendencies towards combination and consolidation, should alone be sufficient reason for placing railroads into a distinct category. In an ordinary business, if trade falls off, the working force can readily be reduced, capital can be contracted, unused machinery can be protected without difficulty or expense, and unsold goods may be kept in store until there is a market for them; expenses can more readily be adjusted to the volume of trade; and the constant (fixed) expenses form a much smaller part of the total outlay. And if trade should not revive there is still the alternative of going into another business. Illustrations of this are easily found in every industrial community. With railroads the case is very different. In the first place, there is a very much greater investment — railroads costing from thirty or fifty to over two hundred thousand dollars per mile. The "plant" is good for no other business. The rolling stock may be sold to another railroad company, but the right of way, tunnels, bridges, ties and rails would involve an enormous loss in case of failure to continue business. When traffic is poor the company may discharge a number of employes and run fewer trains; but ties rot, rails rust, axles run dry, grades are washed away whether much or little business is done. A GREAT INVESTMENT AND A RELATIVELY LARGE WORKING FORCE IS NECESSARY FOR EVEN A MINIMUM OF BUSINESS. In fact, from seventy to seventy-five per cent. of the expenses are *constant*[18] and independent of the volume of the traffic; so that any possible economy during business depressions can effect only about twenty-five per cent., or the *variable* factor in the expenses. It is along these lines that the statement can be maintained that a railroad is not like an ordinary business. And this once established, railroad legislation (e. g., on the question of pooling) must set up for itself tasks very different from those encountered by legislation on soap factories.

The Germans[19] early discovered and acted upon the premise that a railroad is different from an ordinary business. They soon recognized the limitations of the laissez faire doctrine when applied to railroads. The fundamental railroad law of Prussia is the law of November 3, 1838, which in all its essentials is the law of to-day. It grew out of the discussions and negotiations on the first applications for concessions, especially out of the careful investigations and statesmanlike considerations preceding the granting of the Magdeburg-Leipzig charter, which in turn was based upon "Grundbedingungen der Erlaubniss zu öffentlichen Eisenbahnen durch Privatunternehmungen." By this law[20] the state, acting through the Minister of Public Works, has the right, after the expiration of three years from the first of January next following the opening of the road, to supervise, approve or disapprove (1) all tariff schedules, (2) any proposed change in existing rates, and (3) the establishment of tariff instructions and regulations, exceptional and differential rates. However, the three-year limit is practically void because of the reservations which the state makes in granting concessions.[21] These regula-

[18] Consult *Rank*, Eisenbahnstarifwesen, Wien, 1895.

[19] Stephenson, the father of the locomotive, is credited with the statement, "Where combination is possible competition is impossible."

[20] §§ 36-40.

[21] Consult §§ 1 and 46 of the law of 1838; circular letters of July 30, 1874, and May 2, 1887; Erlass des Ministers der öffentlichen Arbeiten of March 2, 1895.

tions apply only to primary railroads.[22] Secondary roads may, during the first eight years of their existence, raise or lower rates to meet their own desires, provided they do not go above a certain maximum prescribed by the minister for that period of time; and provided further that their rates do not conflict with the general principles of rates enforced on state lines. But in no case can these concessions invalidate the general supervisory right of the state. The rates on local[23] roads are provided for in the law of July 28, as follows: That authority upon which the approval[24] of the project devolves is required to make an agreement with the undertaker as to time-tables and rates, and the periods of time in which such agreements shall be subjected to revision, provided that the undertaker may be allowed to establish his own rates during the first five years, and that

[22] Prussian railroads are classified as:

A. State or B. Private.	Which may be either:	1. Primary (Haupt-Vollbahnen.) 2. Secondary (Neben-Sekundärbahnen.) 3. Local (Kleinbahnen.) 4. Private branches (Privatanschlussbahnen.) 5. Isolated private roads not operated by machines.

Objectively considered, there are no important differences between primary and secondary roads. Both classes have tracks of normal width, use similar cars and engines; but they differ in equipment, corresponding to differences in the intensity of the traffic. Secondary roads have fewer and slower trains, a smaller percentage of brakes to axles, etc. They are subject to different operating regulations and different laws in their relations to the postoffice, rate schedules, etc. The law of November 3, 1838, recognizes only primary and secondary roads. Local roads, legally created by the law (Gesetz über Kleinbahnen und Privatanschlussbahnen) of July 28, 1892, are not "railroads" within the scope of the law of 1838, and hence not subject to the provisions of general railway legislation. LOCAL ROADS ARE PLACED INTO THE SAME CATEGORY WITH ORDINARY BUSINESSES, and as such subject to the Gewerbeordnung. If, however, at any time, in the opinion of the Staatsministerium (§ § 30–38, law of 1892) any local road attains such a degree of importance in public traffic that it may be regarded as a part of the general network of railroads, the state may, on payment of the full value of such a road, and after one year's notice, add the said road to its own system of railroads. A further discussion of the classification of Prussian railroads would lead us too far from the main subject.

[23] § § 14 and 21, law of July 28, 1892.

[24] § 2, law of 1892.

thereafter the state shall only fix maximum rates; in doing which, due consideration shall be given to the financial interests of the road. The law reserves to the state this power, but it does not make it a duty; and it is the policy of the state not to interfere with any arrangements the undertaker may see fit to make, provided he neither practices unjust discriminations nor does anything else contrary to the interests of the public. The law simply reserves to the state the right to act if circumstances require it.

Thus far nothing has been said about external influence in adjusting railroad rates in Prussia. This appears to me to be really the most important and most commendable feature of the system, at least in its bearing upon society at large. First the legal provisions will be discussed, and then a short account will be given of those established customs which exert a powerful influence upon Prussian rates.

IV.

As early as 1874, through on impulse given by the chamber of commerce of the city of Mülhausen,[25] a conference between the representatives of the commercial interests and the general imperial railroad directory at Strassburg was held in that city. The proceedings of this conference made such a favorable impression upon the head of the central railroad bureau that a circular letter[26] was addressed to all the railroads enjoining

[25] Based on my manuscript notes on Dr. von der Leyen's lectures on "Nationalökonomie der Eisenbahnen insbesondere Tarifwesen." To the same source I owe much of what is given near the close of this section on the Generalkonferenz, Tarifkommission, etc. Dr. von der Leyen has also made a thorough study of the railroads of the United States, and his monographs, "Die nordamerikanischen Eisenbahnen" and "Finanz- und Verkehrsgeschichte der nordam. Eisenbahnen" deserve a careful perusal by every American student.

[26] Circular letter of January 11, 1875: "Diese Einrichtung bezweckt vorzugsweise die Herstellung einer innigeren Verbindung zwischen den mit der Verwaltung von Eisenbahnen betrauten Stellen und dem Handelsstande, sowie eine Versöhnung der sich oft nur scheinbar entgegenstehenden Interessen beider. Sie wird die Vertreter der Eisenbahnen mit den wechselnden Bedürfnissen des Handels und der Industrie ver-

them to assist in this movement towards a closer union and better understanding between the commercial and the railroad interests. The railroads were not very ready to respond and the movement made little progress, until with the nationalization of railroads, which was vigorously pushed from about 1878, the reform initiated by Mülhausen was elaborated and given permanent shape in the law of June 1, 1882. This law [27] creates a class of advisory boards or councils known as Bezirkseisenbahnräthe, and one national council, called Landeseisenbahnrath. The national council is the advisory board of the central administration, and the circuit councils of the railroad directories (§ 1).[28] Since the reorganization of the railway administrative system, April 1, 1895, eight circuit councils have been in existence.[29]

The national council is composed of forty members, ten of whom are appointed and thirty elected (§ 10), all holding office for three years. Of the appointed members, three are named by the Minister of Agriculture, Domains and Forests; three by the Minister of Trade and Industry; two by the Minister of Finance; and two by the Minister of Public Works. At the same time an equal number of substitutes is appointed; provided, however, that no immediate state official shall be appointed. The elective members are distributed among departments and provinces, the right to elect, including substitutes, devolving upon the various circuit councils. The presiding officer and his substitute are appointed by the King. In addition, the Minister of Public Works is empowered to call in expert testimony whenever he

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trauter machen und stets auf dem Laufenden erhalten, und Anderseits den Verkehr des Handels u. s. w. eine grössere Klarheit über Eigenthümlichkeiten des Eisenbahnbetriebs, sowie über die berechtigten Interessen der Verwaltung verschaffen und somit, ernst und massvoll gehandelt, durch den Austausch der Ansichten auf beiden Seiten erspriesslich wirken."—Quoted in an article by v. d. Leyen in Schmoller's Jahrbuch for 1888, page 1071.

[27] Gesetz, betreffend die Einsetzung von Bezirkseisenbahnräthe und eines Landeseisenbahnraths für die Staatsbahnverwaltung.

[28] Sections refer to the law of June 1, 1882.

[29] Bromberg, Berlin, Magdeburg, Hannover, Frankfurt a. Main, Köln, Erfurt and Breslau. Consult ministerial order of December 18, 1894.

may think it necessary. Such specialists (§ 11) and all members receive for their services fifteen marks (about $3.60) per day and free mileage (§ 21). The national council meets at least twice during each year (§ 15) and deliberates on such matters as the proposed budget, normal freight and passenger rates, classification of freight, special and differential rates, proposed changes in regulations governing the operation of the roads, etc. It is required to submit its opinion on any question brought before it by the minister; or, on the other hand, it may recommend to the minister anything which it considers promotive of the utility and effectiveness of the railroad system. Its proceedings are regularly submitted to the Landtag and the Herrenhaus (§ 19), where they are considered in connection with the budget of the state household, thus establishing an "organic connection"[30] between the national council and the parliament. In this way the proceedings are made accessible to every one, and an opportunity given to approve or disapprove through parliamentary representatives. It is a system of reciprocal questioning and answering on part of the minister, the national council and the parliament.

The circuit councils, which are equally important and interesting, vary considerably in the number of members.[31] Magdeburg,[32] for instance, has only twenty-four, while the council, whose seat is at Cologne, has seventy-five. Their composition (§ 3) can best be presented in an analysis of the membership of one such council. The council of Hannover, comprising the railroad directories of Hannover and Münster Westfalen, seems to be a fair type. In that council we find, April 1, 1895, one representative from each of the chambers of commerce in Bielefeld, Geestemünde, Hannover, Harburg, Hildesheim, Lüneburg, Minden Münster, Osnabrück, Ostfriesland and Papenburg, Verden, and Wesel; one representative from each of the following corporations or societies: Society of German Foundries in Bielefeld, German Iron and Steel Industrials in Ruhrort, Trades

[30] v. d. Leyen.

[31] Fixed by the Minister of Public Works.

[32] Beilage zum Erlass vom 18. Dezember, 1894, gives the composition of circuit councils.

Union of the Province of Hannover, Branch Union of German Millers in Hannover, Union of German Linen Industrialists in Bielefeld, Society for Beet Sugar Industry in Berlin, Society for the Promotion of Common Industrial Interests in the Rhine Country and Westfalen in Düsseldorf, and the Society of German Distillers in Berlin; four representatives from the Royal Agricultural Society in Celle; three from the Provincial Agricultural Society for Westfalen in Münster; one from each of the following: German Dairy Society in Schladen and Hamburg, Society of Foresters of the Hartz, North German Foresters in Hannover, Union of Forest Owners of Middle Germany in Birnstein, Society for the Promotion of Moor Culture in the German Empire; and, lastly, Society of German Sea-fishers in Berlin. This one illustration is probably sufficient to impress upon us the thoroughly representative character of the circuit councils. If a circuit comprises railroads covering territory of other German states, the chambers of commerce, industrial and agricultural societies of such territory may also be represented in the council (§ 4).

The circuit council, as has been indicated above, stands in a relation to the railroad directory similar to that of the national council to the minister. The law (§ 6) makes it mandatory upon the directory to consult the circuit council on all important matters concerning the railroads in that circuit, especially does this apply to time-tables and tariffs. And conversely, the council may make recommendations to the directory. At the same time there is sufficient elasticity in this arrangement to meet momentary wants. In case of danger or any other emergency the directory may act according to its own judgment, independently of the council; provided, however, that all such cases must be reported to the standing committee (§ 5) of the council and to the council itself at its next meeting.

The significance of these councils becomes apparent when we consider what the conditions were in Prussia before their establishment, and what they are now. And the contrast becomes even more striking when we reflect upon the recklessness with which rates have been and unfortunately still are changed in the United States. While the powers of these councils are merely advisory, no railroad administrative officer can disregard their conclusions with impunity. By giving them only advisory power, full legal responsibility is fixed upon the minister and the directories. And because the administration bears full responsibility, it is not legally compelled to act upon the conclusions of the councils; but, no matter which particular course the administration sees fit to follow, whether in harmony with or in opposition to the advisory councils, in either case it is held responsible to the parliament. A railroad administration can regard properly the commercial and industrial interests of a country only when these interests have not only an opportunity but a right to be heard. This right the Prussian system insures to every man. Any person may either be heard himself or have the testimony of uninterested experts presented in his behalf. This system has been adopted by most of the European states (France, Austria, Italy, etc.), but so far Prussia stands alone in having given it the sanction of a special law.[33]

To an American business man, who often has no more influence on railroad rates than on the appearance of a comet, the enjoyment of privileges like those enjoyed by his Prussian colleague, must appear almost utopian. Yet, we have not exhausted the topic for Prussia. There are still other institutions which must be considered. Foremost among these stands the general conference (Generalkonferenz), composed of representatives of all German railroads. It meets at least once each year, discusses matters relating to tariffs, fees and operating regulations. Votes are distributed according to the number of miles of road represented. A standing committee of the general conference constitutes a permanent tariff commission, which occupies itself exclusively with questions concerning freight rates, and the recommendations or complaints of shippers. Its proceedings form the basis of the deliberations in the general conference. It is composed of sixteen members, fourteen representing German state roads, two representing private roads, and two Swiss roads. Acting as an advisory board to the tariff commission, which represents railroad interests, there is still

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[33] **V. d. Leyen, Lectures. The remainder of this section is largely taken from my notes, supplemented by material from various sources.**

another body known as Ausschuss der Verkehrsinteressenten, or committee of shippers, whose members represent all parts of the empire. It is composed of thirteen members,[34] four representing the trades,[35] four the various industries, four the agricultural societies, and one from Bavaria.

There are also railway, traffic and rate unions, which, through well established custom, exert considerable influence on railway rates. Among these, the Verein der deutschen Eisenbahn Verwaltungen, founded in 1846, is most important. This organization includes representatives of the railroads of Germany, Austria Hungary, The Netherlands, and Luxemburg. Both state and private roads are eligible to membership. The society, having been active during almost the entire period of the development of German railroads, has been an influential factor in shaping the system. The resolutions of this body, long published in an official organ, usually receive the careful attention of administrative officials, whether state or private.

But by far the most significant railway organization in the world is the Bernese Congress—Congrés international des chemins de fer.[36] Its history dates back to 1874, but it was not until 1886 that a permanent and effective agreement was made. The agreement was approved by Belgium, France, Germany, Italy, Luxemburg, The Netherlands, Austria, Hungary, Russia, and Switzerland. It has been modified and supplemented in various ways, partly by international agreements among all these countries, and partly by agreements among several of them. The "convention internationale sur le transport des marchandises" of October 14, 1890, composed of delegates from each of the above-named countries, adopted an international code for freight rates. This was revised by a conference of specialists, who met in Berne in June, 1893. A number of changes have been made since, the last having been approved,

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[34] Frequently there are also members of other railroad councils. Eligible are members of "der Deutsche Landwirthschaftlicherrath und der bleibende Ausschuss des Deutschen Handelstages."

[35] Handel, Landwirthschaft, und Gewerbe.

[36] Consult Archiv für Eisenbahnwesen, 1891, page 394; Railroad Gazette for 1887, page 511, for 1890, page 843.

for Germany, by the Bundesrath on February 7, 1895. The Bernese treaty applies to all international freight traffic, excepting such articles as are regularly monopolized by the post-office departments of the contracting states, and all goods shipped through any of them. It provides for uniform through-bills of lading, prescribes routes for international traffic, fixes liability in cases of delay and loss, prohibits special contracts, rebates, and reductions, except such as are publicly made and available to all under identical conditions, and prescribes certain custom house regulations. It also established a Central Bureau, the duties and powers of which may be grouped under five heads:

1. To receive communications from any of the contracting states, and to transmit such information to the rest of them.

2. To compile and publish information of varions kinds.

3. To act as a board of arbitration on application of the countries interested.

4. To take preliminary steps for necessary changes in the agreement.

5. To facilitate financial transactions among the railroads; that is, the Bureau may act as a clearing house.

The expenses of the Bureau are met by contributions from the contracting states in proportion to mileage.

The original agreement provided that any of the states might withdraw at the end of three years, on giving one year's notice. No such notice has ever been given. The provisions drawn up by the delegates who met in Berne have practically been made permanent, and to see the great states of the continent united on the basis of an international code is a fact of more than ordinary significance. Any violation of this code can be punished in the courts. And a judgment having been given in one country the courts of the other countries are bound to assist its execution, except so far as it would conflict with their own laws. But so far as the question of fact is concerned there is no appeal, and a German court may be bound by the findings of a court in France. Germany, Austria, Hungary, Russia, Switzerland and, to a less extent, France have embodied provisions of the international code in their internal code, thus leading to unification beyond the limits of international traffic. And to what extent the Bernese treaty will influence other phases of national and international law of the states of central Europe can not well be foreseen. However, when we consider the fact that states differing widely in forms of government, geographical position and commercial interests have voluntarily made themselves amenable to a common code of law, we can not help but be again impressed with the great power of railroads, in strengthening, not only commercial, but also the political bonds among nations.

The Prussian system, then, presents two groups of railway administrative organs. The one represents railroad interests in particular, and the other social and economic interests, both groups meeting on common ground for the consideration of common interests. Every industry, every trade, in short, every interest is thus provided with a legally constituted agent, through which it may make its wants and grievances known, and, if necessary, call the railroad authorities to account before the parliament. To summarize: The one group represents the legally responsible railroad authorities, namely, (1) the Minister of Public Works, (2) the Royal Railroad directions, and (3) the General Conference and Tariff Commission. Following the same order, there exist, as advisory boards to the first group, (1) the National Railroad Council, (2) the Circuit Councils, and (3) the Committee of Shippers. These two groups are organically connected. Independent of them are the various traffic and rate unions, and, above all, the Bernese Congress.

V.

A few words must be added on the question of publicity of rates. All Prussian railroads — state or private, primary, secondary or local — are required to publish their rates under the supervision of the same authorities which fix them. Such publication includes all tariffs — passenger (which are also printed on the tickets), freight, local, through rates, terminals, incidental fees, etc. And not only the bare schedules, but also the rules and regulations governing their application, as well as all changes which have been made in them must be published. Every advance in rates must be published, together with the old rates, at least six weeks before the same shall take effect. Neither can any reduction take effect until it has been published by consent of the proper authorities. These are legal requirements, and any violation of them may be punished in the ordinary courts of law. During the last ten or fifteen years there has been a tendency to shift points of dispute more and more from the administrative department over into the regular channels of the civil courts. Paragraph 35, of the law of 1838, names the minister (then the Minister of Trades and Industry) as that authority which shall decide disputes between undertakers and transporters, arising out of rate-questions. The motive which led to this provision was that this official was best fitted to give right decisions. But with the growth of the railroad system and the later development of courts of justice the opinion gained ground that the administrative department should be released from the judicial duties imposed upon it by § 35 of the law of 1838. Legislation of 1876 and 1883 aimed in that direction, and the law of April 1, 1890, transferred all claims arising out of rate-questions to the ordinary courts of law for redress. Thus, questions regarding the application of rate-schedules, computation of distances, fees, etc., all come before the courts, while the minister and his subordinates take care that existing laws are properly enforced.

Madison, Wis.

NEGRO SUFFRAGE IN WISCONSIN.

JOHN GOADBY GREGORY,

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We sometimes hear the principle of the Swiss referendum discussed as if it were a novelty in this country, which it is not. The Wisconsin constitutional convention of 1846 adopted a resolution by the terms of which the question of "colored suffrage" was submitted to the people, to be voted upon at the same time as the constitution, but with separate ballots, to be placed in a separate box. The form of the proposition was that an additional section, as follows, should be added to the article on suffrage and the elective franchise:

"All male citizens of African blood, possessing the qualifications required by the first section of the article on 'suffrage and elective franchise,' shall have the right to vote for all officers, and be eligible to all offices that now are or hereafter may be elective by the people after the adoption of this constitution."

The constitution was rejected at the polls, and the colored suffrage amendment met the same fate. The number of ballots cast on the subject of the constitution was 34,351, and on the subject of colored suffrage 22,179. The number in favor of the constitution was 14,119; the number against it, 20,232. In favor of colored suffrage the number of ballots cast was 7,564; against it, 14,615. The defeat of colored suffrage, therefore, was greater proportionately than the defeat of the constitution — and the assumption is fair that nearly all who were in favor of colored suffrage voted.

The sentiment demanding equal suffrage had undergone rapid growth. Experience Estabrook, who was a delegate from Walworth County to the second constitutional convention, which met in December, 1847, said in a speech before that body:

"When I first came to this territory, seven years ago, a corporal's guard could not be found to favor colored suffrage. Since then the public mind has been progressing. Last spring the County of Walworth gave about 400 majority in favor of it. Racine gave a majority for it. Rock and Milwaukee gave a large vote for it; and Waukesha gave a majority for it."[1]

The article on suffrage originally submitted by the committee on general provisions in the second constitutional convention restricted the elective franchise to "free white male persons, of the age of twenty-one years or upwards," and conferred upon the Legislature only the regulating authority embraced in the following provision:

"Laws shall be made for ascertaining by proper proofs the persons who shall be entitled to the right of suffrage hereby established."

George Scagel, a delegate from Waukesha County, moved to strike out the word "white," which was disagreed to. Horace Chase, of Milwaukee, later in the proceedings made a motion to the same effect, which was defeated by a vote of 45 to 22.

Mr. Estabrook moved to substitute a new section, granting "universal suffrage to those now in the territory, and providing for the further regulation of the right of suffrage by law." This motion failing, he afterward moved an amendment providing that the Legislature should at any time have the power to admit colored persons to the right of suffrage. There was at first a majority of one in favor of his motion, but after a long and spirited debate the plan lost ground, and upon the question coming up a second time the amendment was defeated by a vote of 35 to 34.

The friends of colored suffrage in the convention took the stand that it had been advocated in a resolution passed by the Whig Convention in Walworth County, and that many Democrats were in favor of it, as it was in harmony with Democratic principles. It was further argued that so far from being an Abolitionist measure, it would take from under the Abolitionists

[1] Winnebago, Marquette, Fond du Lac, Dodge and Jefferson Counties also gave majorities for it. The largest majority for it was in Waukesha County, where the vote was: Yes, 1,107; no, 617.

the ground on which they stood, as it would leave them no cause of complaint. The opponents of the principle argued that the people had decided against it, and that if embodied in the constitution it would result in the rejection of that instrument by the voters at the polls; or, if not that, then its rejection by Congress. To the objection last enumerated, the retort was made that Congress could not refuse to accept a state constitution for the reason that it guaranteed a republican form of government.

Finally a compromise was arrived at. The article on suffrage in the constitution adopted by the convention and ratified by the people on the second Monday of March, 1848, conferred the right of suffrage not only upon the whites, but also upon "persons of Indian blood who have once been declared by law of Congress to be citizens of the United States, any subsequent law of Congress to the contrary notwithstanding," and upon "civilized persons of Indian descent not members of any tribe." It furthermore provided "that the Legislature may at any time extend by law the right of suffrage to persons not herein enumerated;" stipulating, however, that "no such law shall be in force until the same shall have been submitted to a vote of the people at a general election, and approved by a majority of all the votes cast at such election."

It is a fact not popularly known that since 1849 members of the African race have been clothed by the law of Wisconsin with the right to vote. There is an element of romantic interest in the circumstance that the law which took down the color-bar to citizenship remained in abeyance for nearly seventeen years.

The state had been organized for less than twelve months when the Legislature provided for the submission to the people of a law extending the elective franchise to persons of African blood. Sentiment on the subject was not confined within party lines. In the constitutional convention, as we have seen, Horace Chase, who was a sterling old-school Democrat, was one of the foremost advocates of a liberal provision regarding negro suffrage. The same Legislature that submitted this law to the people had elected a Democrat, Isaac P. Walker, to the United States Senate. Within three months after Walker's election it had passed a joint resolution calling upon him to resign, because he had worked for the admission of California to the Union with a constitution which did not prohibit slavery. The Free Soil movement had made large headway among the people, and there was a disposition, irrespective of party, to resent the arrogant attitude of the South. The measure that submitted the negro suffrage problem anew to the arbitrament of the people contained ambiguities in its phraseology which occasioned a misunderstanding that lasted for many years. It may be worth while, therefore, to very particularly examine the text of this act. The first section contained these directions:

"A separate ballot may be given at the ensuing general election by every person having a right to vote, to be deposited in a separate box, upon the question of the adoption as a law of section 2 of this act. Upon the ballots given for the adoption of section 2 of this act shall be written or printed, or partly written and partly printed, the words, 'Equal suffrage to colored persons. Yes.' And upon the ballots given against the adoption of section 2, in a like manner, the words, 'Equal suffrage to colored persons. No.' And said ballot shall be so folded that the words 'Equal suffrage' shall appear on the outside. If at the said election a majority of all the votes cast at such election shall be given in favor of equal suffrage to colored persons, then said section 2 of this act shall become a law."

The second section of the act provided that "every male colored inhabitant of the age of twenty-one years or upwards who shall have resided in this state for one year next preceding any election, shall be deemed a qualified elector at such election and eligible to hold any office in the state," subject, of course, to the regulations applying to other classes of voters.

At the general election held on the 7th of November, 1849, there were duly cast in the State of Wisconsin 5,265 votes in favor of this law and 4,075 against it. The total vote on the suffrage amendment being less than 10,000, while the vote for governor at the same election amounted to 30,000, it was tacitly assumed that the suffrage law had been defeated. Gen. Rufus King, the editor of the Sentinel, had been one of the advocates of the ratification of the law. But the Sentinel, commenting on the returns of the election, said:

"If the true construction be, as we presume it is, that a majority of all the persons voting at the election must vote for free suffrage, in order to its adoption, the effect is to count every blank vote on the question as a negative one. Thus, in this city, though there is a majority of the votes cast on the question in favor of free suffrage, there is not 'a majority of all the votes cast at the election.' And so, we think, it will be found throughout the state."

The state board of canvassers construed the law in accordance with this assumption, and no one came forward to dispute the correctness of the assumption until 1865. In the meantime, in the belief that the law of 1849 was invalid, the question of negro suffrage had been twice submitted for the vote of the people. In 1857, when the state was so nearly divided between the Democrats and the Republicans that Alexander Randall, the Republican candidate for governor, went in by a bare majority of 454, in a total vote of nearly 89,000, the number of votes cast on the suffrage amendment was only 60,000, and there was a majority of 12,000 against it. The fullest direct expression of the people on the subject of negro suffrage occurred at the general election of 1865. On the governorship the number of ballots cast in the election of that year was 105,181, while the vote on the suffrage amendment was 100,555. Gen. Fairchild, the Republican candidate for governor, was elected by a majority of 9,097, but the opponents of negro suffrage were successful by a majority of 8,059.

The Milwaukee Wisconsin on the day after this election observed:

"Yesterday the right of suffrage to colored men was undoubtedly defeated. We had hoped this question might be settled at this election; but both Union men and Copperheads determined that equal rights should not prevail in Wisconsin."

Yet at this very moment, when friends of negro suffrage were disheartened, the first steps had been taken in a proceeding which was to demonstrate that negro suffrage was already provided for by law.

On the 31st of October, 1865, Ezekiel Gillespie, a Milwaukeean of mixed African blood, and a resident of the Seventh Ward, requested the board of registry of that ward, then in session, to register his name as an elector, which the board refused to do, on the ground that he was a person of color, and not entitled to vote. On the following election day Mr. Gillespie offered his vote, accompanied by an affidavit giving the reasons why his name did not appear on the registry list of voters, and also accompanied by the affidavits of two householders of the Seventh Ward to the effect that they knew him to be a resident of that ward. The inspectors of election for the ward, Henry L. Palmer, William H. Williams and Andrew H. McCormick, refused to accept his ballot, whereupon Mr. Gillespie brought suit against the board of inspectors in the Circuit Court for Milwaukee county. Byron Paine appeared as counsel for Mr. Gillespie, and D. G. Hooker for the board of inspectors. The defendants demurred to the complaint, setting up the claim that it did not state facts sufficient to constitute a cause of action. By stipulation, notice of trial was waived, and the case was put on the calendar and submitted without argument, judgment being rendered *pro forma* sustaining the demurrer. The object of this was to bring the matter without delay before the state Supreme Court, to which Mr. Gillespie's attorney at once took an appeal. The justices of the Supreme Court at that time were three in number. Luther S. Dixon was chief justice, and Jason Downer and Orsamus Cole were his associates. The main opinion in this case, overruling the order of the Circuit Court, was written by Justice Downer. With reference to the meaning of the phrase, "Approved by a majority of all the votes cast at such election," he said:

"Three different constructions of this clause were suggested on the argument: 1st. That it required that the extension of suffrage should be approved by a majority of all the votes, *on all subjects and for all officers*, cast at such election. 2d. That it should be approved by a majority of all the voters voting at such election. 3d. That it should be approved by a majority of all the votes *on that subject* cast at such election. . . . If the first construction, requiring a majority of all the votes on all subjects and for all offices, cast at such election, in favor of the extension of suffrage, before it can be adopted, is the true construction, then the same voter might cast one vote in favor of the extension, and in voting for the candidates for the different offices cast ten votes which would be counted against the very measure he voted for. The absurdity involved in the first construction is conclusive against it. To adopt the second construction would be to say that the word 'votes,' in the clause in question, meant the same as the word 'voters.' . . . If, however, we should concede that the clause in question could be construed to mean, or was equivalent to, 'approved by a majority of all the voters voting at such election,' it would not follow that it had reference to a majority of voters voting on any other measure than the one mentioned in the proviso; or that the number of votes cast at such election for the candidates for any office should determine whether the suffrage was extended or not. . . . Under the provisions of our constitution, as well as of other constitutions, persons are elected to a particular office who have a majority of the votes cast—not for the candidates for some other office, but for the candidates for *that* office. . . . To declare a measure or law adopted or defeated — not by the number of votes cast directly for or against it, but by the number cast for and against some other measure, or for the candidates for some office or offices, not connected with the measure itself, would not only be out of the ordinary course of legislation, but, so far as we know, a thing unknown in constitutional law. . . . . According to section 1, article 12 of the constitution, the Legislature may propose amendments to it, and if they are approved 'by a majority of the voters voting thereon' at the time prescribed by the Legislature, the amendments become a part of the constitution. The right of suffrage by such amendment could be given to colored persons. Is it probable that the framers of our constitution required more votes to extend the right of suffrage in one way than in another? . . . We see no reason for such a conclusion."

Chief Justice Dixon, agreeing with Justice Downer, wrote:

"I do not see how the language could ever have been the subject of doubt or controversy. To me, to whom the question was new when this case was presented, it has seemed from the very first that the meaning was, a majority of all the votes cast upon the subject."

Justice Cole did not write an opinion, but he also concurred. The decision sustaining the validity of the law was upheld by the full bench.

The day has gone by when suffrage was glowingly regarded as an end. We recognize it now as merely a means toward an end. There are among us intelligent people who grumble at the results — or what they conceive to be the results — of universal manhood suffrage in the United States. Did our fathers blunder when by extending the franchise they sought to expand the limits of human freedom? My purpose in this paper has been to present fact, not to blossom into theory. It is a fact, I take it, that the liberal suffrage provisions of our law are a noble monument to a glorious faith in the approximate perfectibility of humanity. As a native and a citizen of Wisconsin, I am proud that at an early stage of her career, and in advance of nearly all of her sister commonwealths, she turned into the broad path in which they have seen fit to follow.

Milwaukee, Wis.

THE SCIENTIFIC IMPORTANCE OF MORE COMPLETE VITAL STATISTICS OF THE STATE OF WISCONSIN.

U. O. B. WINGATE, M. D.,
Secretary State Board of Health.

Section 1023 of the Revised Statutes provides as follows:

"Every physician, or other professional person, under whose care a birth shall take place, shall at once make a record thereof, in a book therefor, which shall contain, so far as can be ascertained, the full name of the child, if any shall have been conferred, its sex, color, names of any other child or children of the same parents living, full name and occupation of the father, full name of mother previous to marriage, the day, hour and place in and at which such birth occurred, and shall within thirty days after such birth return the same facts in the form of a certificate, duly dated and signed by him, to the register of deeds of the county in which such birth shall have taken place. In case any birth shall occur without the care of a physician, or other professional person, and no physician or other such person shall be in attendance professionally upon the mother immediately thereafter, the parent or parents of such child shall certify and make return of such birth to the register, in the manner and form, and within the period above required."

Section 1024 provides that: "Every physician or surgeon, who shall be in attendance professionally at the time of the death of any person, shall at once make a record of such death in a book therefor, which record shall, so far as can be ascertained, contain the full name, sex, color, age, occupation, place of birth, name of parents, time and place of death, and the disease or cause of death, and, if within his knowledge, the name of the burial ground in which interred, and, if married at the time of such death, the name of the husband or wife; and shall within thirty days after such death, return the same facts in the form of a certificate, duly dated and signed by him, to the register of deeds of the county in which such death shall have occurred."

Section 1028 provides that: "Every physician or surgeon, or other professional person, under whose care a birth shall take place, or who shall be present professionally at any death, who shall neglect to make and return any certificate required to be made by sections 1023 and 1024, shall for every such neglect forfeit not less than $50.00 nor more than $100.00."

The law also provides that every physician, surgeon or other professional person, who shall comply with the provisions of these two sections of law, shall receive for each certificate returned to the register of deeds, and certified to as provided by said sections, the sum of fifteen cents, to be audited and paid out of the treasury on an itemized account, verified by his oath, and that the register of deeds shall keep a carefully prepared copy of these records in books kept in his office, and also shall transmit a copy of the same annually to the Secretary of State. This law does not apply to the City of Milwaukee.

Another section of law provides that the Secretary of the State Board of Health "shall be Superintendent of Vital Statistics, and under the direction of the Secretary of State collect the statistics of marriages, births and deaths, and prepare and publish the report thereof required by law."

There are at present seventy counties in the State of Wisconsin, and for the purpose of ascertaining to what extent these laws are complied with, I have recently sent to the register of deeds of each county the following list of questions:

1st. Is the law requiring the report of births and deaths generally observed in your county; if not, to what extent?

2nd. Are all certificates of death signed by a physician or coroner?

3rd. Are certificates of births signed by physicians or midwives?

4th. Is a burial permit required in any part of your county to be filed with any local authority before the interment of a body?

5th. Do you make complete annual returns of births and deaths to the Secretary of State?

I have received replies to these questions from sixty-eight counties, as follows:

To the first question, "Is the law requiring the report of births and deaths generally observed in your county; if not, to what extent?"

15 reply, "Yes."

1 replies, "Yes, except two physicians."

1 replies, "Yes, as to births; about 10 per cent. of deaths reported."

1 replies, "Yes, as to births; less than one-half deaths reported."

2 reply, "Yes, to a great extent."

3 reply, "Yes, births; deaths, no.

1 replies, "Yes, in city; outside about two-thirds reported."

2 reply, "Yes, except by one physician."

5 reply, "Pretty generally."

3 reply, "Fairly well."

1 replies, "No, except at county seat."

2 reply, "No, very small per cent. reported."

1 replies, "No, about one-half births; hardly any deaths reported."

2 reply, "No, probably one-half one-half deaths and two-third births reported."

1 replies, "No, probably not more than one-third of each reported."

3 reply, "No, about three-fourths reported."

1 replies, "No, births are reported except by one physician and several midwives; very few deaths reported."

3 reply, "No, about one-third reported."

1 replies, "No, only three physicians and one midwife make reports."

1 replies, "No, as many employ no physician or midwife."

3 reply, "Perhaps two-thirds are reported."

1 replies, "Probably one-fourth are reported."

1 replies, "Hardly any deaths; less than one-third of births reported."

1 replies, "About one-half of births, and seventy-five per cent. of deaths reported."

3 reply, "Some physicians report; several not at all."

1 replies, "About one-tenth not reported."

1 replies, "Physicians very negligent; many do not report at all."

1 replies, "About one-fourth deaths, and three-fourth births reported."

2 reply, "About one-third births and deaths reported."

1 replies, "Births about one-half; deaths less than one-half reported."

1 replies, "Only partly; many midwives do not make any report; some clergymen reported births and deaths, but the county board disallowed their bills."

1 replies, "About one half births and one tenth deaths reported."

In answer to the second question, "Are all certificates of death signed by a physician or coroner?"

12 reply, "Yes."
1 replies, "Yes, mostly so."
1 replies, "I think so."
29 reply, "By physicians."
7 reply, "By physicians and clergymen."
2 reply, "By physicians and undertakers."
2 reply, "By physicians and justices of the peace."
1 replies, "By physicians and health officers."
1 replies, "By physicians, coroners and midwives."
1 replies, "By physicians, clergymen and coroner."
1 replies, "By physician or person returning same."
1 replies, "By physician, sometimes by relative."
1 replies, "By physician, coronor, clergyman or relatives."
1 replies, "By clergymen mostly."
1 replies, "No, the only ones received signed by nurse."
1 replies, "No, have had reports not signed by either."
2 reply, "No, mostly by undertakers."
2 reply, "No."
1 replies, "No, some signed by superintendent of cemetery."

In reply to the third question, "Are certificates of births signed by physician or midwives?"

48 reply, "Yes."
7 reply, "Physicians, midwives and parents."
3 reply, "By physicians and clergymen."
2 reply, "By physicians, midwives, clergymen and parents."
1 replies, "By physicians mostly."
2 reply, "By physicians."
1 replies, "No, by nurse."
1 replies, "No, mostly by clergymen."
2 reply, "By midwives principally."

In reply to the fourth question, "Is a burial permit required in any part of your county to be filed with any local authority before the interment of a body?"

1 replies, "Yes."
2 reply, "Yes, in one city; in country, no."
1 replies, "Yes, to be filed with town clerk."
1 replies, "Yes, in one city; in country think not."
1 replies, "Yes, in cities; in country don't know."
1 replies, "Yes, with the health officer in cities and villages."

1 replies, "Yes, in two cities."
1 replies, "Yes, in one city; filed with city clerk."
40 reply, "No."
1 replies, "No, not where parties have lot in cemetery, but otherwise from city sexton."
4 reply, "Think not."
2 reply, "Don't know."
8 reply, "Not that I know of."
1 replies, "In one city, except Catholics."
1 replies, "Health officer is required to keep same on file."

In reply to the fifth question, "Do you make complete annual returns of births and deaths to the Secretary of State?"

All answered "Yes," so far as returns to them are received.

It will be seen by these answers that under the present laws in this great state of nearly, if not quite two million people, and a rapidly increasing population, we have nothing that can be called by the name of Vital Statistics. We do not know how many children are born each year, nor the nationality of the parents thereof; nor do we know how many of our people are dying, of what they are dying, or whether they die a natural death or are killed. It is an easy matter for any one with criminal intent to dispose of a body, outside of a few cities in the state, without any return being made as to the cause of death, or without being required to obtain a permit for burial to be filed with any official authority.

Can there be anything more humiliating to the mind of those who are interested in the growth, prosperity and reputation of this great state?

No state or nation can understand itself without maintaining as accurate a record as possible of all that pertains to its growth and decay. This knowledge is not only necessary for our own present needs, but it would seem to be a sacred duty to transmit such knowledge to our children, and to future generations, for their advantageous use and common welfare.

A German historian has said that, "History is statistics advancing, and statistics are history."

It will require but very limited thought on the part of a careful student, in this age of our world, to recognize the great necessity of the most accurate statistics possible to enable one to arrive at correct conclusions, and there is no more important department in statistics than that of vital statistics, upon which we must depend to gain information relative to the most vital and important questions with which we have to deal, as, for instance, epidemic diseases, their extent and character; diseases of the circulatory, respiratory, and other organs; diseases of the nervous system and the brain, including insanity in its various forms, which are generally recognized to be increasing; the question of degeneracy, and a large number of other morbid or pathologic conditions with the prevalence and fatality of which we must become familiar in order to know how to prevent them and to combat their influences.

The older countries, and some of our older states, have learned the value and importance of such statistics, and have enacted very stringent laws, which are rigidly enforced, and it would seem that the time has arrived for this great state to arise to the dignity of maintaining a position second to none in such an important matter as this, as well as in other matters which she does maintain, and of which her inhabitants may justly feel proud.

Such statistics are of the greatest importance in nearly every relation of life, and are becoming almost indispensable daily in a large number of relations besides those already referred to, as, for instance, in the administration of estates; adjustment of life insurance and pension claims; in the relation of marriage and legacies; the relation of guardians and wards; the detection and punishment of crime; the requirements of foreign countries relative to various matters; the problem of child labor and education; the matter of voting, jury service, etc., etc.

One case recently came under my own observation that may serve as an example of many, where a man died and was buried, but no certificate of death was filed as to the cause of death, nor could any records be obtained that could be used in evidence; the man was a member of an insurance organization, and his heirs entitled under certain conditions to a sum of money, but the requirements could not be complied with, as no records could be produced as to the cause of death.

Many instances similar, or worse, might be related.

For a number of years the State Board of Health has asked to have laws enacted that can be enforced whereby more complete vital statistics can be obtained, and much time and study have been expended by members of that board in framing bills for our Legislature, all of which have failed to receive sufficient attention to become laws.

Is not this subject of sufficient importance to enlist the coöperation of this academy, and is it asking too much to urge you to give this matter your careful consideration, and to aid the State Board of Health in its efforts for better things?

Milwaukee, Wis.

FLORAL STRUCTURE OF SOME GRAMINEÆ.

HERMAN F. LUEDERS.

WITH PLATE IV.

Several years ago, in the study of the native vegetation of Wisconsin, I was able to note in a number of species interesting variations from the admitted specific characters, most of them, however, proving to be only local, or temporary, and therefore not deserving of further notice; but in a few instances they seemed to represent more constant structural modifications from the recognized type, so as to merit a notice from workers in the domain of systematic botany.

Having been unable to give this subject as complete an examination as it seems to merit, I take this opportunity merely to present my observations and suggest the consideration of the subject by others more able to conduct a thorough investigation.

The specific characters quoted below are those given in the sixth edition of the Manual of Botany of Northern United States, embodying, as it does, the conservative authoritative views on classification.

Panicum proliferum Lam.— "Sterile flower none; spikelets pale green, rarely purplish; lower glume broad, $\frac{1}{3}$–$\frac{1}{4}$ the length of the upper, which is little longer than the following one."

All specimens of *P. proliferum* that I have been able to examine possessed a sterile flower which was represented by a large glume and generally a delicate palet so as to make the description of the spikelet run as follows: Spikelet about 1 line long; lower empty glume $\frac{1}{4}$–$\frac{1}{3}$ the length of upper, broad, 1–3-nerved; upper empty glume 7–9-nerved, strongly convex, bluntish: sterile flower present, its flowering glume 5-nerved, slightly shorter than second empty glume, which it resembles in shape and texture; palet (sometimes absent ?) 2-nerved, hyaline, very thin, $\frac{1}{2}$–$\frac{2}{3}$ the length of glume: fertile flower shorter than sterile; its glume and palet chartaceous: whole spikelet purplish.

ANDROPOGON FURCATUS Muhl.—"Sterile spiklet staminate." Instead of the condition thus indicated (both in the description of species and character of section), specimens collected during various seasons in Wisconsin, Illinois, Massachusetts, Pennsylvania, present a wide range of variation in structure of pedicelled spikelet so as to justify apparently the following characterization:

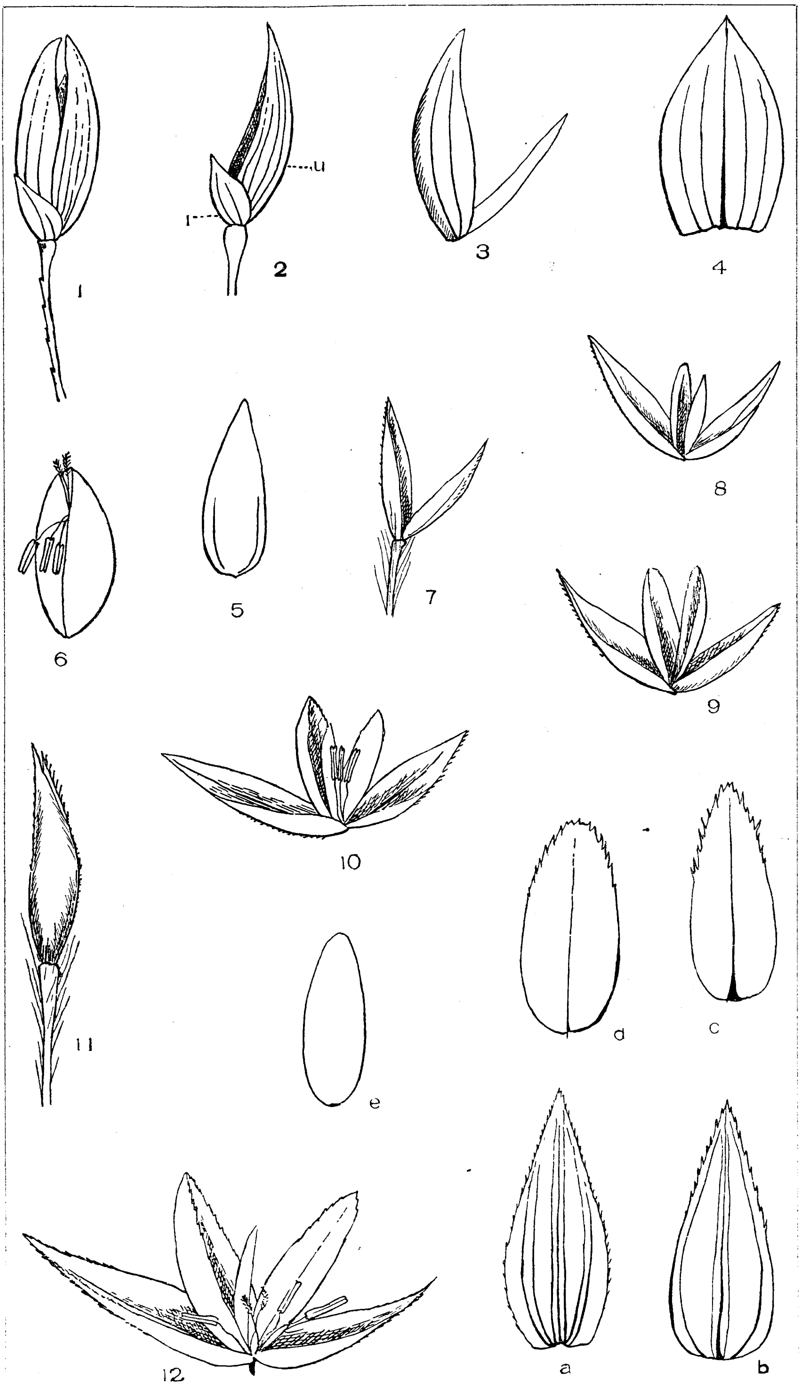
Pedicelled spikelet various, sometimes consisting only of 2 reduced empty glumes, sometimes two-flowered, in which case the lower flower may be perfect.

Between the extremes thus indicated lie numerous intermediate forms. As these: (a) spikelet consisting of two normal empty glumes; (b) spikelet consisting of two normal empty glumes inclosing 1 reduced flowering glume and palet; (c) spikelet consisting of normal empty glumes and sterile flower of 3 stamens inclosed by flowering glume and palet of average size; upper flower represented by the flowering glume. The following is the detailed description of the most perfect condition observed:

Lower empty glume convex-keeled, acute, 7-nerved, longer than upper glume which is 3–5-nerved, carinate, acute, thinner than upper one; both roughened along edge and keel: lower flower shorter than empty glumes, its flowering glume blunt membranaceous, hyaline, 1-nerved, erose-ciliate above; palet hyaline, thin, $\frac{2}{3}$ length of flowering glume, nerveless: stamens 3: upper flower represented by a glume equalling that of fertile flower, broadly-convex, 1-nerved, hyaline, erose-ciliate above.

Thus far I have not ascertained whether these perfect flowers were capable of producing seed, or are still sterile.

Sauk City, Wis.



LUEDERS ON GRAMINEÆ.

EXPLANATION OF PLATE IV.

Panicum proliferum Lam.

Fig. 1. Entire spikelet before anthesis.

Fig. 2. Empty glumes. *l*, lower. *u*, upper.

Fig. 3. Sterile flower.

Fig. 4. Its glume.

Fig. 5. Its palet.

Fig. 6. Fertile flower.

Andropogon furcatus Muhl.

Fig. 7. Pedicelled spikelet in its most aborted state, two reduced empty glumes.

Fig. 8. Spikelet of empty glumes enclosing reduced flower.

Fig. 9. Spikelet of empty glumes enclosing flowering glume nd palet of normal size.

Fig. 10. Spikelet with lower flower staminate and upper flower represented by glume. (Condition described in Manual, though glume of upper flower is not mentioned.)

Fig. 11. Pedicelled spikelet perfect — closed.

Fig. 12. Same as fig. 11, displayed. *a*, Upper empty glume. *b*, Lower empty glume. *c*, Lower flowering glume. *d*, Glume of abortive upper flower. *e*, Palet of perfect flower.

ON THE ANALYSIS OF THE WATER OF A FLOWING ARTESIAN WELL AT MARINETTE WISCONSIN.

W. W. DANIELLS.

Professor of Chemistry, University of Wisconsin.

The mineral matter contained in the water of the well described below differs so widely from that of other similar wells in Wisconsin which I have analyzed that it seems worthy of being made a matter of record.

The following facts relating to the history of the well are kindly furnished me by Hon. Isaac Stephenson.

"The well was drilled in August, 1895, on my residence property in the city of Marinette. The shaft passes through lime rock, light and reddish sandstone and narrow strata of slate for the first two hundred feet. We first struck water in a limestone crevice at a depth of four hundred and five feet. It was quite a flow. We then drilled five feet more and struck another crevice with a greater flow. We continued drilling through limestone, sandstone and slate to a depth of seven hundred and sixteen feet when we struck granite and stopped. There is no flow below four hundred and ten or fifteen feet." "We put packing down at a depth of four hundred and fifty-seven feet, fearing that the water might escape below. Then we piped with four inch pipe with packing down three hundred and thirty-three feet. The water then raised to a height of twenty-one feet above the surface, and comes from the limestone" between four hundred and four hundred and twenty feet below the surface.

Mr. Stevenson also reports the temperature of the water as 49° F., and that (Feb., 1896) "the water continues to flow as rapidly as at first."

The following table gives the various ingredients found in the water expressed in milligrams per liter (parts per million), and in grains per U. S. standard gallon of 231 cubic inches:

	Milligrams per liter.	Grains per gallon.
Sodium as oxide (Na_2O)	63.22	3.6927
Potassium as oxide (K_2O)	11.10	0.6473
Calcium as oxide (CaO)	299.60	17.4721
Magnesium as oxide (MgO)	124.04	7.2338
Aluminium as oxide (Al_2O_3)	9.84	0.5733
Iron as oxide (Fe_2O_3)	4.26	0.2484
Chlorine	115.30	6.7241
Sulphuric acid (H_2SO_4)	713.84	41.6297
Silica (SiO_2)	5.20	0.3033
Carbon dioxide (CO_2)	121.50	6.0856

Following the usual method of expressing the results of water analysis, the constituents found have been grouped as follows:

	Milligrams per liter.	Grains per gallon.
Sodium chloride	119.50	7.649
Potassium sulphate	20.46	1.193
Calcium sulphate	727.60	42.432
Magnesium sulphate	182.34	10.634
Aluminium sulphate	47.27	2.757
Magnesium chloride	69.51	4.054
Magnesium bicarbonate	52.75	3.076
Iron bicarbonate	9.48	0.553
Silica	5.20	0.303

Madison, Wis.

SOME USES OF THE LOW POTENTIAL ALTERNATING CURRENT IN A CHEMICAL LABORATORY.

MILO S. WALKER, PH. D.

Teacher of Chemistry and Physics, Racine High School.

In this paper the author does not claim to have discovered any action of the arc light that is not already known to chemists.

He desires only to give a few suggestions as to the way in which the highest temperature at our command can be obtained and used in every chemical laboratory supplied with a fixture for incandescent lighting.

Many colleges and secondary schools are now equipped with these fixtures and others can obtain them at but little cost. There is no practical reason why we should not use these conveniences for some experiments which cannot be performed with a Bunsen burner or a blow pipe.

In some recent experiments with lamps designed for optical projection I have had experience in working with some of the arc lights now in practical use. It was noticed that the alternating current of about 50 volts and 5 amperes, now generally used for incandescent lighting, furnishes an excellent arc for chemical experimentation. It is very efficient and can be handled by students as easily and safely as a Bunsen burner or alcohol lamp.

The apparatus required is an iron or wooden stand, a screw clamp, like those used for holding burettes, insulated copper wire, some electric light carbons and a rheostat.

The copper wire should consist of a piece of the so-called 10 ampere flexible lamp cord connected at one end with a plug set in the socket from which an electric lamp has been removed. The two parts at the other end of the twisted cord are left free.

Besides this two pieces of ordinary insulated copper wire No. 18, 19, 20 or 21 and 70 cm. long will be required. All the wires can be supplied and fixed by any dealer in electrical supplies.

The rheostat is the most expensive part of the apparatus. Any commercial rheostat capable of carrying 12 amperes will answer all ordinary purposes. It is necessary to have a resistance in the circuit and the current must be started with a high resistance. It may be lessened afterwards until the proper strength is obtained.

The assorted carbons may be $\frac{1}{4}$ to $\frac{1}{2}$ in. in diameter. I use the cored carbons almost entirely. They are much better than the uncored.

Carbons differ much in quality; some contain considerable quantities of metallic carbides and carbonates. I have found that those manufactured specially for optical projection generally contain less of these substances, but these also show variable quantities of metals and earths.

The arc lamp may be used for the following purposes:

1. To show the effect of high temperatures upon difficultly fusible and non-volatile substances.

2. For reduction of ores.

3. As a partial substitute for the blow pipe in qualitative analyses.

4. For synthetic preparation of compounds of carbon from the elements.

There is a wide range of experiments showing the effect of the electric arc upon substances almost infusible by other means. One may proceed as follows:

Fasten or suspend a cored carbon in a vertical position so the lower end is about 10 cm. from top of table. Connect by wrapping around the carbon a piece of insulated copper wire stripped of insulation where contact is made with carbon.

Take a piece of cored carbon about 4 cm. long and bore a conical shaped cavity in one end about 5 mm. deep. Connect this carbon with insulated wire like the first and join both wires with opposite poles of circuit. Fix the lower carbon in a holder, a clamp fastener, a wire test tube holder or a pair of tongs will do. To avoid shocks the handle should be insulated.

Bring the shorter carbon so the lower end of the vertical carbon touches the edge of the cavity. Separate the carbon slightly and adjust the rheostat so an arc $\frac{1}{2}$ to $\frac{1}{8}$ in. long passes between the carbons.

Only a little practice is required to obtain very high temperature under good control.

It is better to protect the eyes with a dark glass.

Place in the conical cavity a small piece of a substance to be tested. Most minerals and the common metals fuse easily. A piece of quartz the size of a grain of wheat can be fused completely. A piece the size of a pea will fuse on one side.

Iron, copper and manganese are easily obtained from their oxides in nearly pure form.

If the core is removed from the upper carbon and a stream of hydrogen or coal gas passed through the carbon tube thus formed, molybdenum and tungsten can be obtained from their oxides in more or less pure condition. The stream of reducing gas prevents reoxidation while cooling.

The manipulation is so easy that even young students can obtain beads of iron, copper or manganese after a few minutes practice.

In using the arc as an aid to or partial substitute for the blow pipe the carbons should be tested for the metals they generally contain and allowance made for such. However, these give but little trouble in ordinary qualitative analyses.

For preliminary tests the upper carbon should be 10 cm. in length and to make the test as delicate as possible it should be passed through a cork fitted into one end of a large glass tube 8 cm. long. A lamp chimney is best. Through the cork a *glass* tube 5 mm. diameter and 6 cm. long should be passed near the carbon and bent above the cork so as to form an angle of 30° with the carbon.

Adjust the large tube so the point of the carbon is about 3 cm. above the opening.

Put the substance to be tested in the cavity of shorter carbon as in case of simple fusion and heat in the same way.

Notice whether there is a perceptible odor at upper end of small glass tube and whether anything collects on the glass of either tube. All volatile substances that condense at ordinary temperatures and all perceptible odors will be noticed in a few seconds. The operator can soon determine whether the analysis should be continued with the high heating arc or the milder heat of an ordinary blow pipe.

The range of blow pipe work is thus increased to a considerable extent.

Some experiments on the synthesis of the hydrocarbons from their elements have been tried.

Acetylene is easily prepared by passing hydrogen through or along side of the arc contained in the following apparatus.

Fit a gas tight cork into each end of a straight lamp chimney. Pass brass tubes 1 cm. diameter and 15 cm. long through each cork.

Into one end of each brass tube put a tube of carbon 3 cm. long. These tubes are made by boring out the core of a cored carbon with a steel wire.

This operation is slow, but after a tube is prepared it will last through many experiments.

The joints of the carbon and brass tubes should fit tightly and be sealed with a mixture of charcoal and sugar syrup dried and charred or of graphite and water.

Fit the corks and brass tubes so the ends of the carbon tubes are nearly together, test the apparatus for gas leakage turn on current and again test after the heat has reached a maximium. If air tight, pass a stream of hydrogen through the brass and carbon tubes. After the oxygen in the apparatus has been consumed it may be necessary to increase the current as hydrogen seems to extinguish the arc. The author hopes to find the cause of this soon as several facts suggest an explanation.

Acetylene passes over mixed with hydrogen and small quantities of an oil resembling benzene.

The latter is generally present in very small quantities and as it is known that acetylene passes into benzene at the high temperatures it is not surprising that it is found here.

The yield of acetylene seems to be about the same as by the usual method of laboratory preparation from illuminating gas burning at the base of a Bunsen burner. This method is more expensive as it requires both hydrogen and an electric current. But the acetylene may be removed by ammoniacal silver oxide solution and the hydrogen collected in a gas holder and used again.

Racine, Wis.

THE FORMS SPONTANEOUSLY ASSUMED BY FOLK-SONGS.

JOHN COMFORT FILLMORE.

Among the interesting problems which the study of folk-music offers us are several relating to the origins of music. We inquire what impulses lead to the production of musical tone, to the orderly arrangement of successive tones into rhythmical and metrical groups; what are the origins of the rhythmic, melodic and harmonic elements of music.

Mr. Richard Wallascheck of London, the distinguished author of the very important work entitled "Primitive Music," has shown conclusively, I think, that the rhythmic impulse precedes the impulse to produce musical tones, and, indeed, leads up to the production of tones. The rythmic impulse is primary; the tendency of certain motions, which are the expression of emotional excitement, to recur in regular rhythmic pulsations is inherent in the constitution of human nature and is due to peculiarities which it is not the province of this paper to discuss. Doubtless the members of this body are already familiar with them. Probably the greatest service which Mr. Wallascheck has done us is to call our attention to the importance of *sonant* rhythm as a means of emotional expression. For example, the rhythm of a war-dance beaten on a *hollow* log is vastly more effective than when beaten on a solid tree or post. The rhythm beaten on a skin stretched tightly over the end of such a log is still more effective; and here we come to a tone which has a more or less definite musical quality; so that the most effective rhythm is that which tends to the production of musical tone.

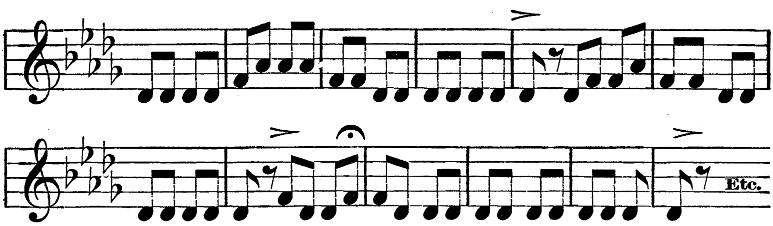
The emotional excitement which generates the impulse to rhythmic beating with the hands or club and to the rhythmic stamping of feet also finds expression in shouts; and these vocal impulses naturally tend to recur in regular pulsations corresponding to the rhythm of the feet, the handclapping, or the drum. The evidence goes to show that these shouts, after a while, tend to become musical in character, to occur in a monotone of definite pitch, or, more frequently, in successive tones which bear to each other well-defined pitch-relations.

Of course these phenomena must be governed by some natural law, and that law must be discoverable. When primitive man begins to produce musical tones varying in pitch, the successive melodic intervals must occur *along the line of least resistance.* He is not working on any preconceived theory; he is expressing his excited feelings freely and spontaneously and it would seem self-evident that the results of this activity must be expressed in forms determined by the universal law of all physical movement.

It has fallen to my lot to become the pioneer as regards special inquiry into the problem: *What is the line of least resistance for the primitive man making music spontaneously;* and it has been my good fortune, as I believe, to have discovered the clue to the solution of the problem. Before I answer, in words, the question just propounded, I desire to call your attention to some phonographic records of songs of the Navajo tribe of Indians. These records were very carefully taken by Dr. Washington Matthews of the U. S. Army, during the time when he was stationed at Fort Wingate, N. M. They are clearly to be taken as the connecting link between excited shouting and

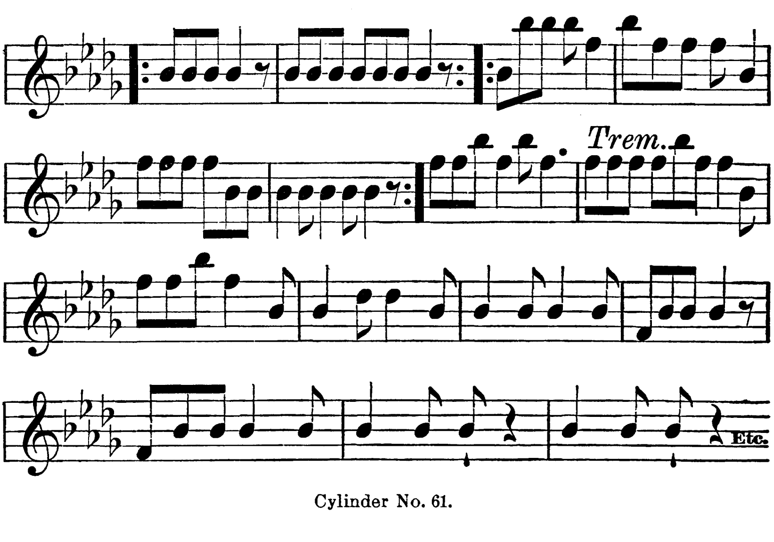
Cylinder No. 41.

excited singing. You will observe that, in the two songs recorded on this first cylinder, (No. 41), the *tone-quality* is that of shouting or even howling; but that the *pitch-relations* into which they tend to fall *are unmistakably those of the major chord.* There is a key-note or Tonic which persistently asserts itself and predominates overwhelmingly throughout both these songs. Associated with this key-note are only three other tones; the major third and the fifth of this key-note with the lower octave of this fifth, making a major Tonic chord. Both these songs are made exclusively of the tones which compose the major chord; *the line of the melody is a chord line, a harmonic line.*



Cylinder No. 135.

The same is true of the two songs on this cylinder (No. 135), only here the keynote predominates so strongly as to make the songs exceedingly monotonous. The song on the next cylinder (No. 61) is made up exclusively of the tones of a minor chord, the keynote predominating very strongly.



Cylinder No. 61.

There are twenty-eight songs in this collection of Dr. Matthews' in my possession. Of these, six have melodies made up exclusively of tones belonging to the major chord; three have only tones belonging to the minor chord; seven follow the line of the major chord but employ one tone not belonging to that chord as a bye-tone; three embody the major chord and employ two bye-tones; six have the minor chord with one bye-tone; two have the minor chord with two bye-tones; and one has the minor chord with three bye-tones. In all these cases the keynote is unmistakable, the chord-tones predominate strongly, and the byetones invariably belong to one or more of the chords most nearly related to the Tonic.

Cylinder No. 146.

I will ask you to listen to two more of these songs which have more developed diatonic melody than those you have already heard. The first song on cylinder 146 has three byetones. It is in a major key and the tones of the major tonic chord predominate; but it employs somewhat prominently the sixth tone of the major scale and much less prominently the second and seventh tones. Its characteristic melodic phrase,

which is repeated many times, is as completely diatonic as our own melodies. The sixth of the scale, as here used, plainly implies a harmony closely related to the Tonic, either the Subdominant or the Relative Minor chord. The seventh of the scale is here used as a mere melodic byetone leading up to the keynote. The second of the scale occurs only once in the whole song and may possibly have been intended for the keynote; for the Indian does not always perfectly realize his own intentions as regards intonation. Indeed, he can hardly be said to have any clear intentions with respect to pitch-relations; he rather seems to be groping blindly and to follow the line of the Tonic chord with occasional digressions into closely related chords, in obedience to a dim, intuitive perception of the harmonic relations of tones.

One more example I present you, recorded on cylinder No. 62. This song is plainly in a major key, the keynote being extremely prominent and the chord-tones predominating. The second and sixth tones of the major scale come in as byetones, the former being so used at the ends of some of the phrases as to imply the Dominant chord.

Two Navajo songs which I took down from the lips of a Navajo Indian at the World's Columbian Exposition exhibit similar characteristics. A number of songs which I obtained at the same place from the Kwakiutl Indians who live at the north end of Vancouver Island have the same qualities of decided tonality and chord-relationship in their melodic intervals. So does a large collection of phonographic records of songs from these same Indians obtained by Dr. Franz Boaz and now in my possession. I also obtained characteristic specimens of songs from different peoples represented on the Midway Plaisance: South Sea Islanders, Dahomeyans, Arabs, Turks, Japanese, and Chinese, representing widely separated race-stocks, varying phases of character and culture and differing grades of advancement. I am indebted to Mr. Carl Lumholz for specimens of folk-songs from the Australian cannibals among whom he lived for four years and for others from two remote Indian tribes in the mountains of Mexico. I owe to Miss Fletcher, a Fellow of Harvard University, one of the leading ethnologists of this country, the opportunity of studying her very large collection of Indian songs, mostly Omaha, but partly Ponca and Pawnee.

I owe to her also the introduction which gave me access to the Omaha tribe and enabled me to take down many songs for myself. Finally, I owe much to Mr. Francis La Flesche, a son of a former chief of the Omahas, who not only sang for me many

Cylinder No. 62.

of the songs of his tribe, but accompanied me to their reservation and made it possible to hear the tribal songs on the occasion of a great festival, to witness the irreligious ceremonies, and to take down some of the songs of visiting Indians as well, among them a song of the Sioux.

All these songs I have studied carefully, and I have compared them with the recorded folk-songs of the different European races. While the music of each race has its own characteristic style and is stamped with its own individual race-character as regards emotional expression, they all have in common the same major and minor tonality with which we are familiar and the same *harmonic* quality. Melody everywhere, the world over, is *harmonic* melody; is based, apparently, on a more or less distinct perception of the natural harmonic relations of tones.

Why this is so I will not now consider; it would far exceed the limits prescribed for this paper to go into speculations of this kind. Suffice it to say that not only are the impulses which lead to the production of music the same for all races of men, but the correlations of the psychical processes with the physiological and physical relations of music are also universal.

The evidence all points in the same direction and each new collection of folk-songs, from whatever source, has thus far made it cumulative as regards the question I raised at the outset of this discussion. If several hundred folk-songs, collected from numerous races of the most diverse character, are sufficient to justify an induction, then am I warranted in concluding that *the line of least resistance for primitive man making music spontaneously is a harmonic line.* Folk-melody is always and everywhere, so far as now appears, *harmonic* melody, however dim the perception of harmonic relations and however untrained and inexperienced as regards music the untaught savage may be.

The first harmonic relations to be displayed in folk-songs are naturally the simplest, — those of the Tonic and its chord. The more complex relations are gradually evolved as a result of the growth of experience.

One point remains to be made. It may be said that we are now forever unable to get at the real primitive man and to observe his processes in the evolution of folk-song. This is undoubtedly true. But surely such songs as these of the Navajos, which show us the actual process of transforming excited howling into songs with unmistakably harmonic pitch-relations, take us very far back toward primitive music-making. What we should find if we could get still farther back I do not know;

but I cannot resist the conviction that it would not be inconsistent with the evolutionary process which I have sought to indicate in this paper nor with the conclusions which seem to me warranted by our present evidence.

Permit me to say one thing more. The aboriginal folk-songs of our own country offer an extremely rich field for the student of musical ethnology and anthropology; a field whose limits are narrowing day by day. It will be anything but creditable to American science if the vast amount of material still to be obtained shall be allowed to perish ungathered and unstudied. Yet there are now no endowments for original investigation of this kind. The collections thus far made have been due to the interest in the subject of men whose main occupations lay in a different field. Not a single competent investigator has yet been given the opportunity to devote himself exclusively to this special domain of science, although there is more than work enough for a hundred, nor is there a single university in the country, new or old, now in a position to equip and send even one student into this neglected field to possess it. It is greatly to be hoped that these conditions may change; but they must change soon, or it will be too late.

Milwaukee, Wis.

THE LEGAL STATUS OF TRUSTS.

EDGAR F. STRONG.

In an able article entitled "Economics and Jurisprudence," [1] Prof. H. C. Adams shows that the English conception of liberty, which "allows every man full control over his own acts on condition of complete responsibility for all that may ensue from them," is carried out in law and government, but that the failure to apply it to the field of industrial activity has resulted, among other things, in the irresponsible use of capital — the most effective power of the present day. The consequent management of capital for purely private ends is contrary to the spirit of English liberty, and it is because we have failed to so adjust matters as to realize responsible control over all economic agencies, that we are confronted with so many serious industrial problems.

Within the last few years there has been a determined attempt to solve one of these problems by legislation in the public interest. The Federal and several of the State legislatures have enacted laws for the purpose of repressing and punishing those combinations of capital known as "trusts," [2] which have created so much alarm and excited the liveliest interest in the public mind. These laws are based on the theory that all combinations among producers and dealers in articles of necessity are contrary to public policy, and should therefore be prohibited. Upon this theory rests also the principle that contracts to carry out such combinations are void.

Trusts have been looked upon as monopolies in restraint of trade, that is, as conspiracies to destroy competition, lessen pro-

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[1] "Science Economic Discussion," New York, 1886.

[2] So called because in many instances they operate by or through a board of trustees.

duction, and raise prices. This idea is expressed by Judge Cooley when he says, "Trusts are things to be feared. They antagonize a leading and most valuable principle of industrial life in their attempts not to curb competition merely, but to put an end to it. The course of the leading trust of the country has been such as to emphasize the fear of them. When we witness the utterly heartless manner in which trusts sometimes have closed manufactories and turned men willing to work into the streets, in order that they may increase profits already reasonably large, we cannot help asking ourselves whether the trust as we see it is not a public enemy, whether it is not teaching the laborer dangerous lessons, and whether it is not helping to breed anarchy." In the minds of the people "trust" has become synonymous with "extortion," and "combination" with "conspiracy."[3]

Unfortunately there has been but little study of the economic character of the trust and of the causes that have produced them, by those who have demanded repressive legislation; consequently it has not been perceived that the trust is an economic evolution which is both natural and inevitable, and which has proceeded from individual effort to partnership, then to corporation, and finally to trust or partnership of corporations. "The modern trust, like the earlier corporation, is grounded in a commercial tendency which grows out of commercial necessity,"[4] and it is interesting to note that the present fear and apprehension is but the counterpart of that felt in the early part of the century in regard to corporations. It was with the greatest difficulty that a charter could then be obtained for any purpose, however beneficial it might be; but this hostility was compelled to give way to the necessities of changed business methods which the revolution in the processes and organization of production and transportation rendered inevitable after the first quarter of the century. It is not within the scope of the present paper to discuss the many causes that have called the modern trust into existence, and to show that they are the necessary result of

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[3] "The Corporation Problem"— Cook, page 234.

[4] "The Trust, an Economic Evolution," an address by C. F. Beach, Jr., at the Union League Club, Chicago, March 30, 1894.

rampant competition, the decline of commercial profit, overproduction along certain lines, and the failure of pools, nor to discuss the benefits that have accrued to society from their formation, and to show that they contain within them the seeds of their own dissolution whenever they violate the conditions upon which their existence depends. "They live and thrive only as they serve the public better than their competitors, and in this country of abounding resources, limitless capital and endless energy, intelligence and enterprise, it is impossible that any sort of business can be made unduly profitable, by an increase in the selling price of the commodity produced, without provoking competition and calling other capital into the same field of enterprise."[5] They must not only contend with residual competition, but avoid provoking potential competition as well. If, therefore, prices cannot be unduly raised, and as a matter of fact are lowered, how does the trust make a profit? By enlarging the margin of profit at the bottom by cheapening production and avoiding the wastes due to ruinous competition, also by realizing the advantages of unity of management. These objects can be secured in no other way than by a combination of the corporations into what is known as a trust; and the same conditions that make this course necessary compel the pursuance of a policy that is beneficial to the public, although the original motive is purely one of self interest.

It is not denied, however, that the trusts have been guilty of many wrong and illegal acts; that their methods are not always to be approved; that they have in some instances injured the public, and that their power has been exerted in Congress and the State legislatures. But it may be asked whether these evils are not largely the result of the absence of regulative legislation on the one hand and of repressive legislation on the other? The trust has been condemned because of certain wrong-doings, whether real or imagined, and because the impression is abroad that the trust is in some way or another doing a public mischief. It is not understood that the trust is but another stage in industrial development; that it is here to stay, in spite of

[5] Ibid.

law and repressive legislation, as is shown by the steady increase in their numbers and capitalization; that it is not the trust itself but the wrong-doing that should be the object of legislation; consequently, that regulation and control should be the aim of the law, not an unwise and fruitless policy of preventing the formation of trusts themselves. In other words, we must apply the principle of responsible power to trusts, and secure responsible control over this important economic agency. It is the purpose of the following pages to state the legal position of trusts, and to indicate briefly how far the repressive measures have proved effective.

In considering the legal status of trusts an examination of their relation to the common law naturally precedes that of the special and recent legislation directed against them by Congress and the State legislatures. Three forms of combination, all of recent origin, must be distinguished and treated separately, namely, partnerships between corporations, corporations controlling other corporations, and lastly, a corporation buying out all other corporations in its line of business. This is the order of their development, and the last is the most important and prevalent form.

I. A partnership of corporations was the original and formerly the most common form of trust combination. Pools and mutual agreements between competing manufacturers in regard to prices, terms of sale, division of territory proved too weak to be effectual. These informal agreements were not only secretly but openly broken, and it was because of their failure that the trust copartnership was devised in order to bind together more securely those entering into the agreement, and also to realize the additional advantages that would result from an union that could not be dissolved or broken without the consent of all. By written agreement all the corporations entering into the combination transferred all of their stock to a board of trustees, who held it subject to the purposes set forth in the compact. These trustees issued trust certificates to each corporation in proportion to the value of its plant, and these were in turn divided among the stockholders in proportion to the interest of each individual holder. These trust certificates were in the form of stock certificates, and had indorsed upon them the usual form of assignment and power of attorney, coupled with a proviso to the effect that the assignee by accepting the transfer assented to the terms of the trust agreement. Each corporation was bound to pay over all profits to be equitably distributed. The trustees had general supervision of the affairs of the corporations partnerships and manufacturers adopting the agreement, by electing as apparent owners of the stock, its directors and officers.[6] This was the character of the Standard Oil Trust, which was the first combination of the kind, and dates from 1869. This famous trust, which was originally composed of the refiners of crude petroleum in Pennsylvania and Ohio, now controls the entire American and western European market. This scheme of organization was successful from the first, and the remarkable financial success of this trust led in the course of a few years to the application of the principle to almost every kind of industry.

Turning to the legal aspect of the question we find that partnerships of corporations have been repeatedly declared illegal because they violate the law of corporations, and also because they are contrary to public policy. Inasmuch as the last objection applies to all three forms it will be best to defer its consideration until the specific legal objections to the first two forms have been considered. A partnership is defined by Bouvier as "A voluntary contract between two or more persons for joining together their money, goods, etc., in some lawful commerce or business, under an understanding, express or implied, that there shall be a communion of profit and loss between them."[7] A combination of corporations in the manner described above certainly constitutes a parternership, but corporations cannot legally enter into a co-partnership without violating the law of corporations.

The reason why a corporation cannot legally enter into a copartnership either with an individual or with another corporation is well stated by a writer in the American Law Review for December, 1892. The corporation cannot lawfully give to its

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[6] Full text of an agreement given in People v. North River Sugar Refining Co., 1890, 121 N. Y. 585.

[7] Bouvier's Law Dictionary, vol. ii., p. 291.

co-partners the powers which by the law of partnership each partner possesses over the rights of his co-partners, and the partnership property; nor can it lawfully assume the liabilities imposed by law upon the members of a co-partnership. The very object of forming a corporation for commercial or manufacturing purposes is to escape the liability of a partnership, and the liability is escaped by restricting the powers of the members. Thus in a partnership, each partner is the general agent of the firm — a purchase or sale by one partner binds the others. It may be said in general that any one partner may do any act in the partnership business that could be done by all the partners together. On the other hand, it is a fundamental principle of the law of corporations that the affairs of the corporation and the business that it carries on shall be managed by its directors, and by them alone. As agents they cannot delegate their powers to others, and as trustees in whom personal confidence is reposed, they cannot abdicate their functions so long as they retain the trust. Since, therefore, the rules of law governing partnerships are so different from those governing corporations that a partnership composed of corporations cannot exist without violating some of those rules, it follows that such a partnership is illegal, and therefore void. This has been adjudged in a multitude of cases, and now may be considered settled law in the United States.[8]

II. In order to escape the legal difficulties of the trust partnership, a new form of combination was devised in what are known as Stock-holding Corporations. These acquire control of other corporations by purchasing a controlling interest in their stock. The Richmond Terminal Company, which formerly controlled in this way a railway mileage of 7,842 miles, included in several large systems, is a familiar illustration among railroads. Another is the Chicago Gas Trust Company, incorporated under the general incorporation law of Illinois (Rev. Ill. C. 32, 1, 5). This company, in addition to the power to build, maintain and

[8] People v. North River Sugar Refining Co., 1890, 121 N. Y. 582; Mallory v. Hanaur Oil Works, 1888, 86 Tenn. 598; American Preservers' Trust Co. v. Taylor Manufacturing Co., 1891, U. S. Circuit Court E. D. Mo., 46 Federal Reporter 152.

operate gas works of its own, was empowered "to purchase and hold or sell the capital stock, or purchase or lease or operate the property, plant, good-will, rights and franchises of any gas works or gas company or companies" in the City of Chicago or elsewhere in Illinois. But the real object of the new company was to bring about a consolidation of the existing companies, and it proposed and promptly proceeded to obtain control of the four gas companies in Chicago by the very simple device of buying up and owning a controlling interest in the stock of each of them, instead of having the stock of these companies assigned to a board of trustees as in the partnership trust.

The power of the company to do this having been questioned by quo warranto, the Supreme Court of Illinois held,[9] first, that the company could not lawfully exercise the power to purchase and hold the stock of other gas companies as incidental to the main purpose of maintaining and operating works for the manufacture and sale of gas; and secondly, that the power to purchase and hold such stock could not be assumed by the company as its main purpose, since such an object, as tending to create a monopoly, was not a "lawful purpose" within the meaning of the law. Judge Magruder said that "to grant to the appellee the privilege of purchasing and holding the capital stock of any gas company in Chicago is to grant to it a privilege which is exclusive in its nature. It is making use of the general incorporation law to secure a special privilege; it is obtaining a special charter under the cover and through the machinery of that law, for a purpose forbidden by the Constitution. To create one corporation that it may destroy the energies of all other corporations of a given kind, and suck their life blood out of them, is not a "lawful purpose."

This decision is the standard for this class of cases, and there have been many other subsequent decisions in harmony with this one.[10] It is now a well settled principle in the law of corporations that in the absence of express legislative permisson, a corporation has no power to become a shareholder in another

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[9] People ex rel. Peabody v. Chicago Gas Trust Co., 1889, 130 Ill. 268.

[10] Valley Ry. Co. v. Lake Erie Iron Co., 46 Ohio St. 44, 1888; Central Ry Co. v. Penna. Ry. Co., 31 N. J. Eq. 475, 1879.

corporation, otherwise it could go into a business entirely different from that allowed to it by its charter. The proceedings in the case just cited were not to oust the company from the power of making and selling gas, but of the power of buying up the stocks of other similar corporations. It is to be noted that this Illinois statute has been repealed, and the recent trend of legislative action has been towards limiting rather than enlarging the powers of corporations.

III. The form of combination to which the least legal objection can be urged is the one known as the Monopolistic Corporation. This is the form now generally adopted in forming trusts. In this case the trust is formed by the purchase on the part of the new corporation of the entire property, machinery, stock in trade, and good-will of all, or the larger number, of the corporations and firms engaged in that particular line of business. The Diamond Match Company is an illustration of this form of trust.

Against combinations of this character, the ground of action has been that they are contrary to public policy, because they create monopolies, and, as previously stated, this objection applies equally to the trusts already described. The law's condemnation of monopolies dates back to the time of Queen Elizabeth,[11] and it has been settled almost as long that contracts or combinations of the producers or dealers in staple commodities of prime necessity to the people, to restrict or monopolize their supply or enhance their price, pooling contracts or combinations between such producers or dealers to divide their profits in certain fixed proportions, and pooling contracts or combinations between competing common carriers, are illegal restraints of trade, and are void.

It is obvious that this principle of law and the statutes against regrating[12] long ante-dated the formation of trusts, and were not directed against any such mischief as their citation in anti-trust arguments assumes, but to corners and pools. Nor do the decisions apply except by analogy. Nevertheless the principle

[11] Case of the Monopolies, 1602, 11 Coke 85.

[12] "Every practice or device, by act, conspiracy, words, or news, to enhance the price of victuals or other merchandise." Coke 3d. Inst. 196- 1 Russell, Crimes 169. From Bouvier's Dict. II, page 432.

has been applied in a long list of cases and held that trust combinations tend to create monopolies, that these restrain trade, that this is contrary to public policy and therefore illegal.

One of the most prominent cases is that in which the Sugar Trust was declared illegal by the Supreme Court of New York.[13] The Sugar Refineries Company was a type of the first form of trusts, and the New York Court of Appeals in passing upon the case declined to decide the question of public policy, preferring to rest their decision upon the inability of corporations to enter into co-partnership; but the Supreme Court in deciding the same case fully considered the question of public policy and expressly decided that the trust was illegal, because it restrained trade in an unreasonable manner, and inevitably tended to create a monopoly. "It is a condition on which a corporation is allowed to be created and maintained that it shall exercise and use its franchise for the benefit of the public, and when it voluntarily declines to do that or places itself in a situation in which that may be prevented as a consequence of its voluntary action, it may be annulled under the statute as well as the decision of the court."[14] The court held that the North River Sugar Refining Company should forfeit its property, and that a receiver should be placed in charge of it. The Sugar Trust was incidentally declared illegal, and the Cotton Seed Oil Trust anticipated this decision by taking steps to change its form of organization. Reference will be made later to the outcome of this decision against the Sugar Trust.

The question now arises, to what classes of business the principle of monopoly and restraint of trade as contrary to public policy is applicable? In order to answer this question it is necessary to examine some of the cases bearing on it, and such examination shows that the principle applies only to articles of necessity and to businesses of a quasi-public character, that is, those in which the general public have a right.

(1) Articles of necessity. That the principle applies to articles of necessity or of such general use that the public is interested in their production, is evident from the definition of

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[13] People v. North River Sugar Refining Co., 1889, 54 Hun 354.

[14] People v. North River Sugar Refining Co., 54 Hun 354, page 385.

regrating given in the note on page 134, and a recent decision will serve as an illustration of this class of articles, namely, that of Foss v. Cummings,[15] where it was held that a combination to enhance the price of an article of necessity, such as wheat or other article of food, for purposes of extortion, is against public policy, although there may be no attempt to corner the market.

At this point a serious difficulty is encountered. What articles are to be considered as necessaries, for what may be so considered at one time may not be so considered at another? There have been several decisions in regard to particular articles, but they do not furnish any general rule for answering the question. It has been held that the following are articles of necessity within the meaning of the law: Coal — Morris Run Coal Co. v. Barclay Coal Co., 1871, 68 Pa. St. 173; Gas — Gibbs v. Baltimore Gas Co., 1888, 130 U. S. 408; Matches — Richardson v. Buhl, 1889, 77 Mich. 632; Salt — Central Ohio Salt Co. v. Guthrie, 1880, 35 Ohio St. 666; Grain — Craft v. McConoughy, 1875, 79 Ill. 346; Sugar — People v. North River Sugar Refining Co., 54 Hun 354, 1889; Lumber — Santa Clara Valley Mill and Lumber Co. v. Hayes, 1888, 76 Cal. 387; Cotton bagging — India Bagging Association v. Kock, 1859, 14 La. Ann. 164; Butter — Chaplin v. Brown, 1891, Supreme Court of Iowa, June.

(2) The principle of public policy extends also to a business in which the public have a right as distinguished from a business which may be purely beneficial to the public. To this class belong the businesses of transportation, communication by telegraph and telephone, the supply of light and water, and similar companies which derive their right to condemn property from the fact that their business is established for a public use. In regard to railway corporations every sort of legal effort has been made in England and in this country to prevent the consolidation of independent roads. According to stringent statutes the original corporation is unable to sell out to the trust, for in the absence of express legislative permission, a corporation in

[15] 47 Illinois App. 665; S. C., 40 Id. 523.

whose business the public is interested has no right to transfer all of its property to another corporation. It must either use its property and carry on its business as contemplated by its charter or dissolve its corporate existence and divide its property among those entitled to it, or else consolidate with another corporation in due legal form. But such consolidation can only be made in case it is provided for by statute. This was the decision of Justice Miller in the case of Pennsylvania Railroad Co. v. St. Louis, Alton and Terre Haute Railroad, 1885, 118 U. S. 309, and this decision was upheld in Oregon Railway Co. v. Oregonian Railway Co., 1888, 130 U. S. 23.

In spite of every statute, however, railway consolidation went on with increasing rapidity, until at the present time the greater part of the railway mileage of the country is comprised within a relatively small number of great systems, and the same combining force has brought about a similar result among the express companies. The telegraph and telephone are now each controlled by a single company, while in cities there is usually but one gas or electric lighting company, and a few large street railway companies. It may be noted here that in no other class of businesses is the tendency to consolidation so strong as among the enterprises above mentioned, for each is a monopoly in its very nature, and does not admit of competition in the true sense of the term.

An examination of the opinions rendered in the cases cited in these two classes of limitations on the principle of public policy shows that in each instance the decision turned on the fact that the subject matter was clearly within one of those classes. It follows, therefore, that there may be commercial combinations in the nature of trusts, to which the doctrine of trade conspiracies, or combinations in restraint of trade, will not, in the absence of a special legislation, apply. So far as articles of necessity are concerned there have been but few decisions, but the following have been held not to be such articles that an attempt to monopolize the trade in them is illegal: Washing machines — Dolph v. Troy Laundry Machinery Co., 1886, U. S. Circuit Court, N. D. of N. Y., 28 Fed. Rep. 553; Patent Curtain fixtures — Curtain Roller Co. v. Cushman, 1887, 143 Mass.

353; Sewing machines — Bi-Spool Sewing Machine Co. v. Acme Manufacturing Co., Supreme Court of Mass., March 2, 1891.

A second and most important exception is based on the now well established rule that the validity of contracts restricting competition is to be determined by the reasonableness of the restriction. If the main purpose or inevitable effects of a contract is to suppress competition or create a monopoly, it is illegal; but contracts made for a lawful purpose, not unreasonably injurious to the public welfare and which impose no heavier restraint upon trade than the interests of the favored party require, have been uniformly sustained, notwithstanding their tendency to check competition to a certain extent. The public welfare is first considered, and the reasonableness of the restriction determined under these rules in the light of all the facts and circumstances of each particular case. It is evident from this that there may be still another class of commercial combinations in the nature of trusts to which the principle will not apply in case there is no special legislation to the contrary. Several decisions which will be considered in connection with the federal anti-trust law of 1890 will illustrate this point clearly and strongly. The above considerations form the basis of the decision of the United States Circuit Court of Appeals in the recent case of United States v. Trans-Missouri Freight Association et al. (58 Fed. Rep. 58). But it is the application of this doctrine that makes this decision notable. It was held that even railway companies and other quasi-public corporations, whose business is of such a character that it has been said they cannot be restrained to any extent whatever without prejudice to the public interests may, within proper bounds, make such contracts and combinations as shall impose mutual restraint, though it diminishes competition.

The matter of combination has been passed upon by the Supreme Court of Minnesota (July 20, 1892) in the case of a combination among the lumber dealers of Minneapolis. In giving the opinion in favor of the combination, Judge Mitchell said: "This is the age of associations and unions in all departments of labor and business, for the purpose of mutual benefit and protection. Confined to proper limits, both as to end and means, they are not only lawful, but laudable. Carried beyond these imits, they are liable to become dangerous agencies for wrong and oppression. Beyond what limits these associations or combinations cannot go without interfering with the legal rights of others, is the problem which, in various phases, the courts will doubtless be frequently called to pass upon." "What one man may lawfully do singly, two or more may lawfully agree to do jointly. Combination in itself does not render such conduct actionable."

In conclusion, the position of the trust before the common law may be briefly summarized as follows: Partnerships between corporations and corporations controlling other corporations violate the law of corporations and are therefore illegal. A corporation that buys out other corporations is illegal only when it is contrary to public policy, that is when the commodity monopolized is an article of common necessity or the service rendered is of a quasi-public character; and provided that the combination is formed for the distinct purpose of fleecing the public or employs improper and unlawful methods in dealing with customers and competitors. The numerous decisions to which reference has been made, show that the trust when brought into court finds no favor under the common law. While all attempts to fasten criminal punishment on the promoters of monopolies has failed, yet the civil courts have been generally successful. This is because their methods require less evidence and are more pliable in procedure. It is easier to dissolve a corporation than to convict and punish promoters of monopoly. As Governor Nelson, of Minnesota, said at the anti-trust convention held in Chicago in June, 1893: "The methods and ways under which trusts and combinations are carried on are so various, intricate, secret, refined, and so involved that the courts, as in cases of fraud and usury, have declined to define, except in general terms, the transactions, agreements, and arrangements which are inhibited and odious to the law. But while the common law holds such contracts to be illegal, it fails to punish them as crimes, and furnishes insufficient and dilatory relief even in civil cases."

It is doubtful whether any permanent result whatever is attained. The usual effect of an adverse decision has been simply a change in the form of the trust. The Chicago Gas Trust was soon metamorphosed, and the same is true of the Sugar Trust. It will be recalled that the suit by the State of New York against one of the companies included in the Sugar Trust resulted in a sweeping victory in the lower courts and a judgment in the higher that the trust was illegal, and could not lawfully transact its business in the state. To carry out the provisions of this decision, the North River Sugar Refining Company was accordingly placed in the hands of receivers, but in a short time the property was returned to the owners by due process of law. Immediately the trust was reorganized as a corporation under the laws of the State of New Jersey, and as a foreign corporation continued to carry on its business with precisely the same force and effect as it formerly did as the Sugar Refineries Company. In spite of all decisions trusts were not only not destroyed, but new ones were constantly being formed.

With such results staring them in the face it is not surprising that there arose among the people a general demand for state and federal legislation. The New York legislature which had failed to pass the anti-trust bills introduced in 1888 and 1889, enacted a law in the following year. In 1889, laws defining and prohibiting trusts, and providing for the punishment of violations of the law, were passed in Missouri, Texas, North Carolina, Nebraska and Kansas; in 1890 by New York, Mississippi, Iowa and Congress; and in 1891 by Illinois, Alabama, Tennessee and Georgia. It was during these years that the popular agitation reached its highest point and found expression in a great body of trust literature, newspaper criticism, party platforms (twenty-three states in 1890).

Passing now from the status of trust combinations at common law to the consideration of some of the recent legislation directed against them, we will examine first the Act of Congress, approved July 2, 1890 (26 Statutes at Large, page 209, Ch. 647). The trust question was called to the attention of Congress by President Harrison in his message of November, 1889, and his views voice the public sentiment and legislative policy of the time. "Earnest attention should be given by Congress to a consideration of the question, how far the restraint of those combinations of capital commonly known as trusts is a matter of Federal jurisdiction. When organized, as they frequently are, to crush out all hostile competition and to monopolize the production and sale of an article of commerce and general necessity, they are dangerous conspiracies against the public good, and should be made the subject of prohibitory and even penal legislation."

The Senate measure entitled "A bill to protect trade and commerce against unlawful restraints and monopolies" was adopted by the House. It provides that "every contract, combination in form of trust or otherwise, or conspiracy, in restraint of trade and commerce among the several states, or with foreign nations, is hereby declared to be illegal. Every person who shall monopolize, or attempt to monopolize, or combine or conspire, with any other person or persons to monopolize any part of the trade or commerce among the several states, or with foreign nations, shall be deemed guilty of a misdemeanor, and, on conviction thereof, shall be punished by fine not exceeding $5,000, or by imprisonment not exceeding one year, or by both in the discretion of the court." The other sections provide that suits may be brought in the Federal courts to restrain violations of the Act, for forfeiture of property used under any contract or by any combination or pursuant to any conspiracy mentioned in the Act, and for private remedies for persons injured by the forbidden acts perpetrated by the classes against whom it is directed.

The first important decision occurred in connection with the proceedings against the "Distilling and Cattle Feeding Company," better known as the "Whiskey Trust." Certain officials of the combination were indicted in Massachusetts for violating the Federal Act. In the District Court of the Northern District of Ohio, application was made for a warrant to remove one of the defendants to the former state for trial. Although it was shown that the company controlled seventy distilleries, or three-fourths of the distillery products of the country, the court decided that there had been no violation of the law, and therefore denied the application and discharged the prisoner.[16] A few months later, in the Circuit Court of the same state, Southern District, another of the defendants was released from custody on a writ of habeas corpus, the court holding that "Congress has no authority, under the commerce clause or any other provision of the constitution, to limit the right of a corporation created by a state in the acquisition, control and disposition of property in the several states, and it is immaterial that such property, or the products thereof, may become the subjects of interstate commerce; and it is not apparent that by the Act of July, Congress did not intend to declare that the acquisition by a state corporation of so large a part of any species of property as to enable the owners to control the traffic therein among the several states, constituted a criminal offense.[17] This decision was similar to that made by the Circuit Court for the Southern District of New York in proceedings[18] to remove another of the defendants to Massachusetts. The whole affair ended in the total failure of the government to deal with the indictments. The Act used terms which left everything to construction, and it was decided that the efforts to control the production and manufacture of distillery products by the enlargement and extension of the business was not an attempt to monopolize the trade and commerce in such products within the Federal meaning. All other persons who chose to engage in such distilling business were at perfect liberty to do so.

Equally unsuccessful was the attempt to break the combination among the lumber dealers of Minneapolis, in the case of United States v. Nelson,[19] in which a demurrer to all the counts of the indictment was sustained. It was held that an agreement between a number of lumber dealers to raise the price of lumber fifty cents per 1,000 feet in advance of the market price, could not operate as a restriction upon trade, within the meaning of the Act of Congress, unless such agreement involved an absorption of the entire traffic, and was entered into for the pur-

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[16] In re Corning, 51 Fed. Rep. 205, June 11, 1892.

[17] In re Green, 52 Fed. Rep. 105, August 4, 1892.

[18] In re Terrell, 51 Fed. Rep. 213, June 28, 1892.

[19] District Court, District of Minn., 1892, 52 Fed. Rep. 646.

pose of monopolizing trade in that commodity with the object of extortion. It is plain that this renders the law of no effect, when one considers that it is practically impossible for the most powerful trust to acquire and retain control of an entire industry. Nor is it easy to prove that a combination was formed for the definite purpose of extortion. This is illustrated in the case of the Dueber Watch Case Manufacturing Co. v. Howard Watch Co.,[20] where it was held that an agreement by a number of manufacturers and dealers in watch cases, to fix an arbitrary price on their goods, and not to sell them to persons buying the plaintiff's watch cases, was not in violation of the statute of 1890, unless it covers the intent to absorb or control the entire market, or a large portion thereof.

Equally suggestive are the words of Judge Putnam of the United States Circuit Court, District of Massachusetts, in the case of J. H. Patterson,[21] who was indicted for violating the Act of 1890. "A combination, contract, or conspiracy in restraint of trade may be not only not illegal, but praiseworthy; as, when parties attempt to engross the market by furnishing the best goods or the cheapest. A case cannot be made under the statue unless the means are shown to be illegal." A similar and recent decision has already been noticed on page 138 in United States v. Trans-Missouri Freight Association et al.

It is apparent from these successive decisions adverse to the government that the law has not only utterly failed in its object, but that no statute however exhaustive and stringent, based on the commerce clause of the constitution, would be any more effective. That monopoly in production does not constitute restraint of interstate commerce is indicated in the cases already cited, but in no other case has it been so clearly stated as in the one in which the Sugar Trust was again brought into court. In the suit brought by the government[22] to test the legality of the Sugar Trust's absorbtion of the four large Philadelphia refineries, Judge Butler decided in favor of the trust. It was charged that the American Sugar Refining Company entered

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[20] U. S. Cir. Court, S. Dis., N. Y., May, 1893, 55 Fed. Rep. 851.

[21] February 28, 1893.

[22] U. S. Cir. Court, Jan. 30, 1894, 60 Fed. Rep. 310.

into an unlawful and fraudulent scheme to purchase the stock of these companies with the design of monopolizing the manufacture and sale of refined sugar in the United States. In the opinion of the court, the only questions raised were: "(1) Do the facts show a contract, combination, or conspiracy to restrain trade and commerce, or a monopoly within the legal significance of these terms? (2) Do they show such a contract, combination or conspiracy to restrain or monopolize trade or commerce among the several states or foreign nations? (3) Can the relief sought be had in this proceeding?" Judge Butler said that the first and third questions need not be considered, and answered the other in the negative. "The contracts of the defendants have no reference and bear no relation to commerce between the states or with foreign nations. Granting, therefore, that a monopoly exists in the ownership of such refineries and business it does not constitute a restriction or a monopoly of interstate commerce. The latter is untouched and unrestrained and open to all who chose to engage in it." The government appealed the case to the Circuit Court of Appeals,[23] where the decree of the lower court was affirmed. Judge Dallas' said: "The most that can be said, and this for the present purpose may be assumed, is that the sugar trust has acquired control of the business of refining and selling sugar in the United States. But does this involve monopoly or restraint of foreign or interstate commerce? We are clearly of opinion that it does not. We do not deem it necessary to say more, inasmuch as the subject has very recently been considered and passed upon in the case of Greene." (See page 142, note 17.)

The cases that have been cited are the principal ones where indictments have been framed under the law of 1890, and it is plain that not only has the act failed in every important case, but it is safe to say that a favorable judgment can neither be obtained or enforced in such a way as to destroy the trusts and combinations which it was expected to eradicate.

State Anti-Trust Laws.—Few cases have been tried under the various state statutes; consequently it is difficult to judge of

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[22] U. S. C. C. A., March 26, 1894, 60 Fed. Rep. 934.

the effectiveness of these laws, and the construction that the courts will put upon them. In general, their purpose is to strengthen the provisions of the common law, and to provide adequate penalties for their violation. It would seem that if the law is framed with a due regard to the constitution and a clear understanding of the difficulties to be met with in enforcing it, an anti-trust law can be formulated that will ensure conviction. In most of the states, however, these considerations have not always been observed, and consequently the laws are either unconstitutional or entirely unsuited to the object for which they were designed.

The Missouri law which was copied in Iowa, is of this character. The law prohibits corporations from entering into certain combinations, and requires them to file an affidavit with the Secretary of State that they have not entered into such combinations, and in default of such affidavit, after due notice, authorizes the Secretary of State to revoke their charters. That officer accordingly called upon all the corporations of the state to file the required affidavit. Some did, and some did not, and the Secretary of State then proceeded to publish an order revoking the charters of the latter, but without effect. In the Supreme Court of the state[24] it was held that the requirement that the corporation inform the Secretary of State whether such corporation has violated such act (for the punishment of pools, trusts, and combinations) is in conflict with the constitutional declaration that "no person shall be compelled to testify against himself in a criminal case," and the section is therefore void.

On the other hand, the New York law approved June 7, 1890 (session laws 1890, page 1069, No. 7), has not only been sustained, but has proved effective in securing conviction. The principles underlying the law are clearly presented in the decision of the Court of Appeals of New York in the case of People v. Sheldon et al.[25] The court held that in determining cases brought under this law the question is, "Is the agreement between the parties, in view of what may be done under it and the fact that it is an agreement the effect of which is to pre-

[24] **The State ex rel. Att'y Gen. v. The Simmons Hardware Co., 109 Mo. 118.**

[25] **34 Northeastern Reporter 785, and 54 N. Y. S. Rep. 513.**

vent competition, one upon which the law fixes the brand of condemnation and which it will not permit?" In other words, in estimating the legal character of the agreement no consideration need be given to what is actually done under it, for if the legality of the agreement depended upon actual proof of public injury or whether it is made the means of raising the price of a commodity beyond its nominal and reasonable value, it would be very difficult in any case, to establish the invalidity, although the moral evidence might be very convincing. The court concluded, therefore, that "if agreements and combinations to prevent competition in prices are, or may be, hurtful to trade, the only sure remedy is to prohibit all agreements of that character. The fixing of prices alone, done under such an agreement, is overt act enough, if any act be needed to make the combiners guilty under the law, even though the prices fixed be reasonable."

Further, "If a combination between independent dealers to prevent competition between themselves in the sale of an article of prime necessity is in legal contemplation, and although the object of the combination is merely the due protection of the parties to it against ruinous rivalry, and no attempt is made to charge undue or excessive prices, the parties to the combination are amenable to the law."

The decision of the federal court in Dueber Watch Case Manufacturing Co. v. Howard Watch Co. has already been noticed. The case was afterwards taken into the New York courts, and in May, 1893, the Supreme Court sustained the former company in its suit for damages. It was held that prices could be fixed and competition crushed in a legitimate business effort, but this was not the object of the defendants, who endeavored to ruin the Dueber Company when the latter refused to join the combination, that is, in an asserted illegal purpose.

The Illinois act approved June 11, 1891 (Session Laws, 1891, page 206), has also been sustained. The law declares that any corporation, partnership or individual which shall create or enter into any pool, trust, agreement, combination, confederacy or understanding to regulate or fix the price of any commodity, or fix or limit the amount or quantity of any article, or commodity, shall be adjudged guilty of conspiracy to defraud, and shall be subject to fine or imprisonment. It also forbids corporations to issue or own trust certificates, or to enter into any trust agreement with intent to limit or fix the price or lessen the production and sale of any article of commerce.

Under the provisions of this comprehensive act, the United States School Furniture Company, which was investigated in 1893 by direction of the Illinois Senate, was recently declared to be an illegal combination.

To examine the legislation and cases in each state would unduly extend the limits of this paper without proportionately adding to the general conclusions that may be drawn. Few suits have been instituted under the various laws that have been enacted, because the statutes are either not enforceable or lead to no permanent result. It must be taken into consideration that the trust can easily remove its centre to some other state and continue to carry on its operations in the state from which it was driven as a foreign corporation. During the last few years, moreover, the public have begun to realize that they have not suffered any specific injury that can be directly attributed to trusts, and also that the source of the general complaint and outcry was not the public as a whole, but that section which desired to compete with the members of the trust. The public has learned, besides, that modern trust combinations are formed not for the purpose of fleecing them, but for legitimate business purposes. "They are normal in their origin, development and practical workings, and therefore are to be accepted, studied and regulated, but not surpressed." [26] It is well for the people of this country that both the common law and special statutes have failed to prevent combination, otherwise all the benefits and economies that flow from production and communication on a large scale would have been lost; we would be confronted with all the results of a ruinous competition which have been escaped by this step in economic development; and we would be threatened not only with industrial stagnation and loss, but retrogation as well.

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[26] "Limits of Competition," Clark.

But the agitation against the trust has not been in vain, for it has warned them to pursue a moderate policy and to keep within proper limits. It is true that any departure from business principles will set forces to work that will bring about the destruction of the combination; but abuse of power and persistent disregard of the interests and rights of the public will awaken a spirit and conscience that will apply and enforce suitable measures of control and regulation. It is true that they cannot be destroyed, but they can be subjected to a proper governmental visitation and control.

Madison, Wis.

DANTE.

HIS QUOTATIONS AND HIS ORIGINALITY: THE GREATEST IMITATOR AND THE GREATEST ORIGINAL.

JAMES DAVIE BUTLER, LL. D.

Dante was above all poets the heir of the ages. He tells us that life beyond life is partly of bliss, and partly of a bale which is sometimes hopeful and sometimes beyond hope. This view has nothing of novelty. It has prevailed for milleniums from the Elysian fields of the most ancient Greek even to the most recent aboriginal stories about the happy hunting-ground. The idea of purgatory has its analogon in Plato. Among early Christians it was defended by Origen, and before the year 600 A. D. it had been fully formulated by Gregory the Great.

In describing the physical universe Dante copies Ptolemy, whose system dates from our second century. From Ptolemy he learned to view the cosmos as geocentric,—seven planets, one of them the sun, revolving round the earth,—the whole hemmed in by the stellar sphere and around that the empyrean. This Ptolemaic hypothesis had pre-determined the whole plan of Dante's paradise, and many details in its nine spheres. Moreover, Greek planetary names, older not only than Ptolemy but than history itself, constrained Dante to place the heaven of orators in Mercury, of lovers in Venus, of poets in the sun, of warriors in Mars, of judges in Jupiter, and of mystics in Saturn.

The last judgment he localized in the valley of Jehoshaphat. All Christendom, and Moslemdom too, had done so before him, because it is written in Joel; "I will gather all nations, and I will bring them into the valley of Jehoshaphat, and I will plead with them there".

Directly under Jerusalem lies Dante's Inferno. So had that of Jews and Moslems always lain. Nor had this local habitation of spirits in prison been unknown to early Christians. Regarding Christ's descent into hell the words of our poet are an echo of what, as a child, he must have read in the Golden Legend of Voraggio.

Many a wanderer in the realm of disembodied souls had been known before Dante. Among these Alberico, a monk of Monte Cassino, had written out his extra-mundane experiences. Nineteen passages where Dante imitated this book have been specified by Cary. Both Alberico and Dante entered a compartment of sighs, not groans; both call Cerberus the great worm, both encounter stenches, flames and scorpions; both describe one river of boiling blood, or blood and fire, and another of hot pitch, swelling into billows, with victims struggling out and then tumbling into rivers here deep and there shallow. Both would have been clutched by demons but for angelic rescue, both rise to higher levels — one borne up by a dove — the other by an eagle. Both behold an angel and a devil in fight for a soul; both see six-winged cherubs and a similar paradise to which they both turn, like homesick exiles hastening home; both observe vacant seats prepared on high for some that were still alive, whose names Alberico was forbidden to mention, though some of them are told by Dante.

Dante's warp and woof are *Biblical* almost as thoroughly as Bunyan's. His very first line has a scriptural allusion. In the Purgatorio you may count twenty-five texts from the Vulgate which he quotes in the *ipsissima verba* of the Latin original, as if he thought them untranslatable. Dantesque imagery constantly recalls the Apocalypse. The interview with Statius affords a representative specimen of Dante's Biblical debts. It was fashioned, as he himself states, after the walk to Emmaus as chronicled by Luke. Virgil's then overhearing what Statius said to our poet is of a piece with the unknown Jesus listening to the report about himself by Cleopas. Dante's Biblical borrowings are noted by Cary one hundred and twenty-one times. Nor has he discovered them all.

Dante is no less indebted to the *classics* than to Holy Writ.

Their lying mythology he swallows as gospel truth. His hundred cantos are viewed by many as only an expansion of the sixth book of Virgil. In traversing the spirit-world he finds Charon the ferryman and Minos the judge and tells us that he followed Virgil's hero, though far his inferior. He was guided by Virgil as Æneas had been by the Sibyl; he met his ancestor Cacciaguida, as Æneas had met his father Anchises, and both heard prophecies from their progenitors. Both tried thrice to embrace a friend among the shades. Old familiar scenes which Æneas saw frescoed on Carthaginian walls Dante gazed at in sculpture on the purgatorial pavement. Cato is a warden at the gate of Purgatory, and had expounded equity among Virgilian spirits. Dante had been vouchsafed Virgil as guide, philosopher and friend, through all his dark and dolorous pilgrimage, and he hence considered himself entitled to all Virgilian treasures. You will perceive in Cary forty specifications where the disciple has appropriated something from the master. He sometimes takes a line out and out, as this: *Manibus date lilia plenis.*

In twenty-seven cases, or more, Ovid was laid under contribution. His metamorphoses of Cadmus into a snake and Arethusa into a fountain are specimens of scores which Dante has repeated. Valerius Maximus, Lucretius, Cicero, Lucan and Statius are not the only other classics called on for a Dantesque tribute.

Such sons of ancient genius helped our mediæval bard, so far as he could be helped, in more than one emergency. Thus spirits emaciated and hunger-bitten were grasping at fruit on a tantalizing tree. "How," it was asked, "could spirits who had no need of food pine away for lack of it?" The answer was: "That is no more a mystery than that, when Meleager's mother threw a certain stick into the fire, he pined away in sympathetic suffering, and died when the wood was consumed." No more mysterious than that — not a whit more.

We read in Dante;

> "Between two viands equally removed
> And tempting, a free man would die of hunger,
> Ere either he could bring unto his teeth."

He had obtained this paradox, as it used to be thought, from

Buridan, rector of Paris University, who, according to tradition, declared that, if an ass were placed exactly between two haystacks, he must starve, being in a balance of motives. Buridan's ass became proverbial. But when Buridan's works were ransacked and the saying was nowhere discovered, the asinine poser was claimed as Dante's invention. The truth is, after all, that this proof of determinism is older than Aristotle. In his treatise *περὶ οὐρανοῦ*, he says that in his time it was a common saying, that "any one" [his indefinite pronoun may mean either donkey or doctor] "any one equidistant from equally good eatables and drinkables, must remain motionless."

Dante was an imitator of *contemporaries* no less than of the ancients. His first lines say he was lost in a wood. An identical phrase had formed the commencement of a poem by his own schoolmaster Brunetto. He denounces usury as "a sin against nature," the very words in which the practice had been stigmatized by Brunetto.

The main scenes in Dante's trilogy he had seen acted on the stage in dramatic mysteries, or carved on cathedral walls in bass-relief and emblazoned on their stained glass,—most of all, in Orvieto. His triple world was symbolized in the architecture of every church. The stone cried out of the wall and the beam out of the timber answered it where a stone inscribed *Sasso di Dante* beside the Florentine cathedral to this day tells us that he was wont to sit.

It is even possible that some magnificent window, emblem of the mystic Madonna rose, was the inspiration of his eternal and infinite rose-amphitheater, the sublimest image in all poetry or speech, in which his Paradise culminates.

At the recent convention of the Modern Language Association one of the best-received papers was entitled, "A forerunner of Bunyan in the twelfth century" by Prof. Francke of Harvard. This relic appears to be just now discovered by moderns, but one is slow to believe that it was unknown to Dante, or that it escaped paying him a tax.

The music which enlivened Dante's march onward and upward was all borrowed from time-honored anthems and theodies of the church. Snatches of its Latin are built into his verses, as

Te Deum, *Salve Regina*, *Summæ*, *Deus clementiæ*. His gerarchy, or nine-fold orders of the heavenly host—angels, archangels, principalities, powers, dominions, virtues, thrones, cherubim and seraphim—had all been prepared for him by the pseudonymous Dionysius, the Areopagite. The seven mortal sins, already defined *ex cathedrâ* as wrath, gluttony, lust, pride, envy, avarice, and sloth, not only suggested but dictated and diversified both seven circles in hell where they were punished, and seven circles in purgatory where they were expiated, or washed out.

The era of his pilgrimage was that very year of jubilee when more pilgrims than ever before, and among them probably Dante himself, flocked to Rome. Thus his poem may then and there have first come into his mind. Some of its images were avowedly derived from that œcumenical convocation.

Long-established lessons to catechumens led to an analogous catechising of Dante through several cantos at the gate of heaven by Peter, James and John, and marked out the lines of his examination. From school divines, and principally from Thomas Aquinas who died in Dante's ninth year, the poet was a snapper up of countless unconsidered trifles—such words as *ubi*, *quando*, *quia*, *quiddity*, substance and essence in scholastic senses, and the subtleties they embody. Thus distinguishing and dividing hairs, he condensed folios as we cork up the fragrance of a garden in a vinaigrette of rose ottar.

The fashion of verse in Dante's vision—the *Terza-Rima*—had been made ready for him by troubadours and trouveres—by Guinicelli and Cavalcanti. He thrust into it many scraps of Latin with now and then a vocable of Greek, Hebrew, Arabic, or tongues yet more outlandish, and eight lines at once of Provencal gibberish quoted from Arnaldo. At first glance his diction recalls the Babylonish dialect of patched and piebald languages in Hudibras.

As to Dantesque minutiæ we note with surprise that so many of them seem to have been received by tradition from more ancient travelers through the world unseen. For one instance, we observe Dante in purgatory discovering that spirits there had lost their shadows while he retained his own. But the same discovery, that the shades in Hades were shadowless while he was not, had been made by Aridaeus the Cilician, soon after the Christian era. Plutarch tells the story and it may come before us again.

In surveying the creations of pictorial old masters we at first consider them altogether original. But as soon as we enter a gallery where pictures are arranged chronologically, we recognize our mistake. Even in the master-pieces of Raphael the subjects chosen, the persons introduced, their grouping and accessories, sometimes the very colors, were by no means new On the contrary, they were traditional, conventional—heirlooms from earlier centuries or imported from Byzantium. Nor were there many among Raphael's own contemporaries from whom he failed to learn more or less, so that, on the whole, no artist caught more from others than this supreme artist.

Scrutiny of Dante points the same way. He made spoil of the Egyptians like the Jews who at their exodus borrowed, every man and every woman of their neighbors, jewels of silver and jewels of gold. More than this, there went out a decree from Dante as from Cæsar Augustus that all the world, and not Egypt only, should be taxed.

But, however much Dante borrowed, he made everything his own. The notion that disembodied spirits cast no shadows is a thousand years older than Dante, and it may have come to him through books or by hearsay. It is noteworthy, however, that he makes the tradition his own as fully as if it had been his own invention.

In the Inferno he never noticed this peculiarity. Perhaps it was too dark there for shadows to be noticed. It was in Purgatory that it first caught his eye. Seeing his own shadow on the hill-side and none of Virgil, he was startled with fear that his guide was gone. Finding him close at hand his next wonder was how it was possible for purgatorians around him to be freezing and burning although they were shadowless. As this puzzle was past his finding out he thus learned to feel that his path was to be among more mysteries than had been dreamed of in his philosophy.

It is worth observing that Dante's shadow was as plain as ever while that described in Plutarch was only "an obscure, shadow-like line." He copied nothing unchanged.

Again, when Virgil inquired the way up the steep of some pilgrims there, Dante's shadow was descried by them with so much surprise that a crowd flocked together to gaze at it, and hence at its owner. Among the gazers was Manfred, King of Sicily, who related his own tragical fate, why he had been detained in Ante-purgatory, and how he had escaped going further and faring worse. Once more. A band singing *Miserere* stopped at the sight of Dante's shadow. They changed their note into a great O! long and not very melodious, and dispatched two of their number to enquire into the matter. These messengers, darting up swifter than stars fall, came back with the whole bevy, etc.

Further on, when our pilgrim arrived where sinners were cleansed by the hunger-cure, his shadow induced an old friend, Forese, to seek his face, and learn his story.

Yet once again, when Dante reached the host being purified by fire he says:

> "Then with my shadow did I make the flame
> Appear more red; and even to such a sign
> Shades saw I many as they went give heed.
> This was the cause that gave them a beginning
> To speak of me. And to themselves began they
> To say: 'That's not an unsubstantial body.'"

The idea that spirits have lost their shadows led Dante on still further. He holds that they never stand in each other's light — more than one ray hinders the passage of another.

Thus the fancy concerning shadows and shadowlessness which in Plutarch was a barren fact forever—a veritable shadow—in Dante became substance and of wide significance. His originality gave it evolution to its highest power, as Euclid drew out a point into every variety of geometrical line and surface and solid. It was to him as suggestive as our new found Roentgen rays.

Many another bit of raw material in the Dantesque laboratory was no longer idle ore,

> "But iron dug in central gloom,
> And heated hot in burning fears,
> And dipped in baths of hissing tears,
> And fashioned by the dints of doom
> To shape and use."

This view I find in keeping with the most recent utterance of the Edinboro' Review (Vol. CLXXXI, p. 298), where it is said; "Much of a great writer's originality may consist in attaining sublime objects by the same means which others had employed for mere trifling."

The shadow of Dante demands a moment's digression. It gave Chamisso the idea of Peter Schlemihl, the man who had lost his shadow,—a work which was at once translated into all European tongues, and which led to an analogous book this side the water entitled "The Modern Pilgrim, or Peter Schlemihl in America," a religious novel which had great denominational popularity. "The Shadow of Dante" also became the title of a volume in 300 pages concerning him by a famous Italian exile, Francesca Rossetti as well as of a review of the same and its subject in the North American. This article by James Russell Lowell, the outcome of "twenty years assiduous study," covers seventy pages and is well-nigh the best tribute ever paid by any Dantophilist to the sublimest of Italian geniuses. But however much Dante borrowed he made everything his own.

A common emblem of originality is the spider who spins his web out of himself. In truth, however, he is no more original than the bee who pilfers from a myriad of flowers. The spider's raw material comes at last from without as really, though not as obviously, as the bee's. Each is alike original, for each produces what no other creature can, a product all its own. The more each takes in, the more it gives out, stamped with its own likeness, in nature's mint of ecstasy.

The originality of Dante is conspicuous in his choice of a *theme.* His epic, and his alone, is extra-mundane from first to last. It has nothing to do with the surface of the earth, where, aside from brief episodes, all scenes in the Iliad, Odyssey and the Æneid are represented. He says, indeed, that earth as well as heaven had a hand in his poem. By earth, however, he means, either its infernal prison, or Purgatory which had been ejected out of its abysses like the volcanic cone of Ætna in the island of fire and piled up heaven-high.

Dante's poem is also exceptionally *religious.* The old epics were in a sense religious; the Iliad setting forth divine vengeance visited upon Trojans who had first wronged Greeks; the Odyssey is divine guidance homeward of one of the ministers of divine wrath; and the Æneid shows a pious Trojan impelled by his guardian gods to the founding of Rome. But the effusions of Dante's predecessors were none of them religious through and through as his was. They were of the earth earthy; his was devotional — the whole duty of man. They reflected the culture of Athens and the glory of Rome; his the holiness of Jerusalem. Hence, readers at once begun to call his drama "Divine."

Dante's subject is the autobiography of a soul God-guided beyond the bounds of time and sense. We go with that soul to the lowest depths, and then, as it rises *de profundis*, behold it purified by pity and terror and soaring into the highest heaven of heavens.

In thoughts beyond the reaches of our souls this pilgrim communes with his own heart, with his guardians and with all types of being from the blackest devil to the brightest seraph. He mingles with representatives of the seven mortal sins and the seven cardinal virtues [or graces], in more than seventy times seven differentiations, and each in its own element, either acting or relating his actions. The secrets of all hearts are revealed in words, or betrayed in deeds. No confessions of St. Augustine or at all priestly confessionals are to be compared with the Dantesque disclosures.

Again, no poet before Dante had dreamed of such a wide universal theatre as that he struggles through. "The measure thereof is longer than the earth and broader than the sea." Milton's writing was four centuries later, well-nigh, but Dante's hell is deeper and his heaven higher than Milton's. The toilsome sinking to the center of the earth, the plunge into the abyss beyond, the struggle, often desperate, up the purgatorial mountain, and nine successive flights through a nine-fold heaven generate an impression of vastness and boundlessness which Milton has never rivaled. If then we looked no further than the unique religiosity and grandeur of his conception we must acknowledge Dante to be a great original. His theme was in his own judgment all his own. He thus speaks:

> "O ye who in some pretty little boat,
> Eager to listen have been following
> Behind my ship, that singing sails along,
> *The sea I sail has never yet been passed.*"

Dante is original in the *development* as well as in the conception of his theme.

It is the first step that costs. His first step took him beyond this visible diurnal sphere. Henceforth his surroundings transcended the laws of nature. This super-human emancipation was not partial or transient, as in the witches of Macbeth and in Prospero of the Tempest, but perpetual and all-pervasive. When we have once been hypnotized with him, nothing seems improbable. Accordingly his imagination can rove and riot without rein or rule.

Horace praises the adroitness with which Homer, beginning with things plausible, brings us by slow degrees to accept his fables about the Cyclops and Charybdis as not beyond possibility, making his "miracula" to seem "speciosa."

But the great Italian's environment is miraculous from the start, and ignores limitations altogether. He is at home among monstrosities at a bound and not by gradual approach.

Dante saw a snake tie a man as with cords, pierce him as with arrows, assimilate him to itself, consume him as fire burns paper, and restore him from ashes to his original shape. Again, he saw a troop of angels take up such a position that their squadrons had the forms of 35 Latin letters so as to spell the words, *Diligite justitiam qui judicatis terram.*

But even such prodigies as these are not out of keeping with the unearthly tenor of our pilgrimage through the world of spirits. All "miracula" are "speciosa" there.

Free from the laws of nature Dante naturally expatiated more freely than poets who were bound by them. With a great sum obtained they this freedom, but he was free-born.

A poem confined to realms preternatural and even unnatural, we think must needs be deficient in *human* interest.

Such a lack would be fatal. It would have brought down the sublime vision to the level of a maniac's ravings, or of those every day dreams which we throw to the winds.

This catastrophe Dante avoids by many an original device.

The wanderer, while out of the world, is yet of it, through multitudinous interviews. Each change of many-colored life, and that in all centuries, rises before him. His talks are with Adam and those of his sons whose careers are the soul of all history, sacred and profane. His gleanings from all sources are all poetical, or become so. So much, however, is recondite that every reader is instructed as well as surprised and charmed. Whatever may be our forte, scripture, classics, history, folklore, astrology, art, or science of whatever name, we are sure to add to our knowledge, and need research for fathoming the learning. We confess that his eye had a more precious seeing than ours, alike for books written with a pen, and for the book of nature, above all of human nature. His sight and his in sight appear alike marvelous.

The Florentine looker-on in three worlds detected more correspondences than Swedenborg with terrestrial life. For illustrating his wayside experience he recalls the Venetian arsenal, Dutch dikes, grave-mounds on the Rhone, the cascade of Montone, the baths of Bulicame, the leaning tower of Garisenda, the famine tower of Ugolino, Alpine lakes, snow and mists. But the line of his side-lights, were we to follow it, would stretch out to the crack of doom.

Italian gestures abound, a universal language thanks to which thoughts flash lightning-like nor linger waiting for words. Dante too stoops for fragments which others think beneath them. Proverbs as about cutting a coat according to cloth, the old tailor squinting into a needle's eye, a sack crammed till it bursts, the bush of thorns for a gap in a hedge, the man in the moon, the currying hostler, the game of odd and even, the doublings of chess-board squares, the animals Adam named, the flowers Eve plucked,— nothing came amiss. He even made obtuse angled triangles poetical. It was not merely the beauty of holiness which he had in hand.

Dante's vision is all a lie, but he lies with a circumstance. His circumstantial evidence is so cumulative and coherent that we believe him altogether, and we sometimes think that he believes his own lies. We say with Macbeth:

"Function is smothered in surmise,
And nothing is but what is not."

The Divine Comedy is original in form and pressure owing to its writer's *religio-political* tenets. We read in Genesis: "God made two great lights." One of these lights, according to Dante, was the Pope and the other the King. They were not related like sun and moon, but coequal like two suns. The king was once represented by the Roman Cæsars, one of whom, Trajan, was even saved, being baptized by miracle. The Roman eagle was "the bird of God." Afterward German emperors, heads of the Holy Roman empire, stood for the king. The papal and the imperial luminary has each its own orbit. If either encroaches on the domain of the other, they no longer discourse heavenly music, but grate harsh thunder. Now such an encroachment ensues whenever the spiritual light grasps temporal power, or the secular light meddles with spiritualities. Some such encroachments are drawn to the life in Dante's vision. Thus, concerning the arrest of a pope by the French it is said:

> "Lo! the flower-de-luce
> Enters Alagna: in his vicar, Christ
> Himself a captive, and his mockery
> Acted again. Lo! to his holy lip
> The vinegar and gall once more are pressed,
> And he twixt living robbers doomed to bleed.
> Lo! the new Pilate of whose cruelty
> Such violence cannot fill the measure up."

On the other hand, when a pontiff was a simoniac, like Boniface, Dante, while kissing the pope's toe, not only ties the hands of the simoniac but points out, in the lowest hell save one, the niche he was ordained to fill.

The actors in atrocities, whether sovereign or sacerdotal,—Dante beheld each in his own place. Thus at the seventh infernal circle, which was redolent of more stenches than Coleridge counted in Cologne, he came to a tomb inscribed: "*Pope Anastatius, whom Photinus seduced from the right way.*" But behold how the whirligig of time brings in his revenges! Modern critics maintain that Dante was here misled by the old and blundering chronicler, and that the Anastatius whom Photinus turned into a heretic was not the pope of that name but an emperor.

If our poet has now discovered his mistake, he has doubtless laughed outright at himself, as he tells us Pope Gregory did on entering heaven, since the first thing he noticed there was that his book on the celestial hierarchy was all a ridiculous blunder.

Another Pope, namely, Celestine, Dante had observed in the infernal vestibule, among wretches who would never know they were born but for the stings of wasps, mosquitoes and vermin yet more vile.

Whoever, no matter of what age or clime, had helped or hindered the advancement of the ecclesiastical or the governmental ideal, comes into judgment, and is doomed.

Poetical justice is dispensed. Sowers of discord pace a treadmill routine and every now and then are cleft in twain, the envious grope with eyelids sewed up, the heads of fortune-tellers are so twisted that their chins hang over their backbones, and suicides are pent up in trees while their bodies hang on stakes beside them. The proud are crushed to the ground under burdens grievous to be borne, and Satan, the first-born of pride, stands frozen in the very center of the globe, where all the weight of the world, drawing from every side, presses upon him. Non-committals, or fence-men, perhaps fare worst of all. Creatures who never were really alive, and whom heaven and hell both hate, they are outcasts from both, and have no hope even of death. Too mean to live, too weak to die.

In contrast to all this, the noble army of well-doers, downward from the earliest martyr, saint and prophet, are seen in a glory ever-brightening. Most of these personages bring to the pilgrim's mind their opposites, or counterfeits, still burdening the earth. Hence his ebullitions of satire. These are so hot and venomous that their victims must have felt themselves already bitten by infernal serpents and scorched in infernal fires. Such Parthian arrows shot back to the earth by one retreating from it, heighten the human interest of his adventures. They thrill us like vengeful furies lurking in the back-ground of Greek tragedy. In this line Michelangelo imitated Dante, and painted a dignitary he hated among the damned. When the Pope begged the artist to place him in better company, the answer was: "Were he in Purgatory you could take him out, but in the Inferno he is beyond help."

Dante is original in his types of *woman*. The female spirits who meet him so often onward from Francesca in the second circle, exhibit traits unlike their classical sisters. They have borrowed a coloring, or at least a tinge, from Christianity and chivalry. Yet it is most of all in Bēātrice that Christian and chivalric ideals are sublimated. Enskied and sainted, she sends Virgil to the lowest parts of the earth for Dante's salvation. In her own person she brings him up a height Virgil could not climb. While living she had delivered him from evil. What she became when etherealized by the moonlight of memory for ten years after death, is best told in the words of Dante's great brother by the higher birth, who says, in words which no man can mend:

> "The idea of her life did sweetly creep
> Into his study of imagination,
> And every lovely organ of her life
> Did come appareled in more precious habit,
> More moving, delicate, and full of life,
> Into the eye and prospect of his soul
> Than when she lived indeed."

The simple truth is that Dante's magic lines were children born of his love. As a boy he had fallen in love at first sight with a girl named Beatrice. *O angelica prezenza!* He won her heart but not her hand. His disappointment turned him from a lover to a worshipper.

In painting the lost on earth restored in heaven and becoming his guide thither through purgatory, lay the veritable inspiration of his immortal vision. The gravel-stone which came chafing into his earthly shell was transmuted by the alchemy of the heart into a pearl which can never lose its luster.

Original genius is shown in saving Dante's march from *monotony.* His path lies, now amid whirlwind and thunder, earthquake and fire,—yes, demons worse than all,—anon beside still waters amid sculptures surpassing Polycletus and even nature, with music which quiets all longings, save to hear it forever, with spirit-dances accordant thereto, and amid flowers bedecking the way and at every turn an angel to show the road, and cheer the pilgrim on, and up.

The *style* of Dante is all his own, and it is multiform.

Sometimes it is diffuse like the oceanic Homer. Ten times as often it is as terse and tart as Tacitus. Sometimes an epigram of a single line is too long. His epigramatic lines are 14,228—but we wish they were more. Here felicities of phrase are more delicate than Gray or Tennyson;—there the dialect of devils outdoes Hudibras, and perhaps Zola.

As it regards vocabulary he seems sometimes supersensitive and finical. He was such a lipogrammatist, so scrupulous about a word that the name of Christ is never once mentioned throughout the Inferno. Pains are taken in order that each of the three epic divisions may end in the self-same word, namely "stars."

Most poets "for a 'tricksy word defy the matter." Dante declares that he never did. We believe him in proportion as we mark how his phrases fit, according to his own words, like a candle to its socket or a ring to its finger. Rhyme and meter, which to so many are chains and clogs, were his wings for soaring above all stars.

Dante was original most of all in his *combinations.*

Whatever materials, no matter how heterogeneous, he had accumulated from nature, life or books, he incorporated into one body, parts into parts reciprocally shot, and fitly framed together. He breathed upon it and it became a living soul. It was marked all over and instinct in every fiber with Dantesque characteristics. Things insignificant he aggrandized by making them subserve a noble purpose as Michelangelo did every stone in the dome of St. Peter's. Where the protoplasmic elements of his vision came from he cared not, but his was the protoplastic hand which molded them into one organic whole, a whole which was greater, mauger mathematics, than all its parts. This whole differed from each and all of its parts not only in degree but in nature. He put those parts into such relations, and correlations that a new element was evolved, one as much superior to those parts as electricity, the fire of heaven and of God, is above the beggarly elements, of the earth earthy, which are its constituents. The outcome is an original creation or a transcendent resurrection.

The grand legacies to mankind from Florence are reckoned two. One is a banker's drafts, and the other is Dante. Dante and drafts! Drafts make money to walk invisible while, like

Satan, it goes to and fro in the earth and walks up and down in it. It thus endows money with the divine attribute of omnipresence.

But Dante's miracle is greater. He makes the world invisible to become visible in all its heights and depths; and so he bestows upon his readers the gift of omniscience.

In reading an original writer we wish we had known him sooner, we resolve to know him better; and, not knowing what we do, we hold up our rush light to show the sun. As Dante gazed on things unutterable his prayer was: "O that I may show to those who come after me one spark only of this glory!" Some glimpse of the morning-star of modern poetry I would fain give. Even if I have failed I rejoice that you need no exhortation to forswear thin potations and addict yourselves to Dante. You may not join the zealots who with Ruskin call Dante "the central man of all the world." You may, however, agree with Lowell, that among sons of genius, if Shakespeare was the most comprehensive intellect, Dante was "the highest spiritual nature," and so as Italians say *L'altissimo poeta.*

Madison, Wis.

SECOND SUPPLEMENTARY LIST OF PARASITIC FUNGI OF WISCONSIN.

J. J. DAVIS, B. S., M. D.

A preliminary list of Parasitic Fungi of Wisconsin by Wm. Trelease was published in the transactions of the Wisconsin Academy of Sciences, Arts and Letters, Vol. VI. In Vol. IX there was published a Supplementary List of which the present is a continuation. No special attempt has been make to revise the nomenclature of the lists, but occasional notes on synonomy are inserted.

In addition to the obligations heretofore acknowledged I wish to thank Mr. H. F. Lueders of Sauk City, Mr. F. L. Stevens, now of Columbus, Ohio, and especially Prof. L. S. Cheney of the University of Wisconsin, for assistance in securing material for this list.

Racine, Wis., March 15, 1897.

HOSTS NOT RECORDED IN THE PRELIMINARY OR SUPPLEMENTARY LISTS.

4. CYSTOPUS CANDIDUS, (Pers.) Lev.
   On *Arabis perfoliata*, Lam. Sauk City. (Lueders.)
   Cardamine rhomboidea, DC., Kenosha county.

5. CYSTOPUS TRAGOPOGONIS, (Pers.) Schrt. var. SPINULOSUS, (DBy).
   On *Cnicus muticus*, Pursh. Mason (Cheney.)

16. PERONOSPORA PARASITICA, (Pers.) Tul.
    On *Draba caroliniana*, Walt. Madison. (Cheney.)

37. MICROSPHAERA DIFFUSA, C. & P.
    On *Desmodium canadense*, DC., Madison. (Cheney.)

40. MICROSPHAERA ALNI, (DC.) Winter.

On *Cornus alternifolia*, L. f. Madison. (Cheney.)

43. PODOSPHAERA OXYACANTHÆ, (DC.) DBy.

On *Prunus pumila*, L. Madison. (Cheney.) *Prunus americana*, Marshall. Fayette. (Cheney.)

44. PHYLLACTINIA SUFFULTA, (Reb.) Sacc.

On *Crataegus* sp. and *Quercus* sp. Madison. (Cheney.)

48. ERYSIPHE CICHORACEARUM, DC.

On *Eupatorium ageratoides*, L. Fayette. (Cheney.)

49. ERYSIPHE COMMUNIS, (Wallr.) Fr.

On *Lathyrus ochroleucus*, Hook. Daleyville. (Cheney.) *Lupinus perennis*, L. Dells of the Wisconsin river. (Cheney.) *Ranunculus acris*, L. Houghton quarries. (Cheney.) *Ranunculus multifidus*, Pursh, Racine.

61. PLOWRIGHTIA MORBOSA, (Schw.) Sacc.

(*Otthia morbosa*, (Schw.) Sacc.) On *Prunus pumila*, L. Montreal. (Cheney.)

67. CLAVICEPS sp.

Sclerotia on *Agropyrum repens*, L. *Phalaris arundinacea*, L., and *Glyceria fluitans*, R. Br. Racine.

78. DIDYMARIA UNGERI, CORDA (*D. didyma*, (Ung.) Pound).

On *Ranunculus septentrionalis*, Poir. Racine.

83. RAMULARIA MACROSPORA, Fres. var. ASTERIS, Sacc.

On *Aster diffusus*, Ait. (?) Somers.

86. OVULARIA MONOSPORIA. (West.) Pound & Clements. (*O. obliqua*. (Cke.) Prelim. List.)

91. CERCOSPORELLA CANA, (Pass.) Sacc.

On *Solidago canadensis*, L. Racine.

111. PHYLLOSTICTA PAVIAE, Desm.

(*Ph. sphaeropsoidea*, E. & E. Suppl. List.)

142. SEPTORIA CONVOLVULI, Desm.

On *Ipomoea purpurea*, Lam. Fayette. (Cheney.)

152. UROMYCES TRIFOLII, (A. & S.) Winter.

Uredo on *Trifolium pratense*, L. Sauk City. (Lueders.) Racine.

152*a*. Uromyces euphorbiae, C. & P.

Æcidium and uredo on *Euphorbia polygonifolia*, L. Kenosha.

158. Uromyces hyperici, (Schw.) Curtis.

Uredo and teleutospores on *Hypericum canadense*, var. *minimum*, Chois. Dells of the Wisconsin river.

191. Puccinia pimpinellae (Straus.) Link.

Teleutospores on *Pimpinella integerrima*, B. & H. Kenosha county.

199. Puccinia rubigo-vera, (DC.) Winter.

Teleutospores on *Elymus striatus*, Willd. Somers.

209. Melampsora farinosa, (Pers.) Shroet.

(*M. salicis-capreae*, (Pers.) Wint. Prelim. List.)

215. Melampsora pirolae, (Gmel.) Shroet.

(*Uredo pyrolae*, (Gmel.) Prelim. List).

Uredo on *Pyrola secunda*, L. Three Lakes.

232. Æcidium sambuci, Schw.

On *Sambucus racemosa*, L. Ashland. (Cheney.)

242. Æcidium compositarum, Martens.

On *Cacalia reniformis*, Muhl. Kenosha county; *Senecio aureus*, L. Racine.

256. Entyloma compositarum, Farl.

On *Aster paniculatus*, Lam. and *Helenium autumnale*, L. Racine.

258. Entyloma crastophilum, Sacc. (*E. crastophilum*, Sacc. (?) Prelim List. *E. lineata*, (Cke.) Suppl. List.)

260. Entyloma physalidis, (K. & C.) Wint.

On *Physalis virginiana*, Mill. Kenosha county.

261. Entyloma microsporum, (Ung.) Schroet.

On *Ranunculus septentrionalis*, Poir. Somers.

264. The fungus on *Sagittaria variabilis*, Engelm. referred herein the preliminary list is *Burrillia pustulata*, Setchell; *fide* Setchell, Annals of Botany VI–XXI–37.

275. Taphrina johansonii, Sadeb. (*T. rhizophora*, Johans. Suppl. List.)

276. ERYSIPHE GALEOPSIDIS, DC.

On *Stachys aspera*, Michx. Racine and *Scutellaria galericulata*, L. Madison. (Cheney.)

279. MICROSPHÆRA VACCINII, C. & P.

On *Vaccinium pennsylvanicum*, Lam. Dells of the Wisconsin river and Big Bay. (Cheney.)

281. SPHÆROTHECA HUMULI, (DC.) Burrill.

On *Physocarpus opulifolius*, Maxim. Platteville; *fide* Prof. S. M. Tracy. *Rubus strigosus*, Michx. Racine.

284. UNCINULA MACROSPORA, Pk.

On *Ostrya virginica*, Willd. Platteville; *fide* Prof. S. M. Tracy.

285. ASTERINA GAULTHERIÆ, Curtis.

On *Arctostaphylos uva-ursi*, Spreng. Three Lakes.

331. PASSALORA DEPRESSA, (B. & Br.) Sacc.

This does not differ from No. 100 of the Preliminary List.

341. MELAMPSORA SCOLOPENDRII, (Fckl.) Farl. (*Gloeosporium phegopteridis*, Frank, Suppl. List.)

351. LEPTOTHYRIUM DRYINUM, Sacc.

On *Quercus alba*, L. Racine.

352. LEPTOTHYRIUM PERICLYMENI, Desm.

On *Lonicera ciliata*, Muhl. Three Lakes.

376. This was properly given as an additional host of No. 89, and then inadvertently given as an additional species under a synonym.

379. RAMULARIA IMPATIENTIS, Pk.

On *Impatiens fulva*, Nutt. Kenosha county.

384. RAMULARIA RETICULATA, E. & E.

On *Osmorrhiza brevistylis*, DC. Somers.

387. This is referred to *Septocylindrium* by Pound and Clements. (Minnesota Botanical Studies Bulletin 9, part ix., p. 651.)

392. SCOLECOTRICHUM GRAMINIS, Fckl.

On *Glyceria fluitans*, R. Br., *Calamogrostis canadensis*, Beauv. and *Alopecurus geniculatus*, L. var. *aristulatus*, Torr. Racine.

395. Septoria osmorrhizae, Pk.

(*S. aegopodii*, Desm. Suppl. List.)

On *Osmorrhiza brevistylis*, DC. Racine.

401. Septoria atropurpurea, Pk.

On *Aster vimineus*, Lam. Racine; *Solidago latifolia*, L. Somers.

404. Septoria canadensis, Ell. & Davis.

On *Solidago serotain*, Ait. Somers.

439. Septoria psilostega, E. & M.

On *Galium circaezans*, Michx. Racine; *Galium trifidum*, L. Berryville. Sporules of the latter 40–60×1½–2 microns, but the perithecia are on spots.

441. Septoria rhoina, B. & C.

On *Rhus typhina*, L. Racine.

Sporules 40–60 microns long.

449. Septoria brunneola, (Fr.)

(*S. smilacinae*, E. & M. Suppl. List.)

On *Smilacina racemosa*, Desf. Kenosha county.

450. Septoria solidaginicola, Pk.

On *Aster puniceus*, L., and *Solidago caesia*, L. Racine.

464. Puccinia eleocharidis, Arthur.

On *Eleocharis palustris*, R. Br. Kenosha.

471. Puccinia curtipes, Howe.

(*P. saxifragae*, Schl. Suppl. List.)

In Uredineae Exsiccatae et Icones, No. 7. Arthur and Holway distribute specimens on *Heuchera americana*, L. collected at Madison, Wis., by W. Trelease, under the above name.

478. Melampsora epilobii, (Pers.) Fckl.

(*Pucciniastrum epilobii*, (Pers.) Otth.)

Uredo on *Epilobium angustifolium*, L. Forest county.

479. Chrysomyxa arctostaphyli, Dietel.

Erroneously referred to *Melampsora sparsa*, Winter in the Supplementary List. Described by Dietel in the Botanical Gazette, August, 1894.

487. Entyloma floerkeae, Holway.

Mr. Holway's description of this species, which I believe has never been published, is as follows: "Spores globose, rarely elliptical or angular, yellowish brown, thick walled, 10–12 microns in diameter." The affected portions of the host are first whitish, then brown and sere.

The fungus makes its appearance in early spring, and the newly formed spores germinate readily, when fresh, for three or four weeks. After that a period rest is apparently necessary. The promycelia are about 3 microns in diameter, and of various lengths. The sporida are 4–6 in number, 10–16 $\times 2\frac{1}{2}$–3 microns. Their bases are in contact, and about half of them develop from their tips slender, acute bodies 30–60$\times 1\frac{1}{2}$–2 microns, which become free.

SPECIES NOT RECORDED IN THE PRELIMINARY OR SUPPLEMENTARY LISTS.

496. Peronospora hydrophylli, Waite,

On *Hydrophyllum virginicum*, L. Racine.

497. Taphrina alni-incanae, (Kuehn) Magnus.

On *Alnus incana*, Willd. Sauk City. (Lueders.) Three Lakes. On *Alnus*, sp. Ashland. (Cheney.) Mason. (Cheney.)

498. Erysiphe aggregata, (Peck) Farlow.

On *Alnus incana*, Willd. Dells of the Wisconsin river.

499. Podosphaera biuncinata, C. & P.

On *Hamamelis virginiana*, L. Racine and Somers.

500. Asterina plantaginis, Ellis.

On *Plantago rugelii*, Dcsne. Racine.

501. Dimerosporium collinsii, (Schw.). Thum.

On *Amelanchier alnifolia*, Nutt. Tomahawk. (Cheney.) *Amelanchier*, sp. Blue Mounds. (Cheney.)

502. Phyllachora plantaginis, Ell. & Evht.
On *Plantago rugelii*, Dcsne. Racine.

503. Physalospora ambrosiae, Ell. & Evht.
On *Ambrosia trifida*, L. Fayette. (Cheney.) Racine.

504. Rhytisma andromedae, (Pers.) Fries.
On *Andromeda polifolia*, L. Forest county.

505. Stamnaria equiseti, (Hoffm.) Sacc.
On *Equisetum hyemale*, L. Somers.

506. Venturia pulchella, C. & P.
On *Cassandra calyculata*, Don. Forest county.

507. Ascochyta cassandrae, Peck.
On *Cassandra calyculata*, Don. Forest county.

508. Cercospora caulophylli, Peck.
On *Caulophyllum thalictroides*, Michx. Somer.

509. Cercospora dioscoreae, E. & M.
On *Dioscorea villosa*, L. Kenosha county.

510. Cercospora geranii, Kell. & Swingle.
On *Geranium maculatum*, L. Racine.

511. Cercospora merrowi, Ell. & Evht.
On *Isopyrum biternatum*, Torr. & Gr. Somers.

512. Cercospora nasturtii, Pass.
On *Nasturtium palustre*, DC. Racine.

513. Cercospora sedoides, Ell. & Evht.
On *Penthorum sedoides*, L. Racine.

514. Cercospora stomatica, Ell. & Davis.
On *Solidago latifolia*, L. Somers.

515. Cryptosporium caricis, Corda.
On *Carex* sp. Kenosha county.

516. Cylindrosporium calamagrostidis, Ell. & Evht.
On *Calamagrostis canadensis*, Beuv. Berryville.

517. Cylindrosporium capsellæ, Ell. & Evht.
On *Capsella bursa-pastoris*, Moench. Somers.

518. Cylindrosporium glyceriæ, Ell. & Evht.
On *Glyceria nervata*, Trin. Racine.

519. Cylindrosporium leptospermum, Peck *in litt.* (*Cercospora leptosperma*, Peck.)
On *Aralia nudicaulis*, L. Three Lakes.

521. CYLINDROSPORIUM SPARGANII, (Pass.) Ell. & Evht.
On *Sparganium eurycarpum*, Engelm, Kenosha.

522. DICOCCUM NEBULOSUM, Ell. & Evht.
On *Fraxinus americana*, L. Somers.

523. GLOEOSPORIUM (MARSONIA) BRUNNEUM, Ell. & Evht.
On *Populus grandidentata*, Michx. Racine.

524. GLOEOSPORIUM CONFLUENS, Ell. & Dearness.
On *Sagittaria variabilis*, Engelm. Racine.

525. GLOEOSPORIUM (MARSONIA) MARTINI, Sacc. & Ell.
On *Quercus* (*rubra?*) Madison. (Cheney.)
On *Quercus macrocarpa*, Michx. Racine.

526. GLOEOSPORIUM TREMULOIDES, Ell. & Evht.
On *Populus tremuloides*, Michx. Racine.

527. MONILIA LINHARTIANA, Sacc.
On fruit of *Prunus virginiana*, L. Racine.

528. PHOMA CRYPTICA, (Nitz.) Sacc.
On stems and twigs of *Lonicera*. Racine. (F. L. Stevens.)

529. PHYLLOSTICTA ACERICOLA, C. & E.
On *Acer saccharinum*, Wang. Racine. *A. spicatum*, Lam. Three Lakes.

530. PHYLLOSTICTA CALAMINTHAE, Ell. & Evht.
On *Mentha canadensis*, L. Racine.

531. PHYLLOSTICTA DECIDUA, Ell. & Kell.
On *Teucrium canadense*, L. Kenosha county; on *Scutellaria lateriflora*, L. Racine.

532. PHYLLOSTICTA FATISCENS, Peck.
On *Nuphar advena*, Ait. f. Kenosha county. *Phyllosticta orontii*, var. *advena*, E. & E. is a synonym.

533. PHYLLOSTICTA LUDWIGIAE, Peck.
On *Ludwigia polycarpa*, Short & Peter. Racine.

534. PHYLLOSTICTA RUDBECKIAE, Ell. & Evht.
On *Rudbeckia laciniata*, L. Kenosha county.

535. PIRICULARIA PARASITICA, Ell. & Evht.
On *Phyllachora graminis*, (Pers.) Fckl. Kenosha county. Sometimes quite abundant on *Elymus* and *Asprella*.

536. Sclerotium bifrons, Ell. & Evht.
On *Populus tremuloides*, Michx. Waterford.

537. Septoria bacilligera, Winter.
On *Ambrosia trifida*, L. Racine.

538. Septoria besseyi, Peck.
On *Fraxinus americana*, L. Racine.

538*a*. Septoria cerasina, Peck.
On cultivated cherry. Racine.

539. Septoria nolitangere, Thum.
On *Impatiens* sp. Forest county.

540. Septoria petroselini, Desm.
On *Apium graveolens*, L. (cult.) Madison. (Cheney.)

541. Septoria rudbeckiae, Ell. & Hals.
On *Rudbeckia laciniata*, L. and *R. hirta*, L. Racine.

542. Septoria rumicis, Ellis.
On *Rumex verticillatus*, L. Racine.

543. Septoria urticae, Rob.
On *Laportea canadensis*, Gaud. Kenosha county.

544. Steganosporium smilacis, (E. & M.) Sacc.
On *Smilax* sp. Kenosha county and Racine.

545. Uromyces caryophyllinus, Schroeter.
Abundant on carnations (*Dianthus caryophyllus*, L.) in a greenhouse in Racine. (F. L. Stevens.)

546. Uromyces howei, Peck.
On *Asclepias cornuti*, Desne. and *A. incarnata*, L. Racine.

547. Uromyces minimus, Davis.
Uredo and teleutospores on *Muhlenbergia sylvatica*, Torr. & Gr. Kenosha county.

548. Puccinia calthae, Lk.
On *Caltha palustris*, L. Madison (Prof. T. A. Williams.)

549. Puccinia dayi, Clinton.
On *Steironema ciliatum*, Raf. Racine and Kenosha county.

550. PUCCINIA PALLIDA, Tracy.

Teleutospores on *Osmorrhiza*. Platteville. (Prof. S. M. Tracy in Journal of Mycology, VII. 3–281).

551. PUCCINIA RIBIS, DC.

On *Ribes prostratum*, L'Her. Montreal. (Cheney.)

552. PUCCINIA RUBEFACIENS, Johans.

On *Galium* sp. Merrill. (Cheney.)

553. PUCCINIA TENUIS, Burrill.

Æcidium and teleutospores on *Eupatorium ageratoides*, L. Kenosha county.

554. CHRYSOMYXA CHIOGENIS, Dietel.

Uredo and teleutoform on *Chiogenes serpyllifolia*, Salisb. Lac Vieux Desert. (Cheney.) Forest county.

555. UREDO CHIMAPHILAE, Peck.

On *Chimaphila umbellata*, Nutt. Three Lakes.

556. ÆCIDIUM IRIDIS, Gerard.

On *Iris versicolor*, L. Granite Heights. (Cheney.)

557. ÆCIDIUM LYCOPI, Gerard.

On *Lycopus* sp. Tomahawk Lake. (Cheney.) Webster. (Cheney.) *Lycopus virginicus*, L. and *L. sinuatus*, Ell. Racine.

557*a*. PERIDERMIUM ELATINUM, (A. and S.) Schm. and Kze.

On *Abies balsamea*, Miller. La Pointe. (Cheney.)

558. USTILAGO CARICIS, (Pers.) Fckl.

On *Carex limosa*, L. Drummond. (Cheney.) *Carex stricta*, Lam. Mason. (Cheney.) *Carex* sp. Lac Vieux Desert. (Cheney.) Montreal. (Cheney.)

559. USTILAGO LONGISSIMA, (Sow.) Tul. var. MACROSPORA.

On *Glyceria fluitans*, R. Br. Racine. Differs from the type in its larger spores, 6–11, mostly 8–9 microns in diameter.

560. ENTYLOMA CASTALIÆ, Holway *ined.*

On *Nymphæa* sp. Madison; *Nymphæa reniformis*, DC. Racine; *Nuphar advena*, Ait. Kenosha county.

In 1885 Mr. E. W. D. Holway collected in Iowa a fungus in the leaves of *Nymphæa* which he distributed to correspondents as *Entyloma castaliæ* but made no publication. The receipt of a specimen is acknowledged in the 45th Report of the N. Y. State Museum of Natural History. In 1887 Dr. Cunningham published a description of a fungus in the leaves of *Nymphœa* in India under the name *Rhamphospora nymphœœ*, establishing the genus for its reception (Scientific Memoirs by Medical Officers of the Army of India, Pt. III., pp. 27–32). During the meeting of the American Association for the Advancement of Science in 1893, Dr. B. D. Halsted mentioned the occurrence of a similar fungus in the leaves of *Nymphœa* in New Jersey and it was found in Madison, Wis., during the meeting of the Association. In the Botanical Gazette for May, 1894, (XIX.–5–188) Dr. W. A. Setchell recorded the occurrence of a fungus in the leaves of *Nymphœa odorata* in Connecticut and Massachusetts and in those of *Nuphar advena* in Connecticut, which he referred to Dr. Cunningham's species, considering it, however, an *Entyloma*. I have not seen the Indian species but infer from the description that in the manner of formation of the spores as well as their form and size the American form corresponds fairly well. Comparison of the germination characters with the behavior of Wisconsin material in germination, however, leads to the belief that the American form is specifically distinct.

The fungus becomes apparent in Racine early in July; and from that time until after the middle of September germination can be obtained in slide cultures, but I have not succeeded with cell cultures. In early July most of the spores would germinate in 36–60 hours, but the proportion gradually decreased as the season advanced and the vigor of germination decreased as well. The promycelium issues from the side of the spore and bears upon its tip three, rarely two or four, sporidia. In the simplest type a protuberance appears on the sporidium at a point above its middle which develops into a branch equal to the sporidium above the point of branching. The sporidium then becomes detached forming a free body consisting of three arms radiating from a center. If the germination is a little more vigorous two branches are formed, which, together with the sporidium above their point of attachment, form the triradiate body. When the germination is very vigorous branchlets form on the branches and these in turn may develop branches until a tree-like growth is produced. The detached sporidia, however, are always triradiate and remind one of the spicules of sponges. I have seen no further development and no conjugation. The absence of septa in the promycelium and especially of the septate bodies described and figured by Cunningham, intermediate between the promycelium and the sporidia, make it certain either that the germination phenomena are widely variable or that the American form is specifically distinct. I have therefor made use of the only name that has been distinctively applied to the American plant.

561. DOASSANSIA DEFORMANS, Setchell.
On *Sagittaria variabilis*, Engelm., Racine.

562. DOASSANSIA MARTIANOFFIANA, (Thum.) Schrt.
On *Potamogeton* sp. Racine and Forest county.

563. DOASSANSIA OBSCURA, Setchell.
On *Sagittaria variabilis*, Engelm., Racine.

564. DOASSANSIA RANUNCULINA, Davis.
On *Ranunculus multifidus*, Pursh., Racine.

565. DOASSANSIA SAGITTARIÆ, (Westd.) Fisch.
On *Sagittaria variabilis*, Engelm., Racine.

566. BURRILLIA GLOBULIFERA, Davis.
On *Glyceria fluitans*, R. Br., Sauk City. (Lueders). Racine.

567. BURRILLIA PUSTULATA, Setchell.

On *Sagittaria variabilis*, Engelm., Madison. (Trelease). Preliminary List, 264 in part *fide* Setchell (Annals of Botany VI.-21-37, April, 1892).

INDEX TO HOSTS.

ON THE LIMNETIC CRUSTACEA OF GREEN LAKE.

BY C. DWIGHT MARSH,

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WITH PLATES V TO XIV.

The investigations on which this paper is based were commenced in August, 1893. At that time I constructed a vertical net, which could be closed at any depth. With this net I made twelve series of five meter hauls in a little more than twenty-four hours. My object was to determine the facts in regard to the diurnal migration of limnetic crustacea,— a migration which I was certain, at that time, took place. The material obtained in these collections was carefully counted, the results tabulated, and reduced to percentages, and a report on the subject was made at the summer meeting of the Wisconsin Academy, in June, 1894, and a brief *résumé* was published in the *American Naturalist* in the same year.

So far as difference of diurnal distribution was concerned, the experiments gave only negative results, but certain facts in regard to the general vertical distribution of the different species came out very clearly. It seemed to me probable, however, that the distribution might not be the same on different days, and, in all probability, would differ greatly in the different seasons. At that time, very little had been published in regard to the occurrence of the entomostraca in different seasons. It seemed to me that if a systematic series of collections could be made throughout the year, the results would be very interesting. The matter was brought to the attention of the trustees of Ripon College, who recognized its importance, and made a special appropriation to pay the necessary expenses of the investigation.

The work was commenced in the latter part of September, 1894. During the fall the lake was visited twice each week, and at each visit from one to four series of collections were made. In the winter, while the lake was closed by ice, only three collections were made. From the latter part of April, 1895, until July, collections were made at intervals of about one week. In July and August no collections were made, but in September the work was resumed, and collections were made at intervals of about one month until July, 1896. From July, 1896, to December, weekly collections were made. Thus I had a series of collections running through a little over two years, with the exception that for the months of July and August, I had only the collections of 1896.

During the time in which this work has been going on, considerable has been published on the periodicity and distribution of the limnetic crustacea, so that some of my results are simply corroborative of the work of others, especially in regard to the seasonal distribution of the crustacea. The peculiar character of Green Lake and its fauna and flora, however, makes simply corroborative work important, and some of the results, I think, are entirely new.

I wish to acknowledge the very efficient assistance of Mr. P. S. Collins, of Ripon, in the work of making the collections and observations. Sherwood Forest Hotel was the headquarters of the station work, and I am greatly indebted to the proprietor, Mr. Beckwith, and Mrs. Beckwith, for innumerable courtesies.

GREEN LAKE.

The general character of Green Lake has been indicated in my former paper. (Marsh, '91, b.) It is a long, narrow body of water, something over seven miles in length, and with a maximum width of less than two miles. At the eastern end where it is fed by a small stream, Silver Creek, the shore is low and swampy. At the western end another small stream enters, and here also the shore is low, but most of the shore line is made of bluffs of greater or less elevation. At Lucas's Point and Sugar Loaf are abrupt cliffs of Potsdam sandstone. There are a large number of springs on the south shore, and it is popularly supposed that most of the water is derived from this source.

The water of the lake is clear, of a beautiful green color, and reaches a maximum depth of two hundred and seventeen feet. The bottom in the deep water consists of a fine, blue clay, containing a large amount of organic matter, in which are found worms, none of which have been determined.

In the general character of its fauna, Green Lake resembles, in a striking manner, the Great Lakes. In its abysmal fauna, we find *Pontoporeia Hoyi* and *Mysis relicta*,—species which have not been found in America outside of the Great Lakes. In the intermediate depths is *Limnocalanus macrurus*,—a species seldom found except in the larger bodies of water, and in the upper layers are found the same species as in the Great Lakes with two exceptions,— *C. pulchellus* and *D. Ashlandi.* There is never any striking amount of vegetable matter in Green Lake except in the months of July and August, when ordinarily an *Anabaena*, which I think is either *flosaquae* or *circinalis* is found all over the lake, and forms little green ridges as it is washed up on the shore by the waves. But even this is not present in sufficient amount to form a scum, and never fouls the collecting net to any extent, as does the "scum" of shallower lakes.

Apstein divides lakes into two groups, which he styles *Chroococcaceae* lakes and *Dinobryon* lakes. According to the general characteristics which he gives to these two groups, Green Lake should be a *Dinobryon* lake, and yet I have never found *Dinobryon* in it.

It seems to me that our lakes in this part of North America can naturally be divided into the two classes of "deep" and "shallow" lakes, the faunae of the two classes being very distinct in their general character. The "shallow" lakes have, in the summer season, a large amount of the chlorophyll bearing algae; there is but little distinction between the littoral and limnetic species of *Cyclops*; *Limocalanus macrurus* is seldom present; and the abundant species of *Diaptomus* is *oregonensis*. *Epischura lacustris* may be present in shallow lakes, but is not always found.

In the deep water fauna of the "deep" lakes the common species of *Cyclops* are *brevispinosus*, *pulchellus* and *fluviatilis; Epischura lacustris* and *Limnocalanus macrurus* are commonly present, and *Diaptomus* is represented by *D. sicilis* and *D. minutus: D. Ashlandi*, is, so far as my observations go, confined to the Great Lakes and bodies of water in immediate connection with them.

The distinction thus made in regard to the distribution of *Diaptomus* is not without exception by any means, and I think that in more northern lakes *D. minutus* is found more abundantly in shallow lakes than it is in the region that has been more especially the subject of my studies. Inasmuch as *minutus* is found in great abundance in Greenland and Iceland, I presume that the real cause of its greater abundance in the deeper lakes of our latitude is not the depth of the water, but the low temperature which is coincident with depth.

In general, we may say that depth rather than extent of surface controls the character of the crustacean fauna. This is strikingly shown in a comparison of Green Lake with Lake Winnebago. Lake Winnebago is situated about twenty-five miles from Green Lake, and is about twenty-eight miles long by eight to ten miles broad. Through its whole extent it is very shallow, being for the most part from ten to thirty feet in depth. Its crustacean fauna consists of those species characteristic of shallow lakes, being very different from that of Green Lake. The same thing is noticed in comparing the fauna of Lake Mendota, as determined by Professor Birge, with that of Green Lake, Mendota falling distinctly into the class of shallow lakes. What depth may be considered as characterizing deep lakes, it is difficult to state with certainty, and I suppose it is doubtful if an exact limit can be fixed, but I think it is about forty meters. Lake Mendota, according to the soundings of Professor Birge, has a maximum depth of twenty-two meters. Lake Geneva is a little over forty meters in depth, and, judging from the collections of Professor Forbes, is somewhat intermediate in the character of its fauna between the shallow and deep lakes. Lake St. Clair is apparently an exception to this classification, as, although it is shallow, it has also the fauna of the deep lakes. This is easily explained, however, if we remember, as stated in my former report, (Marsh, '95, p. 4,) that Lake St. Clair has an immediate and constant connection with the deeper lakes, and there is, doubtless, continual migration into it of the forms characteristic of deep water.

DESCRIPTION OF THE DREDGE.—PLATES XIII, XIV.

The dredge which I have used was constructed after several experiments, and has, I think, answered admirably the requirements of my work. Inasmuch as I expected to use it entirely for vertical work, it did not seem necessary that it should be closed when descending, but that there should be some device for closing it at any desired point on its upward course. The upper frame of the dredge is a brass ring from which by three cords is suspended the bucket. The upper frame is thirty-one centimeters in diameter.

The bucket is like that described by Professor Birge. (Birge, '95, p. 428). Inasmuch as the wire gauze used in the bucket has meshes 1–100 of an inch in diameter, it does not retain the smallest organisms, but serves perfectly well as an apparatus for catching crustacea.

The dredge bag is of India linen, carefully selected so as to get cloth that is fairly uniform in texture, and is suspended between the upper frame and the bucket. The dredge bag is strengthened on its upper edge by heavy cloth, into which are let the eyelets, by which it is laced to the brass rings of the frame.

The cords between the frame and the bucket are continued below the bucket and fastened to a sounding lead weighing about six pounds. To the upper frame are attached three cords which unite in a brass ring, by which the dredge is suspended by the releasing apparatus. About half way of the length of the dredge there are attached to the suspending cords brass rings, through which a cord runs twice in such a way that when it is drawn tight it acts like a puckering string and closes the dredge. This cord is attached to the dredge rope, which, after being fastened to the releasing apparatus, hangs loosely over the edge of the dredge.

The releasing apparatus consists of a brass frame (see Pl.

XIII.) fifteen centimeters long, by five centimeters broad. The frame is strengthened by three transverse braces. The frame and braces are made of strips cut from sheet brass, one millimeter thick and two centimeters wide.

Through the horizontal pieces of the apparatus are drilled two holes large enough so that the heavy brass wire D E will slide easily up and down. To the middle of this wire at E is attached an upright piece which passes through the lower part of the frame B, and strikes against the brace C. The wire is held in place by a rubber band passing around the plate B. The dredge is hung from this central pin at E, and cannot be detached except as the wire D E is lowered so as to throw the ring off the pin.

The releasing apparatus is fastened to the dredge rope by copper wire passed through small holes drilled in the upper and lower plates. The messenger is a brass cylinder five centimeters long and four centimeters in diameter.

The work of dredging is done from a row boat which is fitted with a sail. The mast is unshipped, and in the mast hole is inserted an upright about six feet long, to which is attached a cross piece extending over the side of the boat. From this cross piece the dredge is suspended by a pulley block, and upon the cross piece is a hook from which the messenger is suspended. The dredge is lowered vertically, and after being raised to the required point, is "set off" by the messenger. When the messenger strikes the releasing apparatus the top of the dredge falls over, and it remains suspended by the middle. At the same time the weight of the lead causes the cord around the middle of the dredge to tighten, so that there is a double safeguard against the entrance of any other organisms — the inverted top and the stricture of the suspending cord.

There is one source of inaccuracy in this dredge, and that is the loss of material, when it is released, between the top and the cord passing around the center. My hauls, however, were made through five meter distances, and I do not think that in this distance, the loss would have much effect on the results, and, of course, for comparative work it need not be considered at all.

For winter work, the apparatus is hung from a tripod placed over a hole in the ice. (Plate XIV.)

The tube at the bottom of the bucket was made of a size to fit in the top of an eight drachm homeopathic bottle, and in order to preserve material, I simply washed it with strong alcohol immediately from the bucket into the bottle.

A buoy was anchored in from forty to forty-five meters of water, and all collections were made from that point. In successive years the buoy was located in very nearly the same place, and when collections were made through the ice, it was intended that they should be taken at nearly the location of the buoy.

Collections were made in all kinds of weather, but more were made in comparatively pleasant weather, as naturally one would prefer to visit the lake under such conditions.

The record of observations was kept in a book arranged for the purpose. A sample page of this book appears on the next page.

The temperatures were taken by a Miller-Casella deep-sea maximum and minimum thermometer, which was loaned to me by the United States Fish Commission for the purpose. As those who have used this form of thermometer know, it is very slow in its action, it being necessary to allow at least twenty minutes for each observation. This made it impossible for me to get a record of temperatures at intermediate depths, although such a record is very important in determining the laws governing the vertical distribution.

The temperature curves of the two years, 1895 and 1896, are shown in plates V and VI, with the exception that no observations were made in July and August, 1895. It will be noticed that the maximum range of bottom temperature observed was from 35 to 45 degrees, thus indicating great uniformity of conditions of temperature at the bottom.

SERIAL COLLECTION. No. 13.96.

Made at Green Lake,.................. Aug. 3,...................... 1896, 6-6:40 p. m., with .... closing dredge .... at permanent station............... 4; .... depth 43.5 m. ;............ water, .'.... small waves; .....wind.......... s w.; .... sky .... clear;........ temperature, air ...83;... temperature, surface,.. 75; ... temperature, bottom... 43; ... Observed *Diaptomi, D. minutus, C. fluviatilis* egg-bearing. Much fine sand in collection: is explained perhaps by the high wind earlier in the day.

Names.	0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45	45–50	50–55	55–60	Total
Diaptomus sicilis...	760	1,192	272	40	140	14	11	75	4	.....	.....	.....	2,508
" Ashlandi	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
" minutus	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
" oregonensis	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
Epischura lacustris.	16	4	10	.....	.....	.....	.....	.....	.....	.....	.....	.....	30
Limnocalanus macrurus	....	.....	1	4	8	1	2	13	.....	.....	.....	.....	29
Cyclops brevispinosus.....	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
" pulchellus..	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
" Leuckarti....	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
" albidus......	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
" fluviatilis. ..	72	72	32	6	.....	.....	.....	.....	.....	.....	.....	.....	182
" serrulatus...	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
....	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
Cyclops larvæ.......	160	8	.....	6	4	.....	2	.....	.....	.....	.....	.....	180
Leptodora hyalina.	4	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	5
Daphnia kahlbergiensis.............	12	16	40	8	8	.....	.....	.....	.....	.....	.....	.....	84
Bosmina	56	.....	2	3	6	.....	.....	.....	.....	.....	.....	.....	67
Daphnella	12	24	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	36
....	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
....	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
Mysis relicta........	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
Pontoporeia Hoyi..	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
....	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
Notholca	Nos	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
Ceratium	"	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
....	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
....	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
....	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......

The surface temperature varied from the freezing point of water in winter to eighty degrees in August, 1896. In general the rise of surface temperature in the spring, and the fall in autumn, were both uniform and rapid, but there were some exceptions. Very noticeable is the jog in the curve in May, 1895. In this month there was a period of unusually warm weather, followed by severe frosts.

There was a curious rise in the bottom temperature in the fall of both 1894 and 1895. On November 11, 1894, I found the bottom temperature 45, while the highest point reached previous to that time was $42\frac{1}{2}$.

On October 24, and November 3, 1894, I found the bottom temperature 44, while the highest point reached previous to that time was 43. On November 11, 1895, the bottom temperature was 45, while the highest previously recorded was $42\frac{1}{2}$. My first impression on seeing these temperatures was that there must have been a mistake in the observation. I felt the more certain of this probability in one case, as the observation had been made by my assistant without my direct supervision. But a repetition of the work showed that there was no mistake.

A similar rise in bottom temperature in November has been noticed in Lake Cochituate (Whipple, '95, p. 205, and Fitzgerald, '95, p. 74), and these authors have also noticed a fall in bottom temperature in the spring. These apparent abnormalities in temperature have been explained by the above mentioned authors on the supposition that as the top and bottom temperatures approached each other, the water, being of nearly equal density from top to bottom, would be in a state of unstable equilibrium, and currents would be set in motion, which would effect the whole depth, especially under the influence of high winds. Whipple has shown ('95, p. 208), that under some circumstances an overturning and mingling of the whole mass of water in a lake may take place with almost incredible suddenness.

Although no attempt was made to keep a systematic record of other organisms than crustacea, some notes were kept of the appearance of other animals and of plants.

Of plants, the only one besides diatoms, which occurred in any abundance was the *Anabaena* already mentioned. In 1896 this appeared in the latter part of June, and continued well through August. In other years, I have found it present only during a very short time. I have notes also of a red alga that was found in considerable abundance about the middle of August. In one of the March collections there was also an undetermined green alga.

Rotifera were of course present in large numbers, but no attempt was made to keep any record of them. *Notholca longispina* was found throughout the year, sometimes in great abundance.

Ceratium occurred quite constantly in the collections from June to the latter part of October, and in 1896, until the middle of November.

From May through the year, *Diptera* are occasionally found in the collections. This is what one would expect, for the larvae are found in the bottom fauna.

METHOD OF COUNTING.

The method used in counting was somewhat different from that used by other authors, and a method that perhaps could not be used so successfully in collections containing a large amount of vegetable material. The alcohol in the bottles was largely replaced by glycerine in order to have the material in a medium that would not evaporate rapidly. I had prepared for me a glass plate sixteen centimeters in diameter, ruled with concentric circles a centimeter apart. The circles were divided by diameters into eight segments. The plate was mounted on a tripod such as is used in leveling gelatine plates in bacteriological work, and carefully leveled. The collection was then poured as nearly as possible upon the exact center of the plate. Ordinarily it would spread with great uniformity upon the plate. The fractional part of the whole counted depended upon the numbers of the species under consideration. Commonly I counted only one-eighth of the *Diaptomi*. Of the species present in smaller numbers, I would ordinarily count all on the plate. In any case all parts of the plate were examined in order to detect the presence of any unusual form. This work was done with the aid of a dissecting lens such as is furnished with a Reichert dissecting microscope. This lens answered every purpose so far as determining the species of the crustacea, except that I could not distinguish with certainty *D. minutus* from *D. sicilis.* As the object of the counting was mainly to determine distribution, the fact that I did not distinguish between these species was of little importance, as their habits are the same. In every case, however, a test of the collection was carefully examined under the compound microscope, and in this way a fairly accurate idea was obtained of the seasonal distribution of these species, and notes were made also in regard to the occurrence of other smaller organisms. No attempt, however, was made to keep any record of diatoms.

The accuracy of this method of counting was carefully tested, and the amount of error was found very small,—so small that I do not think the general results would be appreciably affected. As stated before, it is very doubtful if the method could be applied so successfully to plankton rich lakes.

These results were afterwards reduced to percentages in order to show the relative abundance in vertical distribution.

In the following table I have tabulated the conditions under which the various collections were made. The table is, in the main, self-explanatory. To indicate the condition of the surface I have used four terms, "smooth, ripples, waves, and rough."

In the tables given for the various species the "total" column indicates the actual number obtained in my dredge. These numbers might easily be reduced to give the actual number per square meter by multiplying by the coefficient of the dredge, but my object was simply to get comparative results, and, as indicated later in this paper, I myself have only limited confidence in the value of plankton determinations. In the columns following "total" are given the percentages found for every five meters of depth.

No.	Date.	Time.	Temp. Air.	Temp. Sur.	Temp. Bot.	Wind.	Water.	Sky.
1.94	Sept. 27....	6:30-7:30 p. m.	70	....	....	S. W.	Waves	Clear.
4.94	Oct. 6....	10:45-11:45 a. m.	57	60	43	S. W.	Ripples	Clear.
5.94	Oct. 6....	2:30-3:30 p. m.	59	59	43	S. W.	Waves	Clear.
6.94	Oct. 6....	4:50-5:45 p. m.	.. .	....	....	S.	Waves	Clear.
7.94	Oct. 6....	10-11 p. m.	53	....	....	S.	Waves	Clouds.
8.94	Oct. 9....	6-7 p. m.	....	. .	....	S.	Waves	Clear.
10.94	Oct. 10....	6-7 a. m.	45	56	..	S. W.	Rough	Clouds.
11.94	Oct. 10....	9-10 a. m.	....	....	....	N. W.	Rough	Clouds.
12.94	Oct. 16....	6-7 p. m.	....	....	....	S. W.	Waves	Clear.
13.94	Oct. 16....	10:30-11:30 p. m.	54	53	43	S. W.	Waves	Clear.
14.94	Oct. 17....	6-7 a. m.	49	53	....	W.	Waves	Clear.
15.94	Oct. 17....	8:45-9:30 a. m.	51	....	...	W.	Waves	Clear.
16.94	Oct. 20....	11:15-12 a. m.	57	53	43	S. E.	Ripples	Clouds, fog.
17.94	Oct. 20....	2:15-3:15 p. m.	64	54	....	S. E.	Ripples	Clear.
18.94	Oct. 20....	4:40-5:20 p. m.	58	....	....	S. E.	Ripples	Clear.
20.94	Oct. 24....	10-11 p. m.	48	54	44	S.	Waves	Clouds.
21.94	Oct. 25....	6-6:50 a. m.	48	....	....	S.	Waves	Clouds.
22.94	Oct. 25....	8:45-9:30 a. m.	....	....	....	S. W.	Rough	Clouds.
24.94	Nov. 3....	2:45-3:30 p. m.	45	52	44	S.	Waves	Clouds.
25.94	Nov. 3....	4:30-5:20 p. m.	45	....	....	S. W.	Rough	Clouds.
26.94	Nov. 8....	5:30-6:15 p. m.	....	....	....	S.	Ripples	Clear.
27.94	Nov. 8....	10-11 p. m.	35	49	....	S.	Waves	Clouds.
29.94	Nov. 21....	....	38	39	43	W.	Ripples	Clear.
1.95	Feb. 14....	11:30-12:30 m.	29	33	38	N. W.	Ice	Clear.
2.95	Mar. 9....	11:30-12:30 m.	45½	36	37½	S. W.	Ice	Cloudy, and rain.
3.95	Mar. 27....	10:45-12 m.	51	36½	37	W.	Ice	Clear.
4.95	Apr. 27....	1:15-2:30 p. m.	58	42	40½	N. E.	Waves	Clear.
5.95	May 3....	4:30-5:15 p. m.	68½	47	40½	S. W.	Change	Cloudy.
6.95	May 3....	7:20-8 p. m.	53½	....	....	E.	Waves	Clear.
7.95	May 9....	4:30-5.30 p. m.	80½	55½	40½	S. W.	Rough	Clear.
8.95	May 18....	1:25-2:05 p. m.	81	51	41	N. E.	Waves	Clouds.
9.95	May 24....	4:30-5:30 p. m.	74	54	41½	S. W.	Rough	Clear.
10.95	June 1....	10:50-11:35 a. m.	81	63	41½	S. W.	Rough	Clear.
11.95	June 6....	....	70	65	42	S. E.	Waves	Clear.
12.95	June 15....	4:30-5:30 p. m.	78	68	42	E.	Waves	Clear.
13.95	June 22....	12:10-1:15 p. m.	90½	72	42¼	N. W.	Waves	Clear.
14.95	June 28....	3:30-4:30 p. m.	75	72	42	N W-N E	Waves	Clear.
15.95	Sept. 21....	2-3 p. m.	84½	71½	42½	S. W.	Rough	Clear.
16.95	Oct. 2....	4:45-5:45 p. m.	70	60	42½	S W-S E	Ripples	Clear.
17.95	Oct. 5....	4-5 p. m.	70	61	42½	S. W.	Smooth	Clear.
18.95	Oct. 24....	10-11 a. m.	40	50	42½	S. W.	Rough	Clear.
19.95	Nov. 11....	1:30-2:30 p. m.	48	46	45	S. W.	Waves	Clear.
20.95	Dec. 5....	12:15-1 m.	22	42	43	S. W.	Waves	Gray.
1.96	Jan. 28....	1-2 p. m.	32	34	35	S. W.	Ice	Cloudy.
2.96	Feb. 22....	12:30-1:30 p. m.	40	34½	35½	S. W.	Ice	Clear.
3.96	Mar. 21....	11:45-12:30 m.	45	36	36	S. W.	Ice	Overcast.
5.96	May 4....	3:25-4:10 p. m.	86	52	41	N. W.	Smooth	Clear.
6.96	May 18....	3:45-4:30 p. m.	74	55	42	N. W.	Waves	Clouds in west.
7.96	June 1....	3:15-4 p. m.	73	60	43	E.	Waves	Clear.
8.96	June 15....	3:40-4:20 p. m.	88	69	43½	E.	Waves	Clear.
9.96	June 29....	12:05-12:40 m.	101	74	43	N.	Smooth	Clear.
10.96	July 9....	11:45-12:30 a. m.	78	75	43	N. E.	Waves	Clouds.
11.96	July 20....	10:20-11:15 a. m.	78	74	43¾	S. W.	Rough	Clouds.
12.96	July 27....	3:30-4:15 p. m.	88½	75	43	S. W.	Waves	Clouds.
13.96	Aug. 3....	6-6:40 p. m.	83	75	43	S. W.	Waves	Clear.
14.96	Aug. 10....	3:35-4:10 p. m.	....	80	43½	S. W.	Waves	Clear.
15.96	Aug. 17....	12-12:45 m.	72	76½	44	N. W.	Waves	Clear.
16.96	Aug. 24....	3:25-4:05 p. m.	76	74	44	W.	Waves	Clear.
17.96	Aug. 31....	9:50-10:35 a. m.	68	70	44	N. W.	Waves	Clouds.
18.96	Sept. 7....	9:25-10:15 a. m.	78½	66	44	S. W.	Rough	Clear.
19.96	Sept. 15....	3.20-4:05 p. m.	62½	65	44½	N. E.	Waves	Clear.
20.96	Sept. 21....	2:45-3:30 p. m.	70	63	44	N. E.	Waves	Clouds.
21.96	Sept. 28....	2.55-3.40 p. m.	70	61	43½	E.	Ripples	Clear.
22.96	Oct. 6....	11-11:35 a. m.	59	58	44	N. W.	Waves	Clouds.
23.96	Oct. 15....	12:45-1:20 p. m.	67	56	43½	N.	Waves	Clouds.
24.96	Oct. 24....	11:30-12:15 m.	50	51½	43½	N. W.	Waves	Clear.
25.96	Nov. 14....	3.50-4:40 p. m.	49	45	43	S. W.	Waves	Clear.
26.96	Nov. 14....	7:20-8:45 p. m.	....	45	....	S. W.	Waves	Clear, moonlight.
27.96	Dec. 3....	11:15-12 a. m.	41	41½	39½	S.	Waves	Hazy.

DIAPTOMUS.

No. of Coll.	Total No.	Per cent.								
		0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-
1.94..	3,912	58.64	11.63	12.48	7.16	1.23	5.11	1.43	1.02	1.23
4.94..	5,630	60.25	24.58	7.18	2.34	3.81	.85	.78	.78	.43
5.94..	4,171	72.50	14.67	3.93	4.22	.57	2.22	.86	.77	.26
6.94..	4,382	73.80	16.00	4.	3.40	.73	.32	1.40	.29	......
7.94..	2,023	46.27	20.56	11.86	12.46	2.37	1.98	1.19	.34	2.97
8.94..	4,585	68.57	20.54	4.62	2.62	.26	.59	1.22	.87	.70
10.94..	4,040	28.61	26.93	31.78	7.82	2.77	.74	.79	.37	.17
11.94..	3,991	54.92	14.88	17.24	3.66	1.05	7.02	.45	.50	.28
12.94..	6,439	36.77	19.32	17.52	6.21	13.36	5.60	.77	.25	.20
13.94..	4,611	57.73	13.54	16.39	5.12	5.29	1.34	.15	.24	.19
14.94..	4,347	45.73	19.05	23.92	7.72	1.84	1.14	.11	.25	.18
15.94..	3,466	46.39	27.81	14.19	9.81	.52	......	.38	.69	.20
16.94..	1,763	59.44	17.92	13.16	4.36	3.18	.28	.17	.11	.79
17.94..	1,542	71.92	17.38	4.60	3.76	.58	.39	.52	.26	.39
18.94..	1,386	80.81	4.97	10.39	1.44	.58	.36	1.01	.01	.43
19.94..	1,464	......	......	......	......	......	......	......	......	......
20.94..	2,197	59.17	18.02	15.66	1.86	2.82	1.91	.04	.36	.13
21.94..	1,917	35.89	27.33	25.45	4.23	2.87	2.39	1.15	.58	.11
22.94..	3,823	60.27	24.48	9.52	3.19	.71	1.59	.18	......	.05
24.94..	1,972	65.72	12.99	10.34	6.23	1.17	2.13	.56	.61	.25
25.94..	1,695	63.30	28.	2.53	1.35	2.80	.70	.18	.10	.10
26.94..	884	77.83	12.22	1.81	1.47	1.36	2.37	1.36	.90	.68
27.94..	6,447	28.29	21.98	25.56	13.57	9.06	.85	.39	.16	.12
29.94..	1,192	40.60	10.73	11.41	6.03	7.06	10.73	4.03	6.72	2.69
1.95..	1,374	27.80	7.57	22.13	7.57	2.04	5.53	7.57	13.68	6.11
2.95..	1,947	28.35	9.86	2.67	18.02	27.94	4.11	2.92	4.71	1.43
3.95..	2,742	68.27	4.67	4.52	2.77	4.82	3.50	5.11	3.87	2.47
4.95..	676	14.20	17.75	22.49	13.02	8.88	7.69	12.42	3.55	......
5.95..	686	35.27	9.91	14.58	6.99	5.25	11.67	9.04	5.25	2.04
6.95..	694	29.39	18.44	23.05	8.07	4.61	6.48	.14	5.76	4.03
7.95..	286	.69	15.39	14.69	5.59	15.39	24.48	16.08	3.50	4.19
8.95..	295	1.36	10.85	23.73	10.51	11.19	16.27	7.46	11.51	7.11
9.95..	576	44.44	22.22	4.16	10.41	6.08	4.51	2.60	2.79	2.79
10.95..	1,845	66.88	22.98	6.08	.16	1.30	.38	1.30	.65	.27
11.95..	1,250	......	......	......	......	......	......	......	......	......
12.95..	2,950	40.68	29.29	14.10	10.31	1.62	3.12	.47	.14	.27
13.95..	2,612	21.44	18.07	19.91	14.70	7.66	5.51	4.90	4.59	3.22
14.95..	3,039	54.72	22.51	5.79	7.63	4.21	1.71	.66	1.45	1.32
15.95..	2,605	37.77	24.57	12.59	6.45	9.52	1.84	2.46	4.15	.65
16.95..	1,748	34.32	35.69	18.31	4.12	1.83	1.38	1.14	2.75	.46
17.95..	1,813	10.59	43.35	33.54	4.85	4.86	1.27	.88	.67	......
18.95..	1,667	51.35	10.32	11.52	18.23	7.32	.72	.36	.18	......
19.95..	647	42.04	3.71	1.24	21.02	17.93	8.65	3.71	1.70	......
20.95..	520	33.85	17.69	5.38	9.23	6.92	10.77	12.31	3.85	......
1.96..	485	......	19.79	4.95	3.30	36.28	13.20	17.53	1.65	3.30
2.96..	1,324	25.98	11.48	10.88	12.08	23.56	7.25	1.81	3.33	3.63
3.96..	892	35.43	23.32	11.88	9.42	6.28	5.38	5.38	2.24	.67
5.96..	1,712	74.77	5.61	5.84	2.57	.82	2.10	4.91	1.87	1.52
6.96..	297	33.67	10.77	33.67	5.39	2.70	4.04	4.71	3.37	1.68
7.96..	2,712	36.87	50.44	9.44	1.62	.89	.30	.29	.11	.04
8.96..	3,044	27.59	47.83	13.14	3.68	3.71	.65	1.70	.78	.92

DIAPTOMUS — continued.

No. of Coll.	Total No.	Per cent.								
		0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–
9.96..	2,392	56.52	25.09	10.70	5.02	.75	.50	.25	.12	1.05
10.96..	2,354	39.50	33.30	8.84	6.12	.25	.69	1.44	4.76	5.10
11.96..	2,793	36.17	24.63	28.07	2.72	.46	1.25	.68	4.80	1.22
12.96..	3,612	47.84	37.65	9.74	2.99	.30	.17	.75	.17	.39
13.96..	2,508	30.30	47.53	10.84	1.60	5.58	.56	.44	2.99	.16
14.96..	3,803	64.16	19.99	6.42	3.10	......	2.84	2.52	.26	.71
15.96..	1,563	98.91	.13	......	......	.06	.19	.13	.19	.39
16.96..	4,785	62.90	9.01	18.06	1.25	2.01	2.67	1.33	2.17	.60
17.96..	4,933	41.60	28.81	19.62	1.87	2.59	.57	.89	2.27	1.78
18.96..	5,646	70.86	.42	15.02	4.85	.49	.98	4.83	.78	1.77
19.96..	4,766	46.37	33.02	6.73	3.35	2.35	3.02	3.86	1.09	.21
20.96..	5,248	59.18	21.80	6.25	1.22	2.04	3.43	4.08	.69	.91
21.96..	3,772	54.72	26.73	14.21	1.06	.95	1.01	.64	.13	.50
22.96..	4,229	45.40	19.11	23.22	9.27	2.46	.11	.31	.07	.05
23.96..	4,736	78.21	7.43	8.96	4.39	.46	.25	.13	.13	.04
24.96..	1,527	54.49	16.76	23.58	4.19	.26	.20	.13	.26	.13
25.96..	746	18.23	7.51	6.43	15.55	16.09	23.59	7.50	3.76	1.34
26.96..	490	in 0–20	meter	s.						
27.96..	762	42.	7.35	9.98	6.30	4.20	5.77	6.29	15.75	2.36

A glance at Pl. VII will show that *Diaptomus* has a strongly marked minimum of occurrence in December and in January. There is an increase in February and March, but in both 1895 and 1896, the number in May was very small. *Diaptomus* appears to reach its maximum in the latter part of September and October. In the fall months, the collections consist mostly of mature forms. In the winter months most of them are immature. From the latter part of March to the latter part of May, nearly all are mature, and the females egg-bearing. In June there is a great preponderance of larvæ.

Apstein ('96, 179 and following) states that the maximum period of *D. graciloides* differs in different German lakes. The time of the maximum occurrence of Green Lake *Diaptomi* as recorded above, does not agree with any of his observations. Birge (Birge '95 p. 448) states that the maximum time of *Diaptomus* in Lake Mendota is in July. Inasmuch as *Diaptomus* is very little affected by differences of temperature, as will be shown later, I think these differences in maximum periods are probably caused by some differences in the development of food supply.

There are only two species of *Diaptomus* found in Green Lake, — *D. minutus* and *D. sicilis*. In the counting no distinction was made in regard to these species, but a slide was prepared from each collection and examined under the compound microscope and thus a rough idea obtained of the relative abundance of the two forms. During Sept. and Oct. *D. minutus* was much more abundant. In Sept. very few of *D. sicilis* were found. During October and November the relative number of *D. sicilis* increases, and in the winter months the collections were almost entirely of *D. sicilis*.

In 1894 I first found *D. sicilis* in the collection of Sept. 28. In 1895 it first appeared Oct. 5, and 1896 on Oct. 6. Although I did not find this species in the summer months while I was making my serial collections, I do not think that it was probably entirely absent from the lake; for in 1890 and 1891 I found it in summer collections, although I did not find it in 1892. (Marsh, '93 p. 198.) I find, on looking over my notes of 1890 and 1891 that it was not numerous in those years, and I presume that it occurs in the summer months, but only in very small numbers. A reexamination of my notes on the Michigan copepods shows that the same thing holds true there. In the collections made by Professor Reighard in April, in Lake Michigan, *D. sicilis* was always present, while in the summer collections in the Great Lakes and Lake Michigan, *D. minutus* was the more common form, as I have already noted in my paper on Michigan copepods, and *D. sicilis* occurs rather infrequently. In April and May *D. minutus* is entirely lacking in Green Lake, but appears again in June.

Inasmuch as it is claimed by some that some copepods show a seasonal dimorphism, one might raise the question whether we did not here have a case of that kind. I do not think that this is so, although I have not now material to fortify my belief.

The *Diaptomi* are found at all depths, but in the deeper strata only in small numbers. There were very few hauls in which I did not find some representatives of this genus in every five meter stratum, and yet from sixty to seventy-five per cent. were commonly in the upper ten meters.

In order to find out whether there was any difference in the vertical distribution in summer and in winter I took the averages in the upper three levels of collections 7.96 to 17.96 inclusive, and 24.94 to 3.95 inclusive. I took these years because in 1894–5 I made a large number of collections in cold weather, and in 1896 I made the largest number of collections in warm weather.

The following table indicates the results:

	0–5	5–10	10–15
Summer, 7.96–17.96..............	49.31	24.49	12.26
Winter, 24.94–3.95................	50.02	13.50	10.12

It appears from these averages that the seasons make no difference in the vertical distribution of *Diaptomus*, but that it is uniform throughout the year.

Apstein comes to the same conclusion. ('96, p. 180.)

The day and night collections of October, 1894, compared as follows:

	0–5	5–10
Day..	59.44	18.42
Night......................................	53.70	18.40

Here is no evidence of diurnal migration.

I think, then, that I am safe in saying that the vertical distribution of *Diaptomus* varies but little from one end of the year to the other and is not appreciably affected by changes in the amount of light.

Birge finds the same thing to be true of *D. oregonensis*. (Birge, '95, 450.)

EPISCHURA LACUSTRIS.

No. of Coll.	Total. No.	Per cent.								
		0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–
1.94..	155	77.42	20.65	1.23	......	......	......	......	......	......
4.94..	121	59.50	33.06	6.61	.83	......	......	......	......	......
5.94..	100	56.	24.	16.	4.	......	......	......	......	......
6.94..	180	87.	8.30	4.44	......	.55	......	......	......	......
7.94.	149	34.90	32.21	18.79	10.74	2.69	......	......	......	.67
8.94..	390	41.54	33.82	16.41	5.13	.51	.26	1.56	.51	.26
10.94..	220	50.90	21.82	23.63	2.72	.99	......	......	......	......
11.94..	191	54.45	15.71	25.13	2.09	......	2.09	......	.52	......
12.94..	104	19.23	7.69	9.61	38.46	11.54	11.54	.96	.96	......
13.94..	141	28.37	11.35	45.39	8.51	2.84	3.54	......	......	......
14.94..	126	38.09	19.05	22.22	9.52	9.52	.79	......	.79	......
15.94..	214	56.08	18.69	20.56	......	2.80	......	.93	.47	.47
16.94..	96	75.	14.79	8.33	1.04	......	......	1.04	......	......
17.94..	50	64.	28.	6.	......	......	......	......	2.	......
18.94..	183	81.43	3.27	8.74	......	......	......	......	.55	......
20.94..	95	23.16	25.26	47.37	......	1.05	3.16	......	......	......
21.94..	65	49.23	24.61	21.54	3.08	......	1.54	......	......	......
22.94..	32	62.50	21.88	9.38	3.12	3.12	......	......	......	......
24.94..	41	50.	......	25.	......	......	......	......	25.	......
25.94..	22	31.82	45.45	......	9.09	9.09	4.55	......	......	......
26.94..	118	74.57	14.41	4.24	5.93	......	......	.85	......	......
27.94..	330	53.33	5.45	31.52	8.49	.91	.30	......	......	......
29.94..	8	......	......	......	......	100.	......	......	......	......
1.95..	60	33.33	40.	26.67	......	......	......	......	......	......
2.95..	395	50.63	8.10	8.10	16.46	14.17	2.04	......	.50	......
3.95..	24	66.67	......	......	......	......	......	......	33.33	......
4.95..	......	......	......	......	......	......	......	......	......	......
5.95..	......	......	......	......	......	......	......	......	......	......
6.95..	......	......	......	......	......	......	......	......	......	......
7.95..	......	......	......	......	......	......	......	......	......	......
8.95..	......	......	......	......	......	......	......	......	......	......
9.95..	......	......	......	......	......	......	......	......	......	......
10.95..	93	98.72	......	1.28	......	......	......	......	......	......
11.95..	96	33.33	58.33	......	8.34	......	......	......	......	......
12.95..	41	19.51	78.05	2.44	......	......	......	......	......	......
13.95..	64	37.50	37.50	12.50	12.50	......	......	......	......	......
14.95..	196	24.49	69.39	4.08	2.04	......	......	......	......	......
15.95..	24	50.	12.50	25.	4.17	4.17	......	......	4.16	......
16.95..	65	73.84	18.46	4.62	......	1.54	......	......	1.54	......
17.95..	37	8.11	64.86	21.62	5.41	......	......	......	......	......
18.95..	100	48.	20.	8.	16.	8.	......	......	......	......
19.95..	4	50.	50.	......	......	......	......	......	......	......
20.95..	......	......	......	......	......	......	......	......	......	......
1.96..	223	7.79	......	32.29	3.59	......	......	22.87	39.46	......
2.96..	96	58.33	33.33	......	8.34	......	......	......	......	......
3.96..	......	......	......	......	......	......	......	......	......	......
5.96..	......	......	......	......	......	......	......	......	......	......
6.96..	......	......	......	......	......	......	......	......	......	......
7.96..	10	10.	80.	10.	......	......	......	......	......	......
8.96..	41	98.	2.	......	......	......	......	......	......	......
9.96..	32	50.	50.	......	......	......	......	......	......	......

EPISCHURA LACUSTRIS—continued.

No. of Coll.	Total. No.	*Per cent.*								
		0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–
10.96..	140	61.43	34.29	1.43	.71	......	......	.71	......	1.43
11.96..	131	61.07	7.63	30.54	.76	......	......	......	......	......
12.96..	54	44.44	44.45	11.11	......	......	......	......	......	......
13.96..	30	53.33	13.33	33.34	......	......	......	......	......	......
14.96..	29	27.59	48.28	20.68	3.45	......	......	......	......	......
15.96..	203	99.01	.99	......	......	......	......	......	......	......
16.96..	397	84.63	11.34	4.03	......	......	......	......	......	......
17.96..	333	76.58	21.32	1.80	.30	......	......	......	......	......
18.96..	270	91.48	......	5.93	2.22	......	.37	......	......	......
19.26..	107	61.68	37.38	......	.94	......	......	......	......	......
20.96..	100	28.	72.	......	......	......	......	......	......	......
21.96..	120	46.66	40.	13.34	......	......	......	......	......	......
22.96..	46	34.79	34.78	26.09	2.17	2.17	......	......	......	......
23.96..	150	69.33	21.34	5.34	2.67	......	......	.66	.66	......
24.96..	46	69.56	15.22	15.22	......	......	......	......	......	......
25.96..	98	93.88	......	......	3.06	1.02	2.04	......	......	......
26.96..	9	in 0.20	met'rs	......	......	......	......	......	......	......
27.96..	4	100.	......	......	......	......	......	......	......	......

From the table it appears that *Epischura* occurs in the summer and fall months, with no very well defined time of maximum numbers. (See Pl. VIII.) The largest numbers obtained at single hauls were 390 in the evening of October 9, 1894, 395 from a haul made through the ice on March 9, 1895, and 397 on August 24, 1896. In the March haul a large proportion were larval forms. *Epischura* disappears entirely in the latter part of March and does not appear again until June.

The number of my winter collections was, unfortunately, very small, so that one must be very careful about drawing inferences from them. But I think we may consider it fairly certain that *Epischura* is hatched from the egg in the winter,—probably in February or the early part of March. This in itself is a matter of some interest, as, so far as I know, there is no previous record of the occurrence of any considerable number of larval forms of *Epischura*.

It is a curious fact that so soon after the appearance of the larval forms, *Epischura* entirely disappears for several months. I will not in this paper hazard a conjecture as to the explanation of this, as I hope in a later paper to treat more fully upon its life history after further researches.

So far as I know there have been no preceding observations on the seasonal distribution of *Epischura*. Its nearest European relative is *Heterocope*, and this is stated by Apstein to occur from the latter part of July into November, its maximum period being in the summer. He does not record any time of the appearance of the larval forms.

In its vertical distribution, *Epischura* is largely confined to the upper regions. While laboratory experiments would seem to indicate that it avoids bright light, the averages of my collections apparently show that it is more largely controlled by the conditions of temperature. In my collections of August, 1893, I found 81 per cent. in the upper ten meters. The average of the collections of 1894, extending from the latter part of September to the last of November was 53.11 per cent. in the upper five meters and 19.52 per cent. from five to ten meters, thus making 72.63 per cent in the upper ten meters. In order to compare the distribution at different seasons, I computed the average percentages in the collections from the surface to five meters, and from five meters to ten meters for June, July and August, 1896, and from November, 1894 to April, 1895, with the following results:

	0–5	5–10	0–10
Winter, 24.94–3.95	42.53	14.18	56.71
Summer, 7.96-17.96.............	60.55	28.51	89.06

This would seem to indicate that *Epischura* prefers the warmer water, although it is by no means absent from the cold water of the surface in the cold season. It occurred to me that if *Epischura* were, to a large extent, controlled in its vertical distribution by conditions of temperature, there might be a diurnal migration caused by the cooling of the surface water at night, for the surface responds quickly to changes in atmospheric temperature. To determine whether any such effect would be produced, I compared the night and day collections of October, 1894. From Oct. 6 to Oct. 24, I made five collections between six p. m. and six a. m. Four of these were made between ten and twelve o'clock. In these collections between six p. m. and six a. m., 29.44 per cent. were between the surface and five meters, and 22.06 per cent. between five and ten, making 51.50 per cent. in the upper ten meters.

In ten collections made during the same period between six a. m. and six p. m., 62.24 per cent. were between the surface and five meters, and 18.67 per cent. between five and ten meters, or 80.91 per cent in the upper ten meters. The average of all the collections made during this time was 51.31 per cent. from the surface to five meters, and 19.80 per cent. from five to ten meters, making 71.11 per cent. in the upper ten meters.

These results are contrary to my expectations, for I had supposed that *Epischura* came to the surface at night. On the contrary, it appears that in October nights it migrates to greater depths. It appears to me probable that temperature is the controlling cause of both its diurnal and seasonal migrations.

The fact that surface tows in summer evenings are sometimes rich in *Eprischau* is, I think, in harmony with the statements above. For while, as has been stated, *Epischura* prefers warm water, it also avoids bright light. In the daytime during the hot months, it is most abundant in the upper layers, but not at the immediate surface. In the darkness of the evening, however, it is no longer repelled from the surface by the light, and the change of temperature may not be sufficient to affect it.

In the 1893 collections, made in warm weather in the latter part of August, three of the hauls were made between six at night and six in the morning. In these three night hauls, there was an average of 82 per cent. in the 0-5 stratum, while the average in the day hauls in the same stratum was 33.32 per cent.

The fact that *Epischura* comes to the surface in such large numbers on warm summer nights may be accounted for by the fact that it is a large species and a strong swimmer, and moves toward the surface because of the greater amount of food material there.

LIMNOCALANUS MACRURUS.

No. of Coll.	Total No.	Per cent.								
		0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-
1.94..	72	......	......	......	44.44	27.77	5.55	13.88	1.39	6.95
4.94..	133	......	......	......	2.26	1.50	1.50	11.28	38.35	45.11
5.94..	87	1.15	2.30	......	1.15	1.15	3.45	9.20	31.03	50.57
6.94..	96	......	1.04	......	1.04	11.44	8.33	24.90	53.12	......
7.94..	113	.88	.88	......	6.19	38.94	20.35	13.27	7.08	12.39
8.94..	81	......	1.23	4.93	9.87	9.87	7.40	27.16	27.16	12.35
10.94..	59	......	1.69	1.69	1.69	23.73	28.81	13.56	18.66	10.17
11.94..	33	......	......	......	......	6.06	9.09	6.06	54.54	24.24
12.94..	79	......	1.27	5.06	10.13	20.25	15.19	12.66	22.78	12.66
13.94..	38	21.05	7.90	2.63	......	7.90	13.16	5.26	21.05	21.05
14.94..	43	......	......	......	2.32	13.95	16.28	9.30	25.58	32.56
15.94..	8	12.50	......	......	......	......	......	12.50	25.	50.
16.94..	16	......	......	......	6.25	12.50	......	6.25	6.25	68.75
17.94..	10	......	......	10.	......	......	10.	......	80.	......
18.94..	56	......	......	1.79	1.79	......	7.14	32.14	37.50	19.64
20.94..	30	3.33	3.33	40.	......	3.33	43.33	......	6.66	......
21.94..	19	......	......	......	......	......	26.32	15.79	31.58	26.32
22.94..	8	......	25.	......	......	......	12.50	12.50	......	50.
24.94..	20	......	......	......	......	......	10.	10.	20.	60.
25.94..	16	25.	......	......	......	12.50	25.	25.	6.	6.
26.94..	51	5.88	3.92	17.65	17.65	5.88	23.53	7.84	15.69	1.96
27.94..	113	23.01	4.42	14.16	16.81	8.85	6.20	19.47	2.66	4.42
29.94..	101	2.97	3.96	1.98	5.94	27.72	14.85	6.93	7.92	27.72
1.95..	25	16.	48.	8.	4.		......	8.	12.	4.
2.95..	64	37.50	1.56	3.13	1.56	4.69	1.56	6.24	21.88	21.88
3.95..	34	2.94	......	2.94		8.82	8.83	17.65	11.76	47.06
4.95..	140	8.57	22.87	25.71	7.14	14.28	10.	7.86	3.57	......
5.95..	90	11.11	3.33	4.44	4.44	5.56	22.22	27.78	15.56	5.56
6.95..	104	11.54	7.69	9.62	15.38	19.24	18.27	2.88	13.46	1.92
7.95..	85	......	......	3.53	2.35	17.65	35.30	30.59	8.23	2.35
8.95..	20	......	......	15.	10.	5.	10.	10.	25.	25.
9.95..	26	......	......	......	......	3.85	7.69	26.92	26.92	34.62
10.95..	6	98.72	......	1.28	......	......	......	......	......	......
11.95..	5	......	......	......	20.	......	20.	60.	......	......
12.95..	60	......	......	......	3.33	......	35.	40.	10.	11.67
13.95..	27	......	......	......	11.11	......	14.81	14.82	44.44	14.81
14.95..	7	......	......	......	......	......	14.28	......	71.43	14.29
15.95..	6	......	......	......	......	16.66	......	16.67	......	66.67
16.95..	15	......	......	......	6.66	6.66	26.67	......	46.67	13.34
17.95..	16	......	......	......	......	12.50	......	56.25	36.25	......
18.95..	1	......	......	100.	......	......	......	......	......	......
19.95..	22	13.64	13.64	4.55	13.64	......	13.63	27.27	13.63	......
20.95..	12	8.33	33.34		16.66	8.34	33.33	......	......	......
1.96..	8	......	......	......	......	......	12.50	25.	50.	12.50
2.96..	43	9.30	......	27.91	......	18.60	18.60	6.98	18.61	......
3.96..	76	15.79	10.52	3.95	......	......	15.79	21.05	31.58	1.32
5.96..	203	29.56	1.97	13.79	13.79	4.43	5.42	23.64	5.91	1.48
6.96..	52	1.92	23.08	11.54	19.23	15.38	......	19.23	1.92	7.70
7.96..	20	5.	......	......	15.	30.	40.	......	10.	......
8.96..	41	......	......	......	......	......	4.54	27.28	27.27	40.91
9.96..	4	......	......	......	......	......	......	25.	......	75.

LIMNOCALANUS MACRURUS — Continued.

No. of Coll.	Total No.	*Per cent.*								
		0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–
10.96..	32	......	......	......	6.25	......	......	6.25	43.75	43.75
11.96..	17	......	......	23.53	5.88	5.88	......	5.88	17.65	41.18
12.96..	9	......	......	11.11	11.11	......	......	11.12	22.22	44.44
13.96..	29	......	......	3.45	13.79	27.58	3.45	6.90	44.83	......
14.96..	15	......	......	6.66	13.34	......	19.98	6.66	26.68	26.68
15.96..	......	......	......	......	......	......	......	......	......	......
16.96..	42	......	......	16.66	....	......	......	......	66.68	16.66
17.96..	21	......	......	......	28.57	9.52	14.29	23.81	9.52	14.29
18.96..	34	......	......	2.94	17.65	2.94	11.76	14.71	29.41	20.59
19.96..	35	......	......	......	28.57	22.86	5.71	11.43	25.71	5.72
20.96..	51	......	1.96	......	......	11.76	11.76	33.34	25.49	15.69
21.96..	37	......	......	......	8.11	......	5.41	2.70	16.21	67.57
22.96..	7	......	......	......	14.29	28.57	......	......	28.57	28.57
23.96..	34	......	......	5.88	2.94	11.76	11.76	14.71	17.65	35.30
24.96..	26	3.85	3.85	26.92	3.85	11.53	3.85	11.54	7.69	26.92
25.96..	56	1.78	5.36	3.57	25.	28.57	30.36	5.36	......	......
26.96..	200	from	0-2½	met'rs	106	from	0–20	met'rs		
27.96..	43	......	6.98	6.98	4.65	11.63	16.28	9.30	34.88	9.30

Limnocalanus macrurus (see Pl. IX) occurs in collections at all times of the year, but never in very large numbers. The largest single collection that I made was May 8, 1896. While the numbers were very variable, I think I can say that it was most abundant in the months of May and November, thus having two maximum periods,—the spring period showing greater numbers.

In February, March, and April most of the *Limnocalani* are immature.

In its vertical distribution *Limnocalanus* is very interesting. From May to November it is seldom found in the day time in the upper five meters, and only in small numbers in the upper ten. In the winter months it is found at all depths. Thus its vertical distribution would seem to be controlled, in part, at least, by temperature. It also seems to be somewhat sensitive to light, for the night collections in 1894 show a greater number near the surface. As these night collections were not extended through the year, it would perhaps be unsafe to say that *Limnocalanus* comes to the surface in the night, but it is certainly very significant that most of the evening collections show more or less of this species in the 0–5 and 5–10 hauls.

The collections of November 14, 1896, seem to show quite conclusively the effect of light on the vertical distribution of *Limnocalanus.* On this date, the temperature of the surface was 45, and that of the bottom 43, so that the temperature was practically uniform through the whole depth of the water. In the collection made at about four o'clock in the afternoon, *Limnocalanus* was absent in the upper two and one-half meters, there was one in the upper five meters, three in the layer from five to ten, two in ten to fifteen, and an increasing number in the deeper layers. In the evening, at about eight o'clock, there were two hundred in the upper two and one-half meters, and a rapidly decreasing number in the deeper layers. A surface tow taken in the evening consisted very largely of *Limnocalanus.*

I think we can state with positiveness from these observations that *Limnocalanus* is repelled by the higher temperature of the surface waters in summer, and is also repelled by light. There is a further question, however, which it is not so easy to answer, and that is the positive reason of the vertical migration. Why do they approach the surface when there is neither a high temperature or light to repel them. It occurred to me that possibly, while they are repelled by bright light, they may be attracted by a faint light, like that of the moon. A comparison of the collections of cloudy and moonlight nights, however, shows no essential difference.

It is possible that the more highly aerated surface waters may attract them; this is not probable, however, for the fact that during such a large portion of the year they are found in deeper water would seem to imply that they are adapted to the somewhat stagnant conditions of those waters. It seems to me most probable that the larger food supply of the surface waters is the main cause of the vertical migration.

The relation of *Limnocalanus* to the "sprungschicht" is interesting. Unfortunately I have been able to make temperature determinations for only the surface and bottom, so that I do not know the position of the "sprungschicht" in Green Lake at different periods of the year. By the kindness of Prof. E. A.

Birge a set of serial temperatures was taken with the thermophone September 3, 1896, which seemed to show that at that time the "sprungschicht" was located at about fourteen meters below the surface. Probably its location does not change materially during the summer months. In looking over the collection of *Limnocalanus*, I find that during the summer months it is found mostly below the fifteen meter level, its distribution becoming gradually more general in the fall, and continuing so until the late spring. This leads me to infer that the vertical distribution of the *Linnocalanus* varies nearly as the "sprungschicht" varies.

C. brevispinosus did not occur in large numbers in any of the serial collections. The largest number obtained at one time was 291, on June 6, 1895. In both 1895 and 1896 its occurrence was confined almost entirely to the month of June. It was found in both May and July, but only in small numbers. At other times I have found it in Green Lake in August, but it must be comparatively rare at that time, for in my serial collections in 1893 I did not find a single individual. I have found it in the Michigan lakes, too, in July and August.

In regard to its vertical distribution, it appears to be most abundant from five to twenty meters in depth. In the upper five meters only a few are found, and they do not go below 20 to 25 meters to any extent.

CYCLOPS BREVISPINOSUS.

C. brevispinosus not present in collections from 1.94 to 6.95.

No. of Coll.	Total No.	Per cent. 0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–
7.95..	1	......	......	......	100.	......	......	......	......	......
8.95..	......	......	......	......	......	......	......	......	......	......
9.95..	......	......	......	......	......	......	......	......	......	......
10.95..	246	......	......	87.80	4.47	4.88	1.22	.81	.41	.41
11.95..	291	8.25	54.98	10.99	16.84	......	8.25	......	.69	......
12.95..	79	......	50.63	10.13	10.13	6.32	20.25	1.27	1.27	......
13.95..	166	......	......	19.28	62.65	14.46	3.61	......	......	......
14.95..	13	......	......	61.54	15.38	15.39	7.69	......	......	......
15.95..	......	......	......	......	......	......	......	......	......	......
16.95..	......	......	......	......	......	......	......	......	......	......
17.95..	......	......	......	......	......	......	......	......	......	......
18.95..	......	......	......	......	......	......	......	......	......	......
19.95..	......	......	......	......	......	......	......	......	......	......
20.95..	7	......	......	57.15	......	......	......	42.85	......	......
1.96..	6	16.66	50.	.....	33.34	......	......	......	......	......
2.96..	......	......	......	......	......	......	......	......	......	......
3.96..	......	......	......	......	......	......	......	......	......	......
5.96..	......	......	......	......	......	......	......	......	......	......
6.96..	1	100.	......	......	......	......	......	......	......	......
7.96..	33	......	72.73	3.03	12.12	......	12.12	......	......	......
8.96..	52	15.38	46.15	30.77	3.85	3.85	......	......	......	......
9.96..	36	......	......	44.45	44.44	11.11	......	......	......	......
10.96..	7	14.28	......	14.29	57.14	......	......	14.29	......	......
11.96..	3	......	......	......	33.33	66.67	......	......	......	......
12.96..	......	......	......	......	......	......	......	......	......	......
13.96..	......	......	......	......	......	......	......	......	......	......
14.96..	......	......	......	......	......	......	......	......	......	......
15.96..	......	......	......	......	......	......	......	......	......	......
16.96..	1	......	......	100.	......	......	......	......	......	......
17.96..	......	......	......	......	......	......	......	......	......	......
18.96..	......	......	......	......	......	......	......	......	......	......
19.96..	......	......	......	......	......	......	......	......	......	......
20.96..	......	......	......	......	......	......	......	......	......	......
21.96..	2	......	100.	......	......	......	......	......	......	......
22.96..	......	......	......	......	......	......	......	......	......	......
23.96..	......	......	......	......	......	......	......	......	......	......
24.96..	......	......	......	......	......	......	......	......	......	......
25.96..	......	......	......	......	......	......	......	......	......	......
26.96..	......	......	......	......	......	......	......	......	......	......
27.96..	25	100.	......	......	......	......	......	......	......	......

CYCLOPS FLUVIATILIS.

No. of Coll.	Total No.	*Per cent.*								
		0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–
1.94..	336	30.95	2.38	26.19	33.33	......	7.15	......	......	......
4.94..	530	24.15	23.39	21.89	23.77	6.04	.76	......	......	......
5.94..	740	16.22	41.62	14.46	23.78	1.76	.54	.27	1.35	......
6.94..	707	33.94	16.97	24.33	5.76	2.12	.42	.14	......	......
7.94..	968	23.97	3.72	10.74	47.52	9.50	1.26	.42	......	2.94
8.94..	823	14.58	18.97	33.53	26.24	4.13	1.10	.97	.12	.36
10.94..	791	25.79	15.67	11.63	31.86	8.09	3.16	3.54	.12	.12
11.94..	783	33.72	8.43	23.50	25.29	3.58	.38	1.02	.51	......
12.94..	881	21.34	16.34	13.62	9.53	17.71	19.52	1.36	.34	.23
13.94..	378	42.33	22.22	17.99	3.70	9.53	2.12	.79	......	1.32
14.94..	525	54.63	16.76	8.38	12.95	6.10	......	.95	......	......
15.94..	535	27.66	20.93	9.72	36.64	4.86	......	......	......	.19
16.94..	452	17.48	21.24	27.43	22.78	7.30	1.10	.44	1.33	.66
17.94..	378	22.22	16.93	21.43	34.66	3.17	.27	......	......	1.32
18.94..	262	36.87	16.87	24.42	18.32	3.05	......	.38	......	.38
20.94..	1,241	20.63	5.16	58.34	11.60	3.38	.64	......	.08	.16
21.94..	618	26.54	22.01	20.06	25.89	4.53	......	.81	.16	......
22.94..	625	38.40	14.08	9.60	30.40	6.55	.96	......	......	......
24.94..	865	55.49	14.80	9.94	11.79	6.59	.81	.23	.35	......
25.94..	1,043	45.60	24.35	12.20	8.40	7.70	1.10	.20	.30	.10
26.94..	1,912	42.67	33.47	13.39	4.55	3.76	.84	.89	.16	.32
27.94..	564	44.68	17.38	12.77	17.73	5.85	.53	.53	.53	......
29.94..	1,036	40.15	9.26	16.21	8.49	5.02	6.18	3.47	6.18	5.02
1.95..	134	......	......	17.91	47.76	23.88	4.48	2.98	2.24	.75
2.95..	322	24.84	7.45	2.48	14.91	22.36	9.94	12.42	5.59	......
3.95..	324	54.32	6.17	6.17	2.47	6.17	4.94	7.41	4.94	7.41
4.95..	114	14.03	6.14	5.26	10.53	21.93	28.07	10.53	3.51	......
5.9ç..	138	20.29	23.19	31.88	2.17	......	17.39	4.35	.73	......
6.95..	154	20.78	23.38	16.88	18.18	9.09	11.04	......	.65	......
7.95..	93	81.72	16.13	......	......	......	......	......	......	2.15
8.95..	116	91.38	6.89	......	.86	......	......	......	.86	......
9.95..	58	75.87	20.69	......	......	1.72	......	......	......	1.72
10.95..	415	86.75	9.64	1.93	......	......	1.44	......	......	.24
11.95..	357	71.71	8.96	.28	13.73	......	4.48	.28	.56	......
12.95..	68	29.41	11.77	47.05	11.77	......	......	......	......	......
13.95..	85	67.07	18.82	9.41	......	......	......	......	......	4.70
14.95..	400	73.75	14.	12.	......	......	.25	......	......	......
15.95..	397	8.06	2.02	65.49	14.11	10.07	.25	......	......	......
16.95..	340	56.47	25.88	9.41	5.89	1.76	.59	......	......	......
17.95..	385	6.23	14.55	47.79	22.86	8.31	.26	......	......	......
18.95..	610	45.25	11.80	18.36	14.43	3.93	3.93	1.64	.66	......
19.95..	403	23.82	11.91	......	36.24	19.85	3.97	3.47	.74	......
20.95..	280	14.29	14.29	8.57	14.29	8.57	5.71	14.28	20.	......
1.96..	91	......	......	26.38	13.19	52.75	2.19	1.09	......	4.40
2.96..	389	......	4.11	8.22	49.36	32.90	3.09	2.06	......	.26
3.96..	89	2.25	31.46	3.37	8.99	22.47	26.96	3.37	......	1.13
5.96..	23	69.57	17.39	13.04	......	......	......	......	......	......
6.96..	77	72.72	10.40	15.58	......	......	1.30	......	......	......
7.96..	124	77.42	12.90	6.45	......	3.23	......	......	......	......
8.96 .	136	100.	......	......	......	......	......	......	......	......
9.96..	328	82.92	4.88	12.20	......	......	......	......	......	......

CYCLOPS FLUVIATILIS—continued.

No. of Coll.	Total No.	*Per cent.* 0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–
10.96..	423	92.67	1.18	2.83	2.84	.24	......	......	.24	......
11.96..	607	96.21	2.63	......	......	.49	.17	.16	.34	......
12.96..	546	85.35	13.19	.73	......	.19	.18	.18	......	.18
13.96..	182	39.56	39.56	17.58	3.30	......	......	......	......	......
14.96..	153	31.37	31.37	33.99	3.27	......	......	......	......	......
15.96..	331	99.10	......	.60	......	.30	......	......	......	......
16.96..	230	55.65	5.22	24.35	3.48	......	8.69	1.30	......	1.31
17.96..	474	18.57	8.44	60.76	10.97	.84	.42	......	......	......
18.96..	368	32.61	.54	34.78	30.44	.54	.27	......	......	.82
19.96..	525	50.29	4.57	13.71	16.76	3.81	3.05	7.62	.19	......
20.96..	619	51.70	11.63	28.43	3.23	......	3.23	1.62	......	.16
21.96..	369	23.85	19.52	32.52	18.43	2.17	.27	1.64	.55	1.09
22.96..	489	29.45	11.45	8.18	32.72	16.36	.82	.61	.41	......
23.96..	396	51.01	12.12	14.14	22.48	.25	......	......	......	......
24.96..	253	28.46	17.39	22.13	25.30	2.77	.39	......	3.56	......
25.96..	342	25.73	12.86	4.68	8.19	7.02	4.68	18.72	7.60	10.52
26.96..	312	in	0–20	mete	rs.					
27.96..	400	10.	8.	8.	14.	42.	2.	6.	2.	......

C. fluviatilis (see Pl. X) occurs in the collections during the whole year, and generally in considerable numbers. The maximum seems to be reached in the months of October and November, although in 1896 quite large collections were made in July, and the smallest collections were made in the months of May and June.

C. fluviatilis is found in greater or smaller numbers at all depths, but is far the most abundant near the surface, the greater part of the collection being ordinarily within ten meters of the surface, and below twenty-five meters very few are found. In many cases more than fifty per cent. were in the upper five meters. In the winter collections, however, the numbers at the surface were smaller, and the bulk of the collection was frequently in the intermediate regions, between ten and thirty meters. There are apparent exceptions to this, however, as in 3.95, where 54 per cent. were in the upper five meters. But in this case the remaining fifty per cent. was distributed pretty evenly through the deeper regions.

In order to determine with some degree of exactness the difference in vertical distribution in cold weather as compared with that in warm weather I averaged the percentages in the upper five divisions from June until September, 1896, —7.96 to 17.96 inclusive,—and from November to April, 1895,—24.94 to 3.95 inclusive,— with the following results:

	0–5	5–10	10–15	15–20	20–25
7.96 to 17.96—warm weather..........	70.80	10.85	14.50	2.17	.48
24.94 to 3.95—cold weather...........	38.47	14.11	11.38	14.51	10.17

It is evident from these figures that there is a marked difference in the vertical distribution in warm and in cold weather. Nearly 71 per cent. in warm weather are in the upper five meters, while the upper fifteen include 96.15 per cent. In cold weather, on the other hand, only 38.47 per cent. are in the upper five meters, and below that they are somewhat evenly distributed.

To determine the difference between day and night I averaged the five hauls in October, 1894, which were taken between six p. m. and six a m., and compared them with ten hauls taken in the same month between six a. m. and six p. m. The following was the result:

	0–5	5–10	10–15	15–20
Night hauls................................	24.57	13.28	26.84	19.72
Day hauls...................................	29.27	19.88	18.72	23.58

It will be seen that the percentages are very similar, and I infer that there is no appreciable diurnal migration. I conclude from this that they are not very sensitive to changes in the amount of light. I take it, too, that while they are affected by changes of temperature, they are not very sensitive to such changes, or a larger proportion would be found in the warmer deep water in the winter. *C. fluviatilis*, in this respect, differs very markedly from *Epischura lacustris*, which not only has a more pronounced seasonal migration, but moves vertically in accordance with diurnal changes of temperature in the surface water

LEPTODORA HYALINA.

No. of Coll.	Total No.	Per cent. 0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-
4.94..	3	33.33	33.33	33.34	......	......	......	......	......	......
5.94..	1	......	100.	......	......	......	......	......	......	......
6.94..	12	100.	......	......	......	......	......	......	......	......
7.94..	5	80.	20.	......	......	......	......	......	......	......
8.94..	4	100.	......	......	......	......	......	......	......	......
10.94..	5	......	80.	......	20.	......	......	......	......	......
11.94..	11	18.18	9.09	54.54	9.09	......	9.09	......	......	......
12.94..	5	20.	60.	......	......	......	20.	......	......	......
13.94..	1	......	100.	......	......	......	......	......	......	......
14.94..	1	......	......	100.	......	......	......	......	......	......
15.94..	2	......	100.	......	......	......	......	......	......	......
16.94..	......	......	......	......	......	......	......	......	......	......
17.94..	......	......	......	......	......	......	......	......	......	......
18.94..	......	......	......	......	......	......	......	......	......	......
20.94..	1	......	100.	......	......	......	......	......	......	......
21.94..	2	......	100.	......	......	......	......	......	......	......
22.94..	1	......	......	100.	......	......	......	......	......	......
					No *Leptodora* from 23.94 to 2.95.					
3.95..	3	100.	......	......	......	......	......	......	......	......
					No *Leptodora* from 4.95 to 12.95.					
13.95..	6	......	......	83.33	16.67	......	......	......	......	......
14.95..	12	100.	......	......	......	......	......	......	......	......
15.95..	2	......	......	50.	......	50.	......	......	......	......
16.95..	......	......	......	......	......	......	......	......	......	......
17.95..	......	......	......	......	......	......	......	......	......	......
18.95..	1	100.	......	......	......	......	......	......	......	......
19.95..	......	......	......	......	......	......	......	......	......	......
20.95..	......	......	......	......	......	......	......	......	......	......
1.96..	......	......	......	......	......	......	......	......	......	......
2.96..	......	......	......	......	......	......	......	......	......	......
3.96..	......	......	......	......	......	......	......	......	......	......
5.96..	......	......	......	......	......	......	......	......	......	......
6.96..	......	......	......	......	......	......	......	......	......	......
7.96..	......	......	......	......	......	......	......	......	......	......
8.96..	2	50.	50.	......	......	......	......	......	......	......
9.96..	16	37.50	18.75	12.50	31.35	......	......	......	......	......
10.96..	2	50.	50.	......	......	......	......	......	......	......
11.96..	24	100.	......	......	......	......	......	......	......	......
12.96..	8	75.	25.	......	......	......	......	......	......	......
13.96..	5	80.	......	......	......	20.	......	......	......	......
14.96..	6	33.33	66.67	......	......	......	......	......	......	......
15.96..	5	100.	......	......	......	......	......	......	......	......
16.96..	22	63.63	3.82	......	4.55	......	......	......	......	......
17.96..	15	53.34	13.33	26.67	......	......	......	......	6.66	......
18.96..	21	90.48	......	4.76	4.76	......	......	......	......	......
19.96..	1	......	......	......	100.	......	......	......	......	......
20.96..	4	25.	25.	50.	......	......	......	......	......	......
21.96..	8	37.50	37.50	......	12.50	12.50	......	......	......	......
22.96..	1	......	......	......	......	100.	......	......	......	......
23.96..	2	......	......	100.	......	......	......	......	......	......
24.96..	1	......	......	......	100.	......	......	......	......	......
25.96..	......	......	......	......	......	......	......	......	......	......
26.96..	......	......	......	......	......	......	......	......	......	......
27.96..	......	......	......	......	......	......	......	......	......	......

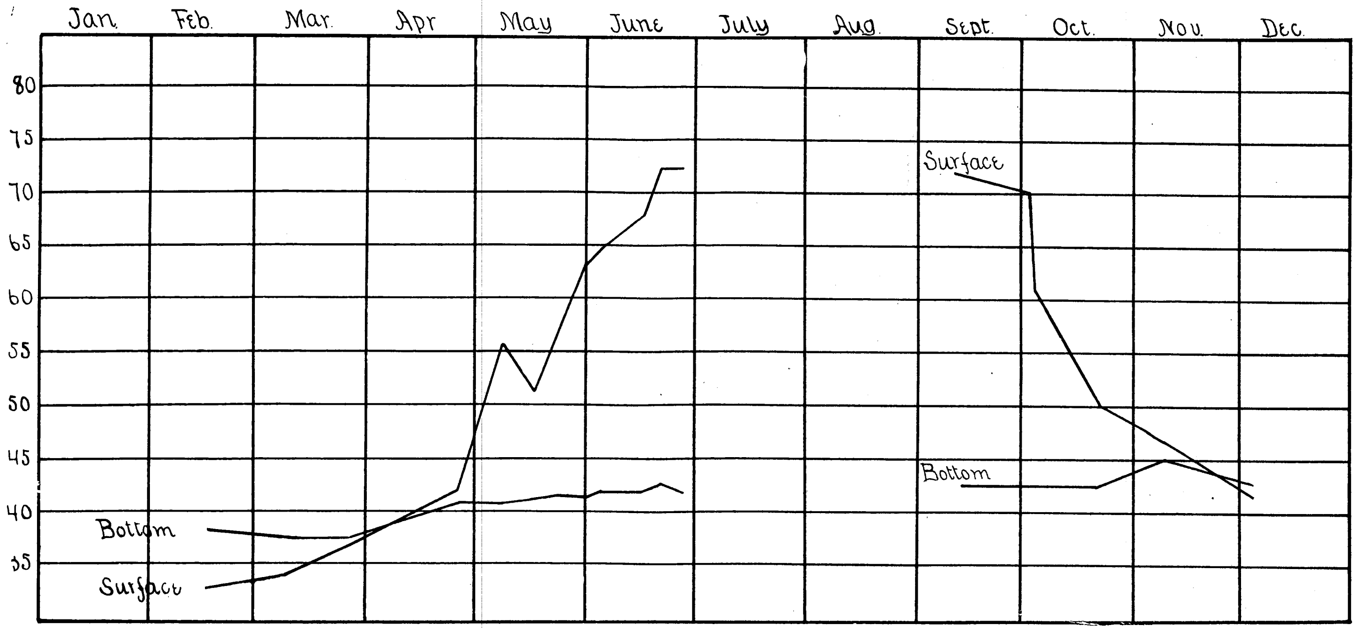
With the exception of three individuals in the collection of March 27, 1895, I found no *Leptodora* from the latter part of October to the middle of June. It was present pretty generally in the summer collections, but never in very large numbers. The largest number that I obtained in any collection was twenty-four.

In its vertical distribution, *Leptodora* is commonly within ten meters of the surface. I have found individuals at a depth of between twenty-five and thirty meters, but it is not a common occurrence.

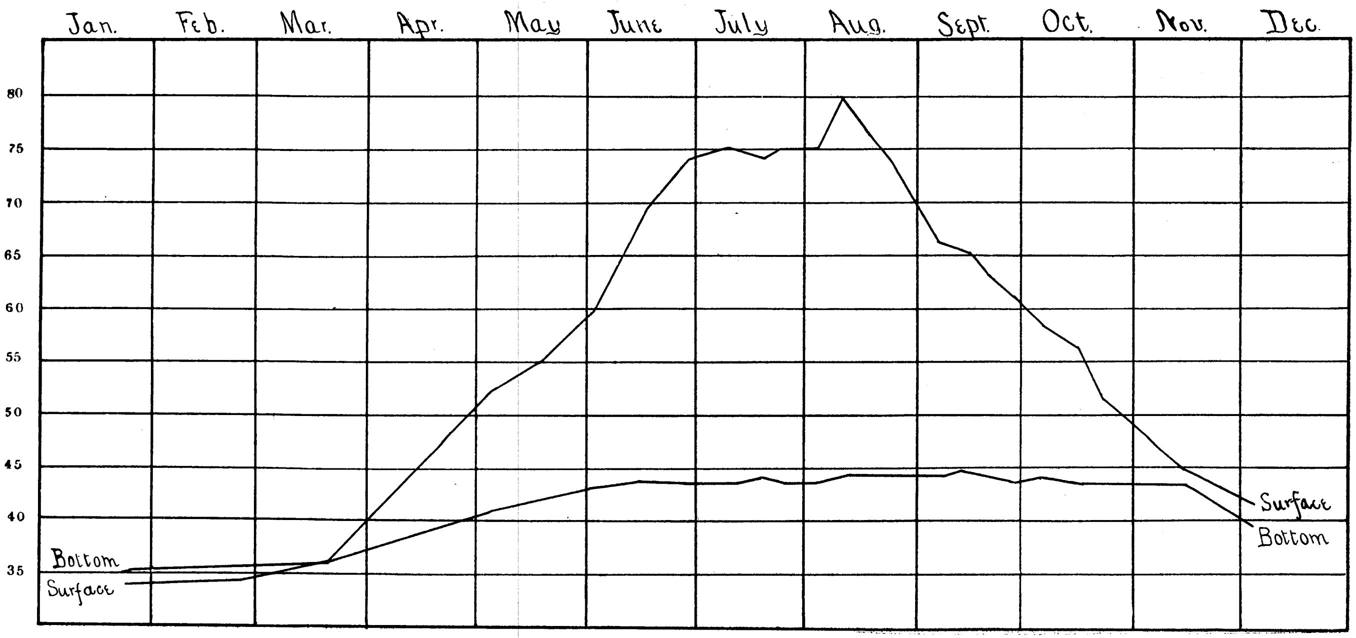
Leptodora was never present in sufficient numbers in my collections so that I could draw any inferences in regard to the effect changes of temperature would have on its vertical distribution.

It will be noticed that my observations in regard to the seasonal distribution of *Leptodora* correspond very closely with what Zacharias says of *Leptodora* in Ploener See, for he states that it disappears in the course of the month of October, and appears again towards the end of May. (Zacharias, '94, p. 100. Also, Apstein '96, p. 175. Friç and Vávra, '94, pp. 55, 108.)

Apstein ('96, p. 80) states that *Leptodora* is found most abundantly in the deep water. This is certainly not according to my observations, as they would indicate that it should rather be considered a surface form, although it is by no means confined to the immediate surface. As Apstein does not state what he means by deep water in this case, the seeming contradiction in our observations may be more apparent than real.



TEMPERATURE CURVES, 1895.



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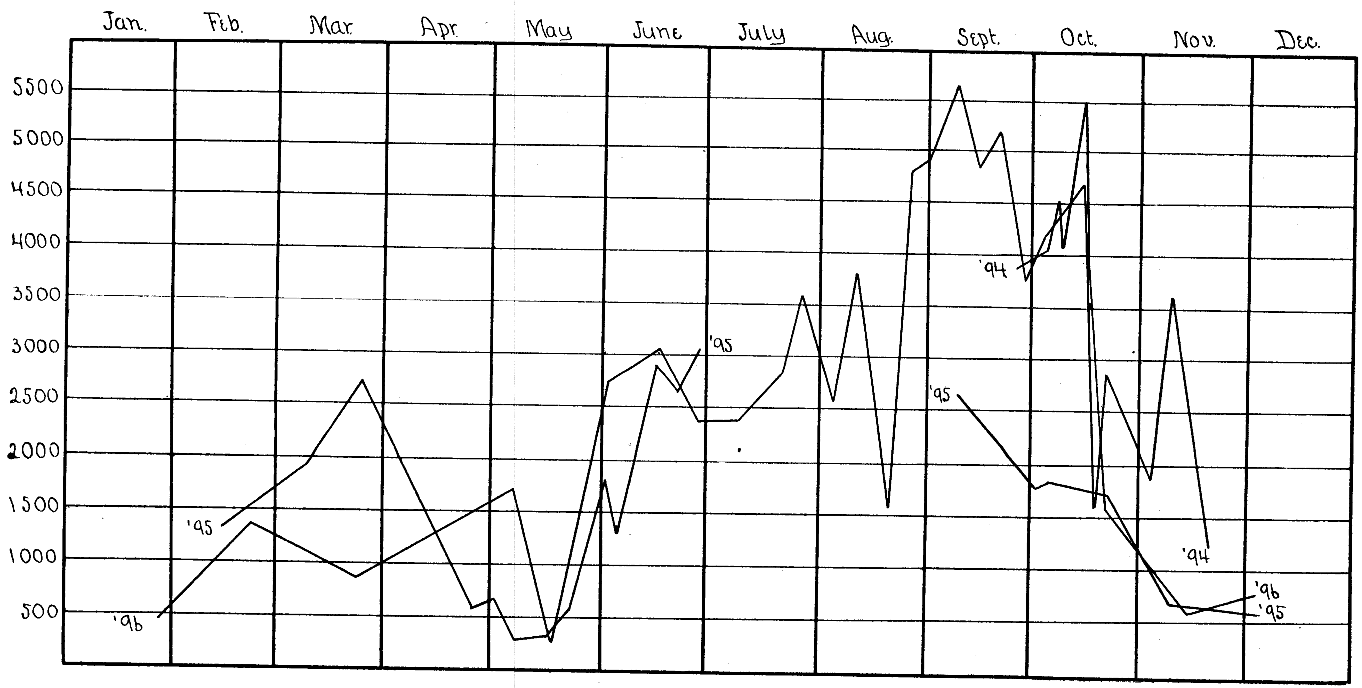
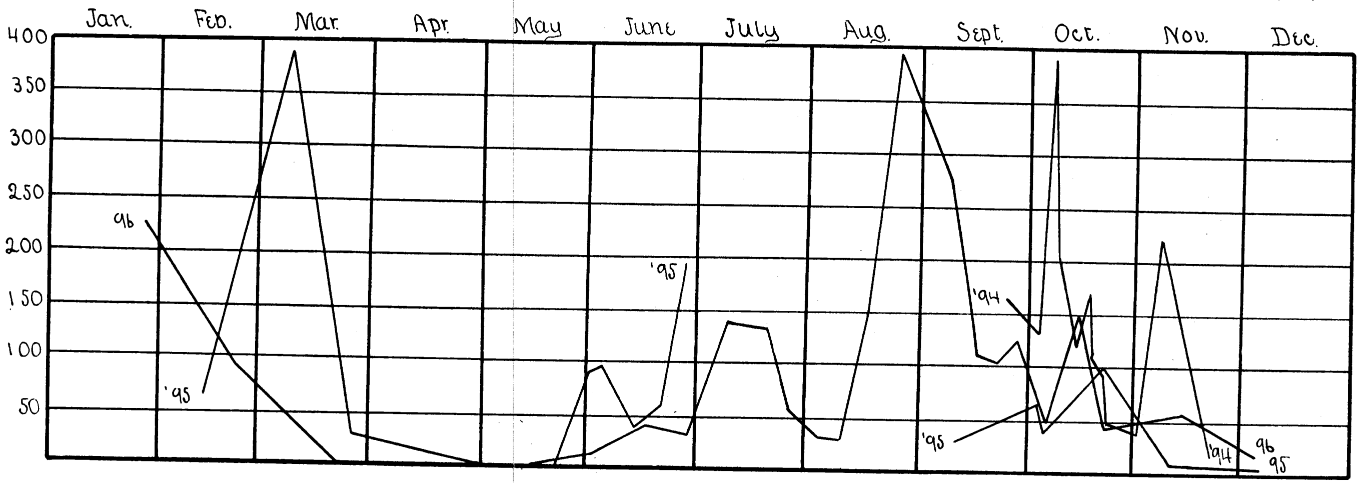


ANNUAL DISTRIBUTION OF DIAPTOMUS.



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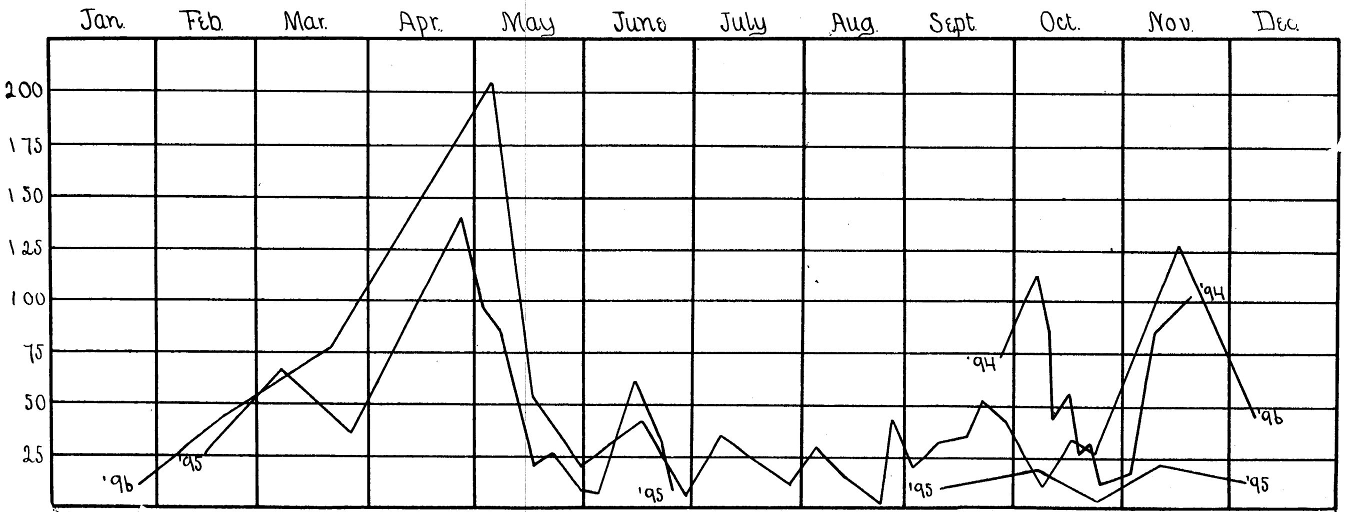
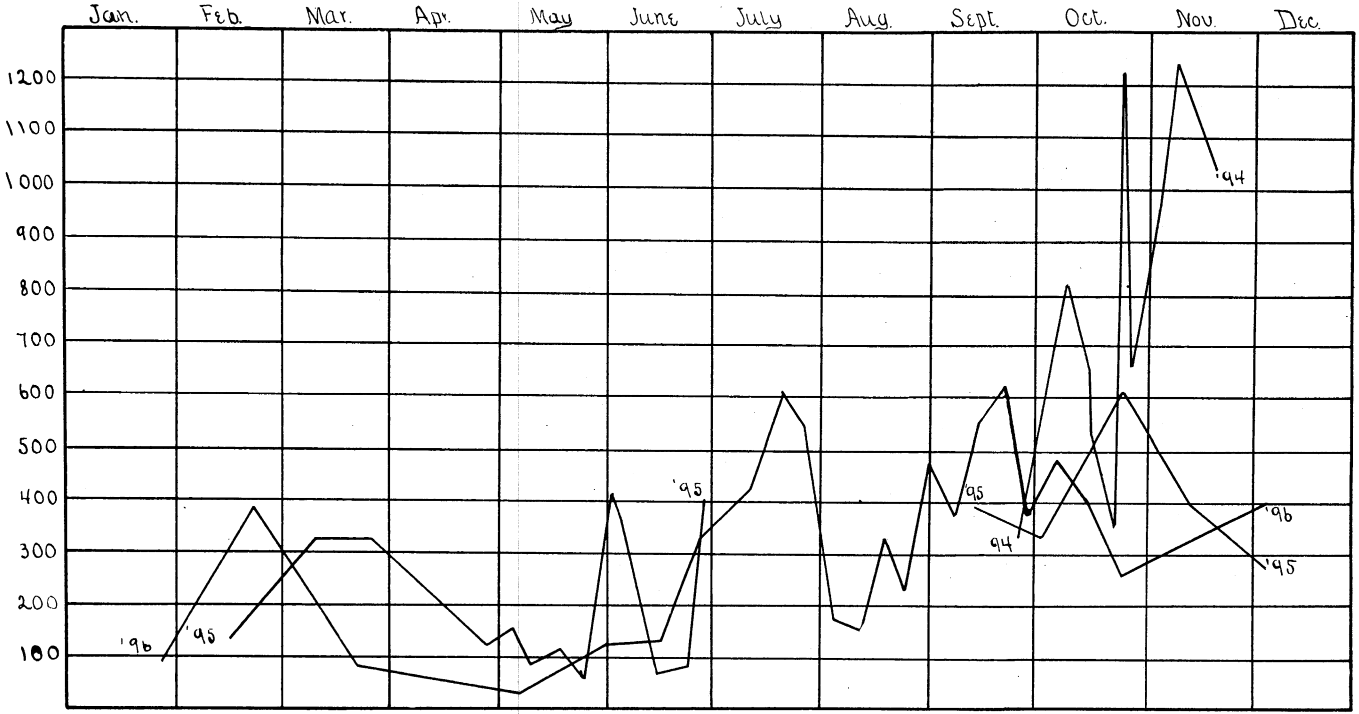
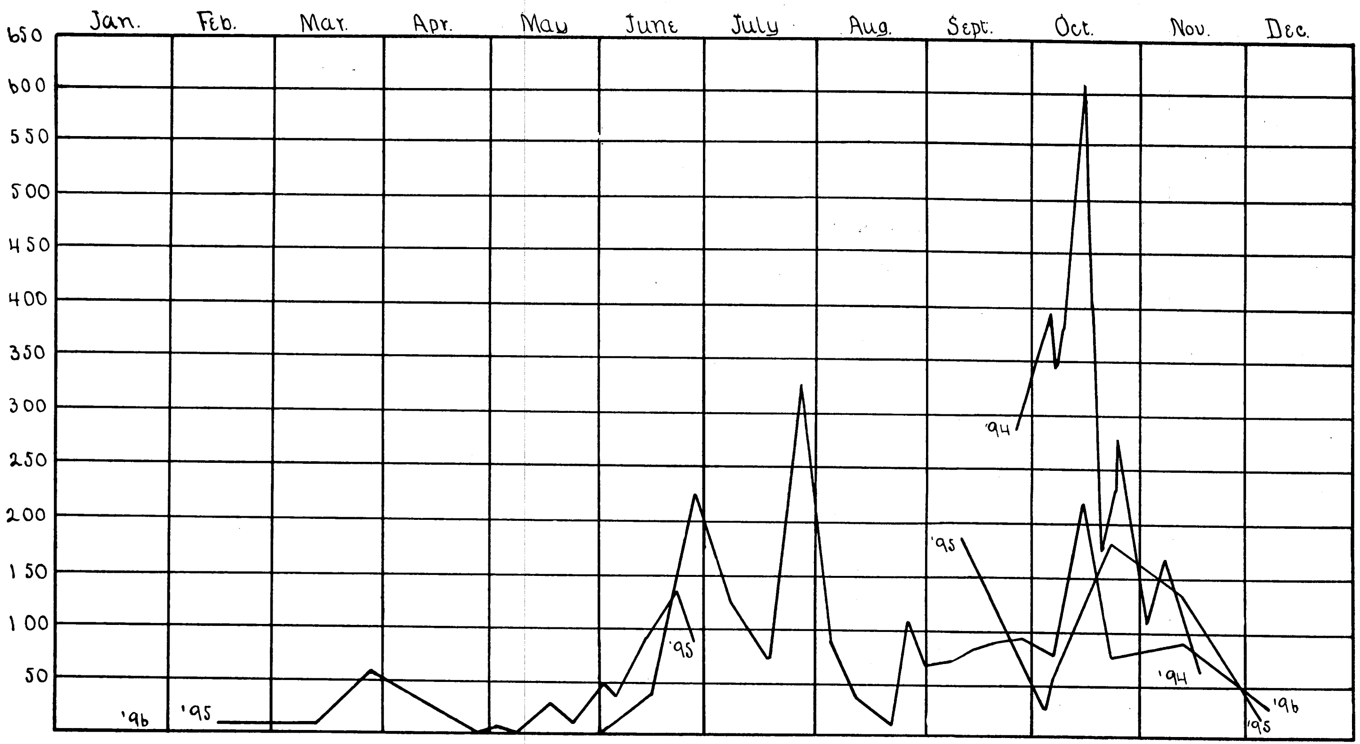


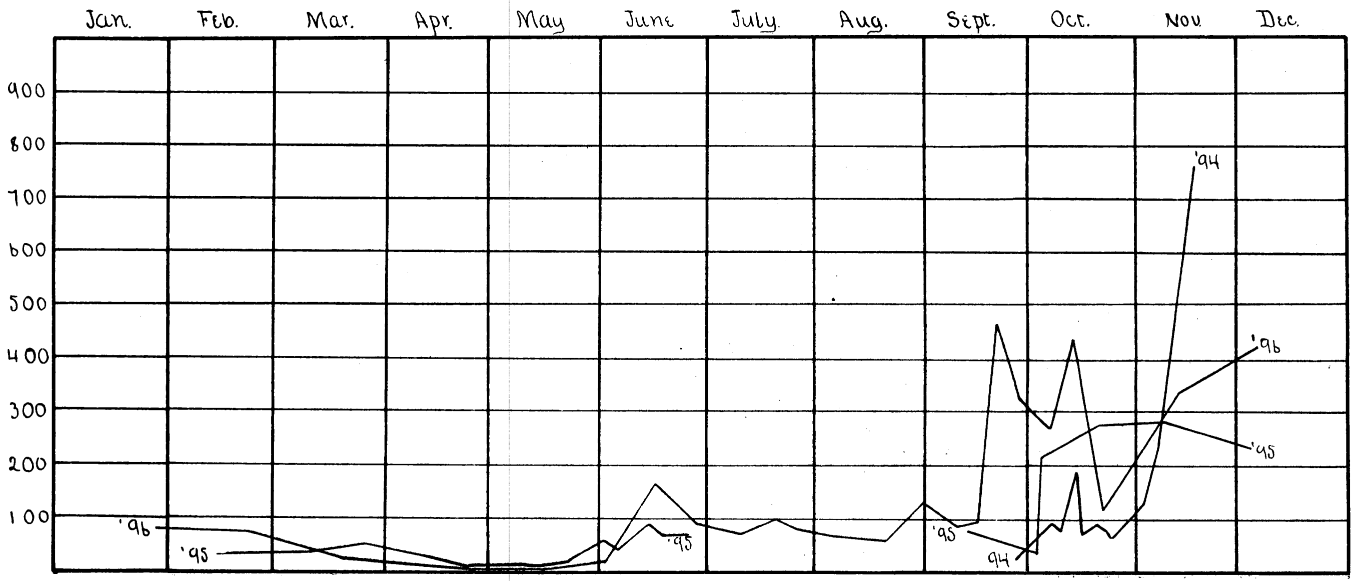
ANNUAL DISTRIBUTION OF LIMNOCALANUS MACRURUS.



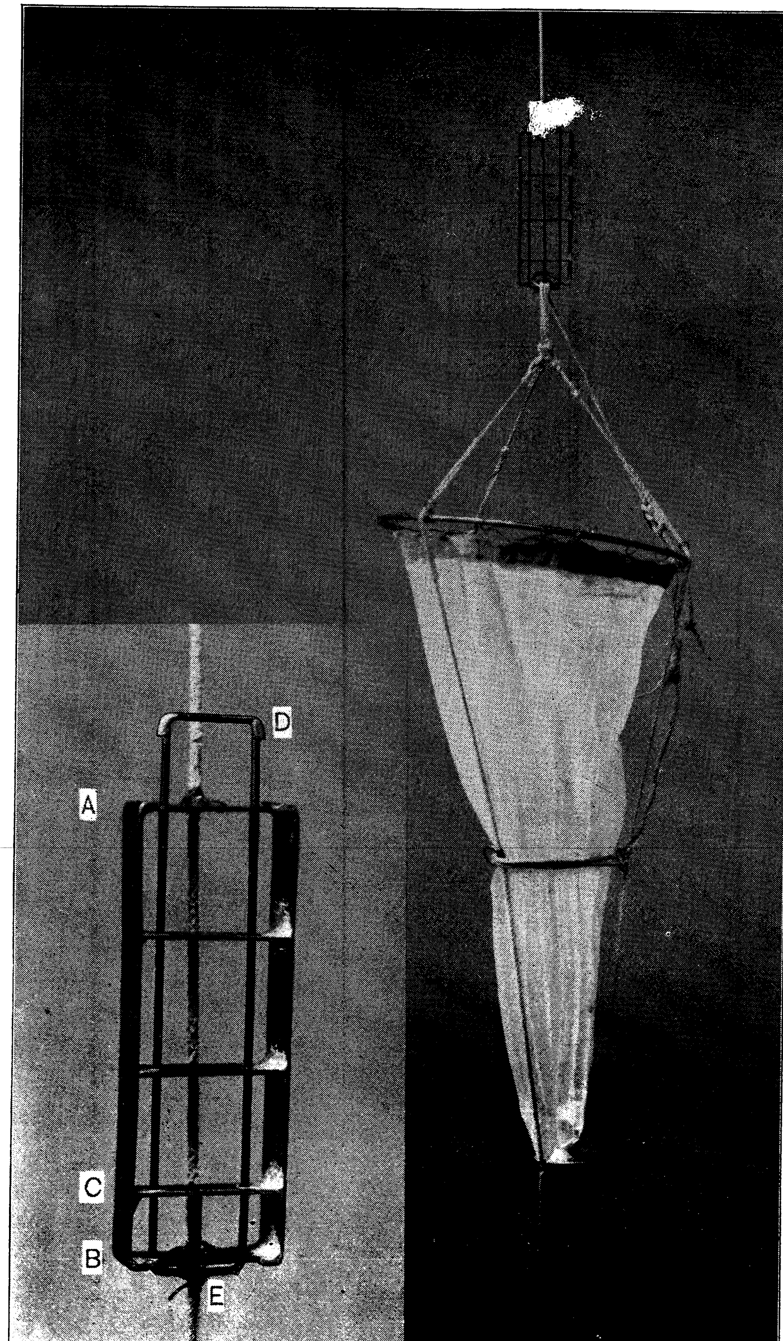
ANNUAL DISTRIBUTION OF CYCLOPS FLUVIATILIS.



ANNUAL DISTRIBUTION OF DAPHNIA KAHLBERGIENSIS.



ANNUAL DISTRIBUTION OF BOSMINA.



Closing Dredge and Releasing Apparatus.

Dredge as Mounted for Use on Ice.

DAPHNIA KAHLBERGIENSIS.

No. of Coll.	Total No.	*Per cent.* 0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–
1.94..	292	60.27	24.66	13.70	......	1.03	......	.34	......	......
4.94..	372	6.45	23.66	22.58	11.83	12.90	6.45	5.91	8.60	1.61
5.94..	377	25.47	21.22	20.16	16.97	3.18	6.37	4.24	2.12	.27
6.94..	419	39.14	21.95	10.50	15.28	9.55	3.34	.24	......	......
7.94..	419	43.91	30.55	16.23	1.91	3.82	......	.24	......	3.34
8.94..	345	46.38	32.47	14.49	2.90	.58	......	2.31	.58	.29
10.94..	353	31.76	37.39	14.73	6.79	3.40	1.98	1.70	1.70	.59
11.94..	414	46.37	13.53	27.06	7.24	1.93	1.93	.25	1.50	.25
12.94..	571	39.23	23.12	16.81	6.30	2.80	10.51	.70	.52	......
13.94..	641	77.38	16.85	2.49	1.23	.62	.31	.16	......	.96
14.94..	495	29.09	22.63	21.82	18.59	7.27	.20	.20	.20	......
15.94..	303	40.59	36.96	13.20	5.21	1.32	......	.33	1.66	.33
16.94..	140	62.85	21.43	10.	3.57	.71	1.42	......	......	......
17.94..	97	24.74	47.42	4.12	21.65	......	......	......	1.01	1.01
18.94..	248	77.41	8.07	9.84	1.61	1.61	......	1.61	......	......
20.94..	232	65.52	12.07	17.24	5.17	......	......	......	......	......
21.94..	236	28.81	35.59	22.03	10.13	.42	......	2.54	.42	......
22.94..	320	48.75	37.50	6.25	5.62	.94	.62	.31	......	......
24.94..	105	51.43	22.86	11.43	7.62	5.71	......	.95	......	......
25.94..	106	56.60	18.90	2.80	.90	20.	.90	......	......	......
26.94..	90	80.01	7.78	4.44	3.33	1.11	......	2.22	1.11	......
27.94..	242	52.07	6.65	23.14	12.81	4.54	.41	.41	......	......
29.94..	58	62.07	5.17	12.07	3.45	......	1.72	1.73	13.79	......
1.95..	3	66.	......	......	......	......	......	......	34.	......
2.95..	2	......	......	......	......	......	......	......	......	100.
3.95..	56	100.	......	......	......	......	......	......	......	......
4.95..	......	......	......	......	......	......	......	......	......	......
5.95..	1	100.	......	......	......	......	......	......	......	......
6.95..	2	......	......	50.	......	50.	......	......	......	......
7.95..	......	......	......	......	......	......	......	......	......	......
8.95..	25	......	32.	64.	4.	......	......	......	......	......
9.95..	9	......	89.	......	......	......	......	11.	......	......
10.95..	49	81.63	16.33	......	2.04	......	......	......	......	......
11.95..	33	3.03	48.49	......	48.48	......	......	......	......	......
12.95..	91	8.79	70.33	3.30	17.58	......	......	......	......	......
13.95..	137	......	29.20	52.57	8.76	2.92	5.84	.73	......	......
14.95..	89	......	35.95	35.96	8.99	3.37	13.48	......	2.25	......
15.95..	182	......	4.39	35.16	6.59	26.37	13.19	13.19	1.10	......
16.95..	28	28.57	57.14	7.15	7.14	......	......	......	......	......
17.95..	57	5.26	70.18	7.02	7.02	10.52	......	......	......	......
18.95..	170	42.35	9.41	9.41	32.94	4.71	1.18	......	......	......
19.95..	131	48.85	12.21	3.05	24.43	......	6.12	4.58	.76	......
20.95..	7	57.14	......	......	......	14.28	......	......	28.58	......

DAPHNIA KAHLBERGIENSIS.

D. kahlbergiensis did not occur in the collections from 1.96 to 7.96.

No. of Coll.	Total No.	0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–
8.96..	40	7.50	60.	20.	10.	2.50	......	......	......	......
9.96..	225	42.67	17.78	21.34	17.77	.44	......	......	......	......
10.96..	129	37.21	18.60	15.50	24.81	.78	......	1.55	......	1.55
11.96..	71	11.27	56.34	16.90	7.04	1.41	4.22	......	2.82	......
12.96..	325	39.38	29.54	24.62	6.15	......	......	......	.30	......
13.96..	84	14.29	19.05	47.62	9.52	9.52	......	......	......	......
14.96..	32	......	62.50	37.50	......	......	......	......	......	......
15.96..	5	20.	......	......	......	......	......	20.	20.	40.
16.96..	108	......	3.70	81.48	11.12	.93	2.77	......	......	......
17.96..	68	......	5.88	35.30	35.29	22.06	......	......	1.47	......
18.96..	73	21.92	......	32.88	35.62	6.85	1.37	1.36	......	......
19.96..	86	37.21	27.91	......	9.30	10.46	13.96	1.16	......	......
20.96..	92	60.87	8.70	6.52	4.35	13.04	3.26	2.17	1.09	......
21.96..	94	34.04	42.55	8.51	8.51	1.07	4.26	1.06	......	......
22.96..	78	10.26	30.77	35.89	12.82	3.85	2.57	2.56	1.28	......
23.96..	223	46.19	17.94	17.94	10.76	5.38	.89	.45	......	.45
24.96..	72	13.88	22.23	33.34	27.78	......	2.77	......	......	......
25.96..	61	59.02	26.23	6.56	6.55	1.64	......	......	......	......
26.96..	102	in	0–20	met'rs						
27.96..	16	18.75	25.	12.50	6.25	12.50	25.	......	......	......

During the fall of 1894 (see Pl. XI) the collections of *Daphnia kahlbergiensis* were quite uniform in amount, reaching a maximum in the latter part of October. During the winter the number was very small, and they did not become numerous again until June. There is a fall maximum again in 1895 in the latter part of October, but, curiously, the total numbers collected during the fall of 1895 are much smaller than in 1894. During the winter and spring of 1896 *Daphnia* was entirely absent from the collections. They appear again about the middle of May, and the largest collections of the year were made from June 29 to July 27. In August and September the collections were rather small, but the number became larger the latter part of October as in the preceding years.

Apstein ('96, p. 170) states that the species of *Daphnia* reach their maximum in August, but that *D. cederstroemi* is somewhat later, so that it would appear that my results in regard to the seasonal distribution of *Daphnia* do not agree very closely with his. It is probable that the various species of *Daphnia* may differ considerable in their periods of maximum occurrence.

Daphnia may be found at all depths, but is most numerous in the upper ten meters. In some cases, however, more than fifty per cent. of the catch is below the twenty meter line.

Very few *Daphnias* occur in winter, and I could not distinguish any effect of season on distribution.

The averages of the day and night hauls of '94 were as follows:

	0–5	5–10	10–15
Day, Oct. '94	38.39	24.43	15.40
Night, Oct. '94	54.48	23.01	13.46

These averages would seem to indicate a movement towards the surface at night. I am not sure that this inference is warranted, however, for the averages are of numbers with wide limits of variation, and I accept the conclusion with considerable doubt.

BOSMINA.

No. of Coll.	Total No.	Per cent.								
		0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–
1.94..	9	89.	11.	......	......	......	......	......	......	......
4.94..	57	56.14	14.04	21.05	7.02	1.75	......	......	......	......
5.94..	112	71.43	17.86	7.14	3.57	......	......	......	......	......
6.94..	98	65.31	16.33	4.08	12.24	......	1.02	1.02	......	......
7.94..	26	11.54	61.54	7.69	3.85	......	......	......	......	15.38
8.94..	95	42.12	29.47	22.15	4.21	......	1.05	......	......	......
10.94..	57	42.10	28.08	3.51	21.06	......	5.27	......	......	......
11.94..	106	75.47	7.55	.94	......	15.09	......	......	......	......
12.94..	280	31.43	10.	34.29	5.71	10.	8.57	......	......	......
13.94..	64	37.50	6.25	18.75	9.37	25.	......	......	......	3.13
14.94..	40	20.	50.	20.	10.	......	......	......	......	......
15.94..	85	47.06	28.24	9.41	14.12	......	......	1.17	......	......
16.94..	51	78.43	3.92	5.88	3.92	......	5.88	......	......	1.96
17.94..	7	77.92	6.49	6.49	5.19	1.29	......	......	......	2.59
18.94..	212	75.47	11.32	13.11	......	......	......	......	......	......
20.94..	64	56.25	6.25	28.12	6.25	3.13	......	......	......	......
21.94..	37	13.51	43.24	43.24	......	......	......	......	......	......
22.94..	72	38.88	50.	5.55	2.78	1.39	1.39	......	......	......
24.94..	151	70.20	13.25	10.59	3.31	2.65	......	......	......	......
25.94..	115	70.	15.	6.10	5.20	1.70	1.70	1.	......	......
26.94..	257	80.93	12.45	1.55	1.95	1.56	.39	......	.39	.78

BOSMINA.

No. of Coll.	Total. No.	Per cent.								
		0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45
27.94..	191	56.54	8.38	8.38	14.66	11.52	......	.52	......	......
29.94..	772	56.48	14.51	9.33	3.11	4.14	4.14	3.63	4.14	.52
1.95..	26	46.15	15.38	15.38	3.85	3.85	7.70	......	3.85	3.84
2.95..	30	26.67	......	13.33	26.67	3.33	3.33	20.	3.33	3.34
3.95..	49	81.63	8.16	......	2.04	8.17	......	......	......	......
4.95..	......	......	......	......	......	......	......	......	......	......
5.95..	5	40.	20.	40.	......	......	......	......	......	......
6.95..	1	100.	......	......	......	......	......	......	......	......
7.95..	3	100.	......	......	......	......	......	......	......	......
8.95..	4	50.	50.	......	......	......	......	......	......	......
9.95..	10	80.	......	10.	......	10.	......	......	......	......
10.95..	48	83.34	2.08	12.50	......	......	......	2.08	......	......
11.95..	40	60.	40.	......	......	......	......	......	......	......
12.95..	91	52.75	8.79	35.16	......	......	1.10	2.20	......	......
13.95..	61	52.46	13.11	4.92	......	3.28	26.23	......	......	......
14.95..	64	25.	37.50	3.12	......	10.94	9.38	......	1.56	12.50
15.95..	75	42.67	10.66	21.33	10.67	10.67	4.	......	......	......
16.95..	42	57.14	4.76	19.05	19.05	......	......	......	......	......
17.95..	205	85.85	7.81	1.95	......	3.90	.49	......	......	......
18.95..	288	58.33	8.34	5.56	11.12	16.65	......	......	......	......
19.95..	279	51.61	11.47	1.44	10.75	17.20	5.73	1.08	.72	......
20.95..	232	24.13	6.90	20.69	6.90	6.90	1.73	25.86	6.89	......
1.96..	75	16.	32.	8.	2.66	16.	13.34	8.	4.	......
2.96..	66	6.06	36.36	7.58	18.18	25.75	3.03	1.52	1.52	......
3.96..	12	......	8.33	8.34	33.33	33.33	8.33	8.34	......	......
5.96..	......	......	......	......	......	......	......	......	......	......
6.96..	2	100.	......	......	......	......	......	......	......	......
7.96..	8	100.	......	......	......	......	......	......	......	......
8.96..	165	82.42	14.55	1.21	......	......	......	1.82	......	......
9.96..	94	51.06	8.51	17.02	17.02	4.26	2.13	......	......	......
10.96..	71	67.60	2.82	1.40	22.53	4.25	......	......	1.40	......
11.96..	99	72.72	20.20	4.04	1.01	......	2.02	......	......	......
12.96..	79	81.01	5.06	5.06	6.33	1.27	......	1.27	......	......
13.96..	67	83.58	......	2.98	4.48	8.96	......	......	......	......
14.96..	2	50.	......	......	50.	......	......	......	......	......
15.96..	57	98.25	1.75	......	......	......	......	......	......	......
16.96..	86	83.72	1.16	......	4.65	8.14	1.16	1.17	......	......
17.96..	134	89.55	1.49	1.49	2.99	4.48	......	......	......	......
18.96..	82	87.80	......	9.75	......	1.22	......	......	......	1.23
19.96..	92	47.83	52.17	......	......	......	......	......	......	......
20.96..	479	67.64	16.70	10.02	2.09	2.50	.21	.84	......	......
21.96..	322	84.47	3.11	4.97	.31	6.21	......	.62	......	.31
22.96..	247	68.02	25.91	.41	.40	4.86	.40	......	......	......
23.96..	435	95.63	2.53	1.84	......	......	......	......	......	......
24.96..	109	88.07	7.34	1.84	1.83	......	.....	......	......	.92
25.96..	280	59.02	26.23	6.56	6.55	1.64	......	......	......	......
26.96..	438	in 0-	20 met	ers.						
27.96..	420	30.48	9.53	11.43	13.33	9.52	19.04	2.86	2.86	.95

Bosmina (see Pl. XII) was present at all times of the year. In only one collection during something over two years,—that of May 4th, 1896,—did I fail to find some individuals of this genus. Its time of maximum occurrence is in November. The numbers found in successive collections vary within very wide limits. For instance, Oct. 20, 1894, in a collection made between 2:15 and 3:15 p. m., I found only seven individuals, while in a collection made about two hours later, I found 212; and yet the conditions were apparently precisely the same.

In regard to its vertical distribution, its home is in the upper layers, although it is found occasionally at all depths.

In order to determine whether there was any difference in the vertical distribution at different seasons, I averaged the summer collections of 1896, from June to September,—7.96 to 17.96 inclusive,—and the winter collections of 1894–5 from November to April,—24.94 to 3.95 inclusive, with results as follows:

	0-5	5-10	10-15	15-20
Winter, 24.94 to 3.95	61.07	10.89	8.08	7.60
Summer, 7.96 to 17.96	78.18	5.05	3.02	9.91

While this would indicate a somewhat larger percentage in the 0–5 layer in summer, the difference is not very marked, and we may say that the vertical distribution is very little affected by the changes of season.

The averages of the night collections of 1894 compare with those of the day collections as follows:

	0-5	5-10	10-15	15-20
Night	35.77	22.70	22.20	5.88
Day	60.93	18.38	9.16	7.71

These figures would indicate that there is a distinctly larger number in the 0–5 layer in the day time than in the night, and I infer that is attracted, to some extent, at least, by the light.

DAPHNELLA.

No. of Coll.	Total No.	Per cent.								
		0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–
1.94..	29	55.17	20.69	3.45	......	3.45	13.79	3.45	......	......
4.94..	31	51.61	9.68	38.71	......	......	......	......	......	......
5.94..	27	88.88	7.41	......	3.71	......	......	......	......	......
6.94..	62	77.42	1.61	1.61	19.36	......	......	......	......	......
7.94..	24	66.66	16.67	8.33	......	......	......	......	......	8.34
8.94..	46	52.18	26.09	13.04	4.35	......	2.17	......	2.17	......
10.94..	25	80.	12.	4.	4.	......	......	......	......	......
11.94..	35	45.71	34.29	2.86	11.43	......	5.71	......	......	......
12.94..	47	59.57	4.26	4.26	17.02	12.77	2.13	......	......	......
13.94..	46	86.96	2.17	2.17	8.70	......	......	......	......	......
14.94..	11	9.09	36.36	18.18	27.27	......	......	9.09	......	......
15.94..	19	15.79	63.15	......	21.05	......	......	......	......	......
16.94..	......	......	......	......	......	......	......	......	......	......
17.94..	7	14.29	14.29	......	71.43	......	......	......	......	......
18.94..	1	......	......	100.	......	......	......	......	......	......
19.94..	2	......	......	......	......	......	......	......	......	......
20.94..	15	80.	......	13.33	......	......	......	......	6.66	......
21.94..	17	35.29	47.06	11.76	5.88	......	......	......	......	......
22.94..	16	25.	37.50	12.50	25.	......	......	......	......	......
24.94..	1	......	......	......	......	100.	......	......	......	......
25.94..	1	......	100.	......	......	......	......	......	......	......
26.94..	......	......	......	......	......	......	......	......	......	......
27.94..	......	......	......	......	......	......	......	......	......	......
28.94..	1	......	100.	......	......	......	......	......	......	......
29.94..	......	......	......	......	......	......	......	......	......	......
1.95..	......	......	......	......	......	......	......	......	......	......
2.95..	......	......	......	......	......	......	......	......	......	......
3.95..	16	100.	......	......	......	......	......	......	......	......
4.95..	......	......	......	......	......	......	......	......	......	......
5.95..	......	......	......	......	......	......	......	......	......	......
6.95..	......	......	......	......	......	......	......	......	......	......
7.95..	......	......	......	......	......	......	......	......	......	......
8.85..	......	......	......	......	......	......	......	......	......	......
9.95..	......	......	......	......	......	......	......	......	......	......
10.95..	1	100.	......	......	......	......	......	......	......	......
11.95..	......	......	......	......	......	......	......	......	......	......
12.95..	......	......	......	......	......	......	......	......	......	......
13.95..	......	......	......	......	......	......	......	......	......	......
14.95..	1	100.	......	......	......	......	......	......	......	......
15.95..	5	60.	......	40.	......	......	......	......	......	......
16.95..	26	66.54	30.77	7.69	......	......	......	......	......	......
17.95..	3	33.33	......	33.34	33.33	......	......	......	......	......
18.95..	8	12.50	12.50	37.50	12.50	25.	......	......	......	......
19.95..	......	......	......	......	......	......	......	......	......	......
20.95..	No	*Daph*	*nella*	from	1.96	to 8.96				
9.96..	8	88.88	......	......	11.12	......	......	......	......	......
10.96..	40	100.	......	......	......	......	......	......	......	......
11.96..	33	48.48	48.48	3.04	......	......	......	......	......	......
12.96..	18	88.88	11.12	......	......	......	......	......	......	......
13.96..	36	33.33	66.67	......	......	......	......	......	......	......
14.96..	50	4.	96.	......	......	......	......	......	......	......

DAPHNELLA—continued.

No. of Coll.	Total No.	Per cent.								
		0-5	5-10	10-15	15 20	20-25	25-30	30-35	35-40	40-
15.96..	201	99.50	......	......	......	......	.50	......	......	......
16.96..	141	56.74	31.21	8.51	......	......	2.12	1.42	......	......
17.96..	143	2.80	5.59	89.51	1.40	......	.70	......	......	......
18.96..	65	73.85	24.61	......	......	1.54	......	......	......	......
19.96..	211	15.16	51.87	26.54	.95	......	.48	......	......	......
20.96..	88	54.55	36.36	9.09	......	......	......	......	......	......
21.96..	22	18.18	45.45	36.37	......	......	......	......	......	......
22.96..	12	66.67	8.33	25.	......	......	......	......	......	......
23.96..	12	8.34	16.67	8.34	66.65	......	......	......	......	......
24.96..	2	......	......	50.	50.	......	......	......	......	......
25.96..	......	......	......	......	......	......	......	......	......	......
26.96..	......	......	......	......	......	......	......	......	......	......
27.96..	......	......	......	......	......	......	......	......	......	......

Daphnella is at its maximum in point of numbers from about the middle of August to the middle of September. From the last of October to the last of June, very few are found. Only in one collection made during the winter months did I find any *Daphnella*,—that of March 27, 1895. Friç and Vávra ('94, p. 103) state that *Daphnella* occurs from April to October. The observations of Apstein ('96, p. 166) very nearly agree with mine.

In regard to its vertical distribution, *Daphnella* may be found at any depth. By far the larger number, however, occur in the upper layers, ordinarily from seventy to eighty per cent. being found within ten or fifteen meters of the surface.

In order to get at the facts in regard to its vertical distribution, and possible migrations, I computed the average percentages in the upper four or five levels for the day and night collections of October, 1894, for the August collections,— all taken in the daytime,— of 1896, for the September and October collections of 1894, and for the collections of 1893, about twenty in number, made within two or three days in the latter part of August, with the following results:

	0–5	5–10	10–15	15–20
August, 1893	48.30	30.60	......	......
August, 1896	39.27	39.89	19.60	......
September–October, 1894	52.01	16.28	15.46	......
October, 1894, day	38.28	17.89	16.54	15.82
October, 1894, night	69.07	9.84	8.23	6.01

I do not think that the number of collections is large enough to draw inferences final in character in regard to the vertical distribution of *Daphnella*, especially since the total number in any collection is small. It would appear, however, that the upper five meters are more densely populated in September and October than in August and that the number is also greater in the upper five meters in the night time than in the day time. I do not feel like speaking in any dogmatic way in regard to the interpretation of these facts, but I venture to suggest that *Daphnella* is, in its vertical distribution, controlled rather by light and darkness than by changes of temperature. If it were very sensitive to changes of temperature the fact that it is found in greater numbers near the surface at night than in the day time, and also in greater numbers in September and October than in August would indicate a liking for cool water: but if this liking were very pronounced, it would seem that it would migrate deeper in August. If we suppose light to be the controlling factor, we would explain the greater number near the surface in September and October by the greater number of cloudy days in those months. Very likely the solution of this problem is not so simple as my speculations would indicate, and a satisfactory result can only be reached by a carefully conducted investigation in the laboratory of the behavior of the animal under different conditions of light and temperature. It may be noticed that Apstein ('96, p. 79) states that the time when the larger numbers are found at the surface, coincides with the time of total maximum numbers, a conclusion quite the opposite of what my observations would indicate. It does not appear, however, that his conclusions were based on any large number of exact observations.

GENERAL CONCLUSIONS IN REGARD TO VERTICAL DISTRIBUTION.

I had supposed that there was a general movement of the whole body of crustacea in such vertical migrations as existed. It is evident that this is not the case, for the different kinds have their individual peculiarities of distribution.

In the case of *Diaptomus* there is little or no vertical migration from any cause.

Epischura avoids bright light, and has a preference for warm water, and shows both seasonal and diurnal migrations.

Limnocalanus is repelled by bright light and by a high temperature, hence its diurnal migration is more pronounced in cold weather.

Cyclops brevispinosus occurs most abundantly between five and twenty meters in depth. I have no evidence in regard to its diurnal migrations.

Cyclops fluviatilis has no diurnal migration, but in its seasonal distribution shows a preference for the warmer water.

Leptodora is a surface form. I have no conclusive evidence in regard to its diurnal migrations.

Daphnia kahlbergienses apparently moves towards the surface at night.

There is no appreciable difference in the seasonal distribution of *Bosmina*. There is a distinct diurnal migration due to its attraction to light.

Daphnella has a diurnal migration due to the fact that it is repelled by light.

I cannot make out from my collections that the winds have any effect on the vertical distribution of entomostraca. The distribution when the surface is roughened by waves seems to be practically the same as when it is smooth. Neither is there any marked difference between dark and moonlight nights.

It must be remembered, however, that all my collections were at five meter intervals, and that there may be migrations within these limits of which I have no indication. I know for instance from surface tows that the immediate surface is almost entirely devoid of entomostraca in the day time, but is populated in enormous numbers in the night. There is evidently a very marked diurnal migration of most of the forms at the immediate surface, but it would take a series of collections at very short intervals to determine the limits of this genera. movement. These conclusions in regard to the surface phenomena are in harmony with the observations of Francé ('94, p. 35) and Birge ('95, p. 477).

THE HORIZONTAL DISTRIBUTION OF THE LIMNETIC CRUSTACEA.

The results of quantitative plankton determinations are entirely dependent on the assumption that the horizontal distribution of the plankton material is uniform. The laborious methods formulated by Hensen and his co-workers are founded on the assumption that over wide stretches of the ocean there is a practical uniformity in the distribution of the plankton. They believe that their investigations prove this assumption to be a fact. Their theory, however, has not gained universal assent. Haeckel (Haeckel, '90), among others, opposes it strongly. The same question has arisen in regard to lakes, and here it has a great practical importance, for if we can assume the horizontal uniformity of the plankton, then collections made in different lakes under similar conditions would furnish us accurate means of comparing the lakes in regard to the richness of the fauna and flora.

If this could be done, it would have a practical value in relation to the cultivation of fish, as we would expect that the lake rich in plankton would be especially adapted to nourish large numbers of fish. The question of horizontal uniformity of distribution in lakes has been actively discussed by many authors, and thus far with no uniformity of conclusions. Apstein ('92, p. 491) expressed his conviction from the measurements of plankton hauls and the counting of three comparative collections, that the distribution of the plankton in fresh water was practically uniform.

Friç and Vávra ('94, p. 118) come to a similar conclusion from their researches on the Unter Poçernitzer Teich.

Francé ('94, p. 34 ff.) from his investigations on Balaton See comes to directly opposite conclusions, and says that the plankton is very unequally distributed, and that the organisms occur in swarms.

Imhof (Imhof, '92) states that many of the organisms of the plankton occur in swarms.

Zacharias ('94, p. 129 ff.) enters into the subject in considerable detail, and gives his reasons for believing that the plankton is not uniformly distributed, one of his arguments being the very different character of the plankton at two distant points in Lake Plön, as determined by him.

Apstein again ('96, p. 51 ff.) takes up the question, and argues it at length, maintaining his original position.

Reighard ('94, p. 38) concludes that the plankton in Lake St. Clair and Lake Erie is distributed with great uniformity, and finds no positive evidence of swarms.

Ward in his report on Lake Michigan ('96, p. 62), concludes from his study of the plankton of that lake that there is no evidence whatever for the existence of swarms.

In my preliminary report on vertical distribution in Green Lake (Marsh, '94, p. 809) I stated that apparently the crustacea were not uniformly distributed. The figures of my collections of the past two years have served to confirm the opinion I expressed in 1894. It seems to me clear, that, so far as the crustacea are concerned, the horizontal distribution is far from uniform, and inasmuch as the crustacea ordinarily form the larger part of any plankton collection, it would follow that the distribution of the plankton is not uniform.

It must be remembered that all my collections were made from a buoy kept in one spot during the whole season, and in successive seasons, an attempt was made to drop the anchor as nearly as possible in the same spot. All collections, then, were made from the same depth of water in any season, and in very nearly the same depth in all the seasons. Now, if the distribution of the crustacea were uniform, collections made for the whole depth of water on the same day, or on successive days, should show nearly the same numbers of each species. Of course, if a species were rare, the fact that two or three individuals were found in one collection, and none in the next would not invalidate the assumption of uniformity. Nor even in cases where the numbers of a species were very large, would the fact that a considerably larger number were found in one collection than in another be any conclusive argument against the practical uniformity of distribution. Nor, on the other hand should it be assumed, because two or three successive hauls show the same, or nearly the same numbers, that the distribution is therefore uniform, because this could be easily explained by supposing that the swarm was of considerable extent or remained stationary for a considerable period.

My collections made in 1893, which were reported in the former paper, were made almost continuously in the course of two days. Now if the plankton is uniformly distributed, those collections should show a practical uniformity of numbers, and the more numerous a species was, the less should be the proportional variation. Yet the collections of *Diaptomus*, the most abundant genus, varied from 291 to 2,966. In many of the collections made in the fall of 1894 on the same day, or successive days, there was a marked uniformity in the numbers of *Diaptomus*, as for example, nos. 4.94, 5.94 and 6.94 show a range of numbers only from 4,171 to 5,630. If one were to base his conclusions on a small number of observations, he might well say that here was clear evidence of uniformity. Yet a few hours later in the same place I found only 2,023; with a difference as great as this, we certainly cannot speak of the *Diaptomi* as being uniformly distributed. In hauls 21.94 and 22.94, made in the forenoon of October 25, there was in one case 1,917 and in the other 3,823 — twice as many. Still more marked was the difference in two collections, one made at about six p. m., and the other between ten and eleven p. m., November 8. In the six o'clock collection there were 884, while in the evening collection there were 6,447. Such an enormous difference as this is certainly not consistent with any theory of uniformity of distribution. In these same two collections of November 8, *Cyclops fluviatilis* showed a similar wide variation,— the numbers in the six o'clock collection being 1,912, and in the evening collection being 564. October 24 I found between ten and eleven o'clock in the evening 1,241 *C. fluviatilis*, and yet the next morning between six and seven o'clock, I found only 618.

Limnocalanus is not a very good genus to consider in connection with this discussion, because it does not often occur in any large numbers. It is significant, however, that in successive hauls there were sometimes differences of from two to five hundred per cent. On November 14, 1896, I found in a collection made in the afternoon 56. In a collection made at about eight o'clock the same evening, I found 200 in the upper two and one half meters. In this case, curiously, the total number obtained in the other hauls from the surface to twenty meters was only 106.

An examination of the numbers of the other species as collected at similar times shows the same variations. None of them, however, seem to me to furnish such conclusive evidence as we get from *Diaptomus* and *C. fluviatilis*, because of the smaller number involved.

Thus my results are in harmony with those obtained by Zacharias and Francé. Inasmuch as one certainly would not question the accuracy of the work of the observers who have come to different conclusions, the question arises whether there is any way of explaining such differences I think a critical examination of their work and the inferences derived from it will show that such an explanation is possible.

In the first place I would state my entire agreement with the school of Hensen, that *only by an enumeration of individuals can we get at exact results in plankton work.* Volumetric determinations have a value in a general way, and may be used even in comparing different bodies of water, but only with a large allowance for the possibilities of error. Many of the difficulties in this method of work have been well pointed out by Ward himself. (Ward, '95a, p. 256 ff.). Most important is the difference in the time of subsidence due to the differences in the character of the plankton at different times and places. Some kinds of material will remain suspended for an almost indefinite period. Consequently, the volumetric method would rarely be sufficiently accurate to indicate even very considerable differences in horizontal distribution. There are, also, questions in regard to the accuracy of any gravimetric method that has yet been devised, although the amount of error by this method must be much less than by the volumetric method.

As a second principle I would say that *only a long continued series of observations on the same body of water will furnish sufficient evidence of the uniformity or lack of uniformity in distribution.* Two or three, or even several parallel, or successive collections do not furnish sufficient evidence.

Now, in criticising other observers, Friç and Vávra apparently determined the amount of plankton entirely by the method of weighing. Reighard and Ward made their comparisons entirely by the volumetric method, but in the results of both, there were certain discrepancies which could be most easily explained on the assumption that some of the organisms occurred in swarms. (Reighard, '94, p. 37, Ward, '96, p. 63.)

Apstein bases his opinion largely on volumetric determinations. He also furnishes an enumeration of individuals in three parallel hauls in the Dobersdorfer See, and two sets of two each in the Great Plöner See. These counts show a remarkable uniformity in the smaller organisms, but there is a considerable variation in the numbers of the crustacea, the difference being in many cases over 200 per cent. The only criticism one can make of Apstein's work is that the enumerations do not include a sufficient number of collections. While apparent uniformity in a few collections would be presumptive proof of a general uniformity, a single well authenticated case of unequal distribution would overthrow any conclusions founded on such collections.

Both Apstein and Ward raise the question as to the definition of the term "swarm." Now, it seems to me, the determination of the fact that limnetic organisms are or are not uniformly distributed is of first importance, and it makes very little difference just what meaning shall be attached to the word "swarm," until this question is decided. Without doubt the term has been used without any very exact meaning, as simply indicating a greater or less local aggregation of organisms, with very little thought of the cause of that aggregation, or of the exact or even approximate density of population that should be designated by the term.

Of course, as the result of my investigations I can speak only of the crustacea, and not of the plankton as a whole, except as the plankton, in many cases, is very largely composed of crustacea.

It seems to me that my collections clearly show that so far as the crustacea are concerned, while parallel or successive collections may show great similarity in numbers, they may, in other cases vary within such wide limits as to make plankton determinations unreliable, unless they are made from the average of a very large number of collections. Inasmuch as it is practically impossible to take a sufficiently large number of collections, it follows that plankton collections largely made of crustacea, cannot be taken as giving the exact measure of the productiveness of different bodies of water that some authors would have us think. We may say, indeed, with reasonable certainty, that one lake is much richer than another, but it seems to me very doubtful if we can express their relative productiveness by any definite numerical ratio.

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THE USE OF PARTIES IN MUNICIPAL GOVERNMENT.

ERNEST BRUNCKEN.

Few matters concerning our public affairs are discussed so much at the present time as the improvements required in the administration of municipal corporations. It is admitted by everybody that our various municipal governments are far from satisfying all reasonable demands of the citizens; but it is not always appreciated by those who are interested in the abolition of existing evils that there is a constant and considerable growth towards perfection in the methods of administration, a growth which is brought about, silently and without notice from the newspapers, by many of the men who are employed in administrative offices.

One of the principles which seem to be considered almost as axioms by most of the persons taking part in these discussions is that municipal affairs, including the election of municipal officers, ought to be separated entirely from party considerations. Yet we observe that the great body of voters continue to vote in municipal elections according to their affiliation with one or the other of the national parties. May not this be one of those cases, not unheard of in history, where the feeling of the masses is wiser than the reasoning of the enlightened?

If the matter is put in the blunt form in which many reformers like to put it: What have the views of a candidate on the tariff to do with his fitness for municipal office?— if, I say, the the question is put in this way, the answer is so obvious that the very plainness of it ought to create a suspicion that such a question does not include the whole of the subject. Even the despised multitude does not ordinarily entertain views which are absurd on their faces. May there not be a good reason why the mass of citizens should prefer to vote for a party to voting for individual candidates upon their own merits, even though that party be primarily organized for purposes entirely foreign to questions of municipal policy?

It may be doubted whether persons without actual experience in administrative office are ever capable of thoroughly understanding the problems of municipal government, no matter how deeply versed they may be in the science of administration and finance from the theoretical standpoint. By no means do I wish to depreciate those theoretical studies. I believe that in no way can our universities confer a greater benefit upon the country than by fostering the growth and propagation of political science. If our administrative officials could all receive a training equivalent to that required of the Prussian bureaucracy, our public affairs would reap an enormous benefit. Yet I maintain that theoretical knowledge by itself is less calculated to give a true idea of administrative problems than mere practical experience without theoretical training.

The excellence of administrative work depends principally upon attention to a large amount of details. This ought to be readily appreciated by the members of this organization who are accustomed to work in laboratories and seminaries. These details are in their nature uninteresting and often incomprehensible to outsiders. Consequently these outsiders never hear about them. They do not furnish "news" for the papers. The reporters pass them by with indifference as "routine matters." But whether an administration is good or bad must be determined by the manner in which "routine matters" are disposed of.

When the voters of a municipality are called upon to judge of the character of an official's work, what are their means of obtaining evidence on the subject? The overwhelming majority certainly have no opportunity of becoming acquainted with the details of the office business. Nobody can become acquainted with them except those in the office and a few persons in other departments of the city government. A limited number of persons who have frequent dealings with the particular department may acquire a partial knowledge of the manner in which the business is done. Yet even their opportunities of intelligent judgment are limited. If their own particular affairs are attended to courteously, promptly and skillfully, they will be satisfied, no matter what becomes of business with which they have no direct concern. But it may be a fair inference that, ir the business of one person is dispatched satisfactorily, the same will hold good as to other persons' affairs. On the other hand, it should not be forgotten that very often the interests of the persons having continuous business dealings with municipal departments are directly opposed to the interests of the city of the people. They will, therefore, in such cases, be satisfied with the work of an official in the exact degree in which he neglects his duty. For this reason he will make enemies of such men if his work is good, and friends if he does poor work. The generality of the voters, being unacquainted with the manner in which the duties of the office have been performed, are very apt to adopt the judgment of these few interested persons, whom they conceive to be competent to judge. Moreover, these persons, having a direct and strong personal interest in the matter, are usually very active either in support of their friend or opposition to their enemy, while the body of voters, who have no interest but of that mild and generally ineffective sort which every citizen has in good government, are indifferent and consequently powerless. Thus it very often happens that a conscientious and skillful official fails of re-election, while a corrupt or incompetent man gains additional popularity and an increased majority.

Besides the small number of persons who have a measure of opportunity of learning the manner in which business is done, through having constant dealings with the department, there is a larger number who come into contact with the official only occasionally. The opportunities of these persons for judging are evidently smaller than those of the first class, but on the other hand such people are not so likely to have interests adverse to those of the city. They are apt to base their judgment upon the impression received at their rare interviews with the official. If that person has an affable, courteous manner; if he shows a willingness to listen to complaints, crude and unintelligent though they may sometimes be, if he displays alacrity in assisting them in the transaction of their business; in fine, if they carry away with them an agreeable personal impression, it will require a great deal of evidence to convince them that a man who has treated them so pleasantly is not a good officer who ought to be re-elected. Now it is certainly highly desirable that a public official should be courteous and obliging in dealing with the public; yet this is but one of the many qualities he should possess, and not the most important one of them. Many an incompetent and even corrupt official has enjoyed great popularity because of his pleasant manners, while not a few faithful, competent men, whose services were of the highest value to the community, have lost their places merely because they lacked the faculty of pleasing the public in this respect.

Finally there is a third class, which comprises the great majority of citizens, who never come into contact with municipal officials unless it be the tax assessor. They have not even the minimum of personal experience enjoyed by the second class to help them in arriving at a sound opinion of an officer's qualifications. How shall they be guided? Some of them may be influenced by the views of the members of the first two classes. But the great majority are absolutely dependent on the newspapers for their information.

Now it is a fact that many departments of a city government but rarely furnish "news" for the papers; and when, once in a while, they do have a matter which in the opinion of the reporters is important enough to be published, it is of such a character that it does not help anybody in forming an opinion on the conduct of the business of the office. Other departments are more prolific of "news," but even in them the amount of work about which anything is published is infinitesimal as compared with the amount of work actually performed. Nor is the matter which is published always of greater importance than that regarding which the newspapers are silent, except from the standpoint of the reporter who wants to write a readable story. That which is printed, from the unavoidable imperfections in the methods of obtaining information by newspaper men, may convey an entirely mistaken notion to the reader, even when it is not colored by prejudice or interest. So it is seen that the chances of the voter who relies upon the newspapers for information to get data upon which to base an intelligent opinion, are very small indeed. These small chances are still further reduced by the voter's own negligence and indifference. For it is safe to say that the accounts of the conduct of municipal business are read systematically and regularly by very few people.

From these considerations it seems to appear conclusively that very few citizens in a large municipality are able to form a just opinion, based on well-considered facts and not on casual impressions, about the manner in which some particular official conducts his business. If an opinion is nevertheless formed, it will be found in ninety-nine cases out of a hundred that such opinion is unreasonable, no matter whether it happens to be right or wrong. It may be that our voter happens to disapprove of some particular measure adopted by the official. Immediately he becomes opposed to him; for that one measure was the only thing in the official's career about which this particular voter happened to know anything. Everything else the official has ever done this good citizen disregards simply because he is ignorant of it. Or it may be that a newspaper criticizes an official for some act it disapproves. The voter, who possibly has never before read or heard a word about this particular office, generalizes the newspaper's criticism, and while the writer merely meant to condemn this particular act, the reader disapproves of the official's entire conduct of office and votes against him at the next election. It may be that if this rash voter had the necessary information he would find that the officer's administration is of extraordinary excellence.

When the candidate about whom the voter is asked to form an opinion has not been in office before, it is even more difficult to obtain the necessary data. In the first place the number of people who have a personal acquaintance with the candidate is likely to be still smaller than that of persons who know a former public official. For the latter has many opportunities of making acquaintances which the man in private station lacks.

Even if the circle of acquaintances enjoyed by the latter is large, a considerable portion of it is of a merely social nature. But you cannot judge very well of a man's qualifications for public office whom you meet principally at the club and the dinner table. Still, a man who is at all likely to be a candidate must be known to a great many people who have business relations with him and are thereby enabled to judge of his business qualifications. Granted; but the largest circle of business friends contains but a small number compared to the whole number of voters in a great city. But may not these other voters safely rely upon the judgment of numerous intelligent men who have opportunities of judging? Assuredly they may, if those intelligent men are also unprejudiced and disinterested. But there's the rub! Both friendship and interest will lead the average man to maintain that the candidate with whom he happens to be connected has all the qualifications needed for the position to which he aspires. It should never be forgotten that with all but a few men self-interest is an infinitely stronger motive than public spirit. Where the two come into conflict, therefore, the latter will be defeated, except upon those rare occasions when men are for a moment lifted above their ordinary selves by the force of some strong emotion — be it love of country or blind fanaticism. Should a man incur the ill-will of a business friend because the public welfare demands it? That doctrine may find theoretical assent, but no practical obedience by the average, shrewd, hustling, money-making American citizen. In practice the voter will find, whenever he inquires about the qualifications of rival candidates, that each is surrounded by a body of supporters of equal intelligence, and having equal opportunities of gaining information regarding him.

But a man's qualifications for the administration of public business may surely be learned from the success he has had in the conduct of his private affairs? If he has succeeded in building up a prosperous business for himself, may one not reasonably expect that public affairs will prosper in his hands? This is a theory dear to the hearts of the leaders in those spasmodic reform movements which periodically sweep over most of our cities, leaving disappointment and confusion behind them. Much might be said on this subject — enough to swell this paper to intolerable proportions. It must suffice here to merely suggest two reasons why this theory does not help the voter very much in the perplexing task of choosing between rival candidates. In the first place it is by no means easy to say whether a man's success in private business is due to his ability or to other causes. Ability is but one of many things which singly or in combination lead to success in business. (Business, of course, is here used in the sense most commonly attached to it in every-day life, that is, money-making.) Besides ability, the amount of capital with which a man starts out; the connections which he is fortunate enough to inherit or acquire; the presence or absence of powerful competitors; complications of the market, over which the individual has no control; new inventions or discoveries which may favorably or unfavorably affect his branch of trade; accidents of flood and fire; and a hundred other things dependent on good or bad fortune are the factors which help to gain success for the business man. Furthermore, it often happens that a man is ostensibly the head of a business enterprise when the real leading spirit, unknown to the world, is some partner or subordinate. As the outside world can rarely learn the details of a man's private business, it is quite impossible for a voter to draw reasonable conclusions as to the qualifications of a candidate merely from his good or ill success in private business.

In the second place, it is a fallacy to infer that a man is well qualified for public office because he shows good ability in the conduct of private business. Both the objects and the methods of public and private business must of necessity differ widely, and consequently the training received in the one does not in all cases qualify for the other. I hope to have an opportunity some day to analyze this difference in detail. But the mere suggestion of the fact must suffice for present purposes.

What conclusion must we draw from these considerations? Simply this, that ordinarily it is quite impossible for the great majority of voters in our large municipalities to obtain information sufficient to form an intelligent opinion as to the merits and qualifications of candidates for municipal office. In the absence of such opinion, how shall the citizen be guided in his choice?

Men who are in the habit of basing their judgment upon evidence will not say for a moment that the voter should be content with an opinion based upon mere hasty generalizations from superficial impressions, and yet, that is all the average voter can do in the matter. He can select a particular candidate because he likes his manners; or because some friend, who may know no more than himself and who may not be disinterested, asks him to do so; or because he belongs to the same church or order as himself; or because he at some time or other did some particular thing of which the voter approved. All these motives and a hundred similar ones undoubtedly influence voters in innumerable cases, but not one of them can be called either intelligent or conscientious.

Here is where the utility of party in municipal government becomes apparent. It is much easier for the body of voters to judge of the general character of a municipal administration than of the details of each particular branch. By no means should it be imagined, that it is easy; but it is easier, or at least possible. Therefore if you may treat the entire administration as a body, and approve or condemn them in bulk, so to speak, your task is materially lightened, and the chances for good government are correspondingly increased. But the only way in which such solidarity of an administration can be attained in accordance with American institutions and habits of doing public business is by the instrumentality of party.

Here I may possibly be met by an objection on the part of some who admit that we should make use of party organizations in municipal government, but maintain that municipal parties should be distinct from those organized for the purposes of national politics. To men who have any experience in actual public life such a proposition hardly needs refutation. If men were purely reasoning beings, without emotions and affections, and above all without selfish interests, such a scheme might work well. But, as human nature is actually constituted, a party is not simply an aggregation of persons who entertain the same opinions on public questions, but to a far greater degree an organization of men who are bound together by common traditions, prejudices, sentiments; by mutual friendships and obligations; by the habit of working together, and finally by common interests. Under such circumstances it would be utterly impracticable for two sets of party organizations to exist side by side —one for national or state, the other for local purposes, in such a manner that men who fought shoulder to shoulder in national campaigns might be found on opposite sides in the intervening local elections. It is clear, therefore, that we must adapt the existing national parties, as best we may, to the purposes of municipal government if we wish so avail ourselves of party at all.

Now let us consider a little more closely the advantage of party government in municipal affairs. If the party is responsible for the administration, it will naturally exert its influence upon each individual official or department to do nothing which might involve the party in difficulties. Furthermore its influence will tend to bring the various branches of government into harmony. This is one of the most important conditions of a successful administration, for nothing can prevent efficiency so much as to have the various departments working at cross-purposes, through petty jealousies and personal dislikes. But such a condition of things is much less apt to arise when the various officials have been long connected through association in their party, than when they are for the first time brought together for a common purpose on the day they enter upon their respective duties.

Another advantage of party responsibility, and perhaps the most important of all, is that it tends to protect a faithful officer against the attacks of selfish interests and ignorant prejudices. In the course of his duties a public official cannot help incurring enmities of a more or less virulent character. It may become necessary for him to defeat the plans of some schemer to rob the public, or he may have to suppress some practice injurious to the public welfare but dear to the heart of its perpetrator. In such cases the public rarely upholds the official. For it is ignorant of the facts, or indifferent, or it may shar the prejudices to which the official ran counter. But the person that thinks himself aggrieved is full of the spirit of revenge, active and loud in his denunciations. In such a case the official is helpless and would almost invariably meet with defeat, if it were not for the sentiment of party loyalty which keeps large numbers of voters from listening to or believing the words of a candidate's personal enemies.

Finally, all the things which may be said in favor of party government in national affairs apply likewise to party government in municipal matters, and it must be admitted that all objections to the party system are equally valid. Now, I know very well that it is easy to make government by party appear absurd. It may even be conceded that if the system had not grown up gradually, but were presented for adoption in its full-fledged forms to persons previously ignorant of its workings, few rational beings would vote for its introduction. But it should not be forgotten that the American people are so used to the party system that they seem to take to it as if by instinct; that under it we have achieved national greatness and a fair degree of good government; that any other system will upon trial prove to be faulty just as well as the present one. It is impossible for the voters to judge fairly and intelligently of the individual merits of candidates. This difficulty can be overcome by the party system, in an imperfect manner, to be sure, but still overcome. Therefore, it is not the part of political wisdom to throw aside this imperfect tool until a more satisfactory one has been fashioned.

The improvement of municipal government lies in another direction. It must be found in devising ways to attract the best talent into public service, and keeping it there after it has been obtained. The administration of a great city in all its departments requires much special skill, training and experience. It is quite possible for the common-sense of all to administer the simple affairs of a rural township; but for the government of a metropolis that common sense must be assisted by specially trained ability or it will become common nonsense. The extension of civil service reform principles will go far to obtain such assistance. But lest, through civil service reform gone to extremes, we exchange our present evils for the greater evils of a Prussian bureaucracy, followed by the death of popular government, we must take care that the party system, through which alone the people can exercise an intelligent although imperfect control over its own affairs, be not lost to us and our posterity.

Milwaukee, Wis.

THE NEED OF A MEDICAL FACULTY IN CONNECTION WITH THE STATE UNIVERSITY.

ARTHUR J. PULS, M. D.

The medical laws in the state of Wisconsin show the following defects:

1st: The laws that regulate the practice of medicine are inefficient.

2d: The same is true of the laws that regulate the granting of charters to medical institutions.

3d: These laws do not provide for the appointment of a medical examining board.

4th: They do not provide for a medical faculty in connection with the University of Wisconsin.

The only medical law on our statute books is headed "An act to prevent quacks from deceiving the people by assuming a professional title." This law provides that the state or any county medical society may issue diplomas and grant licenses to practice medicine. Furthermore, the law allows any three adult persons, who have duly signed and filed articles of incorporation, to establish a medical society or school, giving with it the power to confer the degree of doctor of medicine with the privilege to practice medicine in the state of Wisconsin. Why is it that the Wisconsin legislators should be opposed to medical legislation? Why will they not enact efficient medical laws such as exist on the statute books of our neighbor states? Simply because we have no state medical faculty nor medical department in connection with our state institutions. About thirty states of the union possess stringent medical laws and fourteen states have medical colleges in connection with their state universities.

A radical change can be brought about at once by two legislative enactments:

1st: To establish a medical department in connection with the university of Wisconsin.

2d: To appoint a state board of medical examiners composed of members of the state medical faculty.

The formation of a medical faculty in connection with the state university is warranted:

1st: By history — professional schools come under the domain of state supervision.

2nd: By the tendency to raise the standard of the medical profession.

3d: By a demand for medical schools promoting higher medical learning.

It is true that the development of institutions of learning goes hand in hand with the cultivation of the people, but the professional schools of this country have been slow in development because they have lacked either state support or necessary endowments. In the old countries, to which men of the different professions of the new world migrate for the sake of higher learning, the universities are under full control and support of the government. The arts and their many branches, the sciences, as well as philosophy, theology, law and medicine, are fostered by the state, and the universities are dependent on the endowments of the state.

The University of Wisconsin possesses well equipped laboratories for the study of the natural sciences. A pre-medical course already exists. Now with the addition of two chairs of the medical faculty, anatomy and physiology, students of medicine can acquire an excellent scientific foundation and will be as well prepared to enter upon clinic work as they could in any existing school of medicine.

The first two years of the German medical student's work are occupied with the study of the natural sciences, physics, chemistry, botany and zoology, and with anatomy, histology and physiology. An examination — *tentamen physicum* — passes the student to a three years course of clinic and laboratory work of the many branches of medical teaching.

The need of higher, graded medical schools in America is strongly felt among the profession, and it is only a question of time when the inferior medical colleges will cease to exist.

The American Association of Medical Colleges has taken steps to lengthen the course of instruction from three to four years. Likewise in the German universities a change from ten to twelve semesters for medical departments is a subject for discussion in the Reichstag.

The Confederation of the Medical Examining Boards has under advisement the expediency of prescribing a higher degree of preliminary education for admission. President Eliot of Harvard, after congratulating the Alumni Association of the medical department of Harvard University on its initiation of the fourth year course, says: "The next thing for our medical schools to do (I would urge this on all medical schools), is to require for admission a first degree in arts, letters or science," and, he continues: "The American universities have long been peculiar in that their professional schools were wide open to any passer-by in the street, whereas the colleges were guarded by rigid examinations, but now our leading professional schools should no longer be open to persons of no academic training whatever."

The Johns Hopkins University is the only schoo at present requiring a bachelor's degree for admission, and its medical department is modeled after the German university.

The tendency to-day in medical investigation is toward the application of the researches of laboratory work. Each practitioner should be made an independent investigator. Medicine is rapidly becoming an exact science. Surgery seems to have reached its limits and internal medicine is harvesting the fruit of laboratory work. Private schools unless well endowed will not in time be able to compete with state schools nor meet the requirements of examining boards. To ensure and to promote the further advance of medical learning, it is absolutely necessary to hold the protection and support of the government and state for the American medical schools.

Milwaukee, Wis., December 29, 1896.

TRANSCENDENTAL SPACE.

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In this paper the term "transcendental" has not the same signification as when it is applied to quantities incapable of representation by a finite algebraic expression, but it is used to denote that which is beyond the limits of experience; and the question is presented whether certain space under consideration is not more than transcendental as distinguished from that which is empirical, or, according to Kantian terminology, is "transcendent."

However cordial the welcome constantly offered by the present age to new and broader forms of truth, it is probable that there is no field of investigation in which radically new positions are less generally expected than in mathematics. The fact that there is still in very general use, as a text-book, a mathematical treatise which has brought down through more than twenty centuries the name of its author, even though the Euclid of to-day is very different from the original work, still has seemed to furnish an ever-ready proof that, whatever else might change, mathematical principles remain the same "yesterday, to-day, and forever."

That biological or electrical science should manifest more or less of the traits characteristic of youthful immaturity, that in those realms of thought views formerly maintained should be repudiated, and opposing theories vigorously asserted, might reasonably be expected. Somewhat maturer sciences might perhaps so add to their stores of truth as greatly to modify their general aspect. But to many it has seemed evident that, while the changes in a system of thought and research of the venerable character of mathematics may, perhaps, greatly increase its power and widely vary its methods and details, they surely can affect in no respect the principles long considered to be firmly established.

That the last half of the nineteenth century should bring into notice mathematical views quite revolutionary in character is certainly a most unexpected fact, and one which has failed to receive the large general attention usually bestowed upon new views, partly on account of the greater interest along other than mathematical lines, and in part also because of an incredulity as to any possible place for such views as it has been thought, could be worth the attention of such students only as are specially devoted to the work produced by the genus "crank."

So it has been largely true that theories of multi-dimensional space have been treated as merely ingenious products of a vagrant imagination, worthy perhaps, if ably presented, of an honorable position among fairy stories but, to most minds, of nothing more than that. In fact only imperfectly is it generally realized that these theories present a field for serious consideration.

In a similar spirit have the various presentations of the geometry of "absolute space" been received, although in a somewhat less marked degree, probably because the last-named subject lends itself less readily to a graphic, or even romantic, treatment, such as is employed in books like "Flatland," "A Plane World," and other attempts to make higher space seem possible.

Still during the past quarter century the efforts of Dr. Baltzer of Giessen, and Prof. Halsted of the University of Texas, have brought into notice the work, now nearly seventy-five years old, of the Russian, Lobachevsky, and the Hungarian, Bolyai; and have secured for them a respectful and even highly appreciative recognition, in many cases indeed, as it seems to some who strive to consider the subject candidly, even unduly eulogistic. A hearty assent to the words of Prof. Loud of Colorado, when he writes to Prof. Halsted "You have made it impossible for American teachers of any spirit to shut their eyes to the '*hypothesis anguli acuti*'" may perhaps not be inconsistent with a pause for careful thought when we hear Prof. Clifford of Cambridge say "What Vesalius was to Galen, what Copernicus was to Ptolemy, that was Lobachevsky to Euclid," or when Prof. Sylvester of Oxford also compares Lobachevsky's "release of geometry from Euclid's parallel axiom to Hamilton's extension of the power of multiplication."

This assertion of the broadening of geometric truth calls for a brief statement of the essential principles of the Non-Euclidian geometry, as it was termed by Gauss, although Bolyai gave it the name Absolute Geometry, and Lobachevsky the somewhat more modest title Imaginary Geometry. This system, or these systems, of geometry are based upon a denial of the eleventh axiom of Euclid, known as the "parallel axiom," which declares "if a straight line, falling upon two straight lines, makes two interior angles on the same side less than two right angles, these straight lines continually produced meet upon that side upon which the two angles are less than two right angles," an axiom much longer than the other axioms of Euclid, and so differing from them in character that it has always, as it were, rested under a suspicion as to its being truly axiomatic. In the second century, indeed, Ptolemy denied its axiomatic character, although by no means its truth, and attempted to prove it; in which attempt he has been followed by an almost unbroken line of seekers. The Italian priest, Saccheri, covered one hundred quarto pages with what he considered to be a proof. Even that king among mathematicians, Gauss, undertook the same task, and about one hundred years ago wrote "if we could prove that a rectilineal triangle is possible whose content may be greater than any given surface, then I am in condition to prove with rigor all geometry. Most" he said, "would indeed let that pass as an axiom. I not. It might well be possible that, how far soever we took the three vertices of the triangle in space, yet this content was always below a given limit." In 1621 Sir Henry Saville spoke of this axiom as "a blemish on the most beautiful body of geometry;" and this view has been so general that, as has before been said, there has been an unbroken succession of attempts to remove that blemish, with results mostly of such a character that, when printed and distributed, they have been consigned by their recipients to some limbo dedicated to the productions of Lawrence Sluter Benson who, if still living, is without doubt earnestly engaged in his unappreciated efforts, extending over more than a quarter century, to convince the world of the truth of sundry unique statements like his pet discovery that the area of a circle is just three-fourths of the circumscribed square.

Yet the situation has certainly been remarkable,—an extended system of accepted truths resting upon an axiom which could not but be considered as "off color," and it is no wonder that there came a sense of relief at the assertion of the Non-Euclidian reformers that the parallel axiom is by no means a blemish on Euclid's work, but on the contrary an additional token of the perfect logic characterizing his thought. They assert as the cause of his failure to demonstrate the truth of this so-called axiom that it is not necessarily true, that it rests not upon pure reason, but upon experience, that Euclid attempted and claimed nothing more than "perfect deduction from assumed hypotheses," and that "in favor of the external reality or truth of these assumptions he said no word."

They then proceed to develop a system of geometry in which the two lines of the eleventh axiom need not meet, or, transferring the thought from this conception to one less cumbrous, but involving the same revolutionary change, a system in which the sum of the angles of a triangle need not be two right angles. Prof. Halsted considers it among the possibilities that instruments for the measurement of angles may sometime be devised sufficiently delicate to allow an experimental demonstration that the sum of these angles differs from its long accepted value by at least an appreciable fraction of a second.

A new space is thus presented for our consideration, differing form the space of previous thought in that it has an attribute of curvature, whatever that may mean. The space heretofore recognized, Euclidian space, is said to be space of zero curvature, like the plane of accepted properties. But there may be it is said, space of positive curvature, analogous to the surface of a sphere, on which the sum of the angles of a triangle is greater than two right angles; and there may be, also, space of negative curvature, analogous to the so-called pseudo-spherical surface formed by the revolution of the curve $y = a \log$

$\frac{a + \sqrt{a^2 - x^2}}{x} - \sqrt{a^2 - x^2}$ on which the sum of the angles of a triangle is less than two right angles. This last space is the space of Lobachevsky, while the space of positive curvature has been investigated by Rieman. Prof. Halsted inclines to the belief that the space of our experience is negatively curved, although so slightly that its curvature has thus far defied determination. And it would indeed seem that the attempt to measure this supposed curvature would not be unlike an investigation of the curvature of the surface of the earth by means of a careful measurement of the convexity of the surface of the water in an ordinary tub caused by the force of gravity. This belief about the familiar space about us is not, however, essential to the Non-Euclidian geometry, which only assumes the possibility of the existence of such spaces somewhere, and proceeds to develop corresponding systems of logical reasoning.

It only remains to add that, while curved spaces have only three dimensions, they are supposed to be contained in four dimensional space, as surfaces varying in respect to curvature are contained in space of three dimensions; and we now have the essentials of the entire system, which may justly be termed transcendental, as being beyond experience, even though our familiar Euclidian space be one of the contained spaces.

Entering now upon the central thought of this paper, it must not in candor be forgotten that a very small number of persons are to be found who claim that they possess a conception of four dimensional space, or more correctly, of four dimensional matter; since, curiously enough, for some reason they seem to need the material element to support their mental steps in the so greatly widened fields. But by far the larger part, even of those whose are inclined to believe such space to be possible, perhaps even probable, would assent in respect to their personal experience to the words of one of America's greatest astronomers, when he said that while he could not say what space of four dimensions might mean to him in another state of existence, it had no meaning in this. In fact it will hardly be denied that, to our minds with their present limited conditions of heredity and environment, transcendental space, whether it be transcendental on account of its curvature or its many dimensions, is incomprehensible. We may follow the steps of the mathematical reasoning by which its properties are demonstrated; but when we have done, we have a less definite idea of the architecture of that space than a following of the dream of Coleridge along the windings of "Alph, the Sacred River" gives us of the "stately pleasure dome" decreed in Xanadu by Kubla Khan.

Still, evidently this does not justify a mental consignment of the asserted systems to the realm of fantasy. The fact that mathematicians of acknowledged pre-eminence treat them with respect forbids any such summary disposal. Moreover, it is well for each one to recall the experience of his early years along a mental route not greatly varying from that which had been traveled by his ancestors within the period of recorded mathematical history, and to remember how the unreal negative quantity became a real conception; how those quantities, the general estimate of which as mathematical fantasies is still embalmed in their title as "imaginary" quantities, came to assume a sturdy reasonable existence; how narrow truths so broadened that the evidently true became untrue, as in the case of the commutative law of multiplication, when the conception of that operation was so extended as to include something more than successive additions; and from these and many similar experiences learn to expect further changes.

But with all this caution we can hardly avoid the question concerning such extension of our powers as will make transcendental space really an element of our thought; such as will make it a legitimate realm of mathematical research. Or the consideration may be presented in another form asking whether the mathematicians who with such patient ingenuity and supreme faith in logical truth have developed their conceptions of the possibility of absolute geometry, may not possibly have come to value the instruments of their profession so highly on account of their usefulness, that they have mistaken mathematical symbols for actual existences, and so have woven merely "the baseless fabric of a dream?" May it be that the words with which Bolyai, at the age of twenty, announced his discoveries to his father contain one truth more literal than he intended? He wrote of his new views "It would be damage eternal if they were lost. Now I cannot say more, only so much, that out of nothing I have created another wholly new world." These last words may perhaps remind us of the ancient adage "*Ex nihilo nihil fit.*"

The arithmetics of our grandfathers contained this problem:—"If a third of six be three, what will a fourth of twenty be?" which presented an entirely practicable excuse for certain elementary mathematical gymnastics, but effected no change in the fact that a third of six can under no possible circumstances be three.

Evidently, however, mathematical work can not be judged to be illegitimate merely because it rests upon a suppositious basis. But the question in any case may reasonably be asked whether the supposition is presented as a working hypothesis, a temporary scaffolding to be used in the erection of a real and permanent structure, or as being in itself a finality, although but an expression in mathematical form of an apparently inconceivable somewhat. From a point of view implied in this we may respond to Prof. Smith of the University of Missouri, when having stated the assumptions which distinguish the Euclidian geometry from the other systems, which he terms Hyper-Euclidian, he asserts the logical right of these systems to existence, and adds that "they lack neither interest nor importance." To this it is at least plausible to reply that such geometries, considered as laboriously developed systems of logical reasoning, without doubt have a right to existence, and possess great interest, especially for those whose chosen fields of work include the points of departure of the new thought. But it may still seem that their importance, which, like the importance of all truths, depends upon their place in the system of universal thought, and their relation to other parts of the system, may not be entirely unlike the importance of that harrowing question of our childhood.

"If all the world were apple-pie, and all the sea were ink,
And all the trees were bread and cheese, what should we have for drink?"

After carefully following the Non-Euclidian lines of reasoning, and recognizing their logical exactness, until their very rigidity seems to be a guaranty of a real subject of investigation, after all the question persistently returns, "What does it all mean, or what real elements has it?"

If, however, the question be asked whether mathematics has any right to be really transcendental, that is to deal with that which is beyond mental experience, the questioner may be reminded of the historical illustrations before mentioned, showing that by advances into the unknown it has become the known. But were not these advances essentially different from those of the Non-Euclidians? Negative quantities persistently presented themselves without invitation, and the advances made by Descartes and Harriot and others involved no introduction of new members to the mathematical state, but a bestowal of real intelligible rights upon supposed aliens already present. The same was true of "imaginary quantities" and the body of allied facts. Hamilton's extension of the powers of multiplication introduced no new existences. It merely made clear the existing relations between conceptions already recognized. If we follow the Theory of Functions of a Complex Variable until the magnitudes represented become too complex for our clear comprehension, they seem none the less real; and we may still see that the obscurity is due merely to an increasing complexity differing only in degree from that which we have already fully grasped, and from which as a stand point we trust we may be able to gain clear vision of that which is still beyond our sight.

But our relations to transcendental spaces are so essentially different from this that a belief in their existence comes near being a true act of faith, almost sublime in its completeness, reverently maintaining "Thus say the formulæ. We cannot understand; but we believe." Of course any fragments of experimental evidence must be given due weight. Even though space of four dimensions is utterly inconceivable, yet, if certain so-called spiritualistic phenomena persist in defying all other explanation, to whatever extent the fourth dimension makes otherwise irreconcilable facts consistent, by just so much is the effect of the former inconceivability diminished. So too the occasionally observed negative parallax of stars may perhaps be allowed as evidence in favor of the negative curvature of that space which our ordinary experience reports to be space of zero curvature. But perhaps this is balanced by Zöllner's work upon the darkness of the sky which he considered to give evidence in favor of a probable positive curvature. So in the face of these conflicting witnesses the question returns "What is curved space?" We are referred to the analogy of curved surfaces, and also to the impossibility of forming a conception of infinite space. We are reminded that a spherical surface, although unbounded, is finite, and that it is reasonable to infer an analogous attribute of curved space. But the curved space still declines acquaintance. Even if we seek to cultivate such acquaintance along the converging lines of the eleventh axiom, which after all are never fated to meet, the two lines with the intersecting line persist in maintaining themselves in a plane which, however, evidently cannot be the plane of our experimental knowledge, but some sort of a curved surface; and our space becomes still more inscrutable, as a multitude of curved surfaces stretch away beyond our mental vision.

Assume the possibility of such space, and the discussion of the relations between contained magnitudes is undoubtedly correct. If we close our minds against all questions of actual fact, the way is clear. But the old question remains, unless we are ready to accept an ancient form of assent to theological dogma, "I believe because it is impossible." Kant made all space a transcendental form of intuition, independent of experience, and considered the axioms of Euclid to be therefore necessarily true. But Gauss in opposition declared, "If number is merely a product of our mind, space has a reality beyond our mind, of which we can not fully foreordain the laws *a priori.*" Lobachevsky gave a most emphatic assent to the views of Gauss, basing his rejection of the parallel axiom on the assertion that its truth could be determined only by experience. In his address at the time of entering upon his work as rector of the University of Kasan, about one year after his presentation of the new geometrical views he said: "Mathematicians dis covered direct means for the acquirement of knowledge. But we have not long made use of those means. They are shown us by the celebrated Bacon. 'Stop working uselessly trying to draw all wisdom out of the reason. Ask Nature. She contains all truths, and will answer your questions surely and satisfactorily.'" It cannot then be out of place in the consideration of the views first proposed by Lobachevsky to demur at the logical building of a geometry without the rejected axiom, provided the "space" required for it be "absolute" in the sense of free from all conditions of experience.

In our Euclidian space we can form clear conception of planes, and of surfaces of greatly varying curvatures in widely separated or in intersecting positions. There is a wonderous fascination in the attempt to extend the analogy, and to think of varying forms of three dimensional space scattered through space of four dimensions, not necessarily far apart, but, like plane surfaces here, very near each other through their whole extent, though each of them be boundless. Perhaps we speculate on the possible intersections of the different spaces in surfaces, as in Euclidian space surfaces intersect in lines. We may reach farther, and ask if it may be that the four dimensional space is in turn one of the tenants of space of five dimensions. The grandeur of the thought leads us on, as did an obsolete theory that, as satellites revolve around planets, and planets around suns, so do these suns around others, themselves attendants on still grander centres, until, after long succession the universe revolves about the throne of God. Of this fantasy one of our most noted astronomers has said "The conception is so grand that it seems a pity that it is not true. But there is no evidence to support it." So, recalled from our dream of spaces, awaking we seek with earnest desire for evidence, and ask whether we must accept the belief that Hyper-Euclidian conclusions can have no place in really scientific thought because their space is "transcendent."

Ripon, Wis.

EXPERIMENTS WITH AVAILABLE ROAD-MAKING MATERIALS OF SOUTHERN WISCONSIN.

ELLSWORTH HUNTINGTON.

The subject of road-making has been almost entirely neglected in this country in so far at least as its geological features are concerned. Some attention has been paid to engineering problems in their relation to roads, but almost nothing has been done to find out the value of different materials in the construction of a cheap yet serviceable surface on our common roads. In most parts of the country the only practicable way of road-making which will be good at all times of the year is to put a crust of crushed stone from six to twelve inches thick on a foundation made of whatever soil the country happens to furnish. The most important conditions which the road-material must satisfy are cheapness, hardness or capacity for resisting the wear of horses and of wheels, readiness in cementing into a compact mass, and ease and cheapness of repair.

The necessity of cheapness is of course the most important factor. But it must always be borne in mind that the cost of a road built of any given material includes not only the first cost but also the cost of keeping the road in good repair. The interest on the first cost of a durable but expensive material has to be compared with the extra annual cost of repairs where a less durable and cheaper stone is used. This necessity of cheapness forbids the transportation of large amounts of material for great distances except for the most important roads. Since the glacial drift and the various bedded rocks of the Silurian are the only available material in southern Wisconsin and in a large number of the other states of the Mississippi Valley, it is probable that in view of the recent increase of interest in good roads they will be used in the construction of thousands of miles of roadway within the next half century. Under such circum stances it is well worth while to investigate the most economical and efficient ways of using the materials at hand. With this end in view a series of experiments was begun last fall in the laboratories of Beloit College, the results of which, as far as they have proceeded, are given below.

Experience has shown that almost all limestones are too soft to make good or economical roads. Although they cement readily they quickly wear away producing a disagreeable mud and dust and costing a great deal to keep in repair. The glacial drift, on the contrary, consists in considerable degree of pebbles which are much harder than ordinary limestone but do not cement readily. This hardness is due to the fact that in the process of glaciation the soft parts of any rock are ground to powder and only the hardest parts are left as pebbles. In most rocks the hardest parts are those which contain the most quartz, and in the case of limestone the pebbles which remain in the drift contain a great deal of infiltrated silica. While quartz gives hardness to a stone, it is a very poor cementing material. If we can find some way of firmly cementing the drift we shall be able to construct good and cheap roads. In the experiments carried on at Beloit a few tests were made with Trenton limestone, but in most cases the drift was the basis of work. The pebbles were crushed in the way usually recognized as best for macadam roads, namely into fragments of various sizes, the largest not to exceed one and one-half inches in diameter, and the very fine material screened off. From six to ten pounds of the crushed gravel was taken and to this was added a cement of powdered rock sufficient to firmly bind the mass of gravel. The cement consisted of several kinds of stone or of mixtures of the various kinds. After the crushed pebbles and the fine material were put together in a box and thoroughly mixed, the whole mass was wet down and pounded and rolled and then allowed to dry. This process was repeated several times until the whole became one solid mass. When this was thoroughly dry it was broken to pieces by allowing to fall upon it a weight so shaped as to give a blow as nearly as possible like that of a horse's hoof. In this way the surface was broken to pieces five or six times and the average number of blows required to break up the different mixtures was taken as representing their relative surface strength, the highest being scaled as one hundred. Then the same process was repeated with the difference that this time the whole depth of the mass, about two and one-half inches, was broken up into its original condition of loose gravel and fine material, and the results scaled in the same way as before. The average of these two ways of testing may be taken as indicating approximately the value of the different materials and combinations for use as cementing material on roads. The accompanying table shows the results obtained.

	Coarse material.	Cement.	Strength of surface.	Strength of whole mass.	Value.
1	Gravel.....	Diabase ½, blue limestone ½	100.	100.	100.
2	Gravel.....	Diabase ⅝, sand ⅜.....	81.6	75.5	78.6
3	Gravel.....	Fine granite ½, blue limestone ½............	38.3	86.5	62.4
4	Gravel.....	Fine granite ½, sand ½.	48.9	75.6	62.3
5	Gravel.....	Diabase	52.0	72.2	62.1
6	Limestone.	Blue limestone..........	58.8	58.8	58.8
7	Gravel.....	Fine granite	51.6	60.1	55.9
8	Gravel.....	Medium granite ½, blue limestone ½...........	53.3	55.6	54.5
9	Gravel.....	Coarse granite ½, blue limestone ½.........	45.3	62.2	53.9
10	Gravel.....	Gravel..................	43.4	44.0	43.7
11	Limestone.	Buff limestone..........	48.6	38.6	43.6
12	Gravel.....	Medium granite	42.4	44.8	43.6
13	Gravel.....	Sand	45.0	27.8	36.4
14	Gravel.....	Coarse granite.........	25.9	28.7	27.3

With the exception of the two kinds of limestone all the stones used in the experiments were selected from the glacial drift. The diabase was a compact dark green or nearly black rock. The granite of No. 3 was a fine-grained dark variety containing a large proportion of hornblend, no mica and but little quartz. Most of the crystals were not a sixteenth of an inch in diameter. The granite of number 8 was a little coarser, with crystals ranging up to an eighth of an inch in diameter. It contained rather more quartz and less hornblend than the preceding. The other granite was quite coarse grained and contained a small amount of hornblend with a large proportion of quartz. The gravel used as cement was taken just as the pebbles happened to come and represents the average gravel of Southern Wisconsin. The sand was taken from the drift and had a little clay intermixed. The limestone was of the Trenton variety, the buff being from the upper layer and of average hardness. The blue limestone was from a shaley layer and is the most compact and durable part of the Trenton limestone. It is, however, decidedly softer than the average pebbles of the drift.

If the materials used as cement in numbers ten to fourteen, viz., gravel with a value of 43.7, buff limestone with a value of 43.6, medium granite 43.6, sand 36.4, and coarse granite 27.3, could be placed on the road at equal cost, it would evidently be folly to use either very coarse granite or sand as far as binding is concerned. In many places where coarse granite can be secured cheaply it may, of course, be profitably used as the major part of the macadam if some first-class binding material is added. The other three materials, gravel, quite fine-grained granite, and rather soft limestone show the same cementing value of 43. The limestone is so soft that it can never be used profitably. Granite is usually harder than gravel, and also, for use as the main material of a road, it has another decided advantage. The results of a few experiments in which crushed stone was used, and not crushed gravel, bring out this disadvantage of gravel. In ordinary crushed gravel only about two-thirds of the surface consists of fresh fractures, and these alone cement readily. The other third is rounded and worn and not only does not cement readily, but also by its roundness tends to be thrown out and to make the whole mass of road material less firm and solid. This is an evil which cannot be avoided if gravel is used, but it may be lessened by rejecting a greater proportion of the smaller stones. It would be worth while to transport good granite at quite an expense by rail even if good gravel were close at hand.

Numbers 8 and 9, which are mixtures of medium granite and limestone, and of coarse granite and limestone, show about what would be expected, their values being 54.5 and 53.9. They prove that with stones like granite, which have a low cementing power, a good quality of limestone may be of considerable value as a binder. The diabase of number 5 with a value of 62.1, the limestone of number 6 with a value of 58.8, and the fine granite of number 7 with a value of 55.9 show nearly the same value as binders; but in actual practice limestone is much inferior to the others because of its low coefficient of wear, which is less than half that of diabase. Being rapidly reduced to a powder, it is washed away by heavy rains or blown away as a disagreeable dust. On this account roads on which it is used require constant repairs and its first cheapness is offset by this later expense. Numbers 1 to 4 are rather a surprise since they indicate that the cementing power of mixtures is higher than that of stone of a single kind. The cements and values of these four are as follows: diabase and limestone 100, diabase and sand 78.5, fine granite and limestone 62.4, fine granite and sand 62.3. In actual practice, if diabase were used as a binder for the upper part of a macadam road made of gravel, the cementing value would be 85 or 90 and if granite were used the value would be about 62. This means that a road whose surface was half gravel and half diabase would oppose twice as much resistance to the breaking action of horses' feet as would one made wholly of gravel.

The results of the experiments which have been described above are merely preliminary to future work and rest upon too small a body of data to be taken as final. Future and more accurate tests may and undoubtedly will give results which differ widely from those here given. There is urgent need for extended investigations along this line. Many towns are beginning to build macadam roads and if it be true, for instance, as these experiments indicate, that by spending fifty per cent. more for the transportation of basic rocks like diabase for use in connection with drift material in building the upper parts of the macadam, a road can be built which will last twice as long as one made of pure gravel, it is time the fact were known. The cost of building one mile of gravel macadam road fifteen feet wide and one foot thick is about $3,500 under favorable conditions. If instead of using gravel alone, we use it only for the lower eight inches and use a mixture of one-half gravel and half diabase for the upper four inches, the cost per mile would not exceed $4,800 in any part of Wisconsin. The interest on the extra $1,300 at 5 per cent. would be $65, but the surface of the road would be twice as durable and the cost of repairs instead of being two hundred dollars per mile per year would be only one hundred and there would be an actual saving to the taxpayer.

Beloit, Wis

ALUMINIUM ALCOHOLATES.[1]

ORIN EDSON CROOKER.

We distinguish the alcoholates as being those chemical com pounds in which the hydrogen atom of the hydroxal group in an alcohol is replaced by a metal. The name "alcoholate" has been applied in the past, and to some extent is applied at present, to certain compounds which result from the direct union of the alcohols with many inorganic salts and in which the alcohol seems to serve in the same capacity that water of crystallization does in crystals. In our work, however, it has been found more convenient to give to these substances the name "addition products" and to reserve the name "alcoholate" to those compounds alone which result from a direct attack upon the hydroxyl group of the alcohol itself.

The results of the work which has been done on this subject are to be found scattered throughout the chemical literature for the last thirty or forty years. Most of the more common alcoholates have been prepared, but in many cases not even analyses were made of them; for they are of so little stability, due to their hydroscopic nature, that they do not present a field of the greatest attraction to the chemist. Besides this we have to take into account that there has been found as yet but one class of alcoholates which can be purified by distillation. These are the aluminium alcoholates. They have been worked with only once, and that when Gladstone and Tribe prepared them about ten years ago by means of their aluminium-iodine reaction.[2]

[1] The work on the alcoholates as set forth in this paper, was done by Mr. Rolland Hastreiter and myself as thesis work in the University of Wisconsin under the direction of Dr. H. W. Hillyer, assistant professor of Organic Chemistry. Mr. Hastreiter's work was done on the methylate and propylate.

[2] J. Cem. Soc. 1881, (39) p. 1.; 1882, (41) p. 5; 1886, (49) p. 25.

Briefly told, this reaction consists in bringing aluminium and iodine together in the presence of absolute alcohol. Gladstone and Tribe worked with various alcohols, purified their products by distillation and made analyses of them which usually agreed within one or two per cent. of the theoretical proportions. In only one or two cases did they make melting or boiling point determinations.

While working with aluminium amalgam for the purpose of reducing organic compounds in neutral aqueous or alcoholic solutions, results were obtained which led to an investigation of the aluminium alcoholates which we found could be prepared by means of this amalgam. When metallic aluminium is treated with an aqueus solution of mercuric choloride it becomes amalgamated, and this amalgam possesses the property of decomposing water, thus liberating hydrogen, which, in its nascent state, forms a suitable means for carrying on reduction.[1] This amalgam can be used then as a means of dehydrating alcohol or of carrying on a reduction in an alcoholic solution if water is present or is added. If, however, we dissolve the mercuric choloride in the alcohol itself and place the aluminium in the solution, the metal not only becomes amalgamated but the alcohol itself is attacked in a way quite similar to that of the water—hydrogen being given off and the alcoholate being formed. During the reaction, which starts at once on bringing the aluminium into the solution, there is a considerable rise in temperature, sometimes to the boiling point of the alcohol; and in the case of some alcohols, the contents of our flask became quite gelatinous in the course of half an hour and finally solid. This is then distilled under diminished pressure and the product redistilled and fractionated, after which it is analysed.

During the whole process of the experiment the greatest care has to be taken to keep the substance out of contact with the air, as the slightest moisture will cause it to decompose with remarkable rapidity. Although mercuric chloride was used in our first experiments, it was found to be unsatisfactory because, on distillation, our product was certain to become contaminated by a small amount of mercury being carried over into the re

[1] Ber. d. chem. Ges. 28, 1895.

ceiver. Hence we made experiments to find a substitute which would prove more satisfactory. Good results were obtained in using platinic chloride and stannic chloride, and future work was carried on with fuming stannic chloride.

So far, experiments have been made with five different alcohols, and our results seem to indicate that the reaction is one which can be applied to the alcohols quite generally. The following are the results, briefly stated, which we have obtained by what we call our aluminium-stannic chloride reaction.

WITH ETHYL ALCOHOL.

We used 5 grams of chipped aluminium and 7 c. c. of fuming stannic chloride in 50 c. c. of absolute ethyl alcohol. The action began immediately, accompanied at first by a considerable rise in temperature, and continued at the temperature of the laboratory for three or four days, when the contents of the flask had become quite solid. This was then distilled *in vacuo* as follows. The apparatus was first exhausted to a pressure of from 12 to 25 mm. and the substance gradually heated until the boiling ethylate was just about to pass over into the receiver. During this first heating some alcohol always passed over, and it became necessary to substitute a clean, dry receiver in which to collect the distillate. After this had been done and the pressure again reduced, the distillation was recommenced and continued until signs of decomposition began to appear. The distillate thus obtained was then subjected to another distillation and fractionated, during which process its boiling point was taken. It was then analysed. The ethylate thus obtained was a pure white solid of a gummy consistency, boiling at 235° C. under a pressure of 23 mm. and melting at 135° C. It was only slightly soluble in absolute alcohol but more so in ether and benzene. Chloroform did not dissolve it. On analysis it gave

	Theoretical.	Found.	
		I.	II.
Aluminium	16.66	17.86	17.57

These results show that it corresponds more closely to the ethylate than to any other substance which might be formed, and they agree very well, considering its hydroscopic nature. In the beginning of the reaction there was always a deposition of spongy tin upon the aluminium, and it was found, in using small amounts of stannic chloride and allowing the reaction to take place more slowly, that the yield of the alcoholate was invariably larger.

WITH METHYL ALCOHOL.

In attempting to prepare the methylate by this reaction, Mr. Hastreiter obtained the same result as Gladstone and Tribe. Upon adding the usual amounts of stannic chloride to the alcohol and aluminium, a reaction began but soon ceased. A larger amount caused the action to continue, and finally a gelatinous mass resulted. On heating, however, under reduced pressure, no distillate could be obtained. From the reaction, however, and from other experiments which were made, he was led to believe that the methylate was formed, but that it decomposed on heating even *in vacuo*.

WITH PROPYL ALCOHOL.

Mr. Hastreiter succeeded without difficulty in preparing the aluminium propylate by this reaction; only it was found necessary to keep the temperature at that of the water bath during the reaction. On distillation the yield was large and of a delicate amber color when liquid but white and opaque when solid. It boiled at 255° C. under a pressure of 15 mm. and melted at 65° C. On analysis it gave

	Theoretical.	Found.	
		I.	II.
Aluminium	13.10	14.30	13.20

WITH ISOPROPYL ALCOHOL.

So far, experiments with isopropyl alcohol have been no more successful than those with methyl alcohol. An evolution of hydrogen takes place on the addition of the stannic chloride and continues, if the temperature is kept at that of the water bath, until a solid mass is formed; but no distillate can be obtained on heating under diminished pressure. Here, again, indications are that the isopropylate is formed but decomposes on heating.

WITH AMYL ALCOHOL.

With this alcohol it has been found that the amylate can readily be obtained. It is of a dark yellow color and boils at 291° C., under a pressure of 12 mm. No analysis has as yet been made of it.

The reaction involved in the formation of these alcoholates would seem at first thought to be very simple, since the product is a compound in which the aluminium has replaced, in each molecule of alcohol, one atom of hydrogen. This change in composition could be expressed, with common alcohol, by the equation

$$3\,C_2\,H_5\,O\,H + Al = (C_2\,H_5\,O)_3\,Al + 3\,H.$$

But this does not explain why it is necessary, for the progress of the reaction, to have present other things besides alcohol and metallic aluminium. By the initial reaction, when the stannic chloride is added, metallic tin is precipitated on the aluminium, and aluminium chloride is formed thus:

$$2\,Al + Sn\,Cl_4 = Sn\,Al + Al\,Cl_3 + Cl.$$

Both of these products seem to have an influence, as it is found that aluminium will not dissolve in alcohol in presence of tin alone and but slowly when aluminium chloride is present without the tin. The reaction is probably due to the action of the aluminium, or some compound of aluminium chloride with the alcohol, under the strain of the electric couple of which the tin and the aluminium are the negative and positive metals. The alcoholates so formed are themselves of considerable interest because they are one of a very small class of organo-metallic bodies containing oxygen which can be distilled, and because they show how, through suitable means, such a stable group as the hydroxyl group of an alcohol may be attacked and torn apart.

Further work which is being done will no doubt bring to light other results of interest, and it is quite possible that the reaction may be turned to account in a commercial way as a means of purifying certain alcohols from traces of others which are more easily acted upon by the amalgam.

Madison, Wis.

CODFISH. ITS PLACE IN AMERICAN HISTORY.

JAMES DAVIE BUTLER, LL. D.

The chief bearing on the escutcheon of Massachusetts might well be a codfish. It is more than a century since the legislature voted that the effigy of a cod-fish "should be hung up in the room where the representatives sit, as a memorial of the importance of the cod-fishery to the commonwealth." But even earlier than that date, which was March 17, 1784, the cod-fish had been honored in the Massachusetts legislative hall, for the vote was that it should be suspended there "as had been usual formerly." The truth is such a fish had hung in the Old State House which was burned in 1749. This time-honored monitor hovering over the heads of legislators became the more observed of all observers after a witty retort by the ultramontane Brownson to the Congregational champion Prof. Park who had charged Catholics with worshiping images.

"Indeed we do," answered Brownson, "but what images? We worship images of the saints while you worship the image of a cod-fish, and that in the midst of your grand temple." During the recent rebuilding of the Boston State House the ancient fish appeared to the building commission out of keeping with the modern improvements, and so it was relegated to a corner of the garret. This vandalism, however, roused such indignant protests that the venerable emblem,—reproduced in a more artistic style,—was reinstated in its place of honor which it now holds more firmly than ever.

There is no danger of over-rating the influence of cod-fish on the course of American history.

It is held by not a few French writers that Breton fishermen chasing whales, unawares pushed on so far west that they reached the banks of Newfoundland even before the voyages of Columbus and Cabot. It is certain that within a few years after those voyages the Bretons began there a lucrative cod-fishery which they have carried on to this day. When France was expelled every where from the American main she clung tenaciously to three fishing islands,— St. Pierre, and the two Miquelons — as invaluable for her cod-fishery. She retains them now a century after losing almost all her West Indian territory.

It is argued with much show of reason that but for cod-fish the Puritans would never have set their faces toward New England. We talk of Plymouth rock as its chief corner stone, but in the lowest deep behold a lower deep. Bartholomew Gosnold who in 1602 discovered Cape Cod, so named it from the fish that abounded there, and he thus furnished a descriptive name for the chart of Capt. John Smith. Smith's map was in the hands of the Pilgrims in their temporary Holland sojourn. They tell us that after hesitations whither to emigrate they resolved to go where fishing was best. The name James had on that map supplanted the *cod* of Gosnold but it was known to be given for currying royal favor, and reminded men all the more of the 60,000 cod which Smith had taken there. From the first it was foreseen that the cape could never lose the name Gosnold had given "till shoals of cod were seen swimming upon the top of its highest hills." There was talk of Guiana and Manhattan but, as Governor Bradford chronicles, "the major part inclined to go to Plymouth, chiefly for the hope of present profit to be made by the fish that was found in that country." They had heard that fishers from the west of England had made money on the Banks, and they trusted by planting themselves on a nearer base to make more. When their agents at the court of King James were asked by him what gainful business they could follow on the land-grant they sought for, their answer was the single word,— fishing! The soil at Plymouth yielded no crops till it had been fertilized by a fish thrown on every hill of corn.

Had the first-comers been provided with hooks or nets for catching cod, their first winter would have been exempt from famine. DeRasières,— the first visitor from Dutch Manhattan, wrote within seven years of the original landing: "The bay is full of fish-of-cod. When the people have a desire for fish they send out two or three persons in a sloop who in three or four hours bring them as much as the whole community of about fifty families require for a whole day." Had Plymouth been nearer the grand hive of cod it would to-day probably outrank Gloucester as much as Gloucester outranks it. Within five years after the forefathers landed, Gov. Bradford describes a great ship as clearing from there laden with fish well-fitted to go to Bilboa or St. Sebastian with a cargo that would sell there for £1800.

The larger Puritan colony at Boston a decade later than the planting of Plymouth, was attracted thither by fishing prospects. When an early preacher to settlers in that quarter was expatiating on their having adventured into the wilderness for freedom of worship, Cotton Mather writes that one auditor bluntly ejaculated; "Sir you are mistaken, our main end in coming here was to catch fish." The Puritans knew that in 1563 for the increase of fishing parliament had declared it unlawful to eat meat on Wednesdays and Saturdays under a penalty of £3 for each offense. They needed no such law to convince them that codfish were a richer mine than any one held by the King of Spain on whose dominions the sun never set.

All along the Massachusetts seaboard fishing became the leading industry and main reliance almost from the start. The armorial bearing of the state was early understood by Indians to be the cod-fish. That totem, as the aborigines would term it, was carried by her envoys to the New York Iroquois, a distant tribe, in 1690. Puritan punsters proclaimed a fish the best emblem of justice because both bore *Scales*. The Indian name for a Puritan was *Kinshon*, that is fish.

At every step in the history of New England the value of fisheries was clear. That colony was planted and largely developed by the aid of capital furnished from the mother country. The exports from the new country to the old — furs, lumber, fish and everything else were required for paying old debts or for the purchase of new supplies. No import of money from England could be hoped for. Nor could the emigrants keep the little they had brought over. Within ten years after his arrival Gov. Winthrop writes sadly, "Our money was now [in 1640] gone." (Journal II., 24.)

In this emergency attempts were soon made to keep money in the country by a law which forbade carrying it out on pain of forfeiture, and by a fiat money act for coining ninepences and ordaining that they should pass current as shillings. Hence originated the Pine Tree shillings of the Old Bay State now prized so highly by numismatists. The Puritans would not read Shakespeare, but, like his Jack Cade, they decreed that "seven half penny loaves should be sold for a penny."

Fortunately necessity soon invented a more excellent way for making money plenty in every man's pocket.

A new and better fish market than that in the mother country was discovered and utilized to the utmost. The navigation act commanded that all exports be first carried to England, but when the market there proved poor, exporters pushed on to Spain, Portugal and Italy where it was of necessity good. In those rigidly Catholic countries fish was indispensable,— thanks to fasts which had been abolished in England. The demand was great and increasing. Prices were high, and payments made, when desired, in the one thing most lacking and so most desiderated in the homes of the Puritans,— which was money,— gold and silver. Possibly the term cod-fish aristocracy was an Americanism coined to define the earliest variety of blue blood which cropped out in Boston. Cod had yielded them "the potentiality of growing rich beyond the dreams of avarice" which Dr. Johnson espied in Thrale's London brewery.

But the navigation act — based on the assumption that colonies had no rights which a mother-country was bound to respect — laid on the necks of American colonists a yoke too heavy to be borne. From the outset it was evaded without any conscientious scruples — especially in regard to the trade in fish to the West Indies. It was soon so far relaxed as to authorize sending fish to all ports south of cape Finisterre — the most northern point in Spain. The fish trade,— mainly in cod, expanded and was differentiated. The refuse culls, known as poor Jack became in the sugar islands the only luxury of Sambo, the medium grades contented his creole master, while the selectest variety — the dun-fish, enabled European grandees of the straitest sect in both church and state — to keep the most rigorous fasts without much mortification of the flesh.*

It is safe to say that none of these varieties of cod tasted so sweet to hunger-bidden fasters as the profits from them tasted to the Yankees when they had secured free course through southern markets. Their ciphering was of this sort: A vessel of 100 tons with twenty men fishing on the banks and voyaging to Portugal, Spain or Italy — perhaps selling half her cargo in the West Indies — will expend one thousand pounds. At the year's end her receipts may be expected to show a gain of 200 per cent.

It is no wonder that as early as 1709 the fishing navy was registered as already amounting to 30,000 tons, and that in 1741 the export trade equaled that of England itself and had risen to £100,000.

The cod-fishing was the cradle of an irrepressible conflict between the French and English colonists. In that industry they met each other first and oftenest, as well as in a life and death struggle. In all the history of our colonies we read of no such prodigal outlays and that in such arduous enterprises as those for dispossessing French fishermen. The conquest of Canada — or New France — began on its sea coast in 1713, when Acadia, where the Bretons had built their huts sixteen years before the May Flower sailed, was surrendered. It came to a final end there with the fall of Louisburg, the last maritime French stronghold in 1745, a decade before the seven years struggle for Quebec began. Judging by the order in which the Canadian provinces were conquered, fisheries were "the immediate jewel of the Yankee's soul." It was desirable in his view to repel the Indians from the inland frontiers where they were perpetually kidnapping and scalping, but the first and supreme duty was to extirpate the French who crippled the taking and the curing of cod.

Fisheries, in which cod has been easily the supreme element, have always been the chief nursery of the American marine strength, alike in war and in peace.

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* Hildreth, I., 473–476.

"If we had a war to-morrow," Admiral Porter wrote in 1888, —"we must depend almost altogether on the fishermen of New England to man our vessels." Without these auxiliaries it would seem that our revolutionary war might have been a failure. The captures they made in the first year of it — 1776 ran up to 342 vessels. They were the privateers who intercepted the transport ships bound for the British in Boston and took from them those munitions of war which turned against them their own arms, and crowned Washington's siege with success. But for Glover's brigade of Massachusetts fishermen military critics maintain that Washington and his army must have surrendered to the British in Brooklyn. But for the skill of the same naval experts the crossing of the Delaware — absolutely necessary for the surprise of Trenton — could not have been accomplished, — and probably would not have been undertaken. No statue in Boston was better deserved than Glover's on Commonwealth avenue.

That the fisheries were a chief corner stone of national prosperity was clearly seen by all the north during the war of independence. When congress began to consider on what terms they would make peace with England all members agreed that they would consent to nothing short of independence and territorial areas extending to the Mississippi and the great lakes. New England and New York went further. They demanded all the ante-bellum fishing facilities which their people had enjoyed. Their cry was, no peace without former fisheries. It was concerning this matter that the first important disagreement arose between the north and the south. The north would fight for fish abroad even as for firesides at home. But the states south of New York, having no share in the fisheries, were urged by our French allies not to insist on them as a sine quâ non of peace. France was a jealous competitor for the lion's share of fishing rights. Secret debates were long and heated. The result was that the American negotiators went to Paris without instructions to yield nothing of the ancient fishing privileges.

When the international commissioners came together Franklin at first demanded all Canada in the fullest meaning of the name. He had hopes of securing this concession which would have ended the fishery dispute at once. He was, however, constrained to be content with very nearly our present limits. He then declared one essential of peace to be freedom of fishing on the Banks of Newfoundland as well as elsewhere. This claim was readily agreed to by Oswald, the British commissioner, who wrote home in secret dispatches; "I own I wondered that he should think it necessary to ask for this privilege, and I doubted whether the exclusion of the New Englanders could be maintained without continuing in a state of continual quarrel with them. I suspected that drying fish was included in Franklin's demand though it was not mentioned." After much debate drying was allowed on all unsettled parts of Nova Scotia as well as on most coasts of Labrador and Newfoundland. These and other piscatory claims were most pressed by John Adams, the New England envoy, who was indignant that he was not permitted to proclaim that there could be no peace with the refusal of any iota of fishing freedom. Nothing in his career pleased him so much as what he thus achieved. He had a seal struck with the figure of a fish upon it and the legend *Piscemur ut olim*,* to be handed down in his family from generation to generation.

After the peace which closed the war of 1812 it was held by Great Britain that all fishing concessions had been annulled by that war. This contention was resisted by the United States. "Fishing privileges," said the younger Adams, "are not a British grant as Englishmen assert, they are a British acknowledgment." He spurned the word "concession."

At the international convention of 1818 the ancient fishing facilities were, in the judgment of Adams, substantially regained. But more than one subsequent treaty has been called for.

Webster was charged — his friends say falsely, — with willingness to cede Oregon to Great Britain in exchange for coveted fishing concessions. No one who knew that Webster was nothing if not a fisherman could be persuaded that he would relinquish any particle of fishery rights. No man who had handled cod lines and nets failed of faith in him when he said, "I am

* Hor. Ep. I. 6, 57.

yours, hook and line, bob and sinker, now and forever." A fishing treaty negotiated in London by Cleveland's minister, Phelps, was refused ratification by a republican senate. A reason given in confidence was that so good a treaty would add to the political capital of democrats. In public, however, the treaty was stigmatized as an unconditional surrender.

At no point is there a more galling friction in the relations between the English mother and her prodigal sons beyond tbe Atlantic. New treaties will be concluded, but no settlement beyond a *modus vivendi* seems probable until the granting of all that Franklin asked for — namely, the annexation of the Canadian dominion to the older brother shall in "the unity and married calm" of greater Britain render all treaties superfluous.

Ultimate union between us and our northern sister seems a foregone conclusion. It would be in line with our history, which records analogous unions on every other side. Witness Louisiana, Florida, Texas, New Mexico, California, Oregon, Alaska. One fifth of the population born north of us have removed within our borders, and this emigration is coming faster and faster. We have more persons by four score thousand of Canadian than of English birth. The Canadians who cling to their homesteads and we are more and more drawn together by the cohesive attraction of mutual interest reinforcing the ties of language and religion, as well as of identical aspirations and endeavors.

The quarrel about fishing rights may perhaps be settled in another way, thanks to Seward's securing Alaska. The codfish which are there numberless are in no point inferior to those which are the glory of eastern waters. The occidental banks are more enormous stretching over a larger area than the square miles of Ireland. The facilities for the capture and curing of fish are greater than on the Atlantic coast.

In 1890 the cod taken numbered half a million, and but for glutting the market the supply would have been ten times greater. This industry must advance in equal pace with the growth of the Pacific slope and the extension of trade in the East Indies. According to the United States commissioner's report the gulf of Alaska and Bering sea will whiten with multitudinous sails. In this way we shall outgrow dependence on any possible British favors. Whatever in the matter of bait, fishing or curing we have coveted and contended for will become not worth asking for or even accepting. May our fishery fights die such a natural death. *Requiescant in pace!*

The revolution wrought by codfish in our monetary nomenclature has not been enough considered.

The measures which American colonists brought from England we still for the most part retain. Our terms for length and area, as foot, acre and all through the scale are English. So are our measures of capacity from least to greatest. Our weights too from grains to tons are English. Neither the old French arpent, nor the new French meter has been introduced. We remain English in regard to all measures except those of value. Cleaving to so many heir-looms of English weights and measures why have we discarded the English measures of value, —ignoring the pound sterling while abiding by the pound troy and the pound avoirdupois?

Thanks to codfish! is the shortest answer and it is one not far from the exact truth. No colonies known to me save our own have rejected the monetary standards of their mother countries. But for colonial fisheries I see no reason to think that we should not to this day reckon in pounds sterling as well as in pounds avoirdupois and in pounds troy. But what was the genesis of the federal currency? How could it grow up out of colonial fisheries? How did we get our dollar? our recent apple of discord? The answer is simple. The exported fish brought home to us from their chief markets the bulk of the specie in colonial circulation — namely, those dollars which naturally became the real unit of value — wherever they had become the dominant coin. Any other silver would have done so.

The coin " dollar " came into the American colonies, directly or indirectly, chiefly from Spaniards. The name dollar — unknown in Spanish even now — was derived from the German tongue — and probably came into American use from the Dutch founders of New York.

The word dollar has a curious history. Ten miles from Carlsbad, so well known to American invalids, there was a Bohemian mediaeval mine rich in silver. The place was called Joachim's thal, or the dale of Joachim, so named in honor of an ancestor of St. Joseph. The richness of the mine led in the year 1518 to a coinage with little alloy, and which thus gained high repute and wide circulation. The name Joachim's thaler, contracted as all long words must be if much used, became *thaler*, i. e., valley-piece, and a synonym of good money. Hence its good name was stolen by many inferior coins. "There is no vice so simple but assumes some mark of virtue in its outward form."

Those pieces which were minted in Joachim's thal, which was in the German empire or *Reich*, were called Reichsthäler — that is in English, Rix-dollars, in Dutch, Rijks-daalder, and in Danish with little change from the Dutch form.

The earliest use of the word which I have observed was in 1606. Shakespeare in Macbeth (I. 2. 62). then spoke of slain Norsemen denied burial till their king had disbursed ten thousand dollars.

When the first dollars were stamped, Spain being a part of the German empire, it was natural that the imperial standard-piece, the Reichsthaler, or rix-dollar, should be adopted as the Spanish unit of value. It thus spread abroad wherever the money minted from American mines circulated. The name, or certainly the coin was quickly known in Egypt, for George Sandys, travelling there in 1611, says that he hired a boat for twelve dollars. (p. 117.) Sandys often uses the word dollar. He tells us (p. 205) that Dutch dollers (sic) throughout Jewry and Phenicia "were equivalent with royals of eight, elsewhere less by ten aspers." He adds (p. 86) that "Constantinople was well stored with pieces-of-eight which in no place lose (aught) of their value." He found the monastery on Mount Sinai to be receiving an annual revenue of 60,000 dollars from Christian princes, and thus able to keep open house for all comers. (p. 124.)

On the western continent the name came into use not much more slowly than the coin. In 1642 it was ordained by Massachusetts authorities "considering the often occasions we have of trading with the Hollanders of the Dutch plantation and otherwise, that the Holland ducatour (sic) shall be current at six shillings, and the rix-dollar and Ryalls-of-eight shall be five shillings." (Mass. Col. Rec. II: 29.) The next year a similar ordinance was passed in Connecticut, that good Ryall-of-eight and Rix-dollars should pass at 5 shillings. The prefix Rix is a corruption of the German word *Reich* which means empire, and coins stamped by imperial authority bore the word *Reich.* From the tendency of words to contraction, and because the syllable Rix meant nothing to ears unused to German, it was dropped in common parlance while the word dollar survived.

The name dollar could not fail to be extended to the Spanish pound which is *peso*, or piece-of-eight, [Royals or Ryalls] and to supplant in English speech that latter circumculotion. The value of each was the same. Besides, when a single word expresses the meaning of a phrase, the shorter expression will displace the longer. Thus the French word portage ousted the English word carryingplace.

Pieces-of-eight flowed into New England from southern Europe and the West Indies, partly in return for fish and partly from the half piratical buccaneers who made booty on Spanish commerce. In early Plymouth Gov. Bradford describes one Capt. Cromwell who in 1646, having made rich prizes, scattered a great deal of silver among the pilgrims, and as was feared, a great deal more sin than silver. In 1740 Capt. Hull of Newport, made such a capture that the share of every man on his ship was proclaimed in the Boston News Letter to amount to more than a thousand pieces-of-eight. In 1687 the Yankee skipper Phips, with his divers, brought up a million and a half of such pieces from the sunken wreck of a single Spanish galleon. But these spasmodic windfalls were trifles compared with the steady streams which gushed forth from the perennial fishery fountains.

The codfish dollar thus became early the real unit of value, though the pound so continued in name till near the close of the eighteenth century. The Spanish divisions of the dollar,— as well as the dollar itself, predominated in American circulation, while English names were given to the pieces. Thus the Ryall, or royal was called a nine-pence and its half a fourpence-ha' penny. These Spanish fractions formed most of the small silver — or change — current in the United States during the first half of the present century. This fact is shown by the rates of postage which up to 1845 were fixed in conformity to the size of those bits. We see on old letters the postage marked $6\frac{1}{4}$ cts. because the smallest Spanish silverling passed at that value. Otherwise, full postage could not be fully paid as no quarters of a cent were minted. Economical men used to pay in copper, and thus saved four per cent. on their outlays. During 23 years before 1828 not one half dime was issued from the U. S. mint, and the whole number before issued was but little over a quarter of a million, (265,543); $13,279 in other American coins were struck off on a similarly scanty scale.

Thus we owe our currency formally adopted by congress in 1786, but used in business long before, to codfish. It brought us the coin dollar as its monetary unit, and the name dollar with all its divisions — and some that still survive, as really as though every cod had held in his mouth a silverling like the fish in which St. Peter found the stater for paying his tribute and his Master's.

The minor relations and uses of our great Yankee fish are not to be despised.

The cod is of voracious appetite — and is even less fastidious than the ostrich. It has hence been praised as the great collector of deep-sea specimens otherwise unattainable by naturalists. Many are the rare and curious shells which have been obtained from its capacious and omnivorous stomach.

The oil of cod-fish has often proved more precious than its flesh. No animal oil has been found so digestible as that expressed from the livers of cod. Nothing more enriches blood with red corpuscles or adds more to the store of fat. As a remedy for rheumatic diseases and general debility its therapeutic excellence has been long known and appreciated. Its importance, however, as a specific for pulmonary consumption it was reserved for a recent period to discover, or at least to exploit to its fullest and best applications. The medicinal virtues of cod can be here only hinted at. Were half of them declared in this paper it would be accounted a quack advertisement in disguise. Let me fall under no such suspicion.

In Puritan ages codfish yielded a dish too dainty to be sent away altogether to papists and heathen. It formed so large an element in the Massachusetts food supply that it long ago had the sobriquet of Cape Cod pork. The Puritan would not touch it on Friday lest he should become like his customers Catholic or pagan. But on Saturday he fed upon it with a zest that was all the sharper for his Friday fast, and gathering up the fragments that nothing be lost, ate the remnant on Sunday with double appetite, since he knew he was not breaking the Sabbath by non-necessary cookery.

Surveying the past and present of codfish one easily believes that the greatest is behind. Let no man say that blessings as yet unhoped for and undreamed of are not hidden within the multitudinous depositors in our national fishing banks, blessings that shall be revealed to us or to our children till the Puritan's thanksgiving that God had vouchsafed him to *suck of the abundance of the seas* * shall have a tenfold fullness of meaning.

* Deut. 33, 19.

Madison, Wis.

PLANKTON STUDIES ON LAKE MENDOTA. II.

THE CRUSTACEA OF THE PLANKTON FROM JULY, 1894, TO DECEMBER, 1896.

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INTRODUCTION.

The following paper is a continuation of the work done by myself with Messrs. Olson and Harder, in the summer of 1894, published in the preceding volume of the Transactions of this Academy. (Birge, '95.) The study carried on in that month showed a vertical distribution of the crustacea so unexpected and peculiar that it seemed to me worth while to continue the investigation throughout an entire year. A few observations were made in the latter part of August, 1894, and on September 18th, regular observations were begun and were continued until the close of December, 1896. During the fall of 1894 observations were taken on 28 days. In 1895 observations were taken on 110 days, and on 126 in 1896. The details of the number of observations and of the days on which they were taken will be found stated in Table A given at the close of this paper. During the late spring and summer months as many as three observations per week were taken. During the winter season, the late fall and early spring, observations were necessarily fewer in number, and occasionally a period of two weeks would pass without an observation. At this time of the year, however, the crustacea are not varying greatly in number, so that small error results from these gaps.

I had intended at first to carry my observations through one year only, but as a peculiar annual development of the crustacea was found in the course of the year 1895, it seemed to me advisable to continue the observations through the season of 1896, in order to determine whether the course of development would be the same as in 1895. Until August, 1896, the number of the crustacea in each catch was determined separately, and the average catch for each two-week period was computed. After that date the catches for each two-week period were mingled together, and the average number only was determined. Up to August, 1896, therefore, the average, maximum, and minimum catches are given for each period, in the tables of the appendix, but after that date it is possible to state the averages only. This "two-week average" is the main number used in this paper.

The net employed was that described by me in my former paper, and the method of counting was substantially the same, except that a smaller fraction than one-sixth was often used to determine the large number of crustacea from the upper levels of the lake—one-tenth to one-fifteenth being ordinarily employed, with a view to making the last figure of the resulting number 5 or 0, in order to facilitate adding and multiplying in subsequent operations.

The multiplications to reduce the catch to the number per square meter of surface were performed by the aid of Crelle's Tables. The products are stated in this paper in thousands and tenths, in order to avoid the constant use of ciphers in the last two places. The result would have been quite as accurately expressed in most cases if the nearest thousand had been stated, but in case of the smaller numbers it was necessary to state the hundreds, and as the products were read off directly in all cases in hundreds, I concluded to leave them in the printed results, although, of course, understanding that no reliance is to be placed on the exactness of the enumeration in the last place of figures if the total is large.

The total number of serial observations was 333 besides 97 single catches, and as there were at least six collections in each series, and from three to eleven species of crustacea to be determined, the number of single observations is very large — over 10,000. It has been my aim in preparing this paper to exhibit these results in a graphic form so that they might appeal to the eye, and to print only the summaries of my observations; rather than to confuse the reader by presenting him with the great mass of figures which would be needed to exhibit the results of the single observations.

In preparing the diagrams which accompany this paper, the average number of crustacea for each two-week period was determined and was platted at the center of the space representing the period; and the averages of successive periods connected by a line.

It has been found impossible to use the same scale in platting the annual distribution of the different species of the crustacea. Where numbers range from less than 25,000 to over 3,000,000 per square meter, it is not practicable to use the same scale for all species. The scales employed range from 25,000 to one vertical space, to 200,000 for the same distance. In all cases the scale is stated on the margin of the diagram. No attempt is made to show by a curve the rate of variation within the two-week period, since this variation is quite too irregular to permit a curve to be drawn with any accuracy.

I had intended to introduce this paper by a preliminary account of lake Mendota accompanied by a hydrographic map. Some hundreds of soundings have been made by myself and by the Department of Civil Engineering of the University of Wisconsin, but the preparation of the map has been delayed, and it is therefore impossible to insert the account at this place. I must therefore refer to the brief account given in my former paper, merely stating here that the lake is about 6 miles (9 kilometers) in length by 4 miles (6 kilometers) in greatest breadth, of a somewhat regular shape. No greater depth than 24 meters has been found; a large part of the lake is deeper than 18 meters, and the bottom is very flat without irregular depressions. The principal observing station was near the southern side of the lake, about 2,700 feet (850 meters, from the southern shore, and in 18.5 meters of water. The second principal station was about a mile and a half (2 kilometers) from the southern shore, and in 22 meters. The principal station was marked by a buoy, so that the observations were taken at the same spot.

During the winter observations were made through the ice, the net being suspended from a tripod. While it is very easy to make a single haul of the net at any temperature in the winter, it is very difficult to make a series if the temperature is materially below —6° C. At lower temperatures, or even at this temperature on a cloudy day and with northerly wind, the net freezes so rapidly that work is extremely difficult and slow, as time must be taken for the net to thaw in the water before a second haul can be made. The line also becomes so heavily coated with ice and so slippery and stiff that it is impossible to secure accuracy in the time of raising the net. While therefore the pleasant warm days of winter offer the best possible occasions for working the dredge, the average work in winter is extremely disagreeable. It is, however, more difficult to secure continuous observations during the periods immediately preceding the formation and the breaking up of the ice than it is in winter. The lake freezes near the shore so that it is difficult to get out with a boat, while the ice is still too thin to bear the weight of a man; and as there is no current in the lake, the breaking up of the ice in the spring is ordinarily very slow and there is always a number of days in which the ice is too weak for safety. After the breaking up of the ice a continuation of north winds may keep the sludge ice on the southern shore, and thus still further delay observations, as was the case in 1896.

In carrying out this work it has been my endeavor to make a contribution to the natural history of an inland lake as "a unit of environment," to employ Eigenmann's appropriate phrase. (Eigenmann '95, p. 204.) I have, therefore, discussed somewhat freely the causes which seem to me to have contributed to the peculiarities of the annual and vertical distribution of the crustacea. I do not suppose that my conclusions are correct in all particulars, still less that they are complete. The causes determining the biological conditions of a lake are far too numerous and various, and their inter-relations far too complex to be understood at present with any accuracy. It has seemed to me, however, that the aim of plankton investigations should be to reach an understanding of these conditions, and I have therefore put out the suggestions of the final sections of each part of my paper, with the hope that they will stimulate others to similar attempts and thus lead to an enlargement of our knowledge and to the correction of whatever errors may be present in my conclusions.

THE COEFFICIENT OF THE DREDGE.

One of the most difficult and unsatisfactory portions of plankton investigation has been the determination of the coefficient of the dredge. It is well known that the net when raised through the water offers a certain resistance to the passage of the water, so that a part only is filtered by the net, while another fraction is displaced. The determination of the relative amounts of water filtered and displaced is the determination of the coefficient of the dredge. Many attempts have been made to determine this quantity. The most elaborate investigations have been made by Hensen (Hensen, '87, p. 11, and Appendix; '95, pp. 67–86). Reighard ('94, p. 57) has also devised and carried out another method of determining the coefficient. Hensen has attempted to work out a formula by which the coefficient for a net of given cloth and given area could be determined, and has finally given the best and easiest method of determining the coefficient in lakes abounding in vegetable plankton ('95, p. 92). Reighard's method depends upon mixing with the water a known number of particles and determining the relation between those caught by the net when drawn through the water and the number known to be present. This method was entirely inapplicable to a net constructed like mine, and it was impossible for me to enter upon any elaborate investigation of the coefficients of the cloth which I used. I confined myself, therefore, to a determination of the coefficient of my net under the conditions in which it was used. In the serial investigations which formed the greater and more essential part of my study, the dredge was raised through a distance of three meters. The speed was approximately one half meter per second, although ordinarily a little less, the total time occupied by raising the dredge through 3 meters, being from 6.5 to 6.75 seconds. In order to ascertain the coefficient of the dredge I determined to ascertain the number of crustacea in a column of water 3 m. in length and 10 cm. in diameter and to compare with this number the catch of the net. For this purpose a tin tube was made, of the size indicated. This tube was provided at the lower end with a slide in which was placed a carrier bearing a net and bucket. The carrier and net could be slipped to one side so as to leave the opening of the tube entirely free, and by means of a cord reaching to the surface, they could be drawn back so as to hang immediately below the opening of the tube. The slide and carrier were made of brass plates carefully scraped and fitted together, so that no crustacea could escape between the bottom of the tube and the top of the net, and the net was closely covered when slipped to the side of the tube.

The tube was lowered into the water with the net moved to one side of the opening and was lowered slowly so that the water within the tube might remain at the same level as that without and no appreciable currents should be set up in the water. The tube was also provided with a close fitting cap on the top, which could be closed after the top of the tube had sunk about one-half meter below the surface. When the tube had been lowered this cap was closed and the slide with the net drawn across the bottom of the tube. There was thus imprisoned a column of water 10 cm. in diameter and 3 m. long. The tube was then slowly raised to the surface and lifted out of the water so that the contained water might be filtered through the net, leaving behind the plankton. Several successive hauls of the tube were made, and the number of crustacea so taken was compared with that obtained from a similar number of hauls of the net made at the same time and through the same distance. The number of crustacea thus obtained was carefully determined, $\frac{1}{10}$ to $\frac{1}{15}$ of the number being counted where the number was great, and $\frac{1}{4}$ where the number was small. In determining the coefficient of the dredge, it was assumed that the tube took all of the plankton in the column of water which it contained, and the number of crustacea caught by the tube was compared with that caught by the net. Since the opening of the net was four times that of the tube the catch ought to have been four times as great, provided all of the water was filtered. As a matter of fact, the net caught about twice as many crustacea as the tube, thus indicating that its coefficient is about two.

In this method of determining the coefficient the quantities compared are by no means uniform; indeed, it is known that the number of crustacea caught in a given haul of the tube may be only one-half the number caught in a second haul within a few seconds. A single comparison has therefore very little value and accuracy in the determination of the coefficient by this method can be reached only by a considerable number of observations. In my own work I made use of six sets of observations, taken on May 14th, October 12th and 25th, 1895, February 25, May 18th, and July 11th, 1896. By distributing the observations over so long a time it was possible to get at the coefficient of the net at different times in its life and under different conditions of plankton. In May the number of crustacea is at a maximum, and the amount of algae is small. In October the number of crustacea is considerable, but the vegetable life is at a maximum; while in February the amount both of animal and vegetable life is of course small. From four to six pairs of observations were taken in each set. The ratio of the catch of the tube to that of the net was computed for each observation in the set, and the average of these ratios was computed, using the method of least squares. As a result of these determinations, the following ratio was established: Tube : net : : 49.85 : 100. The probable error of the determination is ± 1. The appended table shows the general results

Several facts appear from the table. It will be noticed that the amount of difference between the maximum and minimum numbers caught varies greatly on different occasions. It is plain also that the net shows no greater amount of variation on the whole than does the tube. On the contrary, on those occasions where the numbers are approximately constant in the tube, they are similarly constant in the case of the net; and where the numbers vary considerably in the case of the net, they vary to much the same degree in the case of the tube. There is therefore no reason to suspect any considerable irregularity on the part of the net due to the stoppage of its openings, or to any other cause.

TABLE I.—*Results of determination of coefficient of net.*

Date.	Pairs of catches.	No. of resulting ratios.	Counted fraction of catch.	CATCH OF TUBE.		CATCH OF NET.	
				Max.	Min.	Max.	Min.
1895, May 14.......	4	16	1-10	2,910	2,400	4,760	2,920
Oct. 12.......	4	16	1-5	1,482	1,170	2,292	1,770
Oct. 25.......	6	36	1-10	8,490	4,290	14,520	10,560
1896, Feb.25.......	5	25	1-4	1,420	760	3,500	1,750
May 18.......	5	25	1-10	5,940	4,310	12,100	10,480
July.11.....	5	25	1-15	4,215	2,430	8,370	5,680
Total........	29	143					

Minimum Ratio; Tube : net : : 21 : 100.
Maximum Ratio; Tube : net : : 100 : 100.
Average Ratio; Tube : net : : 49.85 ± 1 : 100.
Area of opening of tube : area of mouth of net : : 1 : 4.
Hence coefficient of net = 2, approximately.
Area of opening of net = 314.1 sq. cm.
Hence to state catch of net in terms of sq. meter of surface, multiply catch by $\frac{10,000}{314.1} \times 2 =$ catch $\times$ 63.6, which factor was used.

In determining the number of crustacea caught by tube or net, each species was counted separately. The individual species show just about the same amount of variation as does the total catch; although in the case of less abundant species the maximum number caught was not infrequently three times the minimum. In the case of the tube no difference could be detected in the range of variation of the numbers of species which are active, like *Diaptomus*, and those which, like *Chydorus*, or *Cyclops*, are relatively slow in their movements. During the summer of 1896 an attempt was made to determine the coefficient of the dredge from the number of spherules of *Gloiotrichia*, but as this plant is found mainly in the uppermost strata of the water on calm days, it proved an unsuitable object, and its variations in number in successive catches were greater than those of the crustacea.

It may be added that there was no constant position of maximum or minimum catch in any series which was made, but the numbers varied in a wholly irregular fashion.

In all of the work reported in this paper and done before the 11th of July, 1896, a single net was employed. After that date the net was replaced by one of silk bolting cloth, number 16, containing about 3600 meshes to the square cm. This net was cut from the same pattern as the old one. In order to compare the two nets they were similarly mounted in the same frame, and a series of comparisons made to determine their relative coefficient.

To my surprise the two nets showed practically the same coefficient. The numbers caught necessarily varied considerably, but the average of each of two series of five pairs showed practically the same number of crustacea; the silk net catching on the whole about 5 per cent. less than the old net. It did not seem necessary therefore to alter the coefficient of the dredge with the change of the net. On the 20th of August the dredge, with all its appurtenances, was lost by the accidental breaking of the line, and the work for the remainder of the year was done with a similar instrument of smaller size, having a square opening of 100 square cm. The coefficient of this net was determined by comparing it with the tube, one set of comparisons being made by determining the number of the crustacea. A second set was made by determining the bulk of the plankton caught by the tube and net when allowed to settle for the same length of time in similar tubes. Two other determinations were made by Hensen's last method. (Hensen, '95, p. 92.) The net was fitted with a cover having an opening of 2.5 square cm. Ten successive hauls of the net were made with the small opening and their contents mingled. This was preserved and allowed to settle and compared with the amount of plankton caught with the full opening of the net, the two quantities being similarly preserved and allowed to settle in similar tubes. The result of these three methods of determination of the coefficient of the net was substantially identical, the coefficient varying from 1.81 to 2.04. The coefficient 1.9 was selected, and as a result the catch of this net is multiplied by 190 in order to give the number of crustacea per square meter of surface area.

An important question has been raised, first by Hensen ('87, p. 12) and especially by Kofoid ('97, p. 11) regarding the variation in the coefficient of the net due to the accumulation of the plankton within it as the net is drawn through the water. Unquestionably the stoppage of the openings of the net by the accumulating catch raises the coefficient, and if the net accumulates a sufficient amount of plankton it will wholly cease filtering the water. In plankton-rich lakes, therefore, serious error may be introduced from this source. Since lake Mendota during the summer and autumn contains very large amounts of vegetable plankton, it was quite possible that the stoppage of the net should cause errors. In order to determine whether these errors existed, I regularly made hauls of the net from the bottom of the lake to the surface during the season of 1895 and compared the number of crustacea obtained in the hauls from the bottom with the sum of those caught in the six successive levels of my series. I append a table showing the number of *Cyclops* caught in the months from January to July, 1895, in order to compare the series and the single haul. It will be seen that the number of *Cyclops* varies, often considerably. Out of 41 cases prior to July 1, the total haul exceeded the sum of the series in 24 cases and fell below it in 17 cases. There was thus no decided advantage on the side either of the series or the single haul. If the amount of variation in this table be compared with the amount shown in the catches of the tube in Table I, it will be seen that the differences are of much the same order as those disclosed by the tube. There is therefore no evidence that under these circumstances the net suffered any stoppage in passing through the 18 meters of the lake which altered its coefficient to any marked degree over that of the net used through 3 meters.

After the first of July *Anabaena* and similar small plants developed rapidly in the lake, and the amount of vegetable plankton increased to a great amount. Under these circumstances the number of crustacea caught in the total haul varied widely and irregularly from the sum of the series, and soon became uniformly lower than the sum. It was found therefore that the coefficient of the net has been raised by the amount of algae present and the catches made by the total hauls were not employed in reckoning the number of the crustacea after the first

Table II.— *Showing the number of Cyclops caught by the net at the same date and place in a series of six hauls of 3 m. each, and in a single haul of 18 m.*

Date.	Sum of series.	Single haul.	Date.	Sum of series.	Single haul.
1895.			**1895.**		
Jan. 6	400	460	May 16	11,940	14,300
Jan. 9	378	550			17,530
Jan. 16	505	600	May 18	19,470	19,200
		800	May 20	11,780	16,000
Feb. 15	870	1,220	May 22	12,850	11,240
		900	May 27	16,710	15,625
Feb. 23	2,350	1,180	May 30	16,220	17,900
		1,430	June 1	13,220	15,200
Mch. 6	345	620	June 3	10,010	10,080
Mch. 7	678	859	June 10	8,020	7,800
Mch. 12	719	844	June 12	8,070	3 640
Mch. 23	780	1,355	June 17	4,530	5,600
Apr. 12	690	710	June 18	3,809	3,240
		880			5,680
Apr. 15	1,000	600	June 22	4,760	3,750
Apr. 18	2,520	1,290	June 24	3,710	2,120
Apr. 23	2,925	3,550	June 29	3,299	2,400
Apr. 30	9,055	9,510	July 1	3,190	3,700
		6,960			3,600
		7,620	July 4	3,920	3,300
		5,250	July 6	6,105	3,960
May 4	15,470	15,450	July 9	3,416	2,560
May 7	13,630	18,200	July 11	2,960	3,080
May 12	11,980	19,680	July 19	3,434	3,120
			July 24	2,791	1,840

of July. The comparisons of net and tube show no appreciable difference in coefficient between the catches of October when the vegetable plankton is at its maximum, and those of February and May, when it is greatly reduced in quantity. There is therefore no reason to suppose that the coefficient of the dredge is appreciably altered by being raised through the distance of three meters. It may be added that results similar to those obtained in the above table would be shown if any other species of crustacea had been selected, or if the total of all the crustacea had been chosen.

There is still a third question relating to the coefficient to the dredge, namely, does the net function similarly on different occasions, or does its coefficient vary irregularly and in such a way as to vitiate conclusions based on the hauls of the net? This question is partially answered by the determination of the dredge coefficient, as shown in Table I. A second answer can also be given. During the winter the numbers of *Daphnia* and *Diaptomus* do not increase by reproduction, and the successive catches should therefore show no very great variation. In a subsequent section, dealing with the question of swarms, I have given the figures for the catches of these genera during the winter of 1895, from which it appears that the variation in successive catches made within a short time of each other is no greater than may be found between catches made on the same day. Still further, a diagram is given (Fig. 21), showing the numbers of *Cyclops* caught during the year 1895. This diagram shows plainly that when the average number of *Cyclops* is approximately constant, the individual catches do not ordinarily vary greatly from the average, no more than would be expected from *Cyclops'* necessarily somewhat irregular distribution in the lake. An examination of the maximum and minimum catches in the tables for the different species shows the same result.

I do not pretend that I have determined the coefficient of my nets with absolute accuracy, nor that the coefficient of the net is exactly the same on different occasions; but the careful study whose results are summarized above has convinced me that the coefficient of the net is quite as constant as any of the factors entering into the determination of the plankton. The number of the crustacea certainly varies from point to point in the lake. Where a fraction only of the crustacea are counted, the determination of the number caught is an approximation and is subject to error. This error, is, of course, multiplied greatly in stating the number of crustacea in terms of square meter of surface. Among the variables and approximations which enter into the statement of the results of plankton work, I think it may fairly be said that the coefficient of the net is one of the most constant factors, and that it may be quite as accurately determined as any other.

TEMPERATURES.

Figs. 1–5.

The following account of the temperatures of the lake is not intended as a complete discussion of the subject. My temperature observations were made at first with the aim of securing approximate results in order to determine the biological relations of temperature. The methods employed until July, 1896, while accurate enough for these purposes, are not sufficiently accurate for other ends. I have therefore refrained from printing the observations of temperature, and discuss chiefly the temperature diagrams, which give the result of my observations by weekly or rather, quarter-monthly averages.

A. Methods.

Surface temperature observations were taken from the beginning of my study, and temperatures from all depths after October 1st, 1894. A water bottle and thermometer were the instruments employed until July 27th, 1896, after which date a thermophone was used. The latter instrument has proved extremely useful and accurate. A full description of the instrument may be found in Science, Vol. II. of 1895, page 639. As constructed for my work, the instrument ranges from minus 5 to plus 30 degrees C., each degree being graduated into fifths. There is no difficulty in reading the instrument to less than 0.1 degree C., and its readings are exceedingly accurate, agreeing exactly with those of a standard thermometer with which it has been constantly compared. Observations can be made very rapidly, the time of a single reading varying from one to one and a half minutes, according to the amount of change of temperature from the last reading.

Tha temperature bottle contained about 1½ litres and had a small neck. It was lowered to the desired depth; allowed to remain from one to three minutes for the glass to acquire the temperature of the water; was then uncorked by a sudden jerk on the

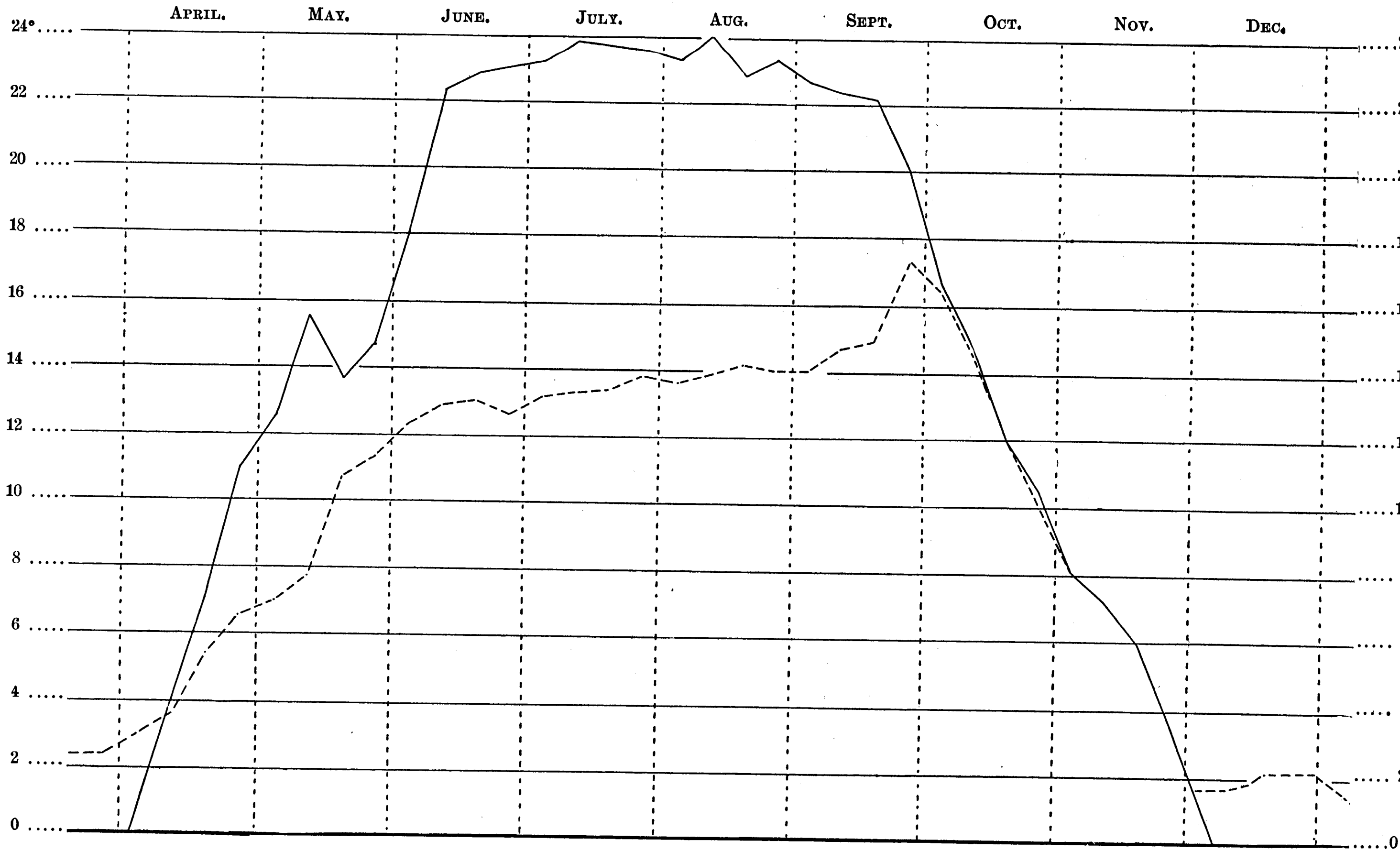


FIG. 1.—Surface and bottom (18 m) temperatures, 1895. Full line, surface: broken line, bottom.

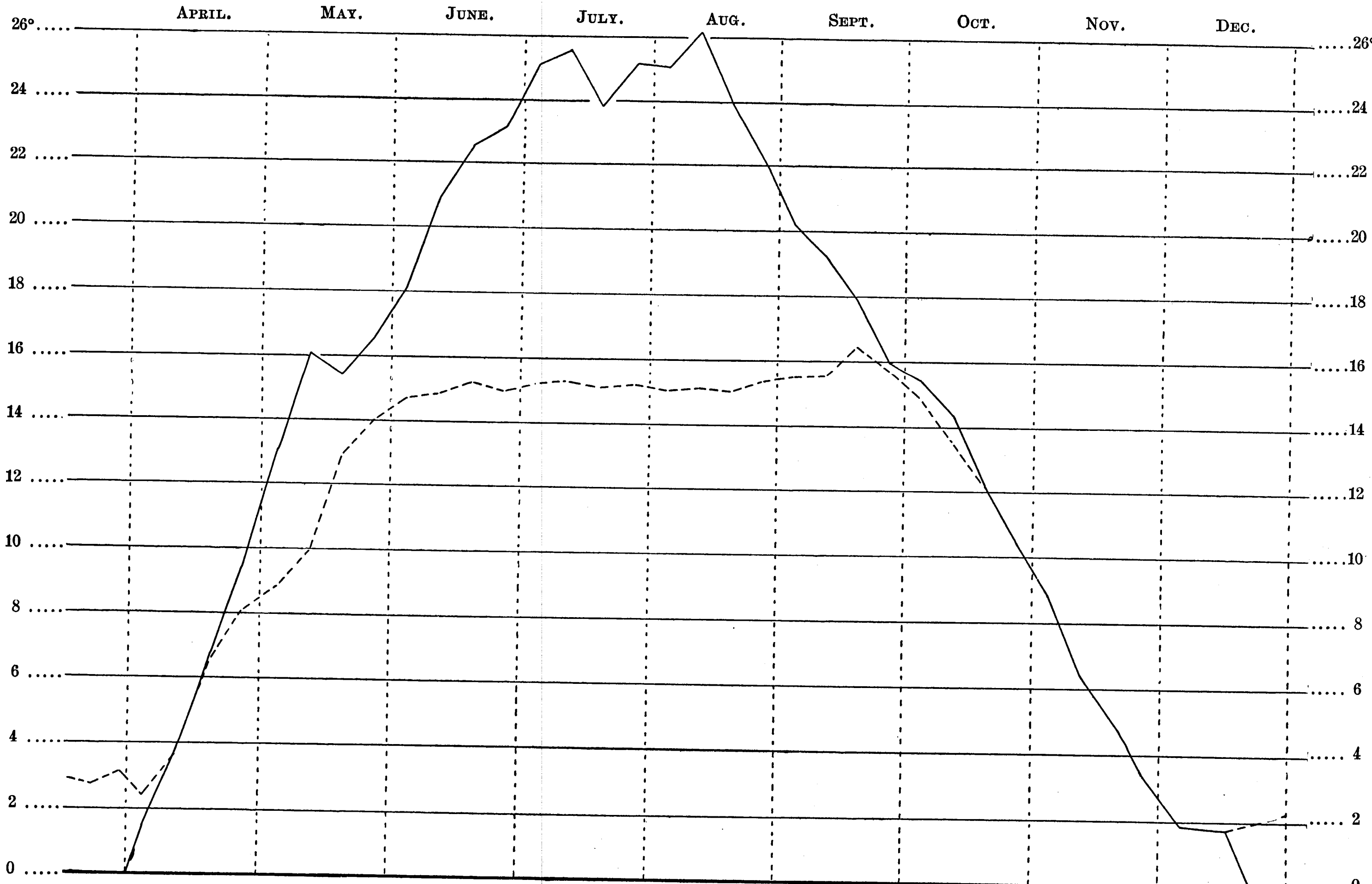


Fig. 2.—Surface and bottom (18 m) temperatures, 1896. Full line, surface; broken line, bottom.

line, and allowed to fill. It was then drawn rapidly to the surface and the temperature read by means of a long-stemmed thermometer graduated to one-fifth of a degree. The time of raising the bottle from the bottom of the lake was ordinarily about ten seconds; and the small size of the opening prevented mixture of the upper water with that in the bottle. The temperature of the water in the center of the bottle, which was measured by the thermometer, did not change perceptibly during the time required for the thermometer to set. The water from the lower part of the lake, however, was somewhat warmed by contact with the glass and the air in the bottle. This error was carefully determined by comparison with the thermophone, and is about one-fifth of a degree C., when the difference between surface and bottom is about 10 degrees.

Errors much more considerable than this occur with the use of the temperature bottle at the thermocline. In this region the temperature may fall as many as nine degrees in a single meter, and not infrequently as much as three or four degrees in a quarter of a meter. It is impossible that the bottle should take in all of its water from the stratum in which its mouth lies as the escaping air sets up currents so that a mixture of the water occurs. A difference of half a degree may therefore occur between the readings of the thermophone and the bottle in this region. In one case the error amounted to two degrees, where the bottle was opened a few inches below the upper level of the cold water and took in a mixture of this water with the lower part of the warm stratum above. The errors at this region, however, while considerable, make little difference in the average results of observations, since their only effect is to make the upper level of the cold water appear to be a fraction of a meter lower than it really is. Since this level is subject to irregular variations, under the influence of the wind, which may amount to two or even more meters, the errors introduced by the bottle are insignificant in the average of a week's readings. It was intended to correct the observations of the bottle by means of the thermophone and to introduce the correction in the diagrams of temperature. It was found, however, that the amount of correction to be introduced in the diagrams was so small as to make it inadvisabie to insert it. In Figure 4 the change from bottle to thermophone is made in the last week of July, and it will be seen that the lines come together with great accuracy.

Above the thermocline the bottle and thermophone agree exactly, except at the surface on calm, sunny days, when the reading of the thermometer is higher than that of the thermophone, since by means of the thermometer the temperature of a very thin stratum can be taken, while the thermophone coil is of such a shape that it reads only the average temperature of a stratum some eight centimeters in thickness.

During the period April — December, 1896, 189 sets of observations were made on 135 days varying from 3 to 6 per week. In 1895, 196 sets of observations were made on 126 days in the same period.

The temperature observations were made at all hours of the day; rarely by night, and must be taken as representing the day temperatures of the water. Little difference, however, would be made in the diagram if the night temperatures had been introduced, as has been shown by an elaborate series of observations made in 1897. Observations were regularly made by single meters by the thermophone, and also by the bottle when the difference between single meters exceeded one-half degree C., and often when the differences were less.

After recording the temperatures, those for meters not directly observed were interpolated, and the average was taken of the observations for each meter and each quarter-month.

In preparing Figs. 3 and 4 the average temperatures for each meter and quarter-month were platted at the proper depth, and in the center of the space representing the quarter-month on the diagram. The position of the full degrees was then platted on the assumption that a uniform decline of temperature is found within a single meter. This assumption is incorrect in the region of the thermocline as the zone of the most rapid decline of temperature is frequently less than a meter in thickness, but as this zone varies in thickness and shifts its vertical position under the influence of the wind, little error results from using this method of platting the average observations of a week. Lines were then drawn connecting the positions of the full degrees. In 1895 the diagram is carried to 18 meters only, the depth at my regular station. In 1896 the temperatures were carried to 22 meters, observations being taken at that depth nearly every week. Two other temperature diagrams are given, showing the movement of the surface and bottom temperatures from April to December of the years 1895 and 1896.

B. Results.

Winter Temperatures.

Lake Mendota freezes at very different dates during the early winter in different years, and the time of opening also varies greatly. The lake is so large that continued high winds prevent its freezing even after long continued low temperatures, and as there is no large affluent, there are no spring floods to move the ice, which therefore remains until it is greatly weakened by the effect of the sun and is broken up by the wind. In 1894 the lake froze on December 28th, and opened April 8th, 1895, being closed for 100 days. In 1895–96 the lake froze December 6th and opened April 28th. The first and last observations through the ice were made on January 1st and March 23d, 1895; and December 9th, 1895, and March 28th, 1896. In the winter of 1896–97 the lake froze December 29th, then broke up again and did not freeze the second time until January 7th, 1897. It opened on April 10th, 1897. The ice usually reaches a thickness of over 60 cm., and in 1895 became nearly 1 m. thick.

During the winter the temperature of the surface of the water is, of course, zero. The water at the bottom when the lake freezes has a temperature which varies in different years. If the lake is prevented by wind from freezing during the first cold weather of December, it may remain open for days or even weeks, cooling very slowly. This was the case in 1894, and the temperature at the bottom on January 1st, 1895, was barely one degree, and at nine meters was about 0.5°. In 1895 when the ice on December 9th permitted observations, the temperature was as follows: 0.5 m., 0.3°; 5 m., 1.2°; 18 m., 1.7°

It is, of course, possible that the lake should freeze when the bottom is at any temperature between 4° and zero. It is hardly probable, however, that it often freezes permanently when the bottom is lower than 1° or higher than 2.5°. Below the ice the temperature of the water rises rapidly, being half a degree or even more within less than half a meter of the ice, and below this level the temperature rises very slowly and regularly to the bottom of the lake, the difference between the water at 0.5 m. and the bottom rarely exceeding two degrees. The mud is ordinarily decidedly higher in temperature than the water just above it. (See FitzGerald, '95, p. 81.) The difference between the temperature of the mud and the water half a meter from the bottom was sometimes found to be as great as 0.7–0.9° in 1894–5, and 1895–6, by the aid of the water bottle; while the thermophone in 1897 showed differences of 0.3–0.8°. This difference varies in different parts of the lake without any assignable reason.

The temperature of the water of the lake rises during the winter, especially during the latter part of February and March (Cf. Apstein, '96, p. 18). In 1895 the temperature reached nearly 2.5° at the bottom, and 1.5° close to the ice on the 27th of March. In 1896, on March 28th, the temperature at one-half meter was 2.9°, at the bottom (18 meters) 3.1°. This was a rise of from 1.5 to 2° during the winter. In 1897, the temperature on January 23rd was: 1 m., 0.6°; 18 m., 1.8°. On March 29th, at 1 m. the temperature was 1.4°, at 18 m., 2.1°. This warming of the water is due to the sun. If it were due to warm water coming from springs the bottom temperature would necessarily rise to 4° before the change appeared in the upper water. But this is not the case. The temperature at the bottom has not reached 4°, in any of the three winters during which observations have been taken, until after the breaking up of the ice in the spring. It would appear, therefore, that this warming must be due to heat which enters the water from above.

While this rise in temperature is very gradual and is small in amount, it has important biological results. The reproduction of *Cyclops* and of the rotifers goes on very much more rapidly at a temperature above 1.5° than at a temperature near 1°. Indeed, at the lower temperature the progress of the development of eggs is almost suspended, while at a temperature of 2.5 to 3° the development of eggs into nauplii and of nauplii into young *Cyclops* goes on with considerable rapidity, and at 1.5–2° it is present, though decidedly slower. The history of *Cyclops* in the spring, therefore, depends to a considerable degree on this warming of the water under the ice. If the winter is cold, so that the warming does not take place, or the rise is only slight, the number of *Cyclops* may remain almost unaltered during the winter; while conditions like those of the winter of 1895–96 permit the development of large numbers of young *Cyclops* ready to take advantage of the increased warmth and food in early spring, and so to develop enormous numbers of this genus.

The spring rise of temperature.

A glance at Figs. 1 and 2 will show that the warming of the lake in the springs of 1895 and 1896 was singularly alike. In each year the month of April was pretty steadily warm, and the surface of the lake rose rapidly and uniformly in temperature for about six weeks following the breaking up of the ice. Immediately after the disappearance of the ice the temperature of the lake frequently falls, since the breaking up of the ice is often caused by a north wind accompanied by a much lower temperature than had preceded the breaking up of the ice. This fall in the temperature of the water amounted to over one degree in 1896. But this slight drop is quickly recovered, and if the weekly averages are considered it will be seen that the surface temperatures in both years rose rapidly and steadily. For a time the rise in temperature at the bottom is as rapid as that at the surface. The length of this time varies, of course, with the amount of wind. A succession of warm days, accompanied or followed by high wind, will mix the warmed surface water with the body of the lake and thus secure uniformity in temperature. In neither 1895 nor 1896 were these conditions long realized; the temperature of the bottom began to lag behind that of the surface, and by the middle of May there was a difference of 7° to 8° between the surface temperature and that of the bottom. In six weeks the temperature of the bottom had risen about 5° or 6°, while that of the surface had advanced about 15°.

The relation of the wind to this warming of the lake is well stated by Whipple ('95, p. 207).

In both of the years of observation, and also in 1897, there came in the middle or latter part of May a marked decline in temperature accompanied with high northerly winds. The effect of this was two-fold: first, the surface water was cooled; secondly, the wind mingled pretty thoroughly the water of the lake, thus causing a sharp rise of temperature in the lower strata. On the 12th of May, 1895, the difference in temperature between top (15.6°) and bottom (7.7°) was 7.9°; on the 16th the difference was only 1.5°, and on the 18th only one degree (12.6°–11.6°). On May 11th, 1896, there was a difference of 8.3° between top (18°) and bottom (9.7°), and a thermocline was evidently formed between 4 and 6 meters. On May 17th the difference between top (15.6°) and bottom (13.4°) was only 2.2°. Thus in both years there was a rapid rise of 3–4° in the temperature of the bottom water. It is probable that if temperatures could have been taken at the most favorable time the lake would have been found nearly homothermous in late May, at a temperature not far from 11° in 1895, and 13.5° in 1896. The effect of the spring warming was therefore to warm a mass of water 18 to 24 meters deep from an average temperature between 2° and 3° in March to an average of 11° to 14° at the latter part of May; with the differences between the top and bottom not exceeding 1° to 2° at the beginning and end of the period.

From these facts it appears that the bottom temperature of the lake may vary greatly in different summers, and that the bottom temperatures of lakes of the same depth, in the same region and season may also vary greatly—much more than the temperatures of the surface. Four factors are effective in determining the bottom temperature; three constant, and one variable: (1) the depth of the lake, (2) its area relatively to its depth, (3) the shape of the lake and the nature of its surroundings as favoring or hindering the influence of the wind, and (4) the amount of warmth and of wind during the spring and the times of occurrence of gales and the succession of warm and cold waves. The same factors are also the chief powers in determining the position of the thermocline and its rate of downward movement.

Very few of the inland lakes of Wisconsin are more than 25–30 meters in depth, and their bottom temperatures vary more with relation to their area than to any other one factor. In the Oconomowoc lakes, which are in the same region as lake Mendota, and are of the same depth approximately, but are much smaller in area, the temperature of the bottom water does not rise much above 7° during the summer. The same is true of Cochituate lake, Massachusetts, having a depth of 60 feet and an area of less than one and one-half square miles. (FitzGerald, '95.) Green lake and lake Geneva, Wisconsin, both of them not greatly differing in area from lake Mendota, but having a depth of 150 to 200 feet, have bottom temperatures of about 6°.

In a lake of large area, like lake Mendota, and about 24 meters in greatest depth, the temperature at the bottom may differ widely in different summers. In 1896 the bottom temperature at 18 meters at the first of June was nearly 15°; in 1895 about 12°, and in 1897 about 11.4°. At 22 meters it was about 0.5° lower in each year. Had it not been for the gales in the latter part of May the bottom temperatures would have been much lower; possibly from 7° to 9°. The extreme possible range of bottom temperature in summer for lake Mendota in different years may perhaps be stated as from 8° as a minimum to 18°, as a maximum, and the probable range as from 10° to 15°.

Summer temperatures.

The temperature of the surface rose rapidly and evenly after the fall in the temperature and mixture of water in the latter part of May. In 1895 the weekly average rose from about 13.6° to 22.5° in three weeks, a rate of nearly three degrees per week. In 1896 the surface rose from 15.4° to 25.1° in six weeks, rising some what less regularly and at a much lower average rate. The period of the summer maximum was reached about the middle of June in 1895, when the average temperature was 23.5°, and about the 1st of July in 1896, when the maximum was about 2.5° higher. The maximum surface temperature recorded was 25.2° Aug. 1, 1895, and 27.8° July 28, 1896, both at 5 p. m. After the maximum has been reached there follows a period in which the temperature of the surface is nearly stationary, and in which the weekly averages do not vary more than two degrees. This period was exceptionally long in 1895, lasting from the middle of June to the third week of September, about three and one-half months, in which time the weekly averages were between 22° and 24°. In 1896 it lasted only about six weeks, from the first week of July to the middle of August, at a temperature of 24° to 26°. At the close of this period the surface temperature falls and the decline once started goes on pretty uniformly as shown by the weekly averages, until the lake nears the freezing point. In 1895 the temperature fell 3° in as many days at the last of September. In 1896 there was a fall of 4.4° during the last ten days of August.

At the opening of the summer period the temperature of the bottom rises somewhat rapidly in the latter part of May, gaining perhaps 1.5–2° in two weeks. After this the bottom temperature is stationary or rises very slowly, not gaining a degree in three months. The bottom temperature at 18 meters lay between 13° and 14° in 1895; close to 15° in 1896, and near 12° in 1897. At the depth of 22–23 meters the temperature was from 0.4° to 0.6° lower in each year. Late in September the water of the lake becomes mingled from top to bottom and the temperature becomes uniform. At this time the bottom temperature rises rapidly by the mixture of the bottom water with the warmer water above.

During the early parts of the period when the bottom temperature is nearly stationary, that of the surface rises until the difference between bottom and surface amounts to 10° and even 15° in late July or early August. As the surface temperature declines, the difference between top and bottom becomes less and usually amounts to between 4° and 5° in late September, just before the time when the lake is rendered homothermous by the fall gales.

The Thermocline.

During the summer, then, the difference in temperature between the surface and the bottom may amount to 10°, 12°, or even 15°. The decline in temperature from surface to bottom is, however, not uniform as the depth increases. If a series of temperatures is taken about the first of August it will be found that there is a layer of surface water from 8 to 12 meters in thickness whose temperature is nearly uniform, the difference between that of the surface and that at 9 or 10 meters being usually only a fraction of a degree and frequently nothing. Immediately below this mass of warm water lies a stratum in which the decline of temperature is extremely rapid. This stratum may be two or three meters in thickness with a decline of as many degrees per meter. It may be only a meter or even less in thickness, and a decline of as many as nine degrees has been observed in a single meter. This layer in which the temperature changes rapidly may be known as the *thermocline* — the *Sprungschicht* of German authors. Below the thermocline the temperature decreases toward the bottom at first more rapidly and then more slowly as the depth of the water increases, but never showing the sudden transitions which are characteristic for the thermocline, the rate of decline rarely exceeding one degree per meter of depth. The thermocline was first noticed by Richter ('91) in a study of the Alpine lakes. Its origin was attributed by him to the alternate action of the sun warming the surface in the day, followed by a cooling at night. The alternation of conditions resulted in the formation of a layer of water of nearly uniform temperature above the colder bottom water. I do not wish to argue against the correctness of this theory as applied to the lakes which have been studied by Richter and others, but in lake Mendota the concurrence of gentle winds and hot weather are essential to the formation of the thermocline. In other words, the warmth of the surface water, received from the sun, is distributed by the wind through a certain depth of the lake, a depth which is proportional to the violence of the wind and the area of the lake. (Cf. FitzGerald, '95; Whipple, '95.) It can readily be seen that in a lake of the size of Mendota the water would be of uniform temperature from top to bottom if the lake were always agitated by violent winds. On the other hand, if the weather were perfectly calm, the lake would be warmed only to the depth which the rays of the sun could directly penetrate. As a matter of fact, the formation of the thermocline is due to the concurrence of gentle winds and a temperature high enough to warm the surface water rapidly.

The temperature observations on lake Mendota have been made chiefly at a station about one-half of a mile from the south shore. On bright days in May, with a gentle north (on shore) breeze, it not infrequently happens that a thermocline is formed, there being a mass of water four or five meters in thickness of uniform temperature, below which there is a rapid descent in temperature to the cooler water below. When, however, the direction of the wind changes and blows off shore, this warm water is carried to the other side of the lake, and the temperature shows a fairly uniform rate of descent from the surface to the bottom. If, however, this condition of warm weather and gentle wind continues, there is produced a mass of warm water on the surface, so thick that however the wind may blow there is always a warm stratum floating on the colder water; and when this condition has been established, a permanent thermocline has been formed.

A study of Figs. 3 and 4 will show the formation and movements of the thermocline as disclosed by the weekly averages. It will be seen that in the early part of May the gain of heat is rapidly distributed through the whole mass of water. The bottom lags behind the surface, of course, but the difference in temperature between them rarely exceeds 5° and the temperature of the surface water reaches the bottom in 10 days or 2 weeks. During the rapid warming of the early summer this condition ceases. The surface warms rapidly, the winds are not constant or strong enough to distribute the heat throughout the water, and the ownward movement of the isotherms no longer extends to the bottom, but they penetrate for an increasingly shorter distance into the water. In 1895, for example, the surface reached an average temperature of 15° during the last week in May,

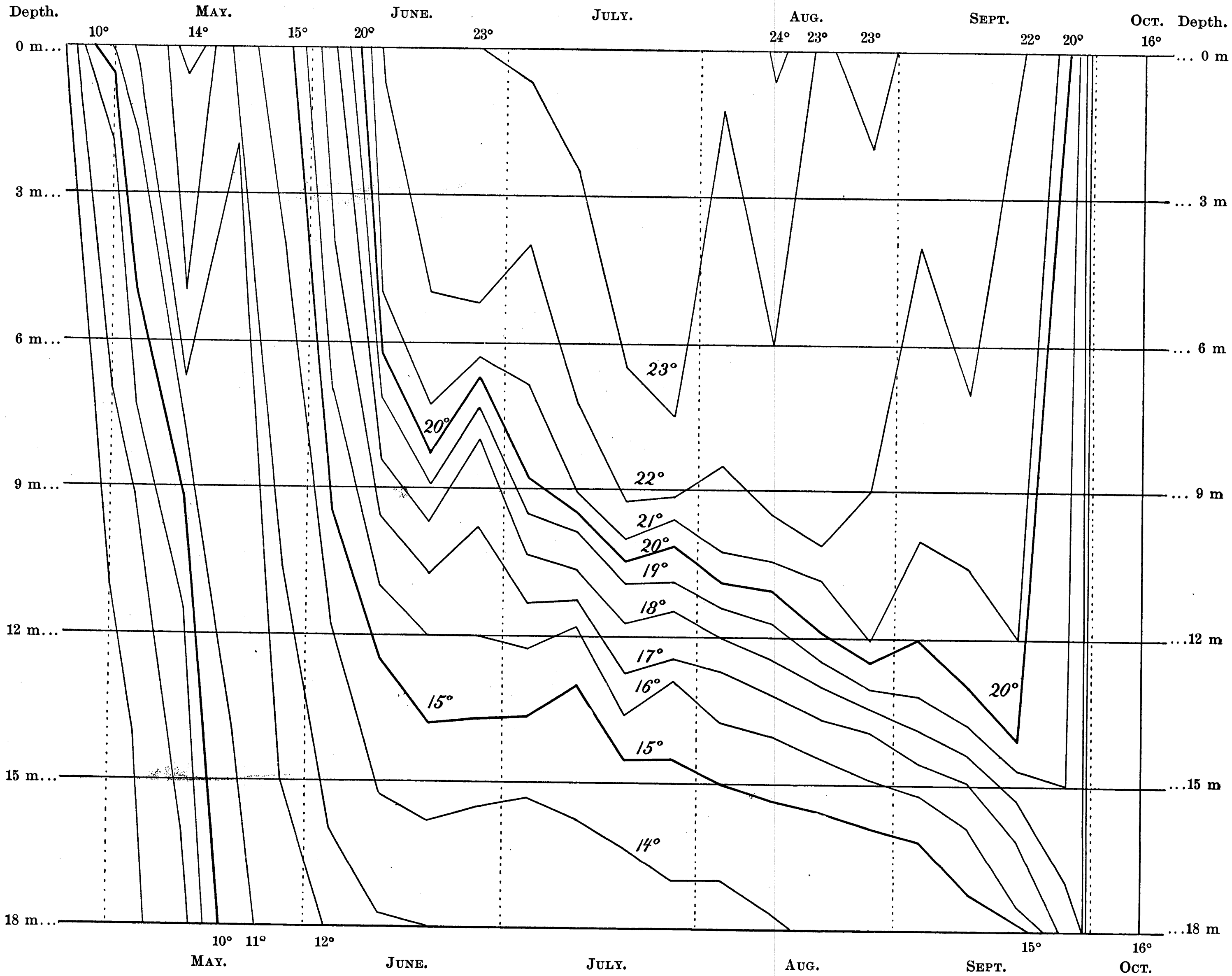


Fig. 3.— Summer temperatures, 1895. See p. 296.

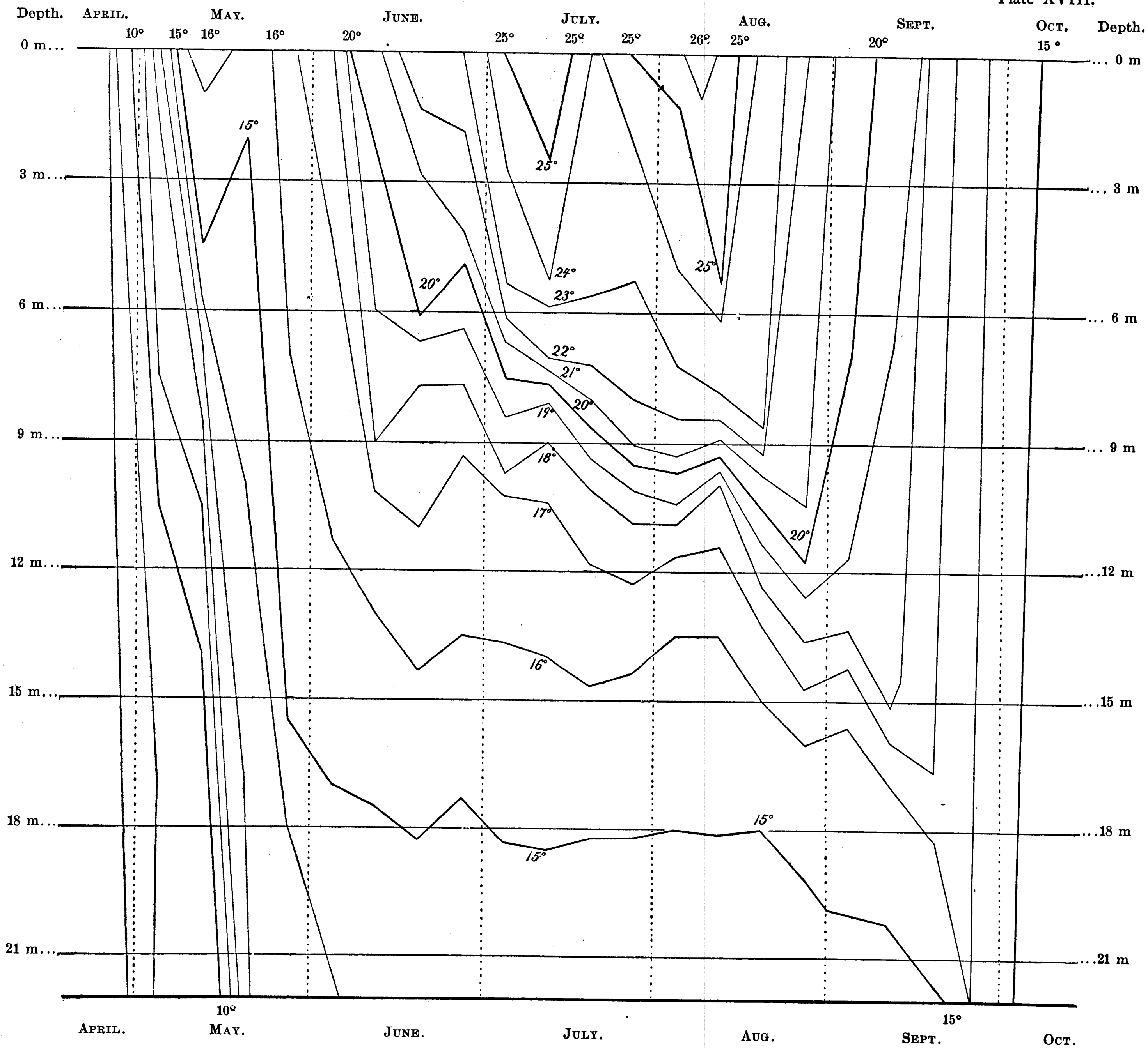


Fig. 4.—Summer temperatures, 1896. See p. 296.

and the isotherm of 15° penetrated nearly 10 meters of the lake in a week; it went down 3 meters further in another week, but thereafter moved downward at a rate little exceeding one meter per month. In 1896 the 15° isotherm was included in the May depression of temperature, but in late May it moved downward nearly 15 meters in one week, 1.5 in the week following, and only one meter in the next two and a half months. As the temperature of the surface rises above 15° the warmth penetrates to a distance increasingly small and the isotherms accordingly bend toward the horizontal at a level nearer the surface. The gain of heat, however, becomes rapidly distributed through the upper water to a depth of 8 to 10 meters, so that the thermocline becomes permanent at about these depths. When the thermocline has once been formed it moves downward very slowly. Beginning at about 8 meters in late June, it descends somewhat rapidly to about 10 meters, but after that moves downward slowly and irregularly, its descent depending rather upon the wind than upon the temperature of the air. In both years the thermocline reached the bottom of the lake in the last of September, which would make its downward movement about 4 meters per month, but the last 5 or 6 meters were passed very rapidly in consequence of the gales of late September.

In 1895 the 18° isotherm was near the center of the thermocline; it oscillated about the 9 meter level in late June, sank nearly 3 meters in July, about 2.5 meters in August, and 4.5 in September, the last 3 in the latter half of the month. In 1896 the 20° isotherm was near the center of the thermocline at the outset and crossed the 6 meter level about July 1st. It lay at 7.5 meters during the first week of July, reached 9 meters about the 20th of the month, oscillated between 9 and 10 meters for more than three weeks following that date — weeks of unusually hot weather — until the middle of August. At that time the weather changed and continued cool with much northerly wind, under whose influence the thermocline rapidly sank more than 2 meters during the last half of the month and continued this downward movement through September until it disappeared in the latter part of the month.

These temperature diagrams, which give the weekly averages of temperature, do not show the actual condition of temperature, and especially the temperature of the thermocline, on any single date. The thermocline oscillates up and down under ordinary conditions of weather through a meter or more; and the effect of averaging the observations of a week is to increase the apparent thickness of the thermocline and thus to diminish the rapidity of descent of temperature in it. Without any considerable change either of wind or temperature the thermocline may oscillate through 2 or even more meters. The action of severe wind is much more apparent. Fig. 5 shows temperature diagrams for August 2, 24, 26, 27, and 28, 1896. It will be seen that the diagrams for the 2nd and 24th of the month were closely similar, although the surface water had cooled a degree or more and the thermocline had descended about 1 meter. On the 24th there was a decided fall in temperature of the air accompanied by violent winds from the northwest. The surface water fell more than one degree in two days, while the thermocline was temporarily depressed at the observing station more than 4 meters. It lay on the 24th between 10 and 11 meters; on the 26th between 14.5 and 16 meters. The temperature at the bottom, 18 meters, was raised about 0.4°, at 14 meters 5.6°, at 12 meters 4.3°, at 10 meters there was a loss of about 0.6°. On the 27th, the wind having fallen to a calm, the thermocline had risen nearly 3 meters, while on the 28th, with a gentle south wind, it had risen still further, and the temperature curve had greatly changed in form. During these three days the temperature to a depth of 8 meters had varied very little — too little to show in the diagram. This example of changes which are going on all the time, shows the following facts: 1. The isotherms of diagrams 3 and 4 represent only the average position of the thermocline. 2. The decline of temperature in the thermocline is ordinarily much more rapid at any given date than is indicated by the average of the week. In other words, the thermocline is not nearly as thick as the week's average would indicate. 3. The greatest daily variation in temperature during summer is found at the thermocline, where a range of 5 or more degrees may be registered in a day. These variations

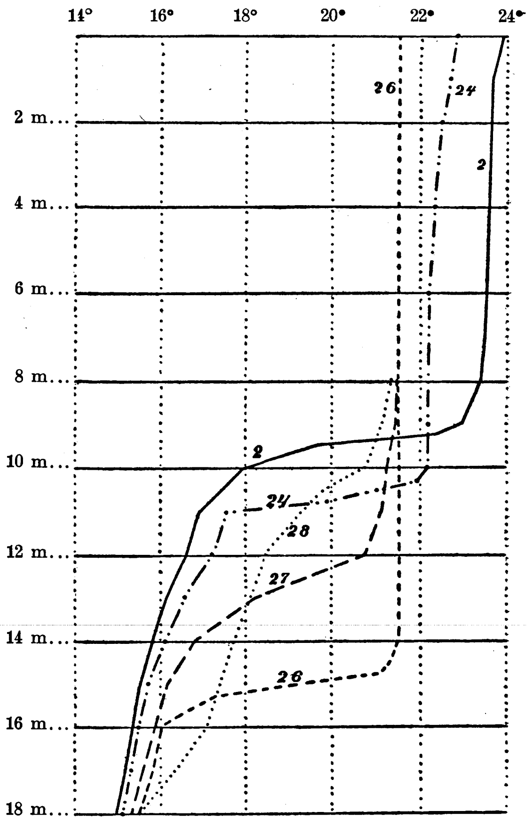


FIG. 5.—Temperatures, August, 1896. See p. 298. The dates of observations are indicated on the temperature curves.

are not caused by the warming or cooling of the water but by the fluctuations in the level of the thermocline. These fluctuations go on to a certain extent without an assignable cause, but the larger movements, at the station where observations were taken, are plainly due to the wind. 4. The upper layers of the cool water become mingled by the action of the wind with the lower part of the warm water above it and are taken into the warm layer. Thus the thermocline moves constantly downward during summer, while the water below it is little or not at all changed in temperature. 5. The water below the thermocline is practically stagnant during the summer, and is cut off from direct exposure to sun and air. As a result, it may become unfit to support most forms of animal life, as is the case in lake Mendota. 6. The larger changes in temperature below the thermocline are due to currents caused by winds.

Autumn temperatures.

By the latter part of September the temperature of the surface water has fallen so that it exceeds that of the bottom by barely 5°. At this time also gales from the north are apt to occur whose effect is to break the thermocline and render the lake homothermous. This result is reached at different dates for different depths, but in both years the lake became homothermous in its deepest parts about two or three days after the time when a similar condition was reached at 18 meters. In each year the homothermous condition was reached at a temperature not much exceeding 16°; and in general the temperature for the 1st of October may be stated as about 16°.

The breaking up of the thermocline is accompanied by a marked rise in the temperature of the bottom water. In 1895 this rise amounted to 2.8° from the 26th to the 28th of September; and in 1896, to about 1.5° in the same time.

During October and November the temperature falls with singular uniformity, as indicated by the weekly averages, passing the temperature of the maximum density of water late in November. The decline continues steadily until a temperature is reached between 2° and 3°, after which the cooling goes on very slowly. The difference of temperature between the surface and bottom of the lake during this time is very small. In the morning the lake is entirely homothermous. On bright, calm days, the temperature of the surface rises, and may become as much as 2° warmer than the bottom. This condition of things, however, is uncommon, and ordinarily it is difficult to find differences between the surface and bottom exceeding 0.1° or 0.2°. It is a feature of especial interest in lake Mendota that the fall homothermous period begins so early and at so high a temperature. The autumnal multiplication of many of the species of crustacea goes on after this period has been fully established, and their vertical distribution at this time is therefore independent of temperature. In the deeper lakes, or in smaller lakes of the same depth the homothermous condition is reached much later. In Green lake, as reported by Professor Marsh (Marsh, '97, p. 187), it occurs in November at a bottom temperature of 4.7°, and at a depth of about 45 meters. The rise at the bottom was 1.4°. In Cochituate lake, near Boston, at a depth of 18 meters, the homothermous condition is reached at about the same time, and at the same temperature. (FitzGerald, '95, p. 74.) This lake has an area of less than one and a half square miles.

During the last of November and the early part of December cooling goes on very slowly. The surface temperature frequently falls to zero, as the result of a calm night, and the lake may skim with ice, which is broken up again by the wind.

THE ANNUAL DISTRIBUTION OF THE CRUSTACEA.

I. General Relations of the Plankton Crustacea.

Figs. 6–11.

Lake Mendota has eleven species of limnetic crustacea, which may be grouped as follows:

A. Perennial species —
- a. Appearing in great numbers —
  - Copepoda.
    - *Diaptomus Oregonensis* Lillj.
    - *Cyclops brevispinosus* Herrick.
    - *Cyclops Leuckartii* Sars.
  - Cladocera.
    - *Daphnia hyalina* Leyd.
    - *Chydorus sphaericus* O. F. M. var. *minor* Lillj.[1]
- b. Usually appearing as isolated individuals —
  - Copepoda.
    - *Epischura lacustris* Forbes.
    - *Ergasilus depressus* Sars.[2]

B. Periodic species —
- a. Appearing in great numbers —
  - Cladocera.
    - *Daphnia pulex* DeG. var. *pulicaria* Forbes.
    - *Daphnia retrocurva* Forbes.[3]
    - *Diaphanosoma brachyurum* Sars.
- b. Appearing as isolated individuals —
  - Cladocera.
    - *Leptodora hyalina* Lillj.

To these might be added *Bosmina* of which a very few individuals appear, chiefly in winter, but of which there are never enough to make a fair determination of their number a possi-

[1]Sometimes absent but not properly periodic.

[2] The specific identification is not certain.

[3] Formerly classed as a variety of *D. Kahlbergiensis* or *D. cucullata.*

bility. Most of the littoral forms of crustacea also appear occasionally in the plankton, especially after storms, as also do Hydrachnids and Ostracoda.

Of these eleven species, the isolated forms do not contribute any appreciable addition to the number of limnetic crustacea. Their combined number is rarely as great as one per cent. of the total crustacea present. They have, therefore, been neglected in determining the total number of crustacea, and this general account will deal with the eight abundant species only.

The limnetic crustacea on lake Mendota show a rhythm of development quite complex, but recurring in closely similar form during the time covered by my observations, July, 1894 — December, 1896. (Fig. 6.) Observations less numerous have been continued to the present date, September, 1897, and show a similar development during the present year. The following periods can be distinguished:

Winter minimum	December to April, then increase to the
Spring maximum	In May, followed by a great decline to the
Early summer depression	June or early July,
Mid-summer maximum	July,
Late summer minimum	Late July or August,
Autumn maximum	September and October, declining to the winter minimum, through late October, November and early December.

There are, thus, three maxima and minima which are of unequal value. The spring maximum is by far the greatest, the crustacea reaching a maximum number of 3,000,000 per sq. m. of surface, and in 1896 reaching an average of nearly 2,500,000 for the first half of May. This maximum is due almost entirely to the rapid development of *Cyclops brevispinosus.* After the maximum has passed, this species rapidly declines in number, and the total number of crustacea sinks with it, so that by the middle or last of June the number is reduced to less than half the maximum. This is the early summer depression, which may be greatest at any time from the middle of June to the first week in July. A rapid, but slight, recovery follows, due chiefly to renewed reproductive activity on the part of the species already present in the lake, leading to the mid-summer maximum, in July. Then follows a decline, usually somewhat slow, reach-

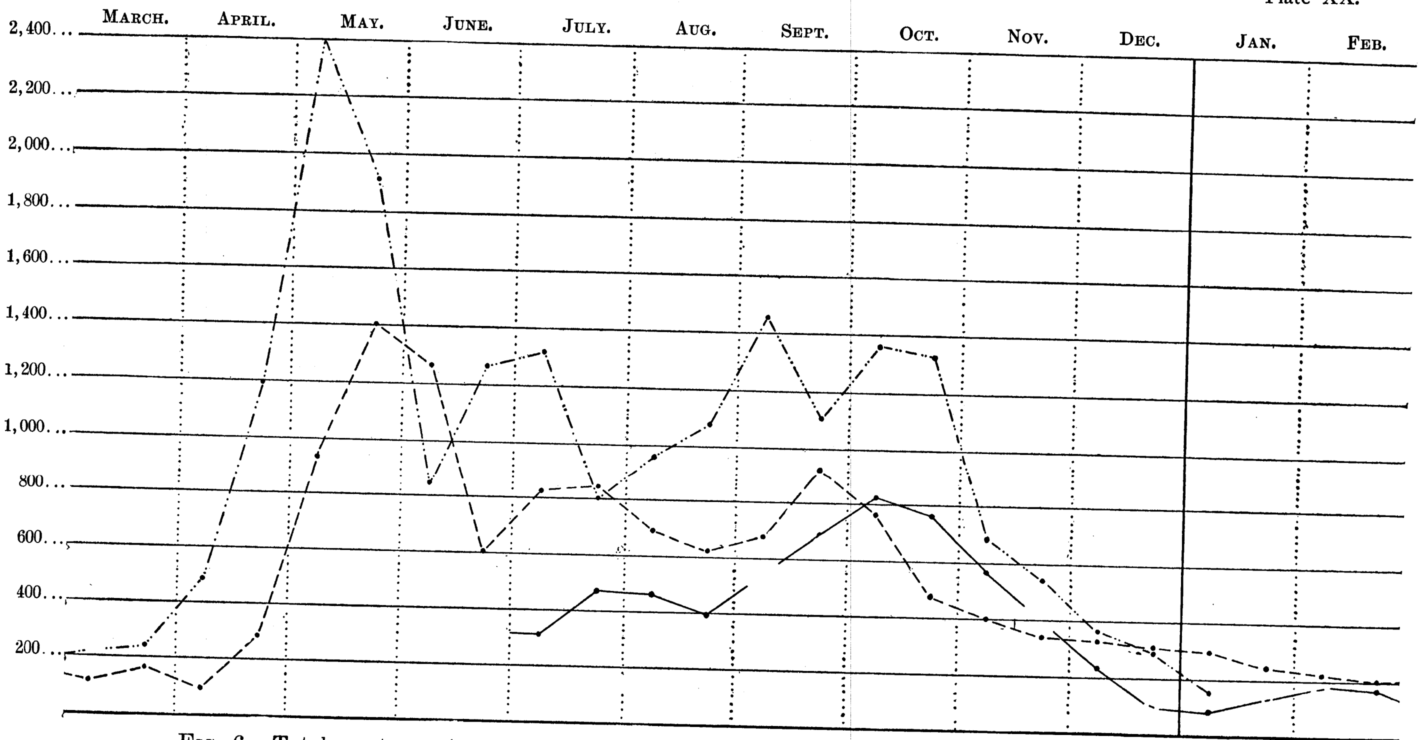


FIG. 6.—Total crustacea, 1894-1896. Scale, 1 vertical space = 200,000 crustacea per sq. meters. See p. 302.

1896....

1894....

1895....

ing a point of greatest depression about the last of August. During this period of decline, most of the periodic species are introduced, but their numbers do not usually compensate for the falling off in the number of the permanent species. In 1896, however, *Chydorus* increased so rapidly during this time as to more than counterbalance the decline in other species.

In September a rise in the number of crustacea begins, caused chiefly by increase in *Daphnia* of all species and in *Cyclops*. This increase culminates in the last of September or in October. This is the fall maximum, which, in general, is decidedly greater than the early summer maximum, the crustacea at this time reaching a number perhaps two-thirds as great as that of the spring maximum. During the later part of the fall and the early winter, the number declines very rapidly at first, and then more or less slowly, until the winter conditions are established with the freezing of the lake in December or early January. The rapidity of the decline varies in different seasons, depending upon the abundance of the periodic forms and upon the number of young *Cyclops* and *Daphnia hyalina*, which are produced in late autumn. The climatic conditions also affect the rapidity of decline; the rate of fall of temperature, the storms, etc., having a decided influence in hastening or retarding the approach of the winter conditions. Near the last of December, however, these conditions are fairly established, and the crustacea pass through the winter with but little change in number and averaging from 100,000 to 200,000 per sq. m. of surface.

A glance at Fig. 6 will show that this complex rhythm recurred with an exactness quite surprising. While the absolute number of crustacea present varies considerably, the shape of the curves indicating the movement of the limnetic population is strikingly similar. The resemblance is the more surprising when we consider that these maxima and minima are due to the increase and decrease of eight species of crustacea, whose numbers are independent of each other, and which appear in very different numbers at different seasons and at the same season in different years. The lines of diagram 6 represent, therefore, the sums of a number of independent variables, never fewer than three in winter nor more than eight in the period from July to October.

In the study of this rhythm of development, three facts may well be noticed in the first place. First, the number of crustacea in lake Mendota is to a singular extent dependent upon the perennial forms. In other lakes it often happens that the periodic forms are the dominant members of the summer population. Of these forms, *Bosmina* is practically entirely absent from lake Mendota; *Diaphanosoma* appears in small numbers only; and *Daphnia retrocurva* only rarely equals in number the related species, *Daphnia hyalina*. There is, therefore, no great increase in numbers in summer dependent on summer forms alone. Indeed, the influence of the periodic species is not greatly felt until September, and the shape of the developmental curve would not be greatly altered, were the periodic species omitted.

Second, *Chydorus* occupies a peculiar place among the plankton crustacea. It is properly a marginal form, and appears in the limnoplankton only under favorable conditions. Apstein has connected its presence in the limnetic region with that of Chroococcaceae. My observations seem to connect its abundance in the limnoplankton with an abundant development of these and similar plants. In other words, it seems true for lake Mendota that periods when the diatoms and *Ceratium* are the only abundant algae, are periods when *Chydorus* is present in small numbers; while in periods when the Schizophyceae or *Anabœna* abound, *Chydorus* is also abundant. The maxima of this species, therefore, have occurred without close reference to temperature or season, and may come at any time from June to late October. These maxima are also very irregular in amount, number, and duration.

Chydorus, also, is peculiar in the limnoplankton on account of its small size. It contains little more animal matter than a good-sized nauplius, and decidedly less than an embryo *Daphnia*. While, therefore, a great abundance of one form of plankton crustacea usually affects unfavorably the number of other species, *Chydorus* appears to be more independent of the presence of other forms. It seems, as it were, superposed on the regular limnoplankton, rather than a part of the general limnetic life, and its rise and fall seem measurably independent of the conditions to which the other species respond.

A third fact concerns *Daphnia pulicaria.* This species had a biennial period of development about thirteen months long, extending from July to August of the following year, and a period of rest, in which it was almost entirely wanting in the plankton, extending from late August to the following July. In 1894 a few representatives of this species were found in July, and it wholly disappeared in August. In 1895 they were an important constituent of the crustacean life from July on, increased greatly in late fall and early winter, and continued numerous throughout the winter. In April and May, they increased enormously, producing males and sexually mature females, and then declined, practically disappearing in September. This species was therefore a constant and important factor in the number of the crustacea during the last half of 1895, the following winter, and the spring and early summer of 1896. It was absent during the latter half of 1894 and the spring and early summer of 1895.

I will now pass to a brief discussion of the general crustacean life as it appears in the different seasons. I shall reserve most of the discussion of the causes and conditions affecting the number of crustacea to a later chapter.

The Crustacea in Winter.

All of the perennial crustacea are, of course, constituents of the winter plankton, and their numbers are not very unequal. The number is by no means small, averaging about 125,000 per sq. m. from January to the middle of April, 1895, and about 235,000 from January to April 1st, 1896. The following list shows the species present during the two winters in question.

TABLE III.—*Species, with average number of each per square meter.*

	1895.	1896.
Diaptomus	24,500	34,800
Cyclops	52,100	120,900
Daphnia hyalina	46,200	22,700
Daphnia pulicaria	....	48,400
Chydorus	....	7,900
Total	122,800	244,500

It will be seen that in 1895 there were present only three species, while in 1896 two others were added. In 1897 the conditions were essentially similar to those of 1895. Indeed, while the time from which my observations have extended by no means warrants any positive assertion in the matter, there seem to be distinct indications of a biennial periodicity in the plankton in respect to crustacea, algae, and rotifers. Observations must be continued, however, over a much longer time before any definite statement can be made on this subject.

The winter numbers of each species are on the whole singularly constant through the season, as will be seen by reference to the tables giving the numbers of the several species. The death rate must be very low. During the period, January–March, the variation in the number of crustacea taken in twenty or more catches made each winter vary to an extent hardly greater than might be found in catches made close together on the same day. It would be very difficult to prove any considerable decline in numbers of *Diaptomus* or *Daphnia* during the winter and they do not increase by reproduction. *Cyclops* produces eggs much more abundantly than the other species, and the adults seem to become fewer in late winter and late spring, but their number is more than made good by young individuals. In 1895 *Cyclops* began to show numerous egg clusters in February, and about ten per cent. of the specimens were egg-bearing females. These eggs developed very slowly, and few nauplii and almost no young *Cyclops* were seen. In 1896 the reproduction of the *Cyclops* hardly stopped at all during winter. In the middle of January nearly one-half the *Cyclops* bore eggs, and numerous nauplii were present. By the middle of March the nauplii had grown to young *Cyclops*, from three-fourths to seven-eighths of the total number of the species were immature young.

The winter minimum therefore falls in the period before *Cyclops* has begun this winter reproduction. In 1895 the minimum came in January and in February in 1896. Yet throughout the winter months the numbers are so constant that no well marked minimum can be placed at any date. In 1897 the condition of *Cyclops* was intermediate between those of 1895 and 1896.

Young *Cyclops* began to appear under the ice, but the condition of the species in the middle of March resembled that in the middle of February in 1896, and the progress of the development was in general about a month later.

The rotifers also show similar differences in reproduction in different seasons. Of this group there are regularly present during the winter, *Triathra*, two species of *Notholca*, *Anurea aculeata*, *cochlearis*, and *brevispinosa*, *Synchaeta pectinata*, and a species of *Oecistes*. All these reproduce more or less actively, and become quite abundant before the breaking up of the ice. Other species are present in smaller numbers.

The difference in the reproductive activity of these animals in different years seems to depend upon the temperature of the water, as will be explained at length in a later section of this paper. In all seasons there is an abundance of food. One of the chief winter algae is *Aphanizomenon*, which continues its development vigorously throughout the entire winter. Several species of the diatoms are also present, and in 1896 *Fragillaria* and *Diatoma* contributed largely to the plankton algae, but in 1895 and 1897 were insignificant in quantity, as compared with *Aphanizomenon*. There is no season of the year in which the crustacea fully overtake the food supply, except at the time of the spring maximum. During the winter the crustacea are active and fat, but those species which do not reproduce do not increase in size. Careful measurements of numerous individuals of *Daphnia hyalina* showed no appreciable increase in the average size between December, 1894, and April, 1895. When the temperature of the water is between 1.5 degrees and 2.25 degrees C., *Cyclops* develops very slowly or not at all from the nauplius state to that of the immature *Cyclops*, but at temperatures above 2.5 degrees the development goes on, although, of course, more slowly than at higher temperatures.

The Crustacea in Spring.

Lake Mendota has no large affluent, and the breaking up of the ice is slow, since it is due to the combined action of rain, sun and wind. The date of the disappearance of the ice differs greatly in different years. In 1895 the last expedition on the ice was made March 27th; in 1896, March 29th. The first collection in water was made April 12th, 1895, April 4th, 1896. In general, the lake opens either wholly or over the greater portion of its surface about the 1st of April. The period immediately following the opening of the lake seems to be a time of trial for most of the limnetic crustacea. The temperature of the water increases very slowly at first, or, indeed, may be lowered temporarily; and the surface is, of course, agitated by gales which are so frequent in April.

During the spring *Cyclops* ordinarily increases in numbers with a rapidity dependent on the rise of temperature in the water, and upon the reproductive condition of the species at the time of the disappearance of the ice. *Diaptomus* and *D. hyalina* do not begin to rise in numbers until after the first of May, as may be seen by reference to Figs. 8 and 9. During April these species are wont to decline in number, so that the smallest catches made during the year ordinarily come in the latter part of April or the first of May. *Cyclops*, however, increases with great rapidity. Reference to the diagrams and tables will show that in 1895 *Cyclops* increased more than fourfold in number during two weeks, and that this increased number was nearly quadrupled during the next two weeks. In 1896 *Cyclops* advanced with even greater rapidity and about two weeks earlier than in 1895. In each year the increase in *Cyclops* was about a month in advance of that of *Diaptomus* or *Daphnia hyalina*, and in 1896, about two weeks ahead of the multiplication of *Daphnia pulicaria.* The spring maximum is reached during the month of May, either in the first or the latter part of the month, according to the temperature. At the maximum the population of the lake consists largely of *Cyclops*, about 70 per cent. of the total in 1895, and 80 per cent. in 1896 consisting of this species.

The multiplication of the crustacea and rotifers during the spring seems to be more rapid than that of the algae, and in late spring at the time of the maximum, the algae are far less numerous with respect to the crustacea than at any other season of the year. In a word, the eaters multiply in excess of the food. This undue multiplication of the crustacea puts a check

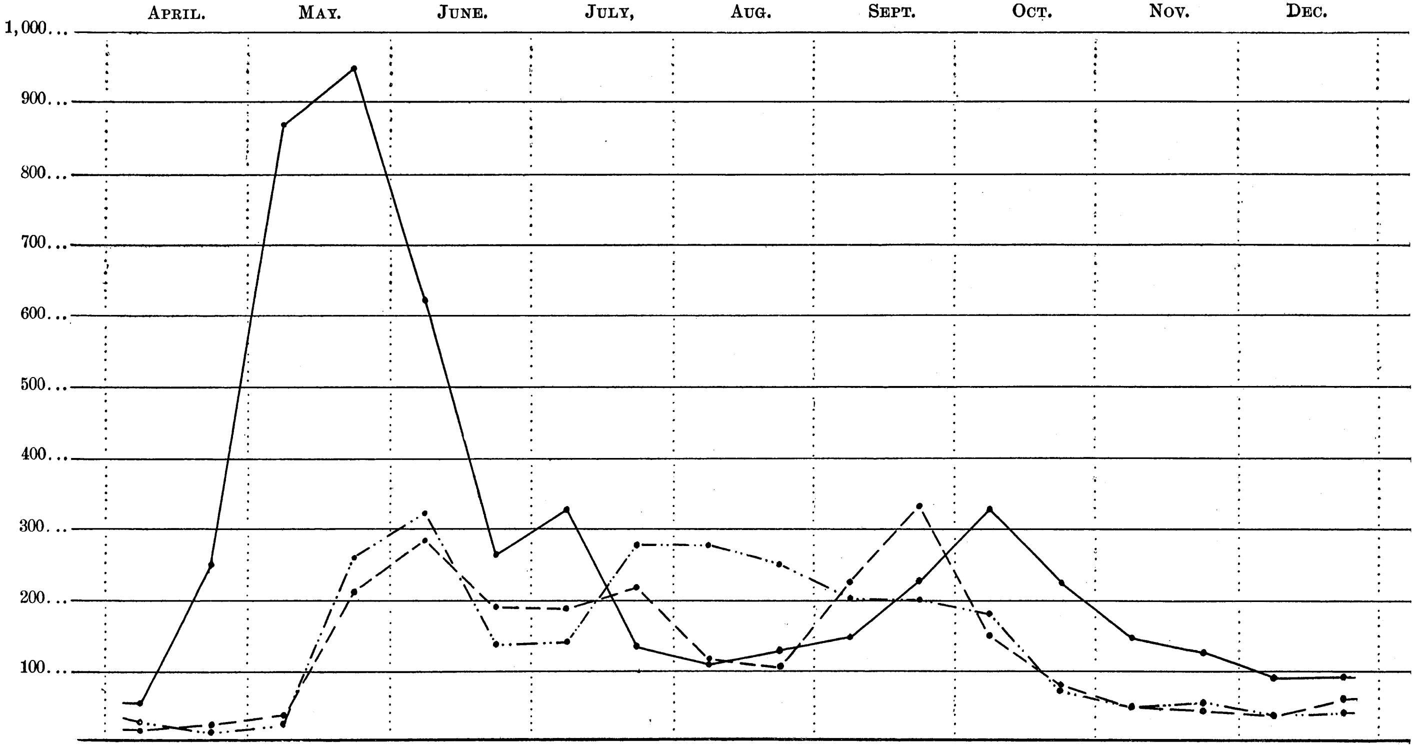


FIG. 8.—Leading crustacea, 1895. Scale, 1 vertical spaec = 100,000 crustacea per sq. meter. See p. 308, 316.

D. hyalina.....

Cyclops........

Diaptomus....

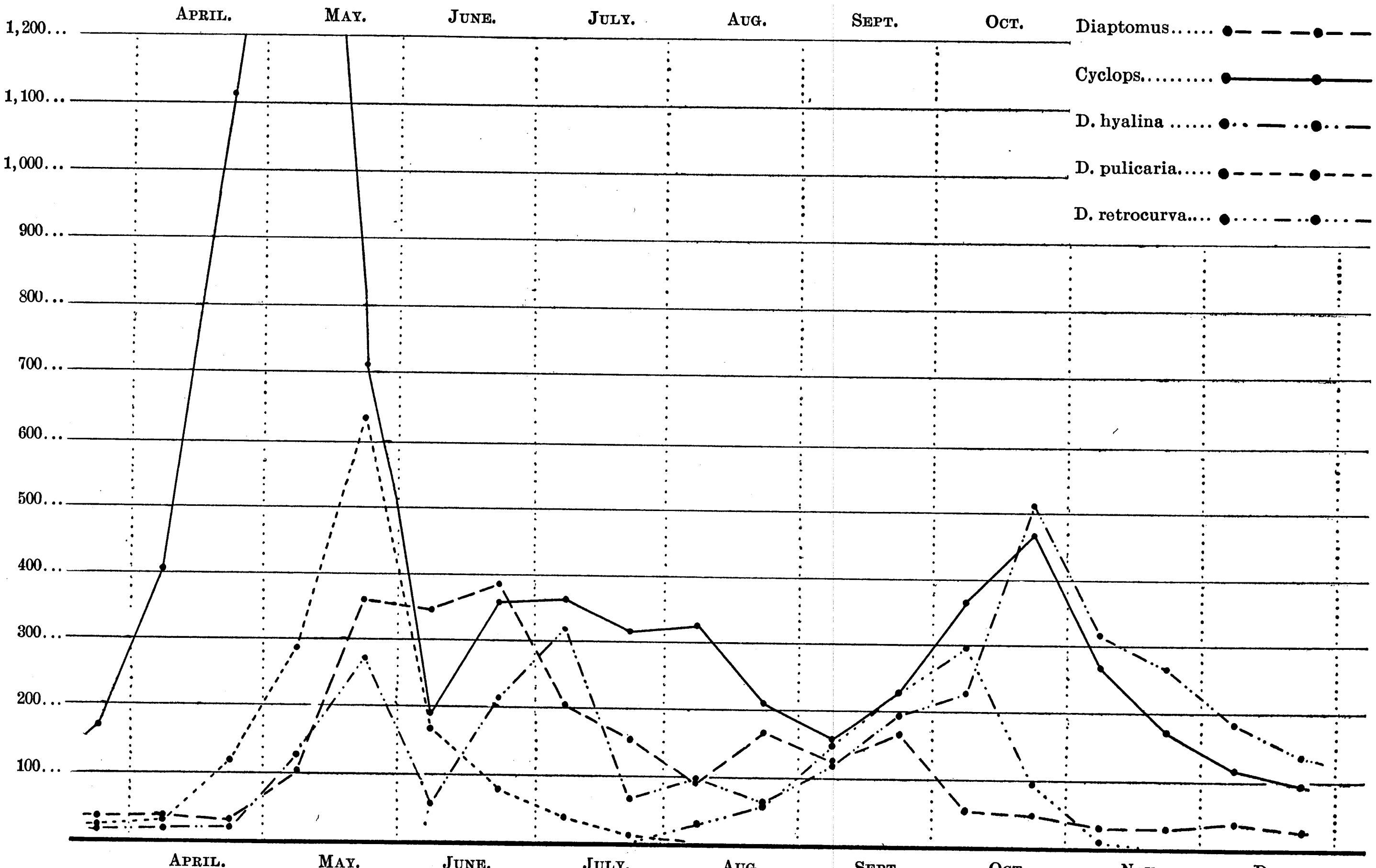


FIG. 9.—Leading crustacea, 1896. Scale, 1 space = 100,000 crustacea per sq. meter. See p. 308, 316.

on their development. At the time of the maximum *Cyclops* may number more than 2,500,000 per sq. m. of surface, but of this enormous number only a very small fraction ever become sexually mature. In any catch made at this season of the year, not more than five per cent. are mature, and not more than one or two per cent. are egg-bearing females. The great majority, therefore, of these *Cyclops* die without reaching maturity, and after the maximum has been passed the number of *Cyclops* decreases even more rapidly than it rose. The decline may go so far that in June the number of this species is scarcely larger than in March.

During this decline of *Cyclops*, the other perennial species are increasing in number, but their combined increase is more than counterbalanced by the decrease in the number of *Cyclops*, so that the late spring and early summer show a marked decline in the total number of crustacea.

The Crustacea in Summer.

The summer life of the crustacea begins with the decline from the spring maximum to the early-summer minimum. This decline is dependent in part on the decrease of *Cyclops*. In part, also, it depends on the fact that both species of *Daphnia* regularly decline after a brief maximum in late May or early June, and in 1895 *Diaptomus* showed the same decline. The total number of crustacea may be thus reduced to one-fourth, or less, of the number present at the spring maximum. The lowest point of numbers was about the middle of June in 1896, and about the first of July in 1895. In 1894, when observations began, during the first week of July, the crustacea were apparently at their minimum, which was exceptionally low in that year, owing to the peculiar character of the vegetation during that season. It was not greater than the number in the winter of 1895–96.

The crustacea increase in number after the early-summer minimum. This increase seems to be due to two causes. First, the development of species hitherto represented in small numbers. In all years there comes at this time an increase of *Cyclops Leuckartii.* The numbers of this species differ greatly in different seasons. In 1894 it was only a small fraction of the total number of *Cyclops* present, while in 1896 it was quite as numerous as *Cyclops brevispinosus.* In 1896 *Chydorus* developed in great numbers in the latter part of June and early July. This development coincided with the presence of great quantities of *Aphanizomenon.* In 1895, which was characterized by a predominance of diatoms among the plankton algae during the summer, there was no marked development of *Chydorus* until autumn. The second cause of this midsummer increase is the renewed reproductive activity of the perennial species, especially *Daphnia hyalina.* These species has a marked reproductive period and maximum in the spring, (Fig 16) at which time from five to nine eggs may be produced. After the production of the spring broods the reproduction is greatly checked, and the species declines rapidly in number; but when the summer temperature of the water has been established, the species again reproduces, so that its numbers increase rapidly. Only two eggs are, however, regularly produced at once during the summer.

The result of these additions of new forms and increase of old ones gives a marked rise of the total number of the crustacea in late June and early July. This rise was very feeble in 1894, owing to the wholly peculiar condition of the vegetation, as stated elsewhere.

From this mid-summer maximum all of the species, except *Chydorus*, usually decline steadily and somewhat uniformly until the middle or the last of August. Three possible causes may be assigned for this decline: first, the exclusion of the crustacea from the deeper water of the lake; second, the increased temperature of that part of the lake inhabitable by them; third, the great development of *Ceratium*, which regularly becomes a predominant alga during this period, and which is much less available as food than the diatoms and Schizophyceae. *Ceratium* exerts a more unfavorable influence on the number of the crustacea from the fact that the young crustacea are quite unable to eat it. It is so large and its shell is so hard that they cannot master it, yet *Ceratium* occupies, with its enormous swarms, the upper strata of water, which naturally belong to the young crustacea. While, therefore, the adult crustacea may find abundant food in the deeper strata, the young are unable to develop, and thus the total number of the limnetic crustacea slowly declines. The insect enemies of the crustacea, notably *Corethra*, are also very numerous at this time, but the number of these which I have found is not great enough to account for the decline in the number of the crustacea, and the increase of the crustacea begins in September, before the insect larvae begin to decline. I assign most influence to the first and third of the unfavorable influences which I have named. During this time the periodic species are added but their numbers are usually not great until after the first of September.

The Crustacea in Fall.

The number of the crustacea begins to increase with the opening of September (compare Figs. 6–9) and the increase continues during that month and into October. This increase is due in part to the increase in number of the perennial species. *Daphnia hyalina* and *Cyclops brevispinosus* multiply and reach a maximum in late September or in October. To these species are added the periodic forms, which are present in August, but ordinarily not in sufficient numbers to balance the decline in the other species. During September, however, all increase in number together, and bring the total number at the fall maximum to a point more than half as great as that at the spring maximum. In 1894 the maximum, 821,000 per sq. meter was reached in the first part of October; in 1895, the maximum was 768,000, in the early part of October; in 1896, there were two maxima, one in early September, numbering 1,441,000, of which more than half was due to *Chydorus*. The other, the fall maximum proper, was 1,368,000 and came in early October, or leaving out *Chydorus*, 1,123,000 in late October. The figures are the semi-monthly averages. The difference in these dates is apparently dependent upon temperature. If October is warm and pleasant, the development of the crustacea continues longer, and the maximum is greater than under other climatic conditions. In all seasons food is present in superabundance at this time of the year. The algae are at a maximum, and are enormously in excess of any demands made upon them by the crustacea. The species present are those which are most easily available as food, so that both in kind and quantity of food, the crustacea find the most favorable possible conditions from early September to the latter part of November. Temperature is the predominant factor in influencing their development.

In 1894 and 1896 *Chydorus* was present in great numbers. Both of these seasons were characterized by the great abundance of *Aphanizomenon*. In 1895 and 1897, when the predominant algae were almost exclusively diatoms, the number of *Chydorus* was extremely small. Diagram 10 shows the number of crustacea from July to December, after subtracting *Chydorus*. It will be seen that the form of the curves is strikingly similar in all years, and that the numbers are extremely close for 1895 and 1896, with the exception of a great rise in late October, 1896, which was due to the sudden multiplication of *Daphnia hyalina* at that time.

From the fall maximum the number declines, at first rapidly, and afterwards more slowly toward the winter minimum. The rapidity of the decline depends upon several factors. If a large number of young forms are produced late in the season, many of them die as well as their parents, and the decline in numbers is correspondingly rapid. The number of the periodic species also exerts a great influence. In 1896, when *Daphnia retrocurva* was present in large numbers, its sudden disappearance at the close of its sexual period aided to cause a rapid decline in the total number of crustacea present. The climatic conditions also exert a great influence. A rapid decline in temperature, accompanied by violent storms, causes the numbers to sink more rapidly than a more equable approach of winter temperatures. In any case the number of the crustacea falls off rapidly during November, more slowly during December, and by the middle or last of that month the lake freezes and the winter conditions are fairly established.

The different species of limnetic crustacea enter the winter in very different conditions. *Daphnia hyalina* produces in the late fall large numbers of young, which serve to carry the species through the winter. The old individuals disappear during November and December, very few lingering into January. Dur-

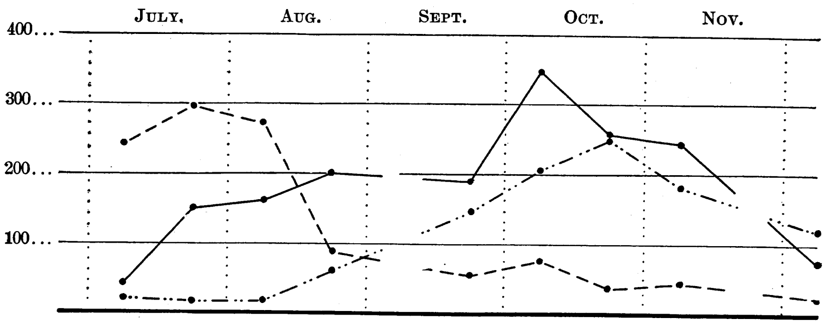


FIG. 7.—Leading crustacea, 1894. Scale, 1 space = 100,000 crustacea per sq. meter. See p. 308.

D. hyalina..... ··—··●··—

Cyclops........ ●———●———

Diaptomus.... ●— — —●— —

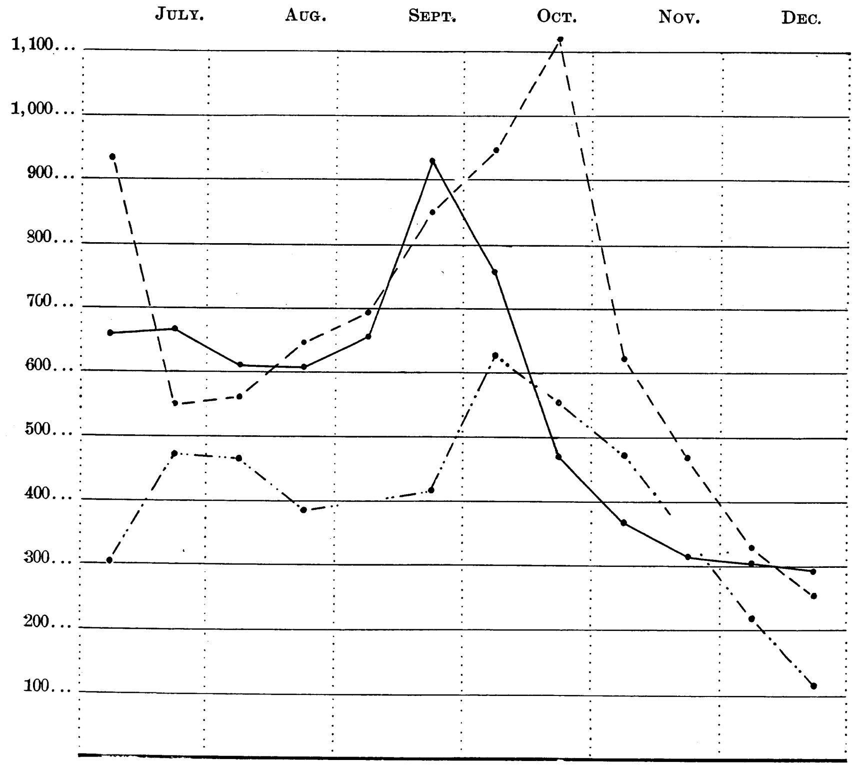


FIG. 10.—Total crustacea, July-Dec., after deducting *Chydorus*. Scale, 1 vertical space = 100,000 crustacea per sq. meter. See p. 312.

1894.... ··—··●··—

1895.... ●———●———

1896.... ●— — —●— —

ing the same months, those individuals of *Daphnia retrocurva* disappear, which have survived the reproductive period. *Diaptomus* begins its decline in September or early October, and seems to make no special provision for winter forms. *Cyclops* continues its reproductive activity through the year, at least in periods when the temperature of the lake is above 2° C., but with a rate of multiplication declining as the temperature falls below 15°. Larval Copepods are present in great numbers at all seasons, but their development into later stages is checked in winter. *Chydorus* seems to have the same habit as *Cyclops;* but, for causes as yet unknown, it almost disappeared in the winters of 1894-5, 1896-7, although abundant in the preceding autumns, and present in considerable numbers in the winter of 1895-6. *Daphnia pulicaria* had a marked reproductive period in early December, and continued reproduction at a slower rate throughout the winter. *Diaphanosoma* disappears in October, and *Leptodora* in late November or early December.

TABLE IV.—*Average number of crustacea for each two-week period and their sum, stated in thousands and tenths per sq. meter of surface.*

	Diaptomus.	Cyclops.	D. pulicaria.	D. hyalina.	D. retrocurva.	Chydorus.	Diaphanosoma.	Total.
1894.								
July 1-15	242.2	39.8	6.4	19.8	a	a	a	306.2
July 16-31	**298.9**	151.0	8.3	13.3	a	a	0.8	472.3
August 1-15	218.7	161.0	1.1	16.6	a	a	6.3	401.1
August 16-31	87.4	200.3	0.8	60.7	a	15.0	18.0	382.2
September 1-15	....	....	....	....	....	....	....	....
September 16-30	54.6	190.1	a	148.4	a	**278.9**	19.6	691.6
October 1-15	67.6	**347.1**	a	207.6	a	193.3	5.2	**820.8**
October 16-31	38.3	261.3	a	**252.5**	a	202.0	3.0	757.1
November 1-15	44.0	246.4	a	183.1	a	97.9	a	571.4
November 16-30	....	....	....	....	....	....	....	....
December 1-15	23.9	75.0	a	121.5	a	9.5	a	219.9
December 16-31	(16.7)	(44.5)	a	(49.0)	a	(1.65)	a	(111.9)
1895.								
January 1-15	17.5	*21.5*	a	40.8	a	1.3	a	*81.1*
January 1-15	(15.9)	(40.0)	a	(55.9)	a	(2.0)	a	(111.8)
February 1-14	(44.5)	(80.8)	a	(75.3)	a	a	a	(200.6)

TABLE IV.—Continued.

	Diaptomus.	Cyclops.	D. pulicaria.	D. hyalina.	D. retrocurva.	Chydorus.	Diaphanosoma.	Total.
1895.								
February 15-28..........	28.0	73.1	a	65.8	a	a	a	166.9
March 1-15	28.3	55.7	a	34.7	a	a	a	118.7
March 16-31	34.7	66.2	a	63.6	a	a	a	164.5
April 1-15................	*14.0*	53.9	a	26.4	a	a	a	94.3
April 16-30...............	20.6	242.5	a	*16.3*	a	scat.	a	229.4
May 1-15..................	34.4	864.9	a	28.9	a	12.1	a	940.3
May 16-31.................	207,9	**944.4**	a	250.7	a	16.5	a	**1419.5**
June 1-15	**285.0**	616.9	a	**319.2**	a	36.7	a	**1256.6**
June 16-30	190.6	262.6	a	135.6	Scat.	21.9	a	610.7
July 1-15	187.4	323.6	Scat.	139.9	9.7	**156.8**	Scat.	817.6
July 16-31	217.8	131.4	11.6	**275.3**	31.5	**163.4**	6.9	837.9
August 1-15...............	110.5	107.6	19.9	**273.0**	68.2	78.6	31.5	689.1
August 16-31..............	101.3	129.6	38.1	252.8	50.1	18.7	32.2	622 8
September 1-15...........	224.6	142.0	33.8	202.8	23.8	15.6	27.1	669.7
September 16-30.........	**331.5**	226.0	98.2	201.6	53.6	Scat.	17.2	**928.1**
October 1-15..............	148.4	**327.5**	26.9	180.5	**72.5**	8.6	3.4	767.8
October 16-31............	79.7	219.7	23.5	76.6	**70.9**	8.1	a	478.5
November 1-15	55.8	144.7	49.6	56.2	59.3	25.9	a	391.5
November 16-30.........	46.0	135.4	58.3	48.2	24.2	19.7	a	331.8
December 1-15............	33.6	90.2	141.1	35.0	5.0	15.9	a	320.8
December 16-31..........	58.0	89.1	99.8	44.6	0.7	20.9	a	313.1
1896.								
January 1-15..............	48.6	111.0	88.2	36.2	a	10.1	a	294.1
January 16-31.............	*28.3*	151.0	24.8	17.3	a	19.5	a	240.9
February 1-14............	38.9	91.6	64.1	19.6	a	4.8	a	219.0
February 15-29...........	35.0	*82.0*	43.9	27.0	a	3.8	a	*191.7*
March 1-15................	....	....	....	....	....	....	....	....
March 16-31..............	33.3	212.5	20.9	*13.5*	a	1.4	a	281.6
April 1-5..................	35.2	400.7	28.0	14.6	a	1.9	a	480.4
April 16-30................	29.9	1,011.2	118.2	15.2	a	9.8	a	1,184.3
May 1-15...................	102.3	**1858.4**	284.9	124.6	a	28.0	a	**2398.2**
May 16-31.................	**360.2**	705.9	**533.6**	**270.8**	a	30.8	a	**1901.3**
June 1-15.................	**343.5**	189.5	168.6	55.6	a	87.6	a	844.8
June 16-30................	**386.2**	358.7	78.2	211.1	a	230.8	a	1,265.0
July 1-15..................	202.9	371.0	39.3	**319.0**	a	**382.0**	a	1,314.2
July 16-31....	152.1	317.5	11.8	65.5	2.5	245.1	Scat.	776.5

TABLE IV.—Continued.

	Diaptomus.	Cyclops.	D. pulicaria.	D. hyalina.	D. retrocurva.	Chydorus.	Diaphanosoma.	Total.
1896.								
August 1-15	91.9	326.8	3.7	95.2	27.6	406.5	8.9	960.4
August 16-31	167.0	209.0	5.9	60.9	57 1	426.0	**147.4**	1073.3
September 1-15	125 9	157.1	23.5	120.4	157.7	**748.6**	108.3	**1440.9**
September 16-30	163.4	228.6	3.4	192 5	**228.6**	263.0	32.9	**1112.4**
October 1-15	52.8	364.8	0.4	228.0	**199.3**	**423.7**	0.4	**1368.4**
October 16-31	48.8	**469.5**	a	**511.5**	92.7	191.9	a	**1314.8**
November 1-15	29.8	267.7	Scat...	314.6	9.9	62.7	a	684.8
November 16-30	23.5	173.9	Scat...	266 0	a	69.3	a	537.7
December 1-15	29.3	115.5	Scat...	182.8	a	38.2	a	365.8
December 16-31	24.7	93.1	Scat...	138.9	a	28.1	a	284.8

In this table maxima are indicated by bold faced type and minima by italics. a, means absent; scat., scattering individuals not enough to count. Parentheses indicate that observations were made on a single date in the two week period; —, indicates no observations.

Although the general course of the development of limnetic crustacea is so nearly the same in successive years, yet the composition of the crustacean population may differ very widely. This will readily be seen from the tables, and still more easily by the diagrams which show the numbers of the individual species of crustacea in the different years. A single illustration is given in Figs. 11, 12, and 13. These diagrams represent the average number of the crustacea in the latter half of September, 1894, 1895, and 1896. The area of the circles is proportional to the total number of crustacea, and the size of the several sectors is proportional to the number of the individual species. It will be seen that while the total numbers are not very widely different, there is a great divergence between the individual species. *Diaptomus*, for example, is by far the most numerous in 1895, while in 1894 it is the next to the smallest. In 1894, on the other hand, *Chydorus* is by far the largest; while in 1895 it is not represented at all. *D. retrocurva* is one of the most important species in 1896, and had a fair development in 1895, while in 1894 it was wholly absent. No reason can be given in most cases for these variations in individual species; but where a cause can be assigned, the subject is discussed in the section which deals with the single species in detail.

Diagrams 8 and 9 show on single charts the numerical relations of the most important limnetic crustacea during the seasons of 1895 and 1896. Several facts become very plain from these diagrams. First, the development of *Cyclops* precedes that of *Daphnia* and *Diaptomus* by nearly a month, and precedes that of *D. pulicaria* by something more than two weeks. This relation held in both years, although the development of all the crustacea was some two weeks earlier in 1896 than in 1895. Second, in both years *Daphnia hyalina* and *Diaptomus* began their development together in the spring and rose together to the spring maximum. This coincidence was probably due to the rapid warming of the lake in both seasons. Figs. 1 and 2 show that the temperature of the water rose with much the same rapidity in the two years. *Diaptomus* requires a higher temperature for its development than does *Daphnia*, as is shown by the fact that it declines steadily after the lake falls below a temperature of 20°, while *Daphnia* has its great autumnal period of reproduction in the month of October when the temperature is below 15°. In the spring of 1897 the warming of the lake was slower than in either of the two years covered by my study, and the development of *Diaptomus* lagged decidedly behind that of *Daphnia*. I am not able, however, to give the exact numerical relations.

Diagram 9 shows also that *Daphnia pulicaria* began its course of development about two weeks in advance of *Daphnia hyalina*. Another fact is disclosed by Figs. 8 and 9, namely, that in each summer some one species of limnetic crustacean appears to take the lead, and decidedly dominates the other forms. In 1894, as shown by Fig. 7, this species was *Diaptomus*. In 1895, as shown by Fig. 8, *Daphnia hyalina* maintained its numbers full through July and August, gradually declining through the autumn, and being nearly twice as numerous as

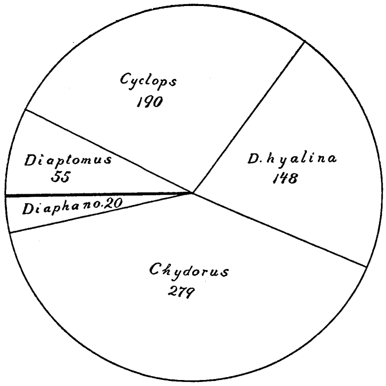


FIG. 11.—Crustacea, Sept. 16-30, 1894.

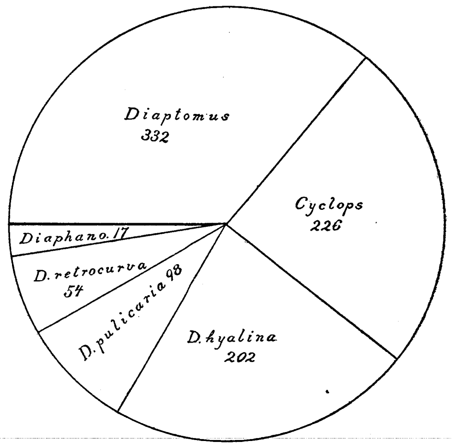


FIG. 12.—Crustacea, Sept. 16-30, 1895.

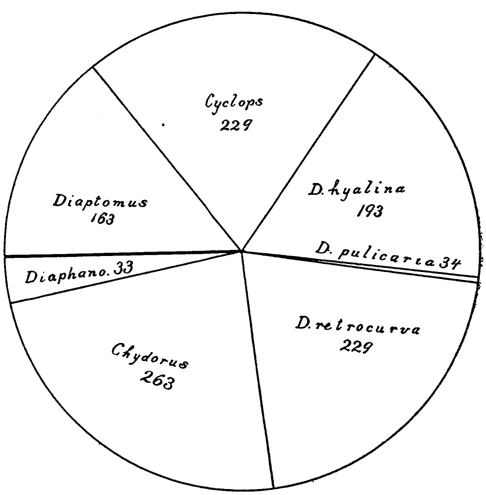


FIG. 13— Crustacea, Sept. 16-30, 1896.
See Table IV and p. 315.

the other two leading genera. In 1896 *Cyclops* held a similar place, recovering rapidly from its early summer depression and maintaining its numbers full throughout July and the early part of August.

The diagrams show further how all the species of crustacea increase in September, and that the rise persists to different dates in the later autumn. In 1895 *Diaptomus* showed a maximum in late September, and that of *Cyclops* came in the first half of October. In 1896 *Daphnia hyalina* and *D. retrocurva* rose together from the latter part of August to the middle of October, when the former species had a period of enormous reproduction, while *D. retrocurva*, which had produced its ephippial eggs, rapidly declined in number. The increase of *Cyclops* in this year also continued until late October. The diagrams show further how all species rapidly decline in number in November, and then more slowly during December, reaching their permanent winter condition in December, or at latest about the first of January.

The feature of the annual distribution of the crustacea which surprised me most in the progress of my work is the great difference between the numbers of the same species of crustacea present in successive years. I do not refer so much to the larger or smaller numbers of forms like *Cyclops*, for whose variations causes can be assigned, at least in part, but rather to such facts as those shown by *Daphnia retrocurva* and by *Diaphanosoma*, which are either absent, or present in very small numbers in one season and appear in great numbers in another year. For such variations it is very difficult to assign even conjectural causes.

A similar fact has appeared in the succession of the algae. It is not true for lake Mendota that the forms of algae succeed one another in a definite order in successive seasons, so that one can be sure of finding certain forms at certain times of year, as would be the case with plants of woodland or prairie. For example, in the winter of 1894–95 *Aphanizomenon* and *Clathrocystis* were the predominant algae after the early part of January. In the succeeding winter these plants were almost entirely absent and *Diatoma* was the predominant form. In the winter of 1896–97 *Aphanizomenon* and *Diatoma* were present together; the latter form being more abundant at the opening of the winter and the former relatively increasing towards spring. *Asterionella* has been regularly present in all years as a small part of the summer plankton, but never has been predominant except during a short time in the spring of 1897. *Ceratium* has been a leading alga in the summers of 1895 and 1896, but in 1894 and 1897 there was no *Ceratium* period. *Lyngbya* predominated in July, 1895, but scattered filaments only were present during the succeeding two seasons, while in August and September, 1897, it was again present in considerable numbers, though nowhere near as great as in 1894. The summer of 1895 was definitely a diatom season, as was also that of 1897, very few of the Schizophyceae being present; while in 1896 the latter plants predominated, although a considerable number of diatoms were always present. In the autumn there has always been a diatom period, but the predominant forms have been *Diatoma*, *Fragillaria*, and *Melosira* in different seasons. The first alga to develop in the spring is one of those which has predominated during the winter, but the order of succession in the forms which follow is wholly uncertain, as the few illustrations given above sufficiently indicate.

LARGEST NUMBER OF CRUSTACEA PER CUBIC METER.

The following list shows the largest number of crustacea found per cubic meter. It is computed on the assumption that the animals are equally distributed through the three meter space covered by each haul of the net and gives the average per cubic meter for the distance of three meters. In reality the maximum at the stratum of greatest abundance would be greater than the table shows. Probably 600,000 would not be too high as the maximum for the total number in a cubic meter. The numbers are given as thousands per cubic meter. All, except *D. pulicaria* are from the upper, or 0–3 meter level.

Table V.

Diaptomus.	*Cyclops.*	*D. hyalina.*
June 17, 1894 88	October 8, 1894......... 56	July 24, 1895 101
June 12, 1895 84	May 18, 1895............ 180	Aug. 21, 1895 102
September 16, 1895....... 98	May 8, 1896............ 290	June 29, 1896 145
June 5, 1896 120	....	July 7, 1896 170
June 10, 1896 157	....	Oct. 26, 1896............ 122

D. pulicaria.	*Chydorus.*	*Total crustacea.*
Aug. 22, 1895..41, 9-12 meters	Sept. 22, 1894........... 71	May 9, 1896 347
Sept. 22, 1895..41, 15-18 meters	July 12, 1895............ 45	May 18, 1896 392
Dec. 23. 1895..73, 0- 3 meters	June 22, 1896............ 96	June 19, 1896............ 415
May 18, 1896..78, 0- 3 meters	July 7, 1896............ 131	June 22, 1896............ 337
....	Aug. 6, 1896............ 111	July 7, 1896 426

It thus appears that where most thickly massed, the crustacea number nearly one to 2 ccm. of water.

Diaptomus Oregonensis Lillj.

Figure 14. Table D, Appendix.

The numbers of *Diaptomus* have varied from season to season less than those of any other species of the limnetic crustacea and they are also the least variable in daily numbers. Possibly the greatly developed locomotor organs of the animal aid in securing uniformity of distribution and also enable it to obtain so much food in times of scarcity, that its numbers remain constant when others decline.

Diaptomus does not reproduce during the winter and its numbers show little variation during that time, as the following table will show.

TABLE VI.— *Diaptomus. Average number expressed in thousands per square meter of surface.*

	1894-5.	1895-6.	1896.
October 1-15	67.6	148.4	52.8
October 16-31	38.3	79.7	48.8
November 1-15	44.0	55.8	29.8
November 16-30	....	46.0	28.5
December 1-15	23.9	33.6	29.3
December 16-31	(16.7)	58.0	24.7
January 1-15	17.5	48.6	....
January 16-31	(15.9)	28.3	....
February 1-15	(44.5)	38.9	....
February 16-31	28.0	35.0	....
March 1-15	28.3	....	....
March 16-31	34.7	33.3	....
April 1-15	14.0	35 2	....
April 16-30	20 6	29.9	....
May 1-15	34.4	102.3	....
May 16-31	207.9	360.2	....

Numbers enclosed in a parenthesis rest on observations made on a single day during the half-month.

These figures show that *Diaptomus* begins to decline toward its winter condition early in the autumn. There is no marked reproductive period in the fall which supplies the individuals which are to live over winter, but the numbers steadily and rather rapidly decline after the time when the lake has decidedly cooled from its summer temperature. The table also shows that the mortality must be very small in winter. In spite of the fact that there is no reproduction, the numbers show very little decline after the winter conditions are fairly established, and only a slow decrease in the late autumn. Indeed from the middle of October until the first or middle of May, the semimonthly averages show no more variation than might easily appear in two catches made on the same day at the same place. This persistence of the numbers of the species must be attributed to the absence of competition and of enemies during this season. The food supply is ample for the winter stock of crustacea and

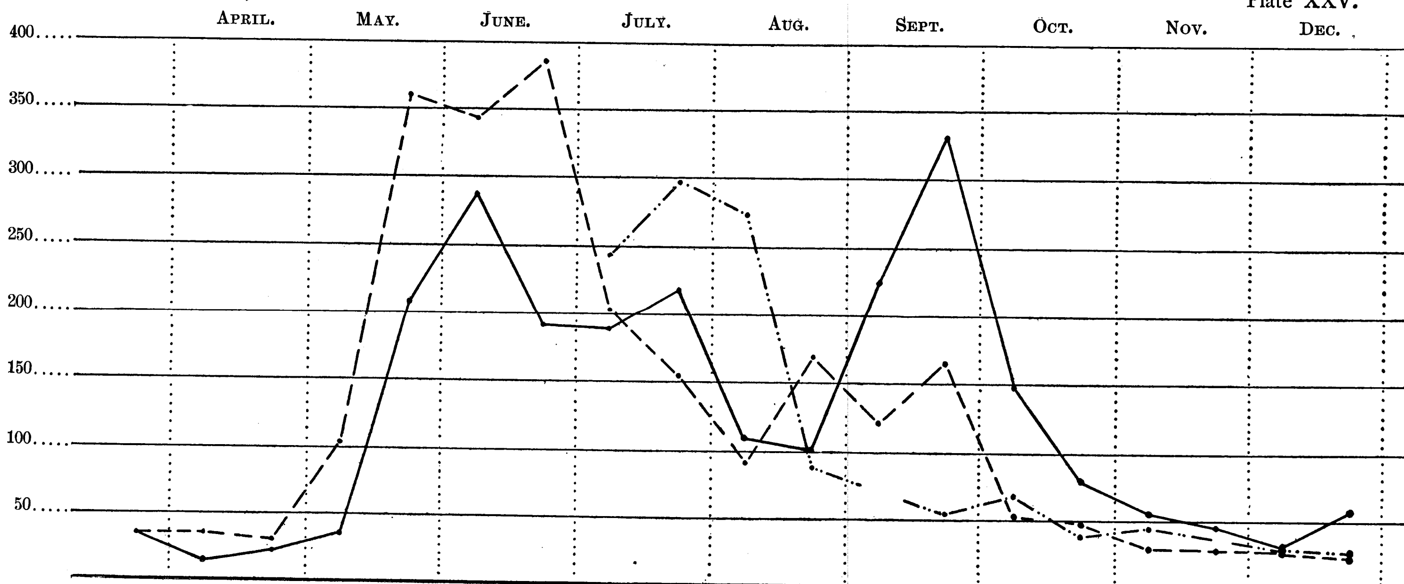


FIG. 14.—Diaptomus. Annual distribution, 1894, 1895, 1896. Scale, 1 vertical space = 50,000 crustacea per sq. m. See p. 319.

1894....

1895....

1896....

the reproduction of the crustacea in winter is slower than that of the algae. It is not impossible that the slight decline in numbers noticeable in 1895–6 may be attributable to the multiplication of *Cyclops* in that winter. The decline in *Diaptomus* is too small to allow of certainty in the inference, but the adult *Cyclops* fell off rapidly in March of that year as they did not in the preceding winter when little reproduction took place. Food also became much more scanty in the spring of 1896 than in the preceding year. The amount of food material in the spring of 1895 was estimated as at least four times as great relatively to the number of crustacea present.

The chief enemies of the crustacea are the larvae of insects and the young fish, both of which are absent or few during the winter. *Leptodora* also, though living chiefly on *Cyclops* and *Daphnia*, must devour some *Diaptomi* during the summer; while it is wholly absent in winter. At this season the perch, which also feed on the small crustacea, are at the bottom and apparently do not feed at all. There seem therefore to be no enemies of the crustacea during the winter and their numbers are correspondingly constant.

Throughout this season also *Diaptomus* is fat — fatter than in summer, as the drain on tissue for reproduction is absent.

In April after the ice breaks up the crustacea are wont to decline in numbers. This is especially true for those species whose reproductive period comes somewhat late in the spring, and in which only the individuals which have lived all winter are present in the spring. These find the conditions of the open water of the early spring harder than those under the ice, especially as they are exposed to the competition of the increasing swarms of *Cyclops* and sometimes of *D. pulicaria.* The smallest catches of *Diaptomus* which are met during the year, are obtained in the latter part of April when the number of *Cyclops* has risen greatly — more rapidly than the food has increased.

In May there comes a great increase in the number of *Diaptomus.* It shows itself first by the presence of a great number of immature animals in the upper strata of the water. In both years the appearance of these new members of the species was very sudden, as will be seen from the following table.

TABLE VII.—*Showing the actual number of Diaptomus caught during May.*

1895.		1896.	
May 4	270	May 2	730
May 7	410	May 4	660
May 12	710	May 6	980
May 16	780	May 8	600
May 18	2,200	May 9	560
May 20	1,650	May 11	1,945
May 22	3,820	May 15	6,110
		May 18	10,250
		May 21	3,690

It will be seen that these catches divide very sharply into two sets, the division coming between the 16th and 18th of May in 1895 and between the 9th and 11th in 1896. Catches earlier than those given in the table show the same general character as those given, as also do those taken later. There is no earlier catch which is larger than 1000, nor one later in May smaller than 2,000 in 1895 or 3,500 in 1896.

There is no reason to think that the increase of numbers is due to small, local aggregations of the species. The increase persists without intermission for long periods of time during all conditions of wind and weather. This alone shows that the large numbers must occur over great areas of the lake. On May 15, 1896, observations were made at different points, and the numbers were found practically constant at a distance of 2.5 kilometers in various directions from the regular place of collecting.

It will be seen that the spring increase came just a week earlier in 1896 than in 1895—on May 11th and May 18th, respectively. This acceleration of development, which was shared by all of the crustacea, was chiefly due to the higher temperature of the water in the latter year.

In 1895 the ice went out on April 8th, in 1896 on April 2d. In each year cold and rainy weather followed the departure of the ice and at the middle of the month the temperature of the water was almost the same in both years.

April 15.	1895.	1896.
Surface	4.5°	4.0°
Bottom	4.2	3.9

Later the temperature showed a nearly parallel rise at the surface, but a marked acceleration at greater depths for 1896, the following table shows:

	SURFACE.		BOTTOM.	
	1895.	1896.	1895.	1896.
April 18	6.0°	7.2°	5.0°	6.1°
April 24	8.0	8.0	5.8	7.4
April 30	11.5	9.6	6.9	8.5
May 7	10.8	16.4	6.3	9.9
May 18	15.5	15.2	11.2	13.4

It thus appears that the average temperature of the water was decidedly higher in 1896 than in 1895, and to this fact I attribute the earlier appearance of the spring swarms of crustacea. There was nothing apparent in the increase of the algae to make any difference.

When the young *Diaptomus* appear the number rapidly rises to a maximum which is maintained for some weeks, as the table shows:

TABLE VIII.—*Average number of Diaptomus during late spring and summer stated in thousands per square meter of surface.*

	1894.	1895.	1896.
May 1-15	....	34.4	102.3
May 16-31	....	207.9	360.2
June 1-15	....	285.0	343.5
June 16-30	....	190.6	386.2
July 1-15	242.2	187.4	202.9
July 16-31	298.9	217.8	152.1
August 1-15	273.3	110.5	91.9
August 16-31	87.4	101.3	167.0

It will be seen that the numbers found in all three years are closely parallel. Indeed the July averages for the three years differ no more widely than catches might differ though made on the same day and close together.

In each of the two years where the conditions of the preceding winter were known, the summer maximum was close to ten times the winter average. In all three years there was a marked decline of numbers to a late summer minimum in August; at which time the average number is $\frac{1}{3}$ to $\frac{1}{4}$ of the maximum. In 1895 there was a very marked drop in numbers about the first of July; while in 1896 the maximum number was maintained throughout June and early July and then there was a steady decline for a month or more. In 1894 observations began on the first of July. *Diaptomus* was practically stationary during the month and rapidly declined after the early part of August.

These variations in number in different years are at present without complete explanation. Yet the most singular fact — the notable drop in numbers about July first, 1895—certainly extended to the species all over the lake. Observations were made between the first and tenth of July in that year even in the remoter parts of the lake, and with substantially uniform results. Whatever the cause it was probably the same as produced a similar fall in the numbers of *Daphnia hyalina* at the same time.

The autumnal condition of *Diaptomus* varies with the temperature of the early fall. In 1894 and 1896 there was substantially no recovery from the August minimum. 1896, indeed, showed minor variations of number but on the whole the number did not increase. In 1895 on the other hand there was a very marked rise of numbers in September, culminating in the third week of that month. We shall hardly be wrong in attributing this additional brood of *Diaptomus* in 1895 to the higher temperature of the water in that year. There was very little decline of temperature until the very last days of the month as the following observations will show:

1895.	Sept. 2, 6 a. m.	Sept. 26, 6 a. m.	Sept. 30, 6 a. m.
0 meters	21.9°	20.0°	16.3°
10 meters	20.9	20.0	16.5
18 meters	13.9	17.7	16.5

Thus the decline of temperature for the month occurred in the last three days. In 1896 the temperatures at the opening and close of the month were much the same as in the preceding year, but the decline was pretty equably distributed.

1896.	Sept 1, 9:30 a. m.	Sept. 17, 4 p. m.	Sept. 28, Noon.
0 meters	21.2°	18.4°	16.0°
10 meters	20.2	18.2	15.75
18 meters	15.3	16.1	15.6

It therefore appears that the long continued warmth of 1895 gave *Diaptomus* a chance for an additional brood which did not appear in 1894 or 1896. Food, of course, is always present in superabundance during September.

TABLE IX.—*Diaptomus. The autumnal numbers stated in thousands per square meter of surface.*

	1894.	1895.	1896.
September 1-15	....	224.6	125.9
September 16-30	54.6	331.5	163.4
October 1-15	67.5	148.4	52.8
October 16-31	38.3	79.7	48.8
November 1-15	44.0	55.8	29.8
November 16-30	....	46.0	28.5
December 1-15	23.9	33.6	29.3
December 16-31	(16.7)	58.0	24.7

The winter numbers are seen to be reached early in the season — at latest in the first part of November. The winter numbers are also seen to be not very different in the three years in question and are strikingly independent of the condition earlier in the season. The number in September, 1895, was nearly six times as great as in the preceding year, while in December the difference was less than 50 per cent. in favor of 1895.

The maximum catches of *Diaptomus* were 460,000 June 12, 1895; 651,000 May 18; and 741,000 June 10, 1896. The females carry 20-30 eggs in a single sac, during the spring. In summer the number declines to 9-15.

Apstein ('96, p. 179), finds that *D. graciloides* has its maximum in lake Ploen in winter and in the Dobersdorfer See in summer. Its relations in the latter lake agree very well with those of the same genus in lake Mendota. He concludes from the striking difference in the two lakes that temperature has no effect on the species. Marsh, who finds that *D. minutus* has its maximum in Green lake in September and October ('97, p. 192), also thinks that temperature affects the genus very little. I am unable to agree with this conclusion, so far as the form studied by me is concerned. It is the first of the perennial crustacea to slacken its reproductive activity in the autumn, and this occurs when food is at its maximum. I can attribute this check only to the fall in temperature. Indeed, my observations show that the reproductive activity of *D. Oregonensis* is more promptly checked by the decline of temperature than is that of any other of the perennial species.

Cyclops.

Figures 15, 21. — Table E, Appendix.

There are two species of *Cyclops* which are at times conspicuous in the plankton of lake Mendota, *C. brevispinosus* Herrick and *C. Leuckartii* Sars. *C. pulchellus* Koch was rarely seen. *C. brevispinosus* is by far the more numerous and is practically the only species except in summer. From October to May only scattered individuals of any other species are met, but during summer *brevispinosus* declines and *Leuckartii* may be as numerous as it or even more so. The numerical relation has not been determined because of the great labor involved in discriminating the species, especially in the immature examples which always constitute by far the greater part of the catch.

Cyclops brevispinosus is the most abundant species of limnetic crustacea at almost all times, and at its maximum is far more numerous than any other species ever becomes. It is the only abundant Copepod which reproduces under the ice; *Daphnia pulicaria* among the Cladocera has the same habit.

The winter numbers are as follows, stated in thousands per square meter of surface:

TABLE X.—*Winter number of Cyclops, stated in thousands per sq. m.*

	1894–95.	1895–96.	1896.
November 1-15	246.4	144.7	267.7
November 16-30	....	135.4	173.9
December 1-15	75.0	90.2	115.5
December 16-31	(44.5)	89.1	93.1
January 1-15	21.5	111.0	....
January 16-31	(40.0)	151.0	....
February 1-14	(80.8)	91.6	....
February 15-28	73.1	82.0	....
March 1-15	55.7	....	....
		old. yg.	
March 16-31	66.2	51.2 161.3	....
April 1-15	53.9	400.7	....
April 16-30	242.5	1011.2	....

It will be seen that the winter numbers are more variable during the season than are those of *Diaptomus*. This results from two causes; first, the fact that reproduction continues longer in the autumn than in *Diaptomus* and therefore the species reaches its winter minimum at a later date; second, reproduction may begin again during the winter and cause a considerable increase before the opening of the lake in the spring. A third fact ought to be added. During the winter there are often caught large numbers of *Cyclops* in the deeper water, where there are plainly aggregations of the species. Such catches of course raise the average for the two-week period in which they happen to come.

The spring rise comes on immediately after the opening of the lake or, as already said, begins while the lake is still covered with ice. The increase is rapid but by no means so sudden as is the case in *Diaptomus*. This may be seen from the following table of catches, in which by no means all the observations of the periods are given.

TABLE XI. — *Cyclops. Average number per square meter, stated in thousands per sq. m. of surface.*

1895.		1896.	
April 12	43.8	April 4	297.0
April 18	90.3	April 11	358.7
April 25	112.8	April 14	863.2
April 30	575.8	April 20	770.8
May 3	979.8	April 30	984.5
May 12	763.2	May 2	1,710 2
May 18	1,234.2	May 9	2,359.5
May 30	1,030.4	May 18	1,294.9
June 6	636.0	May 26	386 6
June 14	293.1	June 1	176.1
		June 6	168.5
		June 15	139.2

In each column the numbers begin with the first catch after the disappearance of the ice. It will be seen that on April 12, 1895, there was no evidence of increase over the winter average and that none of the catches prior to that of April 30, are decidedly larger than those of the winter. In 1896, on the contrary the open season begins with numbers far larger than those of the winter and there is a steady and rapid increase from the very first.

TABLE XII.— *Cyclops. Average for the spring and early summer stated in thousands per square meter of surface.*

	1895.	1896.
April 1-15	53.9	400.7
April 16-30	242.5	1,011.2
May 1-15	864.9	1,858.4
May 16-31	944.4	705.9
June 1-15	616.6	189.5
June 16-30	262.6	358.7

The maximum came earlier in 1896 than in 1895. The greatest number were caught from May 18th to 30th in 1895, and from

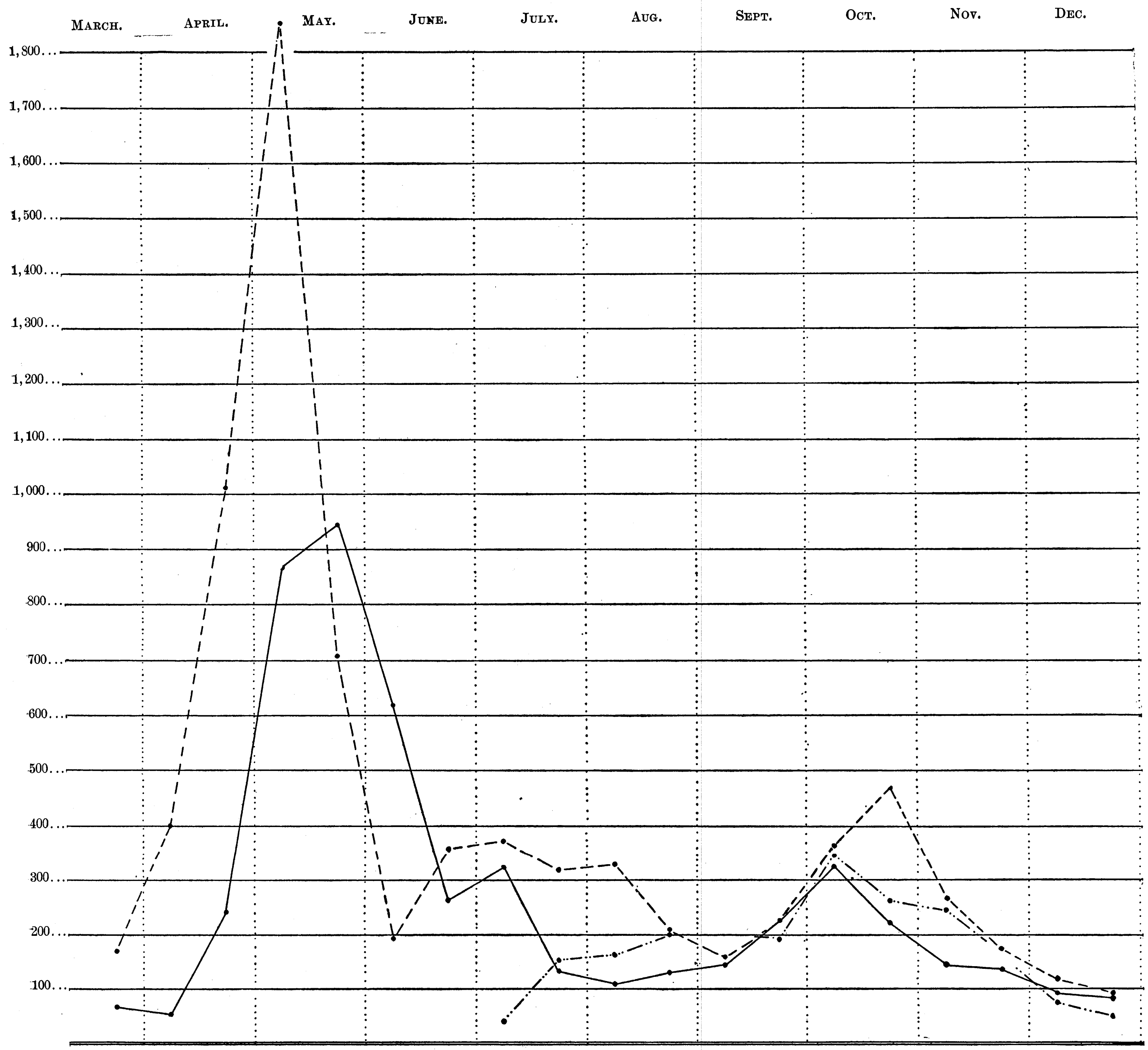


Fig. 15.—Cyclops. Annual distribution. Scale, 1 vertical space = 100,000 crustacea per sq. m. See p. 326.

1894....

1895....

1896....

May 2d to 9th in 1896. The entire month may be included in the maximum in 1895, as all the catches made between May 3d and June 6th, 26 in number, were between 636,000 and 1,234,000 per sq. m. In 1896 the limits of the maximum period may be set at April 14th and May 20th, during which time the numbers ranged from 763,000 to 2,359,000 per sq. m. The observations were 20 in number. The maximum catch recorded was nearly one-third larger than any other, although there were 7 catches made, ranging from 1,300,000 to 1,700,000 per sq. m.

From these figures and from the averages, it is plain that the numbers were far greater in 1896 than in the former year. I attribute the difference to the earlier start which the species had in 1896. In that year reproduction began under the ice so that the numbers at the opening of the season were three or more times as great as in 1895. While the lake warmed somewhat more rapidly in 1896, the difference was chiefly marked by the higher temperature of the lower water, which would aid the development of the species during the first part of April.

The decline of *Cyclops* is seen from Table XI and diagram 15, to be as steady and rapid as its rise. In 1896 the numbers in the first half of June were smaller than in the latter part of March. In less than two weeks after the maximum the number had fallen to less than one-sixth of the maximum and a week later it was less than one-half of the smaller sum.

This decline is doubtless due to the scarcity of food, to the increasing temperature of the water and, to increasing competition. At no time during the spring rise are as many as five per cent. of the species provided with egg-sacs and almost none of the animals in the lower strata of the water become sexually mature. This fact indicates that the lake becomes so crowded with the early swarms of the species that the food is insufficient to allow their development to maturity. Not only so, but those individuals which are compelled to migrate into the deeper water find there little food and must perish in a short time. At the height of the *Cyclops* period there is very little alga visible in the catch.

The influence of temperature is shown by the fact that the maximum is reached when the temperature of the lake is about

15° and that no considerable rise comes later in the season until the lake has fallen to about the same temperature in the fall. Development, begun actively while the water is little above zero, is gradually checked as the water warms during the spring, yet the nauplii may be very abundant in summer.

A reaction follows the early summer minimum and there is a moderate increase in the numbers of *Cyclops*. This is due chiefly, if not wholly, to the introduction of *C. Leuckartii*. This species is very rare during the cooler parts of the year, though always seen occasionally, and at all times capable of reproduction. In the summer, however, it develops more rapidly and numbers of the species may considerably exceed those of *C. brevispinosus*. This was not true in 1894, especially in July. At that time the number of *Cyclops* was very low, lower indeed than in the winter following. The rise in August of that year was largely although not wholly due to *C. Leuckartii*, and was apparently maintained into September when *brevispinosus* again became abundant. In both the other years *Leuckartii* declined in August and *brevispinosus* did not increase so that there was visible a late summer minimum during the whole or part of that month. The small numbers of 1894 are probably due to the excessive development of *Lyngbya* in the early part of that summer, as is stated more fully on page 353.

TABLE XIII.—*Cyclops*. *Average numbers for the last half of the years.*

	1894.	1895.	1896.
July 1-15	39.8	323.6	371.0
July 16-31	151.0	131.4	317.5
August 1-15	161.0	107.6	326.8
August 16-31	200.3	129.6	209.0
September 1-15	....	142.0	157.1
September 16-30	190.1	226.0	228.6
October 1-15	347.1	327.5	364.8
October 19-31	261.3	219.7	469.5
November 1-15	246.4	144.7	267.7
November 16-30	....	135.4	173.9
December 1-15	75.0	90.2	115.5
December 16-31	(44.5)	89.1	93.1

The foregoing table gives the average numbers of summer and autumn for the three years, stated in thousands per square meter of surface.

The table shows an autumnal maximum in October, followed by a steady decline and a slow one as compared with that which follows the spring maximum. The fall increase is due wholly to *C. brevispinosus* and the maximum comes when the lake is at or below 15° C. The decline is occasioned partly by the gales of autumn causing the death of adults, and chiefly by the increasing slowness of development of the nauplii as the temperature of the water falls. The eggs are still produced and the nauplii hatched, but the young *Cyclops* are slower in coming forward and the deaths exceed the production of young. Food is present in excess of the demands of the crustacea and so forms no factor in the decline.

By the middle of December if not earlier the winter conditions are fairly established although the number of the species may continue slowly to decline until February.

A comparison of the charts showing the curve for *Cyclops* and that for the total crustacea brings out the fact that *Cyclops* is the dominant factor in determining the number of crustacea. All the peculiarities of the general curves are repeated in those for the genus. *Cyclops* is absolutely the most numerous species except in the summer, when it is sometimes surpassed by *Diaptomus* and *Chydorus* and less often by *Daphnia hyalina.* Two causes contribute to this relative disadvantage of *Cyclops* in summer. First, the species is unfavorably affected by the warmth of the water; second, it is unable to retire into the cooler and deeper water as it might do in lakes which are habitable below the thermocline. In such lakes it may well be found that *Cyclops* leads the number of crustacea throughout the year. A few observations indicate this to be true for Pine lake, but the facts are not well known as yet.

Zacharias ('96, p. 54) finds only a fall maximum for *C. oithonoides* in lake Ploen. There is a trace of a spring maximum but very feebly marked. Apstein ('96, p. 178), finds maxima in the Dobersdorfer See in May, September, or July and thinks that the maxima may come at any time in summer. He finds on this species 5–6 or at most 9 eggs and considers the small number an adaptation to limnetic life. *C. brevispinosus* often carries 18 eggs in each sac without difficulty. He finds no eggs from October to February, while I find egg bearing females at all seasons. Marsh ('97, p. 205), gives the maximum for *C. fluviatilis* in Green lake in the autumn and gives no spring maximum. I think that the difference in our observations is a characteristic of the species rather than of the lakes examined.

Epischura lacustris Forbes.

This species found only occasionally in my collections. It is so large in the adult condition as to be readily distinguishable by the unaided eye and was counted in this way along with *Leptodora*. Young, if present, were doubtless counted as *Diaptomus*. No observations were made on this species in 1894. In 1895 it appeared on June 20th, two specimens being seen. It was not seen again until July, in which month it was found in 6 out of 18 observations, the number not exceeding 2 individuals in any one catch. In August they were seen 6 times out of 13 observations, the maximum being 4, and the total number being seen during the month being 12. In September the number was about the same, but in October the number was greater, averaging 6 in each of the 5 cases where they were seen, with a maximum of 9. In November they were present in every observation, 7 in number, up to the 20th, with an average of 6.5, and a maximum of 19. The species thus showed a decided tendency to a maximum in late autumn. In 1897 the species appeared on May 17th and in the latter part of that month averaged 4 in each catch. In the first half of June the average was 3, and maximum 7; in the last half the average was 4, and the maximum 7. In July the average was 2, and the maximum 7. Only a very few scattered individuals were seen in August, and none were found later.

It is evident that the records of the two years are not at all similar, and that the numbers of the species which were found are too small for profitable discussion.

Ergasilus depressus Sars.

This animal is about the same size as *Cyclops*, although readily distinguishable both by color and form. I am not sure of the correctness of the specific identification, although I can see no differences between my specimens and Sars' description. It is present at all seasons of the year, ordinarily in very small numbers. More than one individual is rarely found when one-tenth to one-twentieth of the catch is counted. This number is so small and the resulting probable error in computing averages so great that it has not been thought profitable to state the numbers in terms of a square meter of surface, and to include them in the total number of limnetic crustacea.

Ergasilus is present throughout the year, although it may often be missed for long periods from the collections. It was first noticed in July, 1895, although doubtless present before, and from 1 to 9 specimens were seen in each collection. The number increased during the latter part of August and in September, when from 10 to 13 specimens were found, indicating nearly 10,000 per sq. m. In the latter part of September the numbers rose to a maximum of 27–30 specimens, or nearly 27,000 per sq. m. In October only 1 to 5 were present, and the species was found occasionally during the winter and spring in single specimens. In July and August, 1896, it became more plentiful; about as is 1895. But no such large number was found in September as in the former year. The animal seems to prefer the stratum of water just above the thermocline, but is not confined to this layer.

Copepod Larvae — Nauplii.

The dredge with which my study was carried on until the middle of July, 1896, was provided with a bucket whose openings were closed by a wire mesh of 1-100 in. This, while retaining the crustacea and a great part of the nauplii, did not retain all of the latter, so that no study was given to these larval forms until work began with the silk net. The following table shows the average number of larvae from the middle of July to the end of December, and also the numbers found in single observations made since that date. In all cases the larvae of all species of Copepoda were counted together; it being practically impossible to assign them to their proper forms. Unquestionably, however, the great majority of these animals belonged to *Cyclops brevispinosus.* All larvae beyond the nauplius stage were assigned to and counted with their proper genera.

TABLE XIV.—*Nauplii. Average numbers, expressed in thousands per square meter.*

1896.			
July 16–31	1113.8	October 16–31	712.5
August 1–15	529.7	November 1–15	477.8
August 16–31	685.9	November 16–30	350.8
September 1–15	310.9	December 1–15	613.7
September 16–30	408.8	December 16–31	606.6
October 1–15	200.4		

Maximum, July 18, 2,037,920.

1897.	Nauplii.	Cyclops.		Nauplii.	Cyclops.
January 11	1,550	118	April 17	204	390
January 21	1,284	76	April 28	418	619
February 17	513	70	May 4	357	1,121
March 3	722	93	May 10	1,007	921
March 29	714	87	May 15	616	774
April 8	726	154	May 21	257	1,767
April 14	798	560	June 6	2,470	1,169

It is difficult to correlate the numbers of the nauplii with those of the older and adult crustacea. While *Cyclops* remained numerous throughout the summer of 1896 there was no such rise of numbers in late July and August as would be expected from the great number of larvae which were present in the latter part of July. The number of nauplii found in the early and middle part of October is not as great as the increase in the number of the crustacea would have led us to expect. It is evident, however, that the decrease of the Copepoda in the late fall and during the winter is due rather to the failure of the nauplii to develop toward the adult form than to the absence of these larvae, or to the failure of *Cyclops* to produce eggs. It will be seen that the nauplii were exceedingly numerous throughout the winter and into the spring, and during the month of May a certain relation can be traced between the numbers of nauplii present and those of immature *Cyclops* — the nauplii decreasing in number as the *Cyclops* increase. It is evident further that the death rate of these larvae during the winter must be very low, or that the losses are balanced by the production of young which develop to this stage, without going further until the warming of the water in the spring.

During the month from the middle of July to the middle of August numerous determinations were made, from which it appeared that the maximum and minimum numbers of the nauplii vary in about the same ratio as do those of the adult crustacea. In July, out of six observations the maximum was 3.8 times the minimum, and in August the maximum was 3.4 times the minimum. The largest number observed was 2,040,000 per sq. m. of surface on July 18th. A larger series of observations would undoubtedly have shown, in the spring of 1897, numbers equal to this.

Daphnia hyalina Leydig.

Figure 16.—Table F, Appendix.

The autumn numbers in both years show a decline to a minimum which extends throughout the winter and until the first or middle of May. In 1895 this minimum was established in November, but in 1894, not till late December or January. In 1895 there was no marked reproductive period in the autumn. This was apparently due to the continuation of summer conditions until near October 1, and the sudden change at that time. The final reproductive period of this species lies at the end of October or early in November. After the close of this period, the old females rapidly decrease in number, and almost, or wholly, disappear before the first of January. The young grow somewhat rapidly until they have reached about half the mature size, and after that, grow very little or none at all until the following spring. Reproduction is practically wholly absent during the winter, although it occasionally happens that a single female can be found in March, having eggs in the brood-case.

The following table gives the average number of *D. hyalina* from fall to spring.

TABLE XV.—*D. hyalina. Averages from October to June expressed in thousands per square meter.*

	1894.	1895.	1896.
October 16-31	252.5	76.6	511.5
November 1-15	183.1	56 2	314.6
November 15-30	....	48.2	266.0
December 1-15	121.5	35.0	182.8
December 16-31	(49.0)	44.6	138.9
January 1-15	40.8	36.2	....
January 16-31	(55.9)	17.3	....
February 1-14	(75.3)	19.6	....
February 15-28	65.8	27.0	....
March 1-15	34.7	....	....
March 16-31	63.6	13.5	....
April 1-15	26.4	14.6	....
April 16-30	16.3	15.2	....
May 1-15	28.9	124.6	....
May 16-31	250.7	270.8	....

Numbers enclosed in a parenthesis rest on observations made on a single day.

The females which have lived over winter produce at least three broods of young, and die in June, chiefly in the early part of the month. Those individuals which have lived over winter are readily distinguished from those hatched in the spring by the smaller size and different shape of the head. It is easy, therefore, to determine the average length of their life at about six to eight months, from early October to early June, as a maximum. It is not possible to get similar data for the summer form of this species, for the shape of the head-crest gradually alters in all individuals as the water cools in the autumn.

The swarms of young produced in October rapidly diminish in number at first, but an equilibrium is reached by the first of January, and thenceforward the decline through the winter is very slow, or imperceptible. The statements made regarding *Diaptomus* fully apply to this species also. During April and

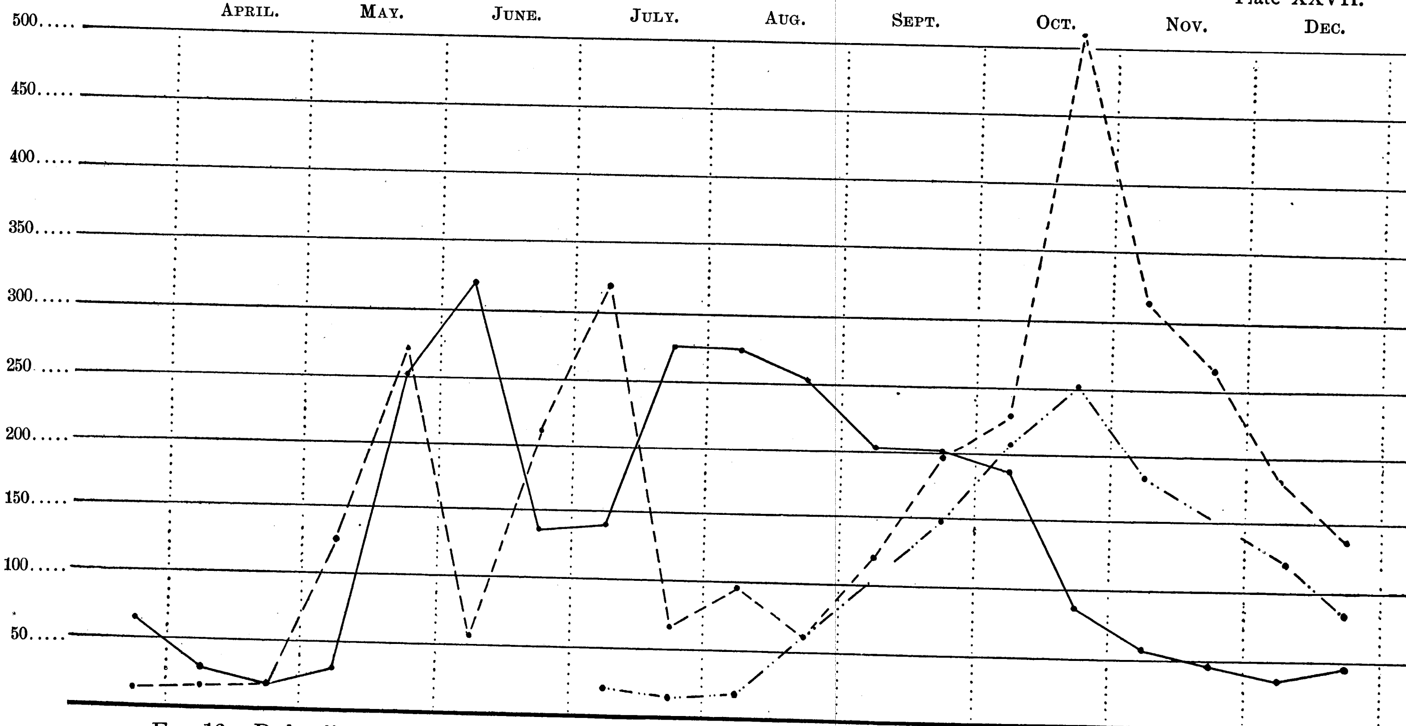
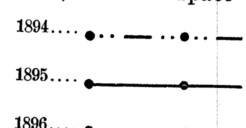


FIG. 16.—D. hyalina. Annual distribution. Scale, 1 vertical space = 50,000 crustacea per sq. meter. See p. 335.



and the early part of May, the species declines on the whole, and the smallest catches of the year have been made at this time. The rise in number in the spring comes on very rapidly. The species apparently reproduces first in the warmer and shoaler waters at the edge of the lake, and the individuals thus produced are distributed over the surface of the lake by favorable winds. This supposition is necessary in order to account for the extraordinarily rapid increase in numbers which the species shows. The following table gives the actual number caught in 1895 and 1896 on the dates stated:

TABLE XVI.—*D. hyalina. Actual number of specimens caught.*

1895.		1896.	
April 25	144	April 22	380
April 30	510	April 27	120
May 7	442	April 30	140
May 12	1,000	May 2	1,360
May 16	380	May 4	1,140
May 18	3,060	May 8	1,600
May 20	1,210	May 11	1,620
May 22	4,820	May 15	5,660
May 27	4,510	May 20	4,900
		May 26	5,460

It will be seen that the number of the species increased nearly tenfold in two days, and that this sudden increase was held with fair uniformity, so that, while all the catches up to May 16, 1895, and April 30, 1896, were small, all those made after those dates were large.

In 1895, the appearance of the eggs was carefully studied. On April 15th, when the surface temperature was 4.5° C., all of the specimens seemed to have freshly molted, and one contained eggs. Three days later more than a third of the specimens contained eggs, which were mostly young. On the 25th all had eggs, many of which were half developed. On May 4th, young were found. On May 12th, a very few young were seen, including one male, but many had no doubt been hatched at this time, as on the 18th the numerous young were developing ovaries, and the head-crest was fairly well grown. On the 22d, a very few of the first generation born in the spring, had laid eggs. On May 12th males were first seen, but 175 females were counted without finding any males. On June 3d, it was noted that many of the individuals which had lived over winter were affected by a microsporidial disease, and the young in the brood sacs were attacked and killed by fungus. They were also attacked by bacterial diseases. At this time, or a little earlier, the old individuals were settling into the lower strata of the water, and on the 6th of June nearly all were gone.

In 1896 the development of the species was in general parallel to that of 1895, but was some two weeks earlier, owing partly to the more rapid warming of the water and partly to the fact that the temperature of the water in winter was slightly higher, and the animals emerged from the winter life in a more advanced condition of development. In each season the surface water had reached an average temperature of 15° C., when the marked rise in numbers occurred.

The summer numbers of this species appear from the following table:

TABLE XVII.—*D. hyalina—Average numbers, June—December, stated in thousands per square meter.*

	1894.	1895.	1896.
June 1-15	No	319.2	55.6
June 16-30	Obs.	135.6	211.1
July 1-15	19.8	139.9	319.0
July 16-31	13.3	275.3	65.5
August 1-15	16.6	273.0	95.2
August 16-31	60.7	252.8	60.9
September 1-15	No obs.	202.8	120.4
September 16-30	148.4	201.6	192.5
October 1-16	207.6	180.5	228.0
October 16-31	252.5	76.6	511.5
November 1-15	183.1	56.2	314.6
November 16-30	No obs.	48.2	266.0
December 1-15	121.5	35.0	182.8
December 16-31	(49.0)	44.6	138.9

The table shows that the summer history of this species was very different in the three years of my study. In July and August of 1894 the numbers were exceedingly smal' smaller than in any of the three winters during which I have studied the species. In 1895 the numbers were large and remained large throughout the summer, gradually declining in September and October, and falling off rapidly in the latter part of October to the winter minimum without showing any marked reproductive period in late autumn. In 1894 and 1896 the numbers, which were small and nearly equal in the latter part of August, rose steadily through September and October to a maximum in the latter part of October, and then fell off rapidly to reach the winter minimum in December or January. In late October, 1896, there were present enormous broods of new hatched Daphnias, which raised the number for that period beyond the records of any other. In 1896 the spring maximum was followed by a minimum about the middle of June, in which the numbers were scarcely one-quarter of the maximum. From this minimum there was a rapid recovery, which lasted for about a month and was followed by another marked depression. In 1895 the spring maximum continued into June, and the early summer minimum came about the first of July. Portions of this minimum are included for the averages of the latter part of June and the early part of July, so that the number at the minimum appears greater in the tables and diagram than it actually was. As a matter of fact, there was very little difference in the number present in 1895 and 1896. In 1895 the recovery of the species from the early minimum came on as in 1896, but there was no reaction from the increase, and the number remained substantially unchanged through the entire summer.

No observations were made in the spring of 1894, but the probable history of the species was similar to that in the other years. There was a spring maximum followed by a marked minimum from which there was no reaction. This failure of the species to develop a summer brood seems to have been due to the presence of *Lyngbya* in the upper strata of the water.

The largest catches of this species were 331,000 per sq. m., Oct. 17, 1894; 565,000 June 6, 1895, and 1,049,000 Oct. 26, 1896.

Males are found during and after the spring and fall reproductive periods, although in very small numbers, never exceeding 4 per cent. of the number of females and rarely being as numerous as this. Ordinarily it is only possible to find one or two males by careful search through the entire collection. These males are somewhat more abundant after the fall reproductive period than earlier, and may be found as late as the middle of December or even the first of January. It seems, therefore, that originally this species had two main reproductive periods, in the fall and spring. Each of these was probably closed by the production of males and the development of ephippia. The sexual reproduction has, however, almost entirely disappeared, and the species has practically passed into a acyclic condition.

Apstein ('96, p. 167,) finds that *Daphnia hyalina* is present from September to July, with a maximum in winter. This history is so wholly different from that of the species as found in lake Mendota that no profitable comparison can be made.

Daphnia pulex var. *pulicaria* Forbes.

Figure 17.—Table G, Appendix.

The following table gives the average number of *Daphnia pulicaria* taken during the period of my investigation. From this and from the diagram it appears that the species was present in very small numbers during July and August, 1894; that it then entirely disappeared until the early part of July, 1895; it increased in numbers during the summer and autumn, increased greatly during December, and was present in considerable numbers during the winter. About the middle of April, 1896, a period of rapid reproduction began, the species rising to a maximum in the latter part of May. At this time, and in the early part of June the males appeared and not infrequently numbered from one-third to one-fourth of the total catch. The females developed ephippia and the sexual eggs were produced early in June. The species rapidly declined after this date, although present in somewhat larger numbers early in September. Scattering individuals only were found from the first of October through the winter of 1896–97. The species entered upon

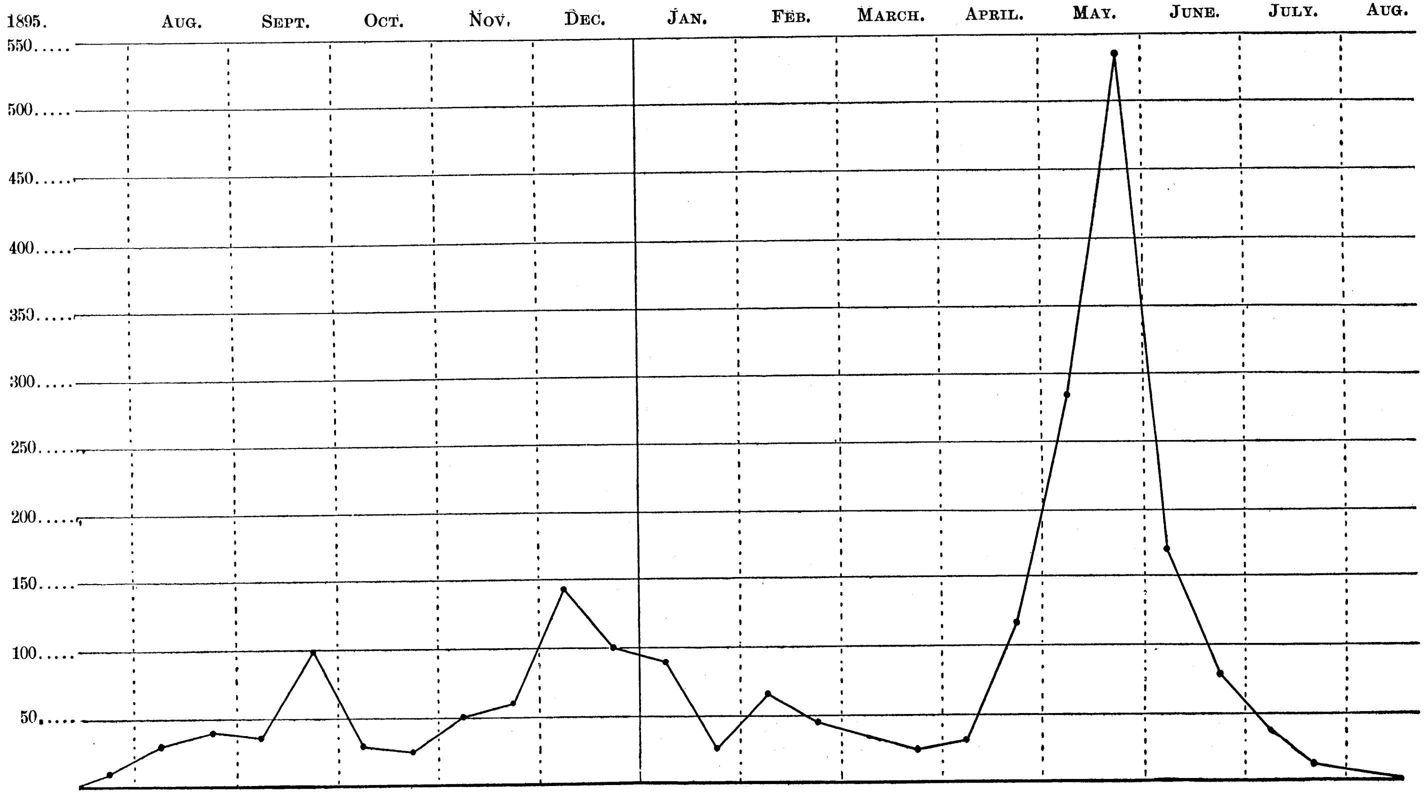


Fig. 17.—D. pulicaria. Annual distribution, 1895, 1896. Scale, 1 vertical space = 50,000 crustacea per sq. m. See p. 340.

a new period of development in July, 1897. From this statement of fact it appears that *Daphnia pulicaria*, as found in lake Mendota, has a biennial period of development extending from July of one year to July of the next, followed by a year in which the species is either absent or its numbers are exceedingly small. The study made in July, 1894, seems to have taken the species at the very end of its developmental period after the production of the sexual eggs. One entire cycle was included from July, 1895, to July, 1896, and a second period when the numbers were extremely small, although never entirely absent, from July, 1896, to July, 1897.

TABLE XVIII.—*D. pulicaria. Average number per sq. meter, expressed in thousands.*

	1894.	1895.	1896.
January 1-15	....	a	88.2
January 16-31	....	a	24.8
February 1-14	....	a	64.1
February 15-28	....	a	43.9
March 1-15	....	a	....
March 16-31	....	a	20.9
April 1-15	....	a	28.0
April 16-30	....	a	118.2
May 1-15	....	a	284.9
May 16-31	....	a	533.6
June 1-15	....	a	168.6
June 15-30	....	a	78.2
July 1-15	6.4	s	39.3
July 16-31	8.3	11.6	11.8
August 1-15	1.1	19.9	3.7
August 16-31	0.8	38.1	5.9
September 1-15	a	33.8	23.5
September 16-30	a	98.2	3.4
October 1-15	a	26.9	0.4
October 16-31	a	23.5	a
November 1-15	a	49.6	s
November 16-30	a	58.3	s
December 1-15	a	141.1	s
December 16-31	a	99.8	s

a, absent; s, scattering individuals only.

The following statement shows the general numerical relations of the species, observations beginning in July, 1894:

Season.	1894.	1895.	1896.	1897.
Spring	? Abundant	Absent	Abundant	Very few
Early summer	? Ephippia	Few	Adult males and females	Increasing.
Late summer	Few	Abundant	Few	Abundant
Autumn	Absent	Abundant	Very few	...
Winter	Absent	Abundant	Very few	...

As was stated in my former paper, (Birge, Olson, and Harder, '95, p. 473), this species is found through the summer in the deeper water only. Scattering individuals may be found extending to the surface, but even where one-sixth of the total number of crustacea was counted, the number of this species found rarely exceeded one individual; and in my studies during 1896, no individuals of the species were found from the upper levels of the lake. As will be stated more at length on the section on vertical distribution, *D. pulicaria* is confined in lake Mendota during the summer to the space immediately about the thermocline. It is unable to rise higher on account of the high temperature of the water, and is unable to descend lower on account of the impurity of the deeper water in late summer and early autumn. This fact limits greatly the number of the species during the warm season of the year, and in lakes whose bottom water is cold and not contaminated by decomposition products the number of the species is far greater during the summer months, and the period of active sexual reproduction is a much longer one.

This species varies much more in numbers from day to day than does any other of the species whose numbers are at all considerable. The station at which most of the observations were made was not far from the southern shore. As a result of the action of the wind the thermocline is subject to considerable variation. A violent southwest wind, especially has the effect of driving out the warm water near the bottom of the lake, and thus temporarily raising the temperature of the deeper levels at the station. Under these conditions the members of this species which ordinarily live between the station and the shore become driven out from their ordinary place of abode, and the numbers at the observing station are correspondingly increased. Thus on August 21, 1895, the number of this species caught was 493, a number not far from the average of the month up to that time. On the next day, the wind being strong from the southwest and the thermocline lying at an unusually low level, the number caught was 2,600. On the following day 954 were taken, and four days later only 85. The following table shows the details.

TABLE XIX.

Date.	Wind.	Depth.	Temp.	No. D. pulicaria.
1895.				Above 9 m. 0
		9 m.	21.4°	9-12 m. 480
Aug. 21	Southeast	12 m.	18.4°	12-15 m. 5
		15 m.	15.4°	15-18 m. 5
		18 m.	13.8°	
Aug. 22	Southwest.			Above 9 m. 90
	Strong all day	9 m.	21.7°	9-12 m. 2,120
		12 m.	20.4°	12-15 m. 360
		15 m.	17.3°	15-18 m. 18
		18 m.	14.7°	
				Above 9 m. 90
Aug. 23	Nearly calm.	9 m.	22.0°	9-12 m. 640
		12 m.	20.8°	12-15 m. 220
		15 m.	14.8°	15-18 m. 40
		18 m.	13.8°	
Aug. 27	Calm	9 m.	22.0°	Above 9 m. 0
		12 m.	20.8°	9-12 m. 0
		15 m.	17.3°	12-15 m. 80
		18 m.	13.9°	15-18 m. 5

In September of the same year 415 specimens were taken on the 18th, 2980 on the 22nd, and 3615 on the 25th. The conditions of temperature in the deeper water were much the same as on the former occasion. The rise in numbers shown by the tables and diagram in the latter part of August and in September are therefore due to these unusual accumulations of the species and do not indicate a corresponding average rise in numbers extending over any considerable area of the lake. The case is wholly different with the increase which comes in late November and December. This is occasioned by a very rapid multiplication of the species. The brood-sacs contain from 5 to 9 eggs. This reproductive period does not begin until after the temperature of the lake has fallen below 10°, and multiplication continues, although at a slower rate, throughout the winter.

In the spring comes the main period of reproduction; and during May, 1896, the numbers were uniformly large, yet even here they were subject to very considerable variation. At the time of the maximum, the species was the most abundant of the limnetic crustacea, with the exception of *Cyclops*, and since the individuals are so much larger than *Cyclops*, the species was the most important constituent of the crustacean plankton.

It would seem necessary to suppose that the ephippial eggs deposited in June and July of one year remain unhatched for nearly a year. This is a very long period, and I have no direct observations which would make the conclusion certain. I am sure, however, that the species was practically absent from the plankton after August, 1894, since it was carefully looked for and only one specimen was found, and that in December. There was also no reproductive period in 1896 after the first of August, the increase in numbers in September of that year depending on an aggregation of individuals corresponding to that in 1895, there was no reproductive period during November or December, and the species declined in number, so that it was not practicable to enumerate it in the plankton. The winter eggs of *Diaphanosoma* must remain unhatched from about Oct. 1 to June of the next year.

The peculiar history of *Daphnia pulicaria* in lake Mendota is conditioned in great part by the fact that the species is unable to live in the cooler water of the lake below the thermocline. In lakes which are relatively plankton-poor, the

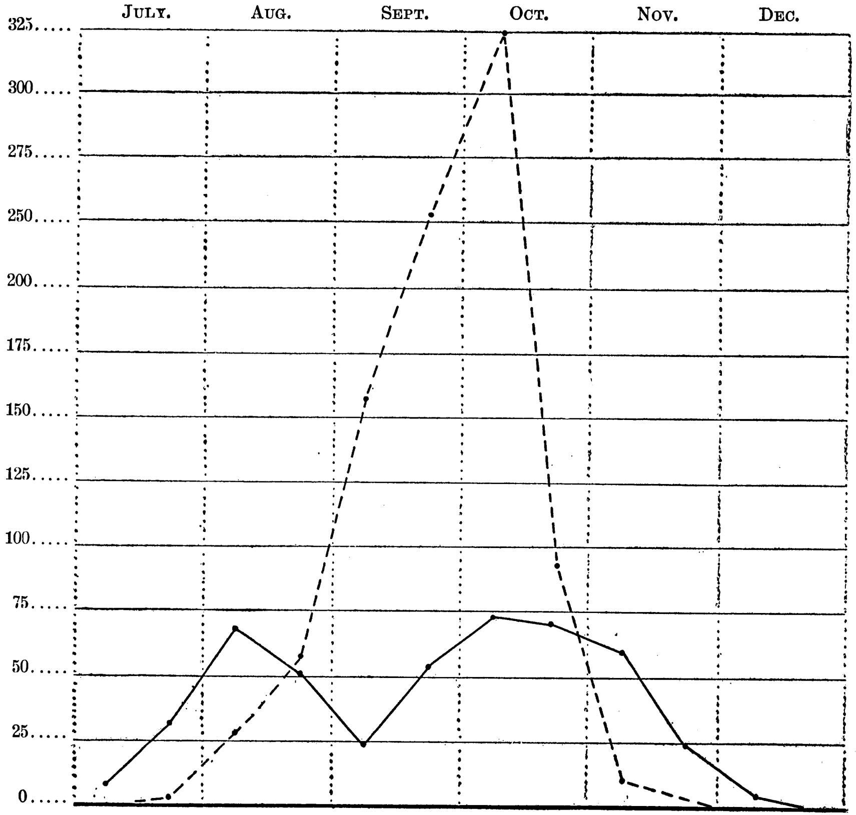


FIG. 18.—D. retrocurva. Annual distribution, 1895, 1896. Scale, 1 vertical space = 25,000 crustacea per sq. m. See p. 345.

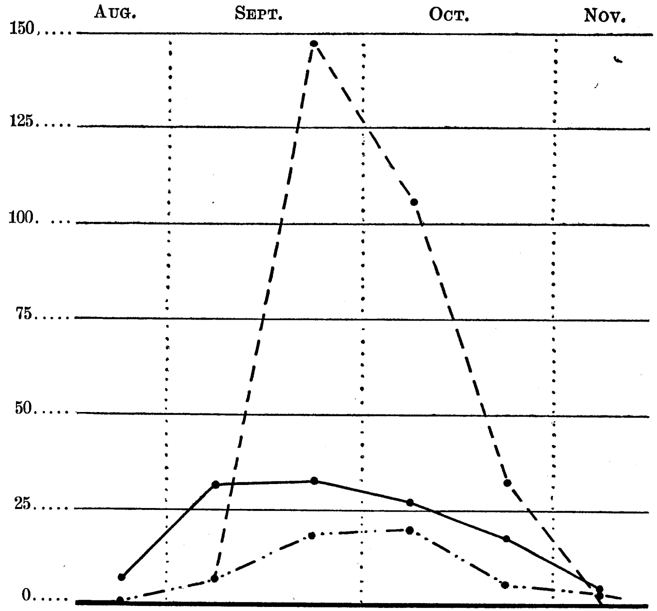
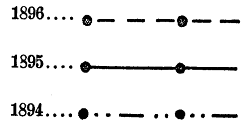


FIG. 19.—Diaphanosoma. Annual distribution, 1894, 1895, 1896. Scale, 1 vertical space = 25,000 crustacea per sq. meter. See p. 347.



species is found in far greater abundance during the summer in the cool, deeper water, and extends to the bottom of the lake. In the lakes of the Oconomowoc group, this species is abundant and is by far the most conspicuous of the crustacea which are found below the thermocline.

Daphnia retrocurva.

Figure 18.—Table H, Appendix.

TABLE XX.—*Number per sq. meter of surface stated in thousands.*

	1895.	1896.
June 16-30	s	a
July 1-15	9.7	s
July 16-31	31.5	2.5
August 1-15	68.2	27.6
August 16-31	50.1	57.1
September 1-15	23.8	157.7
September 16-30	53.6	228.6
October 1-15	72.5	299.3
October 16-31	70 8	92.7
November 1-15	59.3	9.9
November 16-30	24.2	s
December 1-15	5.0	s
December 16-31	0.7	a

Daphnia retrocurva belongs to the periodic crustacea, and its numbers have been very different in the three seasons of my study. In 1894 the species was practically absent; two specimens only were seen in July, and none were found in later months. In 1895 it was present in moderate numbers, and in 1896 the numbers in September and October were very considerable. The small number in 1895 is probably the result of the absence of the species in 1894. Perhaps also the competition of *Daphnia hyalina* had something to do with preventing the increase of the species in 1895. In that year *Daphnia hyalina* was present in large numbers throughout the late summer and the autumn. In 1896 *D. hyalina* declined greatly in numbers in

August, and in the latter part of the month both *retrocurva* and *hyalina* were practically equal and their numbers rose together during September and October. It is quite possible also that the lower temperature of the water in September, 1896, as compared with the same month in 1895, favored the development of both species. In 1895 the summer temperature of the lake was maintained until late in September. The result of this was apparently a great increase in the number of *Diaptomus*, and a steady decline in the number of Daphniae.

D. retrocurva first appears in the latter part of May. The numbers are small, but two or three specimens can be found by search in almost every catch. During June it apparently disappears, or is much more rare than on this first appearance. It is not possible to estimate its numbers with any accuracy before July or August. The males begin to appear in late September or in October. They were first noticed on September 17th, 1895, and October 1st, 1896. The ephippia developed during October, and the species declines rapidly in November, and finally disappears from the lake by January 1st. The ephippia float, and many of them are doubtless driven to the shore, so that if the level of the lake is much lower in the spring and summer than it was in the fall, these ephippia may fail to develop, and thus cause a scarcity of the species.

The maximum of this species coincides with the presence of the males. These, when at their greatest abundance number from 18 to 50 per cent. of the full number caught. They are always more abundant, relatively, in the upper strata of the water than are the females, agreeing in this particular with the young of most species of the limnetic crustacea.

The food of this species agrees with that of the other members of the same genus. It eats *Anabaena* and diatoms in preference to other plants. It makes very little use of *Ceratium* and avoids *Clathrocystis* whenever possible.

Marsh ('97, p. 210) assigns the maximum of *D. Kahlbergiensis* to late October, thus agreeing with the corresponding species in lake Mendota. He does not say anything about males and since the species was present during the winter of 1894-5 it would seem to belong to the perennial crustacea of Green lake.

Zacharias ('96, p. 53), gives August and September as the maximum, and also says nothing about males. The species was only occasionally present in the winter. Apstein ('96, p. 170), gives August as the date of the maximum for all species of *Daphnia.* He does not mention a sexual period, though he gives no especial attention to the subject. Had there been such a period as is shown by *D. retrocurva* it could not have been missed.

Diaphanosoma brachyurum Sars.

Figure 19. — Table I, Appendix.

TABLE XXI.—*Average number per square meter of surface, stated in thousands and tenths.*

	1894.	1895.	1896.
July 1-15	....	s	s
July 16-31	0.8	6.9	s
August 1-15	6.3	31.5	8.9
August 16-31	18.0	32.2	147.4
September 1-15	No obs.	27.1	108.3
September 16-30	19.6	17.2	32.9
October 1-15	5.2	3.4	0.4
October 16-31	3.0	0.0	0 0

This species is the least numerous of the limnetic crustacea which appear in large numbers, and has the shortest season. Scattering individuals may be seen as early as the middle of May, but they do not become a regular constituent of the plankton catch before the middle of July or the earlier part of August. They disappear in October, and are greatly reduced in number by the cold storms which usually come in late September. Males appear about the middle of September, and the winter eggs are then produced. The species was far more abundant in 1896 than in either of the two preceding years, which agree with each other fairly well. For this difference I can assign no reason. The numbers were constantly greater in 1896, so that the increased number was not the result of a few large catches. The life history of this species practically belongs to the period when the temperature of the upper water of the lake is above 20°.

Apstein ('96, p. 166), Frič and Vávra ('94, p. 103) find the relations of *Diaphanosoma* quite as I have done. It does not seem to belong in lake Ploen. Marsh ('97, p. 215) gives the species as present from June to November in Green lake. All find it a little earlier in the spring than I have done.

Chydorus sphaericus O. F. M.

Figure 20.—Table J, Appendix.

TABLE XXII.—*Chydorus sphaericus. Average number per square meter expressed in thousands.*

	1894.	1895.	1896.
January 1-15	No observations.	1.3	10.1
January 16-31		a	19.5
February 1-14		a	4.8
February 15-28		a	3.8
March 1-15		a	No obs.
March 16-31		a	1.4
April 1-15		a	1.9
April 16-30		s	9.8
May 1-15		12.1	28.0
May 16-31		16.5	30.8
June 1-15		36.7	87.6
June 16-30		21.9	230.8
July 1-15	s	156.8	382.0
July 16-31	s	163,4	245.1
August 1-15	s	78.6	406.5
August 16-31	15.0	81.7	426.0
September 1-15	No obs.	15.6	748.0
September 16-30	278.9	s	263.0
October 1-15	193.3	8.6	423.7
October 16-31	202.0	8.1	191.9
November 1-15	97.9	29.9	62.7
November 16-30	No obs.	19.7	69.3
December 1-15	9.5	15.9	38.2
December 16-31	1.6	20.9	28.1

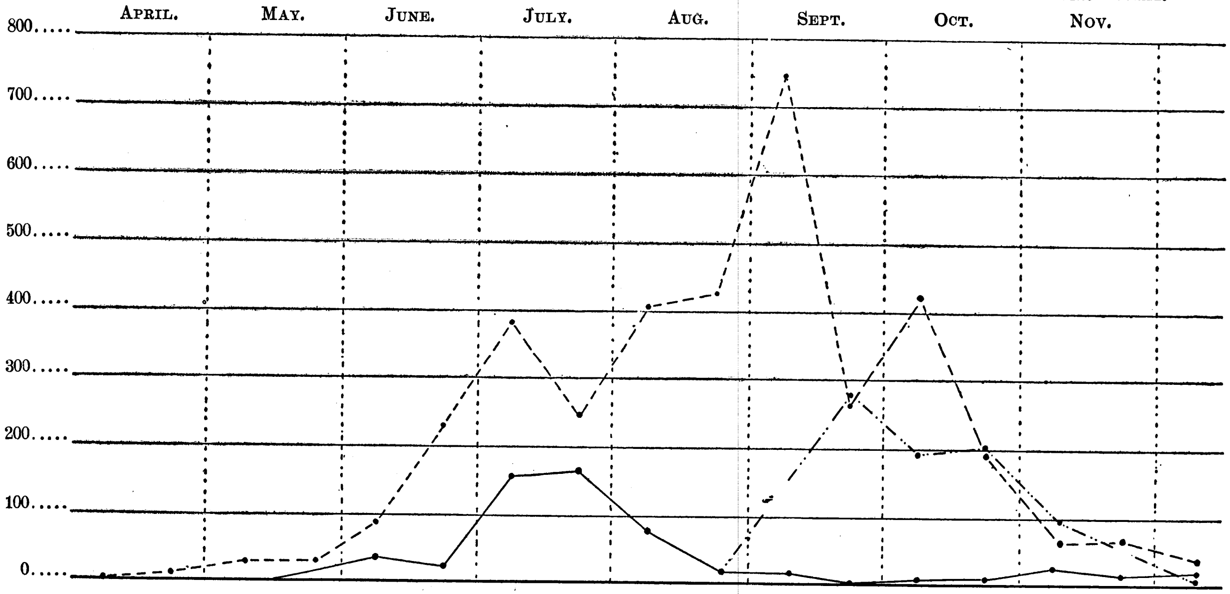
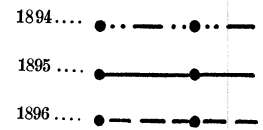


FIG. 20.—Chydorus. Annual distribution, 1894, 1895, 1896. Scale, 1 vertical space = 100,000 crustacea per sq. m. See p. 348.



The above table shows that the number of this species is subject to very great variation; yet there is a certain degree of regularity in its appearance. The years 1894 and 1896 resembled each other in having a maximum in autumn, which was wholly absent in 1895. A large number was also found in July, 1895 and 1896, while practically none were present in 1894. In the winter of 1895–6, *Chydorus* was regularly present; while in that of 1894–5 there were found only isolated individuals from time to time. I believe that these periods of abundance are correlated with the abundance of *Anabaena* and allied algae in the water. The autumn of 1894, and the whole season of 1896 were characterized by a great abundance of these plants; while they were exceedingly rare in 1895 after the spring and early summer. The summer of 1894 was marked by an enormous development of *Lyngbya*, an alga quite too large to serve as food for *Chydorus*, and at the same time occupying the upper stratum of the water to the exclusion of the smaller algae.

The development of *Chydorus* is therefore dependent on the kind of food to a degree unusual among the limnetic crustacea. It is also dependent on temperature. In both 1895 and 1896 it was the last of the perennial crustacea in its development, no marked rise occurring before the last of June or the first of July. This is the more noteworthy, since eggs may be found in the brood sac at any time during the winter.

In 1894 and 1896 the maximum came about the middle of September, while in 1895 only one small maximum was present, and that was in July. In 1896 there was no decline of the species in August, but rather an increase, and in this season *Anabaena* and allied forms were abundant throughout the summer.

In 1894 the number increased very greatly between the 6th and 10th of June, as is shown by the following record of the number of individuals caught.

June 3	90
June 5	450
June 6	120
June 10	4,200
June 13	4,430
June 17	1,740
June 19	4,100

Earlier and later catches agree with those given. On the 8th and 9th of the month there was a violent wind from the north and northwest, which probably brought this species out from shore water where it had been developing.

These facts indicate that *Chydorus* is not properly a limnetic form but that it gets into the limnetic region by accident and maintains itself there so long as suitable food is present. I agree with Apstein in regarding this form as characteristic for lakes abounding in Chroococcaceae or, perhaps, Schizophyceae. He has not observed its dependence on the seasonal appearance of these plants in the lake, as is the case in lake Mendota. In the limnetic region the species is acyclic so far as my observations go. The largest catches of this species were 440,000 per sq. m. Sept. 21, 1894; 221,000, July 28, 1895; 661,000, July 7, 1896; 674,000, Aug. 15, 1896.

Leptodora hyalina Lillj.

TABLE XXIII.—*Leptodora hyalina. Average catch per square meter of surface.*

	1894.	1895.	1896.
June 1-15	No obs.	63	s.
June 16-30	No obs.	680	254
July 1-15	324	986	1,208
July 16-31	362	827	585
August 1-15	445	2,512	642
August 16-31	1,081	3,078	1,881
September 1-15	No obs.	1,068	2,850
September 16-30	871	775	2,945
October 1-15	1,469	457	2,375
October 16-31	966	661	1,026
November 1-15	95	292	247
November 16-30	....	25	31

The table given above shows the average number of *Leptodora* during the seasons of 1894, 1895, and 1896. The species first appears in May, being first observed May 29th, 1895, and 1896. The nauplii must appear earlier, but I have never seen one, although careful search was made for them in both years. The number of the species is so irregular that the average per square meter represents very little. On August 22nd, 1895, the species was present in the upper meter at the rate of nearly 2700 per cubic meter. These were all young females, either without eggs or having the eggs just laid. On October 6th, 1894, three sets of observations gave respectively a catch of 9, 38, and 13 individuals. On July 19th, six catches, at different hours, gave 0, 34, 11, 4, 3, 0. On August 1st and 2nd, there were taken: 4, 24, 16, 10, 4, and 2 individuals at different hours. These examples are sufficient to show that the figures for *Leptodora* are subject to a far greater variation than those of the other crustacea. For this reason, and also because the size and habits of *Leptodora* are quite different from those of the other limnetic crustacea, the species has not been included in the total number of crustacea. The maximum catch was 79, Aug. 7, '95; 75, June 22, 96; about 5,000 per sq. m.

Males of this species appear in October, the numbers decline rapidly during November, and no individuals were caught by the vertical net after November 26th in either year. Horizontal collections, however, show that they were present until after December first. The limits of this species, therefore, extend from the middle of May to the first of December, and the maximum numbers occur in late summer and early fall. It is worthy of note that in no year does the maximum number coincide with the production of males. This is to be expected, as the large summer catches were due to the presence of numbers of young or half grown *Leptodora* at the place where the net was hauled. It is therefore not surprising that these swarms should be irregular, and they would not be expected at the time when the adult females are producing the winter eggs.

Many observations were made upon the food of *Leptodora*, and it was found that they eat chiefly *Cyclops* and *Daphnia*. The attempt of the animal seems to be to squeeze out and swallow the interior of the prey. In a considerable number of instances the intestine or the ovary of *Daphnia*, nearly entire, was seen in the stomach of *Leptodora*, and only occasionally were any parts of the skeleton of this species found. The legs and similar appendages of *Cyclops* were not infrequently seen. Large *Daphnias* have ordinarily a shell so thick that the weak jaws of *Leptodora* are unable to pierce it, and a very large proportion of the *Daphnias* seized by *Leptodora* escape apparently uninjured.

Apstein ('96, p. 175), notes that this animal in the Einfelder See was very large, over 1 cm. long. It is not at all uncommon to find specimens measuring 18 mm. in lake Mendota. The average size is dependent apparently on the abundance of food. In Green lake and the Oconomowoc lakes the length is decidedly less than 1 cm.

FACTORS DETERMINING THE ANNUAL DISTRIBUTION.

Our knowledge of the conditions of limnetic life is at present far too fragmentary to permit any complete explanation of the factors which determine the number of crustacea present in the plankton. Certain provisional results however, may, be reached as a result of this study of the crustacea. The following factors are present and combine to determine the total number of the crustacea present at any time and the number of the members of each species.

1. The food, both in quantity and quality.
2. Temperature.
3. Competition.

Food.

It is plain that the quantity of available food must set an upper limit to the number of crustacea. Available food must be carefully distinguished from plant material, since all plants are by no means equally edible by the crustacea. *Gloiotrichia*, for example, is present in lake Mendota in considerable numbers from the latter part of July to the early part of September. It is never the dominant alga, as it is apt to be in the plankton-poor lake. But it is often the most prominent alga to the eye, and is present in such numbers as to form on calm days a thin scum on the surface. It does not appear, however, that any species of crustacea regularly eats it. I have given very careful study to this point during three seasons, and have never seen any evidence that any of the limnetic crustacea feed upon it. Of course in cases of necessity it may be eaten, but even where other food is comparatively scanty, *Gloiotrichia* seems to be avoided. It should, therefore, be subtracted from the quantity of available food.

Clathrocystis and *Coelosphaerium* appear also to be far less readily eaten than other species. I have made very numerous observations upon *Daphnia* of all three of the species present in lake Mendota and have uniformly found that while the diatoms, *Anabaena*, and *Aphanizomenon* are greedily eaten, the colonies of the genera first named are uniformly rejected. During the autumn and winter of 1894–5, *Clathrocystis* and *Aphanizomenon* were almost the only algae present. The food of *Daphnia* was almost exclusively the latter species, and I have seen hundreds of *Daphnia* persistently rejecting *Clathrocystis*, while greedily collecting and devouring *Aphanizomenon*. *Daphnia* eats freely all of the filamentous diatoms, including *Fragillaria*, *Melosira* and *Diatoma*, while *Diaptomus* seems to prefer *Anabaena* and *Aphanizomenon* to the diatoms, when all are present in large numbers. Since these preferences for various kinds of food are so strikingly marked among the crustacea, it may easily happen that a period when vegetation is superabundant in the lake may be one of scarcity for the crustacea. The most conspicuous case of this sort occurred in the summer of 1894, when my observations on the crustacea began. In July and early August of that year a species of *Lyngbya* overgrew all the other species of plants, constituting more than 95 per cent. in bulk of the vegetable plankton. It was so abundant as to constitute a thick scum on the surface of the lake during calm weather. The filaments of *Lyngbya* are large and perhaps for other reasons than size are little available as food. The Daphnias present were carefully examined and hardly a single filament of the species was found in them, nor could I find any evidence that the other species ate it, although the remains of diatoms and other species of plants were found in their intestines. The number of every species of limnetic crustacea, except *Diaptomus*, was far smaller during this period than in other years, as the following table will show:

TABLE XXIV.—*Number of limnetic crustacea during July, 1894–1896, stated in thousands per sq. m. of surface.*

July.	1894.	1895.	1896.
Diaptomus	260.5	202.2	177.5
Cyclops	95.4	227.8	244.2
Daphnia hyalina	15.5	207.6	192.2
Chydorus	....	160.1	313.5

Daphnia retrocurva was entirely absent in 1894, while beginning its regular development in the two latter years.

It seems quite evident that the presence of *Lyngbya* in the lake was the determining factor in causing the numbers of all species except *Diaptomus* to be so exceptionally small. The influence of this alga is not by any means confined to the adults. It is even more important in its action upon the young. In all the species of crustacea the immature forms are found near the surface, and during the day the upper one-half meter, or thereabouts, is occupied by immature crustacea. This is the same region as that in which the *Lyngbya* is most abundant, and since *Lyngbya* is wholly unmanageable as food for the immature crustacea, its presence in the upper water exerts a very unfavorable influence upon the development of the new broods which may be hatched while it is the predominant alga. It is noteworthy that *Diaptomus*, which maintained its numbers through the *Lyngbya* period, is the species of crustacea which combines great locomotive powers with effective means of collecting food. *Daphnia* has the most effective food collector, but is inferior in locomotive powers. *Cyclops* is inferior to both species in both ways, but ordinarily has an advantage in its omnivorous habits and its greater adaptability to different conditions of life.

In late July *Lyngbya* began to decline, and *Aphanizomenon* and *Melosira* began to develop. Parallel with this change in the character of the algae, *Cyclops* and *Daphnia hyalina* increased rapidly, and in late August, when *Melosira* was the predominant alga, *Cyclops* and *Daphnia* were the predominant crustacea. *Chydorus* had fairly entered upon its period of rapid multiplication at this time but its numbers only became large as *Aphanizomenon* multiplied in September.

Ceratium offers an instance of an alga which, while not absolutely unavailable as food, is far less rapidly eaten than other species. So far as my observations extend, the adult *Cyclops* devour it more freely than do any other species of crustacea. *Cyclops*, indeed, is the most omnivorous of the plankton crustacea. It seizes and devours rotifers, nauplii, and other small animals, as well as plants. I have seen it pounce upon and devour *Ceratium* several times, while I have never seen *Diaptomus* do the same, and have only very rarely found fragments of *Ceratium* in the intestine of *Diaptomus*. During 1895 I did not find in a single instance *Ceratium* within the shell of *Daphnia*, but in 1896 I found it in a very few cases. *Ceratium* is a prominent alga during the summer, and at some time ordinarily becomes the dominant form, so that there is fairly a *Ceratium* period. In 1895 this period fell from the middle of June to the middle of July, and for a week on each side of the first of July, *Ceratium* constituted more than 90 per cent. of the plankton algae. In 1896 this period was later, coming in August and early September. It was present in large numbers from the early part of the summer, but seemed to be hindered in its development by the great numbers of *Aphanizomenon*, which were present in the water. For nearly a month it seemed doubtful whether there would be a *Ceratium* period at all, but finally in August, *Ceratium* predominated decidedly over *Aphanizomenon*, although a considerable quantity of the latter species and *Anabaena* was always present. *Ceratium*, like *Aphanizomenon*, occupies the upper strata of the water, and its presence there is a hindrance to the development of the young crustacea, since it is so large and its shell is so hard that it cannot be eaten by them. The *Ceratium* period in 1895 marked the beginning of a decline in the numbers of the crustacea. The same was true to a less marked extent in 1896. I have no doubt that the presence of this alga in great quantity is one of the factors which influences the late-summer minimum in the numbers of the limnetic crustacea. In 1894, *Ceratium* was present, but its numbers were always far inferior to those of of *Lyngbya*.

The quantity of food also exerts an influence on the number of the crustacea. In a lake in which the plankton is so abundant as in lake Mendota, the quantity of algae is ordinarily in excess of the demands of the crustacea, and any scarcity of food is wont to be brought about rather by changes in the quality of the algae than by an inadequacy in the total supply of vegetable material. There is, however, one line of facts regarding the quantity of food to which sufficient attention has not as yet been given, namely, the correspondence of the relation of the rhythm of development of the algae with that of the crustacea. As is well known, the successive species of plankton algae come on in waves of development, and between the periods when given species are plentiful, there are intervals, longer or shorter, when the food supply may be small. This relation may be best seen in lake Mendota at the time of the spring maximum. The crustacea, during the spring, increase more rapidly than the algae, and when the crustacea are at their maximum, the mass of plankton appears to the eye to consist of little except crustacea. Under these circumstances the food supply must be inadequate, the number of crustacea must fall off, and, especially, their reproductive power must decline. If the rate of increase of the algae coincided with that of the crustacea, so that the time of maximum amount of food agreed with the time of maximum needs on the part of the crustacea, this quantitative oscillation would be of little importance; but, if at any time the decline of the dominant algae coincides with the reproductive period of a species of crustacea, it may be long before the species recovers from the injury thus caused. This relation between food and crustacea is one of the most important, and at the same time one of the most difficult to investigate, and one to which as yet but little study has been given. It is plain, however, that the number of a species of crustacea must be determined—so far as determined at all by food—by food relations when most unfavorable, and that the quantitative relations of food and crustacea must be followed from day to day, if this relation is to be understood.

Zacharias ('96, p. 60) expresses his surprise that the small crustacea do not increase beyond a certain number when they are provided with so abundant food throughout the year. To this question he states that there is at present no answer. I am very far from supposing that I can answer the question completely, yet Zacharias's own figures show that at certain times of the year the food supply must be exceedingly small. For example, his figures show that the quantity of plant life is apparently abundant during the spring and early summer, but that in the late summer the amount of vegetation is small in proportion to the number of eaters.

On August 20, 1895, the number of crustacea (l. c., p. 45) was nearly 1,360,000 per square meter of surface, the diatoms less than 30,500; *Dinobryon*, *Eudorina*, and *Ceratium* 459,010; and *Gloiotrichia* 70,650. Thus, including *Gloiotrichia*, there was less than one colony of algae to 2.5 crustacea. On Sept. 20, there was hardly more than one plant to 10 crustacea. Under these conditions a daphnia would have to strain a good many liters of water to satisfy her eternal hunger.

It never happens in lake Mendota that the ratio of food to crustacea falls as low as these observations in lake Ploen, and while I am convinced that the occasional scarcity of food is an important factor in limiting the number of crustacea, I am equally sure that there must be other conditions, still unknown, which at times are even more important. My studies on the vertical distribution of the crustacea in 1895 and 1896 show that all or nearly all of the increase of the crustacea which causes the fall maximum is brought about by the increase in the numbers of the crustacea in the deeper part of the lake from which they are excluded during the summer. In other words, the number of crustacea in the upper three meters of the water remains nearly constant from a date near the close of the spring maximum to the decline in numbers in late autumn. In 1896 the number of the crustacea in the upper strata increased somewhat during the autumn, owing to the occasional presence of large numbers of new-hatched individuals, but even in this year more than three-fourths of the increase in the number of the crustacea was due to the increase of the population of the lake below the nine-meter level. In the upper water, however, the increase of plants is most rapid. It begins in August at latest, and the quantity of vegetation goes on increasing, for two months at least, until in October the amount of food may easily be four or five times as much as in mid-summer. During this period the conditions of temperature are by no means unfavorable for reproduction, and it is at present impossible to see why crustacea should not increase more rapidly and thus reach a greater number at the period of the fall maximum.

Temperature.

The temperature of the water, as such, independent of its influence on the food supply, determines the reproductive powers of the crustacea and the rate of their development, and thus limits their numbers. Perhaps, also, it exerts an influence on the length of life of the adults, although this influence is less certain.

The different species of limnetic crustacea differ greatly in their relation to temperature. The periodic species are necessarily more greatly influenced by it than are the perennial. *Diaphanosoma brachyurum* is the most stenothermous of the periodic species. The first scattering individuals appear late in May but the species does not become a regular constituent of the plankton until late in July or early in August. The species increases in number throughout August and early September. The males appear towards the middle or last of September, when the species rapidly declines and wholly disappears from the plankton before the 1st of November. Its active period, therefore, lies during the time when the temperature of the water of the lake to a considerable depth equals or exceeds 20° C. The individuals found in October are the survivors of the September swarm, which show no reproduction and which disappear rapidly.

Daphnia retrocurva comes next in its relations to temperature. The species first appears late in May, but develops very slowly, and does not become plentiful enough to be counted as a regular constituent of the plankton until late in July or early in August. Its appearance thus coincides approximately with that of *Diaphanosoma*, but its autumnal history is quite different. The species continues to increase sexually until mid-October. The immature males appear late in September or early in October. The females begin to develop ephippia in the first half of October. The first ephippial females were seen on October 1st, 1895, and October 12th, 1896. By the middle or last of October nearly all the females bear ephippia, and the ephippia are cast off before November 1st. After this date the species rapidly declines, and the last females practically disappear about the first of December, although scattering individuals may remain until after January 1st. The sexual period of this species, therefore, instead of coming, like that of *Diaphanosoma*, when the temperature of the lake is still in the neighborhood of 20°, does not begin until the temperature has fallen below 15°. It should be remarked that in all these cases of an autumnal sexual period, scarcity of food can play no part in bringing it on. At this time the lake is crowded with algae of those species which are most greedily eaten by the crustacea, and in the case of the Daphnias there is always present a large mass of food material between the legs.

Leptodora is closely parallel to *Daphnia retrocurva*, although of course, its numbers are far smaller. I have never been able to see the nauplius of this species, though I have looked for it carefully. The young females appear late in May. The species reaches a maximum in late August or September. The males appear in late September or early October, and the species disappears about the middle or last of November.

In the perennial species the effect of temperature is chiefly seen in its action upon reproduction. *Cyclops brevispinosus* is by far the most indifferent to low temperatures. Its chief reproductive period is in the spring, and the young may appear during the winter beneath the ice, when the temperature of the water is below 3.0° C. The rate of reproduction increases as the lake warms, but the maximum of the species is reached by the time the surface of the water has been warmed to 15°. During the summer the species makes no marked recovery from the spring decline. In Pine lake this species is found during the summer in great numbers, close to the thermocline, living chiefly in the colder water just below it. It seems probable, therefore, that the species is unable to reproduce rapidly in the warm water of lake Mendota, to which it is confined during the summer. The young of the fall reproductive period do not appear in large numbers until after the lake has fallen below 15° C. The production of eggs and nauplii continues throughout the year, but the development goes on with increasing slowness as the temperature of the lake falls. When the temperature of the lake has fallen below 2.0° C., there seems to be little or no development of the nauplii into young *Cyclops*, but as the water of the lake warms toward the spring, the development goes on once more. There is, however, no time in the year when female *Cyclops* may not be found in considerable numbers bearing eggs.

In summer the number of Copepoda is smaller than that of the nauplii would lead us to expect. It is fair to conclude that at this time the temperature is higher than the optimum for their development into the adult forms.

Diaptomus does not reproduce during the winter, although a very few females may be found in late February or March bearing egg-sacs. No nauplii of this species have ever been seen during the winter, and the total number seen with eggs has not exceeded a dozen during the three winters of my study. Nor does reproduction begin immediately upon the disappearance of the ice. Females bearing eggs are seen from the middle of April on, but the young *Diaptomus* do not appear in numbers until the water of the lake, to a considerable depth, is near 15° C. Although the numbers of the species vary through the summer, it remains on the whole more constant during the heated term than any of the species, and the late-summer decline in August is apt to be less marked than in other forms. The number of eggs is less in summer than in spring. It may be as great as 30 early in the season but declines to 10–15 later. In 1895, there was a marked rise in the number of *Diaptomus* during September, which was not seen in 1894 or 1896. Since in all years food is abundant at this season, we must look for the cause of this exceptional increase in 1895 to the persistence of the warm weather during September of that year. A glance at Figs. 1 and 2 will show that in 1895 the surface temperature of the water remained practically constant through the summer and to the end of September above or near 20°, while in 1896 the temperature began to decline about the middle of August, and the decline continued steadily through September. Similar conditions of temperature to those of 1896 were found in 1894.

There is no fall reproductive season for *Diaptomus*, but as the temperature declines the number of egg-bearing females diminishes, and the number of individuals of the species becomes steadily smaller. The winter level is reached comparatively early, in late October or the very first of November. After this level is reached, no increase takes place until after May 1st of the following year. The number however, remains singularly constant throughout the winter, and the individual members are well nourished, containing large quantities of fat at all times during the winter.

Daphnia hyalina has two great periods of reproduction, in the spring and fall. The ovaries begin to develop before the ice has disappeared from the lake in late February and in March, when the temperature of the water is 2.5° C., or above. A very few of the largest individuals produce eggs at this time, but no considerable number of eggs are found until the temperature of the lake reaches 4–4.5° C., which has been about the middle of April. In 1895 the first numerous broods of young Daphnias appeared about the middle of May, when the upper water of the lake had reached an average temperature of about 15° C., and the reproductive period lasted until about the middle of June. During this time the number of eggs is considerable, usually as many as five and occasionally nine, or even more. These eggs are smaller than those produced in the summer, the yolk is peculiar in color, and in general the eggs resemble more nearly those of the ephippia than the eggs produced in midsummer. About three broods are produced during the month by the females. Toward the end of this reproductive period males appear in small numbers. They never exceed 4 per cent. of the total number of the females, and I have never found ephippial females at this season though I have searched carefully for them.

During the first part of June those females die which have lived through the winter, and at the same time there seems to be a break in the reproductive activity of the species. Whether this is due to the increase in the temperature of the water or not, I find it difficult to decide. In each year, as will be seen by reference to Fig. 16, the number of this species fell off rapidly and greatly at the close of the spring reproductive period, and this decline was followed by an equally rapid rise. So great a fall, followed by so great a reaction can hardly be attributed to the progressive rise of the temperature of the water, and it seems to me probable that this break in reproduction is due rather to a reproduction-pause following the imperfectly indicated sexual period. This species seems to have had originally two reproductive periods, which would naturally have been closed by the production of sexual eggs. There is left now barely a trace of sexual reproduction, but the break in the sexual reproduction is still indicated in the history of the species for spring and early summer.

When reproduction again goes on rapidly during mid-summer, the females produce only two summer eggs, which are large, transparent, and quite different in appearance from those laid in the spring. The number of eggs increases to four in early September if the temperature of the water has fallen from the summer condition.

The period of rapid reproduction in the spring falls at a time when the temperature of the water is from 15° to 18° C. In the autumn the main reproductive period is not entered upon until after the lake has fallen to a temperature of 15° C.

Daphnia pulicaria. The reproductive periods of this species are also limited by temperature. A high temperature exerts an effect more unfavorable than it produces on *Daphnia hyalina,* and the main periods of reproduction come earlier in the spring and later in the fall than do those of its sister species. Reproduction also continues through the winter with considerable rapidity. The period of active reproduction in the fall begins after that of *Daphnia hyalina* closes, and the largest broods appear in late November and early December, when the temperature of the lake has fallen below 5° C. It is apparently not until the lake has fallen below 10° C. that eggs are produced in great numbers, and in the cold water of the late fall, the females deposit in the brood-sacs from five to nine eggs, and the birth of these broods is followed by a marked rise in number. As the lake cools and freezes, reproduction still goes on, though more slowly than at the earlier date and more slowly than in *Cyclops.* Yet, during the winter of 1895–6, when *Daphnia pulicaria* was abundant, it was always possible to find females bearing in the brood-sac eggs in various stages of development. Active reproduction begins again in the spring, as soon as the ice has disappeared. The temperature of the water rises so rapidly and uniformly at this season that it is impossible to state the optimum temperature, but the large spring broods were produced shortly after May 1st, when the lake had reached a temperature somewhat over 12° C. The maximum number of the species was found about the middle of May, at a time when the maximum rate of reproduction was past. Males appeared in the latter part of May, and the ephippia were ripe early in June and were deposited before the middle of that month. After this date the species rapidly declines, but lingers for a time in the cool bottom water of the lake. The numbers become so few in late July and in August that no fair average can be given. They did not entirely disappear, however, in 1896, as they did in 1894, and it was always possible to find a few individuals in each catch by careful search.

This species is confined to the cool water of the lake during the warm season of the year. In plankton-poor lakes it occupies the whole region below the thermocline. In lake Mendota this region is not inhabitable except at the very top, and the species is confined to the narrow zone which includes the thermocline. It is probable that this unfavorable influence on the life of the species is the cause of its disappearance or great reduction in number during the warm season of the year.

The relations of *Chydorus* to temperature are less definite than those of the regular plankton crustacea. I have already said that *Chydorus* is a littoral form, which occupies the limnetic region only under favorable conditions. These seem to be rather determined by food than by temperature. The active life of the species, however, lies from the first of June to the last of October, and the maxima may fall at almost any time within these limits. In 1894 the species was practically absent during the latter part of August, rising rapidly to a maximum in September (Fig. 20), and then declining slowly until late October, when it fell off more rapidly and finally disappeared, with the exception of occasional scattered individuals. In 1895 it reappeared in May, reached a small number which it maintained about six weeks, rose rapidly to a maximum in July, and then declined to a small number which was maintained with approximate constancy from the latter part of August, through the autumn and winter, declining, but not quite disappearing, in the following April. In 1896 the species was much more abundant than in either year, a fact which I have connected with the greater abundance of *Aphanizomenon* during that season. The species had a great development from July to the middle of October, reaching its maximum early in September. There was also a minor maximum in early July and one in the first half of October. It appears, therefore, that the maxima of this species have come in July, 1895, in September, 1896, and in October, 1894, and that in other years these months have been marked by the presence of very small numbers of the species or its total absence in other years. It is, therefore, impossible to say more on the relation of temperature than that the maxima fall in the warm season of the year. During the winter of 1895–6, when the species was regularly present, reproduction went on, as was evidenced by the regular presence of eggs in the brood-sac of the females.

Summing up these results of temperature, it may be said that in lake Mendota, temperature exerts a greater control over the number of the plankton crustacea than does food. The number of the crustacea falls off in autumn, while food is still abundant; reproduction is checked in winter, although the food present would permit reproduction; and the reproductive periods of the perennial species are arranged rather with reference to temperature than to food supply.

If I were to sum up my impressions as to factors affecting the numbers, I should state them as follows:

1. Food sets an upper limit to number.
2. The algae of the upper strata of water determine the development or failure of the young broods.
3. Temperature determines the rhythm of reproduction.

Competition.

The connection between the number of a species and the competition to which it is exposed from the other limnetic crustacea is a subject on which little can be said, yet indications of the effect of competition are not wanting in my observations, and it may be worth while to point out some of them. The details fo heve trtical distribution of the crustacea show that while the number of individuals present in the upper strata of the water may vary considerably from year to year, nevertheless the number does not rise beyond a certain maximum during the season, and when this maximum has once been reached the number remains singularly constant. We cannot, therefore, avoid the conclusion that there is a certain number of crustacea which the water can support, and that this number cannot be greatly exceeded. If this is the case, the numbers of one species must exert an influence, more or less unfavorable, on the number of the other forms present.

In each of the summers during which I have studied the crustacea, one form predominated in the plankton, and in each year the species was different. In 1894 *Diaptomus* was more numerous than all the other crustacea put together. In 1895 *Daphnia hyalina* was the predominant species in number, and still more in bulk, as its individuals are so much larger than the other species. In 1896 *Cyclops* was almost equally predominant, although at times *Daphnia* was nearly or quite as important. My explanation of these facts is that when a species secures possession of the water it is difficult for another species to oust it so long as its reproductive power continues. The causes which give an opportunity to any given species thus to occupy the water are still largely unknown, or conjectural. It may be said, however, that as the species become successively predominant, a form whose reproductive period is at hand at the time of the decline of a dominant form will be able to occupy the vacant space for a time.

An instance in which the numbers of a species seem to have been affected by competition is afforded by *Daphnia retrocurva.* In August, 1895 and 1896, the number of this species was substantially equal, being 57,000 per square meter, in 1896 and 50,000 in 1895, but in 1895 the number of *Daphnia hyalina* was very great, being 260,000 or more during the entire month; while in 1896 *Daphnia hyalina* had fallen off to 61,000 in the latter part of August, being therefore substantially equal with *D. retrocurva.*

The autumn history of *D. retrocurva* was very different in the two years. In 1895 it declined in the early part of September and showed only a feeble rise in October, while in 1896 both species of *Daphnia* rose together at an equal rate, and remained practically identical in numbers until the sexual reproductive period of *D. retrocurva* was passed. I can hardly attribute this difference in the development of the species to anything excepting the occupation of the water by *D. hyalina* in 1895.

Another case in which competition may possibly play a part may be found in the spring development of the crustacea. In no year do *Diaptomus* or *Daphnia hyalina* begin to develop their swarms in the upper water until *Cyclops* has begun to decline, and its numbers in the upper water are greatly reduced. It would seem as though these latter species waited until *Cyclops* was out of the way before they began their main development. But in this case the increasing temperature of the lake is unquestionably a factor in the development, and the relation of competition is accordingly more doubtful.

HORIZONTAL DISTRIBUTION: SWARMS.

"Ob man die Befunde als Beweise der Ungleichheit oder der Gleichförmigkeit bezeichnen will, kann freilich so lange Geschmacksache bleiben, als man den Ausdruck nicht präcisirt. Falls man aber präcisirt und gleichmässig nennt wenn durchschnittlich die Dichte nur um das Doppelte oder Dreifache wechselt, ungleichmässig also, wenn die Vertheilung als so unregelmässig erweisen wird, wie etwa die Bewohnung der Erdfläche durch Menschen oder Thiere, so kann eine Meinungsverschiedenheit nicht wohl bestehen bleiben. Ich betrachte die Bewohnung einer Stadt noch als ziemlich gleichmässig und wenn einmal an einer Stelle einige tausend Menschen zusammenströmen, so wird dadurch die Bewohnung noch nicht ungleichmässig." (Hensen, '95, p. 172.).

I have placed at the head of this section Hensen's words which seem to me to express with great clearness and wisdom the general truth regarding the still disputed question of the uniformity of the distribution of plankton animals. On no question relating to the plankton are opinions so widely at variance, yet no question is more fundamental to the value of numerical work in investigation. For example, Wesenberg-Lund says ('96, p. 153) that plankton animals occur "saa godt som altid i Svaerme." On the other hand Apstein says: ('96, p. 64) "Es ist bis jetzt nicht ein einziger wohl verbuergter Schwarm beobachtet worden." Thus in the same year opinions diametrically opposed are expressed, each based upon investigation. Under these circumstances the result of my work extending over two and a half years, including some 400 catches, each of which contained from 3 to 12 species, may contribute something to the discussion.

It is not easy to define what is meant by a "swarm." No student of the plankton expects to find the plants and animals distributed with absolute uniformity, and it is impossible to state the degree of variation in distribution which will entitle us to say that the species in question occurs in swarms. I agree with Apstein ('96, p. 53) that two- to fourfold variations are not to be counted as swarms. Apstein computes the actual distance of individuals of *Diaptomus* when the numbers are about 198,000 and 540,000 per square meter, and finds in the first case the average distance would be 2.2 mm. and in the second 1.36 mm. He rightly states that such a difference in distance does not justify the name of swarm. Most will agree, I think, that a ten-fold difference in numbers will justify the statement that such species occur in swarms. Certainly animals whose number differ to that extent are very irregularly distributed, and if they were found in large numbers in compact areas, and the space between these areas was thinly populated, it would not be unfair to say that the species appears in swarms.

In general, there is no evidence of swarms in my observations, either of all the crustacea or of single species. It will be seen from the tables giving the maximum and minimum catches for each two week period that in the more numerous species the maximum catch is about four times the minimum, when the species is neither increasing or decreasing in numbers to any marked degree. Where the species is present in small numbers, the range of variation is far greater. Thus, in July, 1895, *Leptodora* showed a variation from 1 to 50 individuals in the 39 catches made during that month. It varied from 1 to 19 in catches made on the same day, and was wholly irregular in its variations during the month. During the same month the catch of *Cyclops* varied from 1290 to 6100; and on no day were two catches made in which one was double the other. In each of 12 days in 1895 and 1896 two catches were made at points about two kilometers apart, and the ratio of the predominant species in these 12 cases was as follows:

	Average ratio.	Maximum ratio.	Minimum ratio.
Diaptomus	A:B::1:1.62	1:2.4	1:1.1
Cyclops	A:B::1:1.55	1:2	1:1.1
D. hyalina	A:B::1:1.58	1:2	1:1.1

In each case A denotes the smaller catch, which was about equally divided between the two stations.

Again, if comparisons are made of catches extending over a period of time when the average number remains nearly constant, and when there is no reproduction, the distribution can readily be inferred. Fifty-six catches of *Diaptomus* were made between December 1st, 1894, and March 30th, 1895. Of these there were:

Below 10,000 per square meter, 1 catch.
Between 10,000 and 20,000, 14 catches.
Between 20,000 and 30,000, 21 catches.
Between 30,000 and 40,000, 12 catches.
Between 40,000 and 50,000, 5 catches.
Between 50,000 and 60,000, 2 catches.
Over 70,000 per square meter, 1 catch.

The figures also show that all of the December and January catches were below 30,000, all of March above 20,000, and only about one-fourth of them below 30,000; while the February catches were scattered from 15,000 to 50,000. While there is considerable variety in these catches, yet, when the length of time and the number of observations are considered, the extent of variation lends no support to the theory of occurrence in swarms.

TABLE XXV.—*Diaptomus and Daphnia.—December, 1894—April, 1895. Expressed in thousands per sq. meter.*

	Diaptomus.	*Daphnia.*		*Diaptomus.*	*Daphnia.*
December 3	19	103	February 15	17	51
	13	144		32	42
December 5	28	154	February 19	38	76
	27	93		41	109
	24	100		35	83
	22	116		29	86
	18	78	February 23	36	54
	25	91		43	60
December 7	26	138		48	66
	17	118	March 6	24	30
December 19	17	57		29	41
	23	41	March 7	31	48
January 1	13	45		32	69
	17	52		51	45
	25	55	March 9	36	56
January 2	12	48		27	26
	22	65	March 12	28	28
	22	41		45	63
January 6	15	36		56	60
	8	39		27	39
	11	36	March 16	34	83
January 9	29	54		45	102
	16	57		33	86
	20	60		71	103
January 16	16	53	March 18	32	69
	13	61		34	72
	23	53	March 23	33	39
February 14	23	43		27	40

The foregoing table shows the numbers of *Diaptomus* and *Daphnia hyalina* during the winter of 1894–5. Similar results were found in the same species during the winter of 1895-6 and indeed similar tables could be constructed for any species fairly numerous, and neither increasing nor declining in numbers.

On July 21 and August 15, 1896, a series of catches was made extending across the lake some 5 kilometers, at approximately equal distances. The result of the latter catch is given in the accompanying table; the other was substantially the same.

TABLE XXVI.—*Collections on August 18, 1896, expressed in thousands per square meter.*

	I.	II.	III.	IV.	VI.	VII.
Diaptomus	27	51	40	80	74	83
Cyclops	184	203	142	136	127	145
D. pulicaria	57	31	3.3	....	....	....
D. hyalina	37	31	15	33	33	38
D. retrocurva	13	16	7	11	3.3	20
Diaphanosoma	10	18	13	27	33	49
Chydorus	35	217	184	154	174	147
Leptodora	0.7	1.5	....	0.2	0.5	0.5
Ergasilus	17	16	3.3	8.9	....	0.5
Nauplii	241	337	?	236	134	167
Corethra	6	8	1.1	1.2	1.3	4.4
Asplancha	114	101	33	66	40	45
Total crustacea	631.7	921.5	*407.6	686.1	678.8	650

* No nauplii included.

The number of *Cyclops* when at its maximum showed surprisingly little variation. In 1895 from May 1st to June 6th, 26 catches were made on 13 days. The catch ranged from 10,000 to 20,000 individuals actually caught. In 1896, 18 catches were made on 16 days. The numbers ranged from 9,000 to 37,000. A figure is added (Fig. 21) showing the number of *Cyclops* caught during the year 1895. It will be seen that the diagram gives no warranty to the conclusion that this species appears in swarms. Similar illustrations could be taken from any year, and from almost any species, with the qualification that the range in number is greater in the case of those species whose numbers are small.

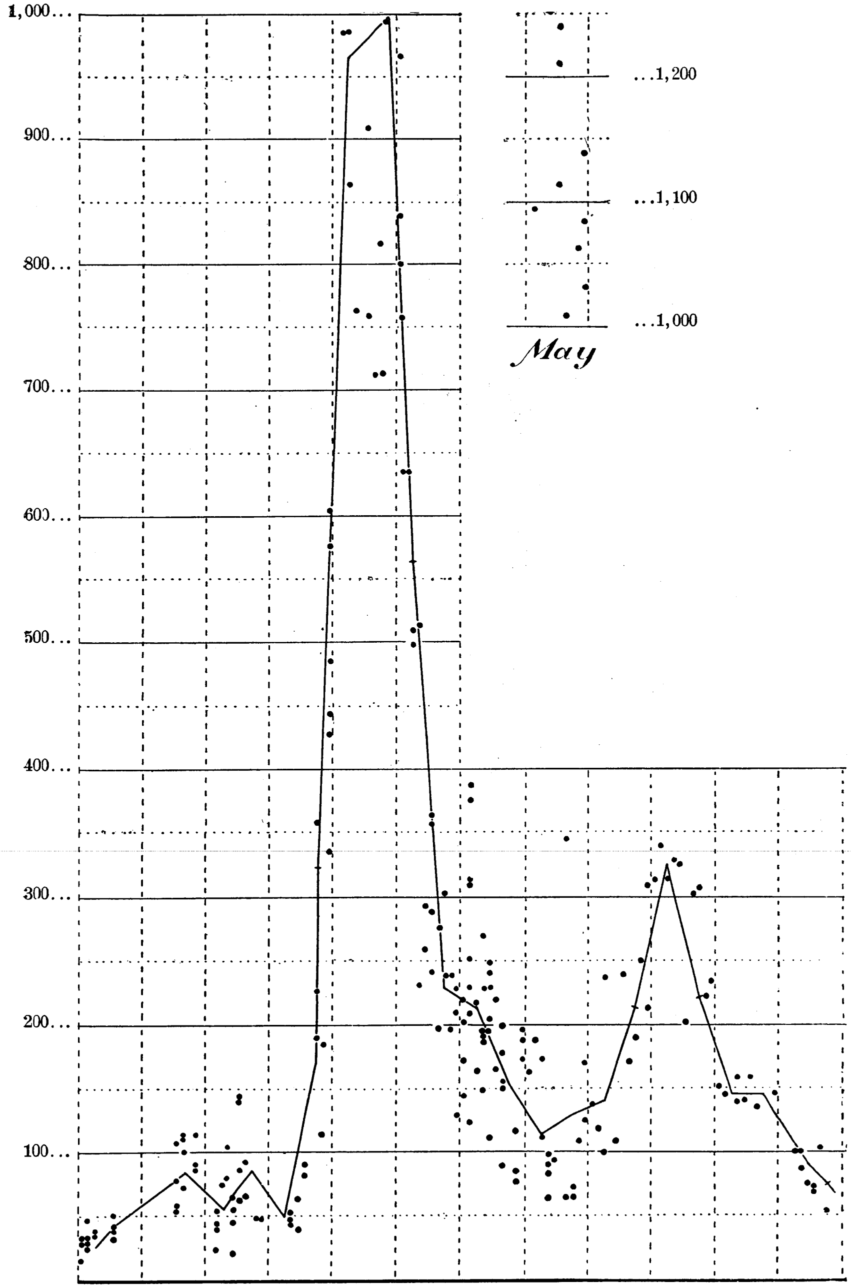


FIG. 21.—Cyclops. Number of each catch, 1895 The curve indicates the average. Scale, 1 vertical space = 100,000 crustacea per sq. m. See p. 370.

The following table gives the variations of the total number of the crustacea during three months of 1896. It will be seen the variations are somewhat smaller than are those of the single species but are of a similar character, and also resemble those of Table XXVI.

TABLE XXVII.—*Total crustacea, May—July, 1896.*

	Average.	Maximum.	Minimum.	No. observations.
May 1-15	2,398	2,966	1,615	8
May 16-31	1,901	2,963	1,177	8
June 1-15	845	1,977	561	9
June 16-30	1,265	1,908	890	9
July 1-15	1,314	2,332	1,005	6
July 16-31	795	1,266	511	11

I think that I have given here and in the tables of the appendix, sufficient evidence to enable the student to undertands the extent of the variation in the distribution of the crustacea. I do not know whether the figures will be interpreted as showing an equal or unequal distribution. I judge that Marsh, from his discussion of the subject ('97, p. 218, ff.) would regard the distribution as irregular. I think that it is quite as uniform as Apstein would expect. For myself, I have never supposed that every square decimeter of the surface of the lake covered an equal number of crustacea. I have been surprised that a net 20 cm. or 10 cm. in diameter should disclose such a uniform number as it actually shows, especially in the case of organisms so highly organized as the Entomostraca.

On the other hand, there is clear evidence for swarms in certain species of crustacea, and at certain times. (1) The distribution of *Daphnia pulicaria* is very irregular, far more so than that of any of its congeners. This species in lake Mendota is confined during summer to the region of the thermocline, and as this stratum works downward through the lake in summer, the area inhabitable by the species is contracted around the edge of the lake, and the crustacea as they move out from the shore to keep in the cool water, may accumulate in swarms. These have already been mentioned in connection with the species. The most conspicuous case occurred in August, 1895. On the 21st of the month the catch of *Daphnia pulicaria* was somewhat under 500; on the 22d it was nearly 2,600, and on the 27th it was only 85. This aggregation of the species was due to the wind carrying a current of warm water through the deeper levels at the point of dredging and so driving into deep water the individuals near shore, and the decline in number was due to the removal of the large numbers by currents rather than to the final scattering of the swarm.

When a species has once aggregated in this manner, the aggregation may last for a considerable length of time; and *Daphnia pulicaria* always showed a greater range of variation in its numbers than did any other species, apparently due to these temperature aggregations in summer. For example, on April 18th, 1896, at one point in the lake, 3,060 of this species was caught; while another catch, at a distance of some two kilometers, showed only 230. On December 23, 1895, two catches were made of 260, and 3,440 respectively. See also the lateral distribution in Table XXVI, above, which discloses a similar want of uniformity. A distribution so irregular as this, it seems to me, fairly warrants the title of "swarm." I may add that late in the spring the species become more uniformly distributed, and when at its maximum showed a variation of less than threefold in 10 catches, distributed over 21 days.

(2) Apstein has found no case where a swarm has been seen. I have observed true swarms of *Daphnia hyalina* on at least three occasions. On October 17th, 1895, about 9 a. m. a large swarm of this species was seen at the surface near the dredging station about 800 meters from the shore. The water was perfectly calm, and the sun was bright. The Daphnias were aggregated at the surface to a depth of about 5 cm. or less and within that depth the water was completely filled with them. The swarm was about 50 meters in width, and its edges were perfectly distinct, as the boat passed slowly in and out of it. The length of the swarm was probably three times the width. All of these animals were adult, so that they were easily seen with the naked eye. The occurrence was the more unusual as the bright sun should have kept this species well below the surface.

Two similar swarms of the same species were seen in 1896 on October 3rd, and on November 3rd; both days when the lake was perfectly calm. On the first occasion there was a fog on the water; on the second occasion the sky was clear. These swarms were nearer the shore and were much more extensive. On the first occasion the Daphnias occurred in patches of irregular extent and shape — perhaps 10 meters by 50 meters, and these patches extended in a long belt parallel to the shore. The surface water was crowded by the Daphnias, and an immense number of perch were feeding upon them. The swarm was watched for more than an hour, during which the fog passed away, and the water could be seen disturbed by the perch along the shore as far as the eye could reach as one was standing in a boat. After a time a light breeze sprang up and, of course, prevented further observation. On this occasion the number was determined to be 1,170,000 per cu. m. in the densest part of the swarm. On November 3rd a similar swarm was seen, and water was again dipped up from the denser part of the swarm. The crustacea were crowded into an extremely thin layer, not more than 2–3 cm. thick. The surface water only was allowed to fall into the vessel and the number determined in 6 catches made by straining 10 liters of water, was from 800,000 to 1,492,000 Daphnias per cubic meter, about 99 per cent. adult. In addition there were present about 1,000 *Cyclops* per cubic meter, but nothing else was found. On this occasion one ephippial female was present, the only one that I have ever seen in this species; the ephippium was fairly developed, but no eggs had been deposited in it. No males were in these swarms.

The highest number is found nearly ten times the maximum number of this species per cubic meter, as derived from the three-meter hauls. It is also nearly fifty per cent. more than the maximum catch of this species as obtained from a depth of 18 meters, and nearly five times as great as the average for November 1–15. On November 3d, catches were made below the swarm from 0.3m. to 3.3m. The average of two gave per cubic meter:

Diaptomus	4,900
Cyclops	26,600
D. hyalina	18,200
Chydorus	15,700

The average of *D. hyalina* in the 0–3m. level for the first half of November was 32,200 per cubic meter, of which at least half were immature, so that the catch of November 3d was not an exceptionally low one. These facts show that the swarm in question was a lateral aggregation and not merely a gathering at the surface of the individuals ordinarily below it.

Great numbers of individuals broke through the surface film of the water on all of these occasions.

This aggregation of *Daphnia hyalina* in swarms is probably more frequent than the number of observations would indicate. The swarms are found in the surface water, so that they are dislodged by the slightest breeze, and it is impossible to see them unless the water is entirely smooth. This condition is not often reached, and I have felt myself exceedingly fortunate in being able to observe this phenomenon on so many as three occasions. I may say, however, that during the autumn of 1896, I looked for these swarms on every calm day when it was possible for me to go out on the lake, but found them only twice.

The significance of these aggregations is difficult to state. The habits of the animal are completely reversed in one respect. The adults are strongly negative in their relation to light, and under the conditions of all these occasions should have been found at a depth of one-half to one meter below the surface. It is possible that these aggregations represent the remains of a former sexual period. This may be indicated by the presence of the ephippial female. I have no doubt that *Daphnia hyalina* had at one time two sexual periods, in spring and fall, of which these swarms may be a remainder, but since the few males which appeared in the fall came at a time decidedly later than the earlier of these aggregations, I do not feel warranted in positively interpreting the swarms in this sense.

These swarms of *Daphnia* seem to be phenomena of the same order as those described by Francé ('94, p. 37). In one case the swarm was near the littoral region, as were those described by him. In the other cases they were well out in the limnetic region. The swarm was confined within vertical limits even narrower than the one meter named by him and in all three cases the swarm was "von weitem erkennbar."

While, therefore, I find swarms occasionally present, I find also that the crustacea of lake Mendota are in general distributed with marked uniformity. Marsh ('97, p. 220) finds an ordinary variation of ten-fold in the numbers of *Diaptomus* and an even greater variation in the case of other limnetic crustacea. With the exceptions already noted the range of variation in lake Mendota has not often exceeded four fold. The number of observations, therefore, necessary to give a fair average for the population of the lake is not so great as that spoken of by Marsh. The examination of my records shows that the general development of the crustacea can perfectly well be determined by catches taken at intervals of a week and that the vertical distribution, if computed from such observations, would agree very closely with that reached from the very much larger number actually used. Of course the larger and rarer forms, like *Epischura* and *Leptodora*, vary in number very greatly. No one would attempt to compute the population of a lake from the presence of a single *Leptodora* in the catch, or from the occasional presence of half a dozen, or more, but the numbers of the crustacea which are the regular constituents of the limnoplankton vary within comparatively narrow limits in lake Mendota, and I feel confident that my averages fairly represent the crustacean population. The variation of the numbers of the crustacea in lake Mendota does not support extreme views either on the side of uniformity of distribution or the opposing theory of swarms.

In connection with reconnoisance observations it may be well to remember the following: Exceptionally large catches are due to the presence of great numbers of young, and exceptionally small ones usually contain few young. A catch containing great numbers of young may therefore be suspected to be unusually large and one with few young, if taken in summer or fall, to be small for the lake from which it comes.

THE VERTICAL DISTRIBUTION OF THE CRUSTACEA.

In making collections to determine the vertical distribution of the crustacea the same general method was followed as that described in detail in my former paper. (Birge, '95, p. 429.) The dredge was lowered to the bottom of the level from which specimens were to be taken, raised through the proper space, and then closed by means of a messenger sent down the line. It was then drawn to the surface, washed out, and the collection preserved for future study.

My observations show so much variation in catches made at the same place and in succession that I have little confidence in the differential method of determining vertical distribution; unless a very large number of observations is made and averaged, so as to eliminate the chance of variation in the single observation. See p. 281.

The distance employed in all of my collections was three meters. This interval was selected because it divided the lake at the point of observation into six levels of uniform thickness, and also because of the close correspondence between three meters and ten feet. Experience has shown that the distance was fortunately chosen as the number of crustacea begins to decline rapidly between 2 and 3 m. from the surface. The place of regular observation is about 850 meters from shore, where the water is about 18.5 meters in depth or somewhat more when the water is highest in the spring of the year. The greatest depth observed in the lake is between 23 and 24 meters. The slope of the bottom in the deeper water is very gradual, and a depth substantially greater than 18 meters is only reached at a considerably greater distance from the shore. If observations had been made in the deepest part of the lake, the distribution as shown in thousands per cubic meter would not vary from the facts as shown in the tables, nor would the summer percentile distribution be altered, since during the summer the deeper parts of the lake contain no crustacea. During the fall and winter months the distribution is nearly uniform in the lower water. The average percentile distribution would, of course, be changed by the addition of one or more levels during winter, and the aggregations of crustacea, especially *Cyclops*, which are found in the bottom levels, would of course, be moved from the 15–18 m. level to those lying below. Observations were made occasionally in the deeper water, as often as once a week during the summer and fall months; less frequently during the winter. But as the observations were few in number in comparison with those made at the regular point of observation, they have not been used in the preparation of the tables.

During the last half of the year 1894, 75 serial observations were made, 127 during 1895, and 131 during 1896. These were most numerous during the summer months. In general it may be said that on every day on which observations were made as stated in Table A of the appendix, a series was taken, and on some occasions more than one. The general distribution, of the observations, however, can be ascertained from the table. At least five were made in each two week period from the middle of April to the middle of November. During the winter of 1895, some observations were made by six meter intervals in the lower water of the lake, and the result of these observations was equally divided between the two levels covered by them.

In Table B, accompanying this part of the report, the population of each level is given in thousands per cubic meter, the total population of the level being divided by three on the assumption that the crustacea are equally distributed throughout the level. Under some circumstances this assumption is incorrect. In the 0–3 m. level, the upper meter contains more than one-third of the crustacea, especially when there are large numbers of young. It may contain twice as many as any meter below. On the other hand, on bright calm days, when few young crustacea are present, the upper meter may contain less than one-third of the total catch from the upper level.

In the level which includes the region of the thermocline the population of the single meters varies greatly, as will be shown later in this paper; the crustacea being found in considerable numbers above this stratum and practically absent below it. A third error arises at times when large numbers of crustacea are settling to the bottom and dying. This occurs with *Cyclops* during the winter and spring, and with *Daphnia hyalina* in the early part of June. At such times the lower meter of the lower level would contain more than one-third of the crustacea present in that level. These variations from an approximately uniform distribution are however so varying themselves that it has not been thought wise to attempt to distribute the crustacea among the three meters of each level on any other assumption than that of uniform distribution.

THE GENERAL VERTICAL DISTRIBUTION OF THE CRUSTACEA.

Figs. 22–28, Tables B and C, Appendix.

Winter — January, February, March.

The months during which the lake is covered with ice show a great equality of distribution on the part of the crustacea. This is due to several facts. First, the lake is thoroughly homothermous, at least in a biological sense. Differences exceeding a degree between the temperature of the water at one meter from the surface and at the bottom of the lake are only found in late winter. Second, the food has no such concentration toward the surface as is found in the summer, though the algae are more abundant in the upper strata. Third, the action of the wind is removed, and the influence of the sun is greatly reduced, both by the snow and ice and by the low temperature of the water. Fourth, there is no reproduction of most species of crustacea and consequently no difference in age to influence distribution.

A few forces act in the other way: First, the food is more plentiful near the surface, as the algae reproduce more abundantly there. Second, when *Daphnia pulicaria* is present it is far more abundant in the upper strata of the water than below. Third, *Cyclops* often appears in swarms near the bottom of the lake. Fourth, If *Cyclops* reproduces during the winter the young are more numerous toward the surface.

Tables B and C of the appendix show that during January, February, and the early part of March, 1895, there was very little difference in the population of the four upper levels. In January of that year the lower strata were decidedly poorer in number than those above; while in the latter part of the winter they were the most populous, owing to the accumulation of *Cyclops* in those levels. In the winter of 1896, the 0 – 3 m. level was at least twice as populous as any below, owing to the large num-

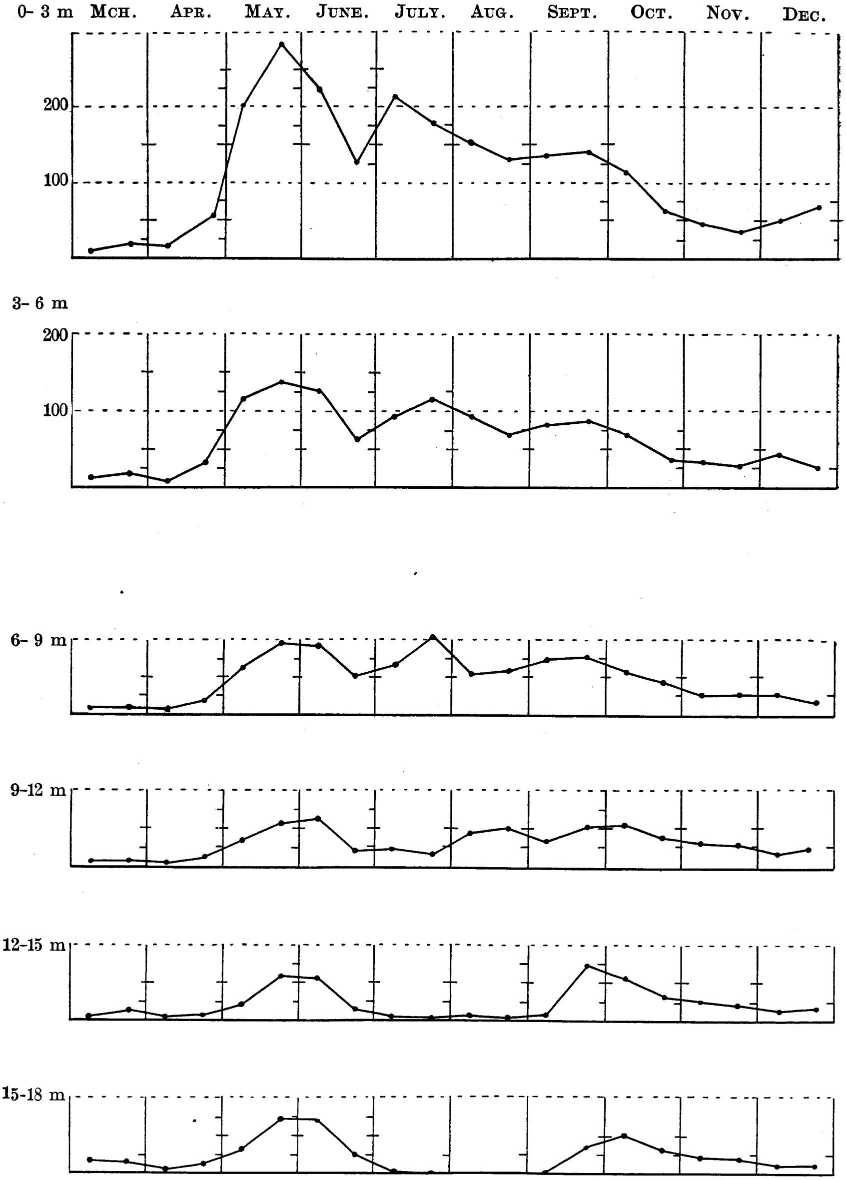


FIG. 22.—Population of the 3 m. levels, 1895. Scale, 1 space = 100,000 crustacea. The 25,000 and 50,000 divisions are indicated. See page 387.

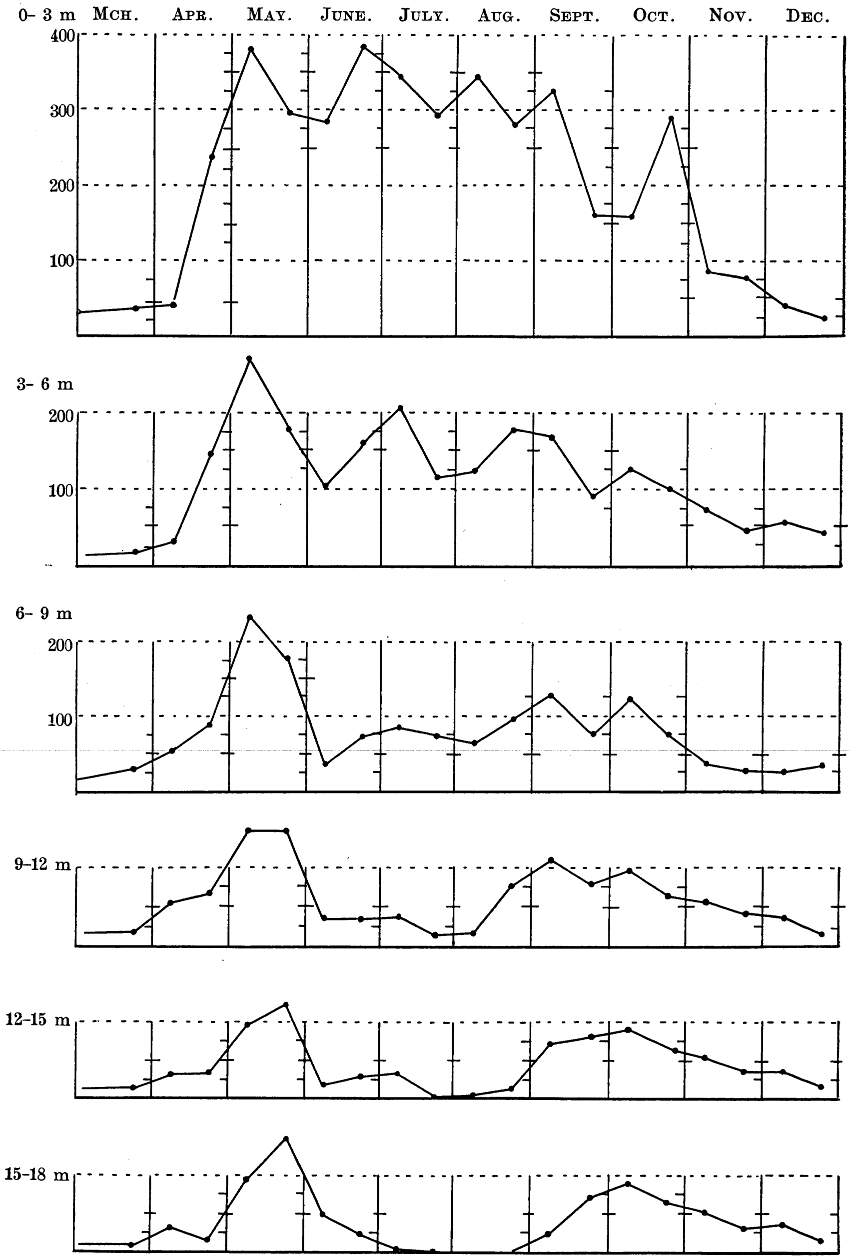


FIG. 23.—Population of the 3 m. levels, 1896. Scale, 1 vertical space = 100,000 crustacea per sq. meter. See p. 387.

ber of *Daphnia pulicaria* present in that winter. The 15–18 m. level was the second in population, except in the early part of January, owing again to the accumulation of *Cyclops* in that region. The middle strata of the lake were the poorest in population in both years.

Some illustrations may be added showing the concentration of the two species in question in the lower and upper water of the lake respectively. On February 15th, 1895, out of 870 *Cyclops* taken by the net, 570 were below 12 meters; on the 19th 880 out of 1,130. On March 9th, 1,017 were found below 15 meters, out of a total of 1,650; on March 12th, 485 out of 710. This aggregation at the bottom was not seen in January, and some few catches of later date did not display it.

In 1896 the same tendency was shown, and began as early as January. On the 7th of that month 1,250 *Cyclops* out of 2,070 were below 12 meters, and similar catches were made through January and February. In March the old *Cyclops* were greatly reduced in number, aggregated only about 640 individuals for the whole depth, and showed no tendency to collect at the bottom. At this time the young *Cyclops* were present, averaging over 2,000 to the catch, and the 0–3 m. level contained about twice as many as any other.

Daphnia pulicaria was absent in 1895 but was numerous in 1896. During January and until the middle of February there were at least five times as many in the 0–3 m. level as in any lower one. As the numbers declined in February they fell off chiefly where they were the greatest and the 0–3 m. level became about twice as populous as any below.

Thus the tables of distribution in winter for 1895 and 1896 show resemblances and differences. In 1895 the 0–3 m. level shows no noteworthy excess over those below, while in 1896 it is about twice as populous. Between 65 and 70 per cent. of the population of this level in 1896 are due to *Daphnia pulicaria.* In both years the bottom water is more populous than that at the middle of the lake, due to the settling of *Cyclops.* This species furnished from 75 to 85 per cent. of the population of the bottom level in both years. The average population per cubic meter is much greater in 1896 than in 1895, especially so in

January; but the population fell off more rapidly in the latter part of that winter, and there was no very noticeable difference in March.

TABLE XXVIII.—*Average percentile distribution for the winter — January, February, March.*

	PER CENT. IN EACH 3 M. LEVEL.						
	Average No.	0-3m.	3-6.	6-9.	9-12.	12-15.	15-18.
1895	123,000	18.1	19.3	13.7	12.8	15.8	20.3
1896	237,000*	34.1	15.7	14.8	10.8	10.3	13.6

* *Chydorus* omitted on account of its rapid decrease in late winter.

Spring— April and May.

Tables B, C, Appendix.

The distribution of the crustacea during the first half of Apri is on the whole fairly equal in the different levels of the lake, but with irregularities which mark it as an accidental distribution. The ice breaks up in the first days of April, and the lake is consequently exposed to the action of the wind. The temperature is fairly uniform at all depths, and the algae hardly begin rapid multiplication much before the middle of April. The water at this time has a more active circulation than at any other, as is shown by the presence in the net of numerous particles of vegetable debris from the soft mud at the bottom of the lake.

During this time *Cyclops* begins its rapid increase towards the spring maximum, if the multiplication has not already begun under the ice. Its swarms of young are in the upper strata of the water. It may be laid down as a general rule that large numbers of young of any species of crustacea appear first in the upper levels of the water, and the animals later pass toward the middle of the lake; and later still, occupy the water toward the bottom. It may be said, therefore, in general, that the presence in the upper water of a very high percentage of the catch of any species indicates the beginning of a period of re-

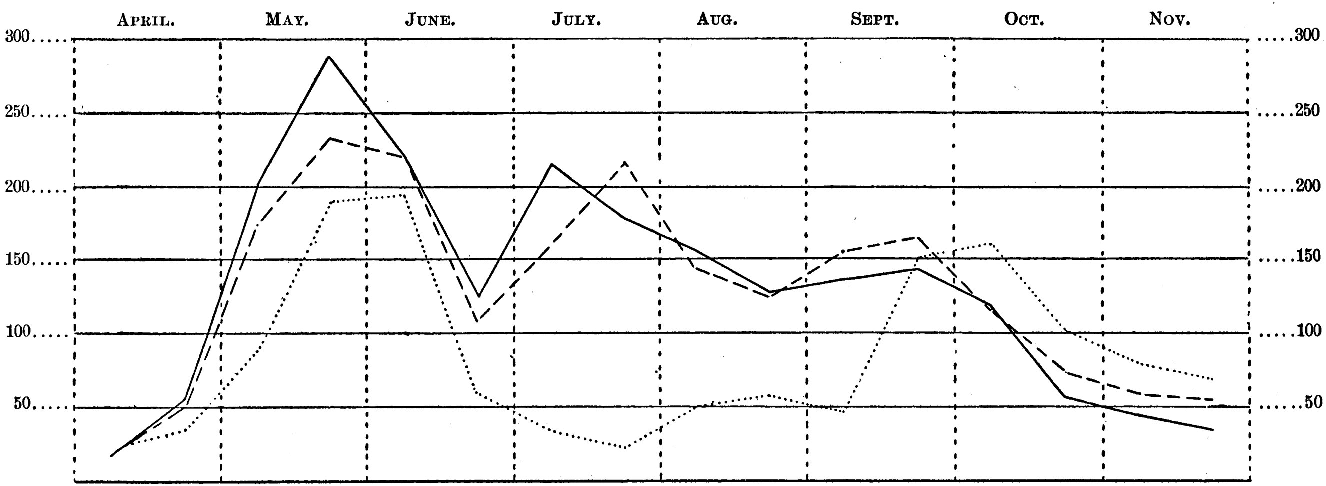


FIG. 24.—Vertical distribution, 1895. Scale, 1 vertical space = 50,000 crustacea per square meter.

0- 3 m.... ————

3- 9 m.... — — — —

9-18 m.... ....

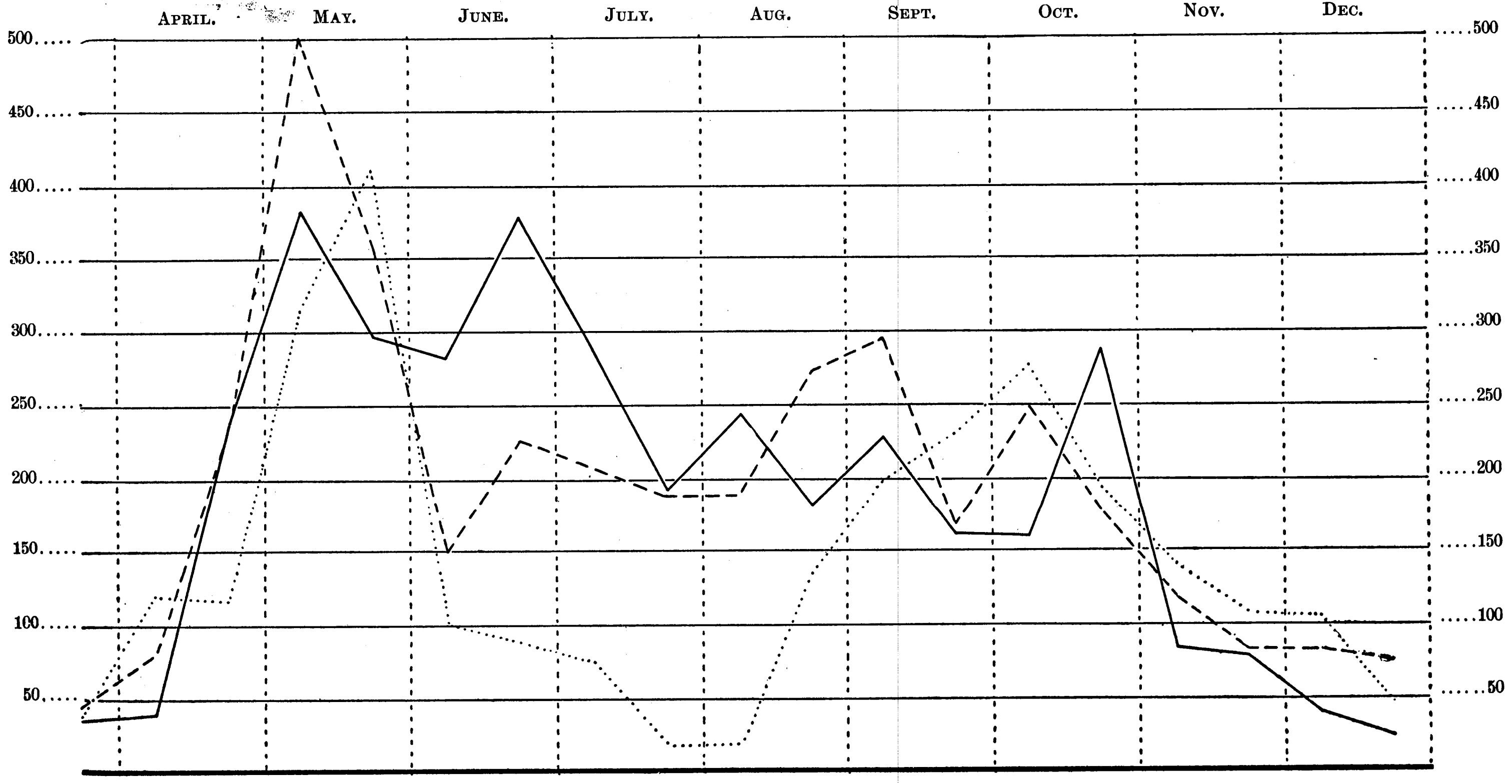


FIG. 25.—Vertical distribution, 1896. Scale, 1 vertical space = 50,000 crustacea per sq. meter. See p. 381.

0- 3 m.... ————

3- 9 m.... — — — —

9-18 m.... . . . .

production of the species, while the presence of a larger number in the bottom water of the lake than in the surface water indicates that the species is past its maximum and is already beginning to decline in numbers.

In both years the numbers of crustacea in the upper water show an increase during April, due to the multiplication of *Cyclops*. This increase went on, as was shown in the early part of this paper, much more rapidly in 1896 than in 1895. As a result, the population both of the surface water and of the lower levels increased much more rapidly in 1896, and the latter part of April, 1896, represents about the same condition of the development of the crustacea, as does the first half of May in 1895. In each case more than 40 per cent. of the crustacea were present in the upper stratum, while the 15–18 m. level had not increased greatly in numbers above its condition in winter. In the latter part of April, 1896, the 15–18 m. level contained less than 3 per cent. of the whole number of crustacea present; and in the first part of May, 1895, it contained less than 7 per cent. As the number of *Cyclops* and *Daphnia pulicaria* became greater, they moved downward into the deeper water, so that it became relatively more populous. In the latter part of May, 1895, the 15–18 m. level contained 10 per cent. of the crustacea, while in 1896 it contained over 40 per cent. This increase in the population of the lower strata goes on after a considerable decline has come in that of the upper strata. The lower water lags behind the upper both in the increase and decrease of its population, and the maximum population of the lower strata comes from two to three weeks after the maximum population of the lake has passed.

These relations become more obvious if we divide the lake somewhat arbitrarily into three levels, 0–3 m., 3–9 m., 9–18 m. The distribution of the crustacea among these three regions is shown in Figs. 24 and 25. By reference to these it will be seen that in 1895 the two upper levels increased much more rapidly than did the lower half of the lake from the latter part of April to the middle of May. In the latter part of May the reverse is true; and in early June the population of the lower water was stationary, while that of the upper half of the lake was rapidly declining. In late June the population of all levels declines altogether.

This relation is even more conspicuous in the diagram for 1896. The population below 9 meters did not increase at all until the end of April, while that of the upper levels increased several fold, the 0–3 m. level growing more rapidly than that below. In the first half of May the lower half of the lake gained absolutely more than either of the levels above, its gains per cubic meter being about half as great as those of the upper water. In the last of May the levels below 12 meters continued to gain, while the 9–12 m. level was approximately stationary, and the upper strata fell off rapidly and about equally. At this time the lower half of the lake contained nearly 40 per cent. of the total number of crustacea, nearly equally distributed, while the upper three meters contained only about 28 per cent. In early June all the strata below the 0–3 m. level lost heavily, owing to the disappearance of the spring broods of *Cyclops* and *D. pulicaria;* while the 0–3 m. level remained approximately stationary, the new broods of *Chydorus* and *Diaptomus*, which appeared in that level, compensating for the decline in other species. The result of this decline in the population of the lower water serves to give the 0–3 m. stratum over 50 per cent. of the whole population, and the number in this level continues between 45 and 50 per cent. during the remainder of the summer.

Summer — From the middle of June to the middle of September.

The change from the late spring to the early summer has just been spoken of. The most important fact influencing the vertical distribution at this time is the formation of the thermocline, and the accompanying exclusion of the crustacea from the lower waters of the lake, and ultimately from the entire region below the thermocline. The thermocline was observed in each year about the middle of June — June 11th, 1895, June 13th, 1896 — and was present regularly afterward. The depopulation of the lower waters does not coincide with these dates, as will be seen from the tables. This would be expected since the exclusion of the crustacea is due to the chemical condition of the lower water, resulting from the temperature conditions. In both years the population of the lower half of the lake in the latter part of June is equal to or greater than that in the same region in the early or even the latter part of April. The population of the 9–12 m. level remained substantially stationary until the middle of June, 1895, and the same was true of this level and the level below until the middle of July, 1896. In June, 1895, the population of the bottom level was high, owing to the accumulation there of large numbers of diseased and dying *Daphnia hyalina;* but as soon as these had died, the numbers rapidly fell off, and the population in the 15–18 m. level was very small in the first half of July.

In 1894, observations begun with the 1st of July, and at that time the population below 9 m. was extremely small, far smaller than in either of the succeeding years. At that time the temperature conditions below the surface were not observed, but it is fair to infer that the thermocline was established at a comparatively early date in that year. A second fact which influenced the distribution in 1894 is the unusual preponderance of *Diaptomus* among the crustacea in that year. A very high percentage of this species is found at all times in the upper water, while *Cyclops*, whose per cent. in the lower water is greater than that of any other species, was represented by very small numbers.

During July the population of the waters below 9 m. declines very rapidly, as will be seen from the table which gives the population of the lower water during the months of June, July and August.

TABLE XXIX.—*Population per cubic meter.*

	1895.			1896.		
	9–12 m.	12–15 m.	15–18 m.	9–12 m.	12–15 m.	15–18 m.
June 1–15	45,000	36,000	46,600	24,000	12,600	30,600
June 16–30	13,300	9,200	17,500	24,200	18,800	15,000
July 1–15	14,200	4,200	2,200	25,100	20,900	2,600
July 16–31	10,900	2,100	1,400	9,700	700	300
August 1–15	27,500	4,100	600	11,200	1,200	20
August 16–31	32,700	3,500	550	49,600	6,900	500

While the absolute population of the lake during the summer months has varied very greatly in the three years of my observation, the vertical distribution of the animals has been almost exactly the same, as may be seen from the following table:

TABLE XXX.—*Average percentile distribution of crustacea June 15–Sept. 15. (In 1894, July 7–Aug. 23.)*

Average No.	PER CENT. IN EACH 3 M. LEVEL.					
	0–3m.	3–6.	6–9.	9–12.	12–15.	15–18.
1894.......406,000	45.5	30.2	16.0	6.7	1.3	0.4
1895.......707,000	44.0	24.6	18.4	8.9	2.2	1.9
1896.....1,116,000	45.1	27.5	14.9	7.7	3.4	1.2

From this it appears that from 44 to 45.5 per cent. of the crustacea were present in the upper three meters of the lake from the middle of June to the middle of September, and from 25 to 30 per cent. more between 3 and 6 meters, from 15 to 18 between 6 and 9 meters, leaving from 8.5 to 13 per cent. for the lower half of the lake.

The percentile distribution of the crustacea during the summer and its relation to the thermocline are shown in Figs. 26 and 27. In each diagram the depth is computed above which were found in each half month, respectively 25, 50, 75, 90, and 95 per cent. of the crustacea, on the assumption that the crustacea in each of the 3m. levels were equally distributed through it. The points representing the depths for the corresponding percentages were platted on the diagram and then connected by lines. There is added in each diagram the position of the isotherm of 20° which lay in the thermocline in both years, although in 1896 the lake cooled below 20° before the thermocline disappeared. In Fig. 26, the temperature for each date was computed from the average of the week preceding and that following the date. The temperature-line of Fig. 27 is taken from Fig. 4.

The diagrams show that 25 per cent. of the crustacea are almost always found in the upper two meters of the lake. No doubt the position of this line would be higher if it had been

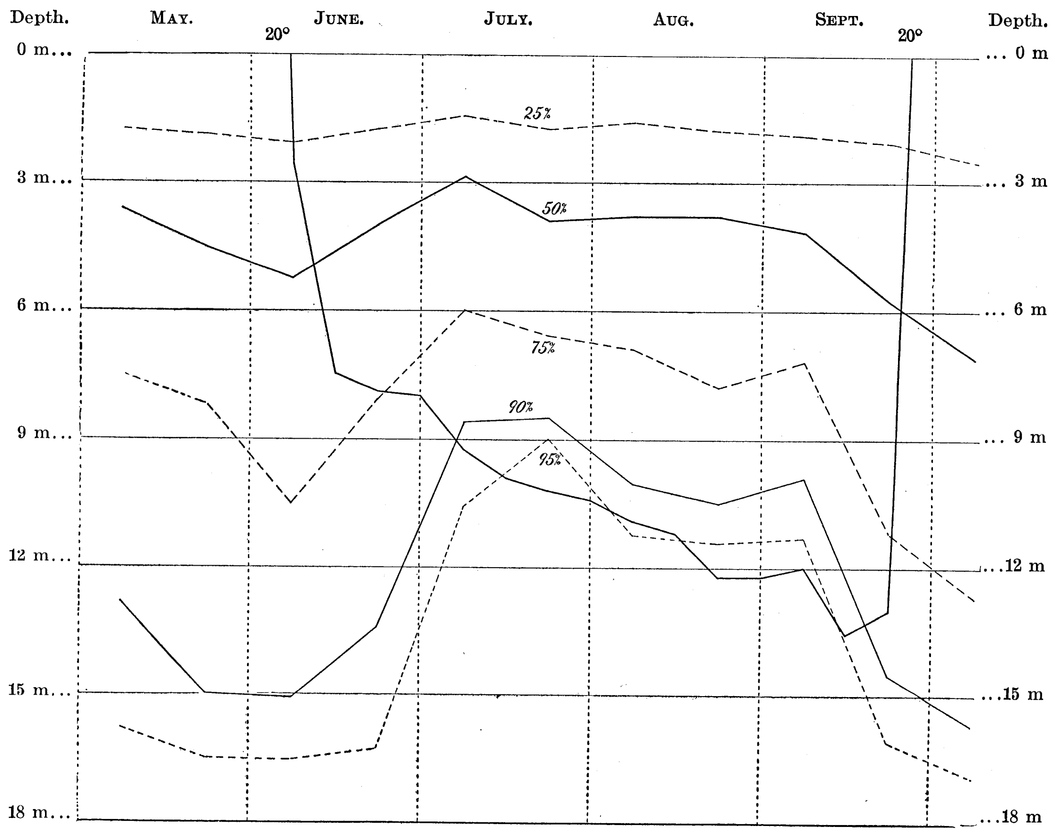


FIG. 26.—Percentile vertical distribution of crustacea, summer of 1895. See p. 384.

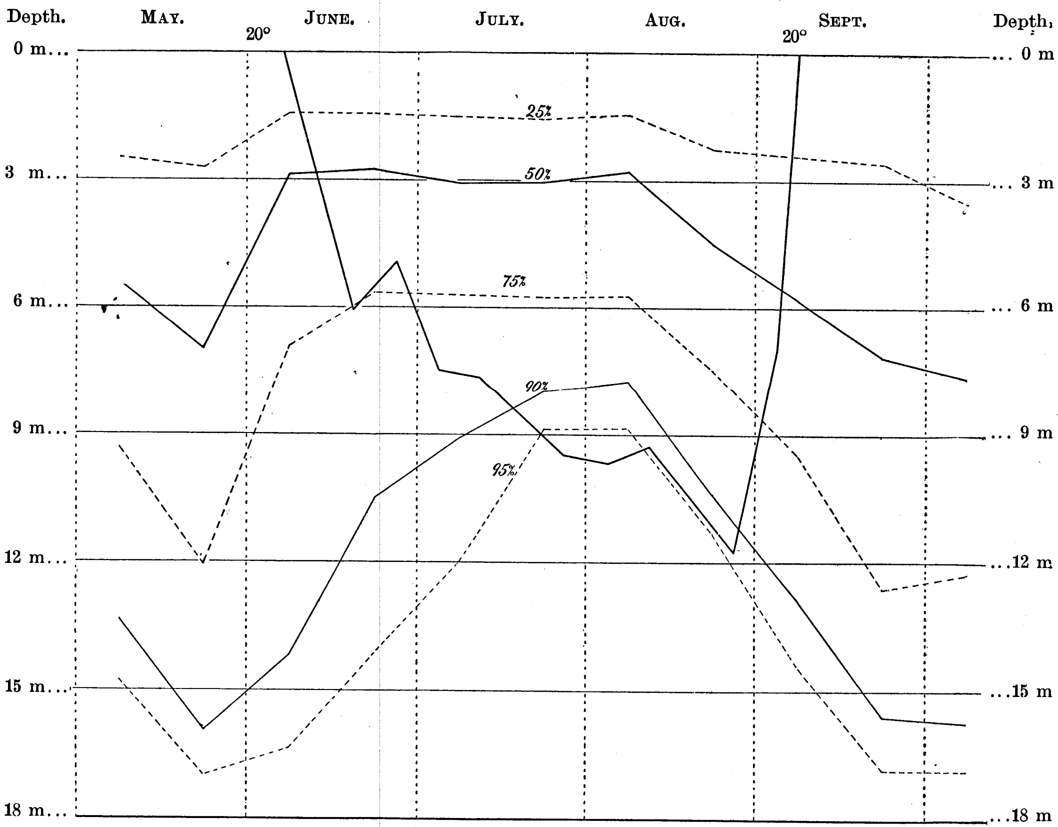


FIG. 27.—Percentile vertical distribution, summer of 1896. See p. 384.

possible to indicate the real concentration of the crustacea in the upper meter. During May the percentage lines all moved downward, owing to the downward movement of *Cyclops* during that month, as its numbers rose to their maximum. The movement extends into June, 1895; while in the early part of June, 1896, the center of population moved upward more than 3 meters, owing to the earlier death of the spring broods of *Cyclops* in that year. The center of population then remains close to the three meter line until the middle of August. In late June and early July of both years there is a rapid decrease of numbers in the lower levels of the lake. The 90 and 95 per cent. lines reach the level of the thermocline early in July, and they remain there through July, August, and early September, closely following the thermocline as it moves downward through the water. The center of population, which remains for some time near the 3 m. level, moves downward rapidly in September, and reaches a depth between 7 and 8 meters in October. If the crustacea were uniformly distributed throughout the lake it should lie at 9 meters. The 90 per cent. level was as high as 8 m. in July and August, 1896; and between 9 and 10. m in 1895, but moves downward to about 16 m. in October.

This practical exclusion of plant and animal life from the lower water during summer is a factor of great importance in the life of the lake, as the following considerations show: First, during this period the number of crustacea and the quantity of the plankton is independent of the depth of the water below the level which the thermocline has reached. Second, the exclusion from the lower water of species unfavorably affected by warmth prevents their appearance in the plankton or causes them to decline during the summer, while in the other lakes in which the deeper water is inhabitable their numbers may go on multiplying. This is pre-eminently true of *Daphnia pulicaria*, whose numbers are small in lake Mendota during the summer, while in many of the Oconomowoc lakes it is abundant during the same period and inhabits the entire depth of the lakes below the thermocline. The summer decline of *Cyclops brevispinosus* may also be due to the same cause. Third, the total number of the crustacea during the summer is far smaller than it would be if the deeper water could be utilized. It is not impossible also that one factor in determining the small number of the periodic species of crustacea in lake Mendota may be in the fact that the upper water is so completely occupied by the perennial forms as to leave little chance for the development of other species. Fourth, the crustacea are not excluded from the deeper water of the lake by the low temperature of the water, as is proved by the occurrence of the same species in the far colder water of other lakes in the same district. The exclusion is due to the accumulation of the products of decomposition in the lower water, which remains entirely stagnant after the thermocline has been formed and is never exposed to the action of sun and air. This water in lake Mendota acquires an offensive smell and a disagreeable taste, though in neither respect does it go as far as certain waters mentioned by the Massachusetts Board of Health (Drown, '90, p. 553.) It is always clear and bright to the eye.

The products of decomposition of the algae and crustacea of winter and spring remain stored in the deeper water, and undoubtedly the addition of this store of nutritive material to the water of the lake as the thermocline gradually moves downward is one of the factors which occasions the enormous increase of the vegetable plankton in the late summer and autumn.

Autumn—October, November, and December.

The summer conditions of distribution end with the breaking of the thermocline and the resulting establishment of the fall homothermous period. This occurs at different times in different years. The date depends on: First, The rapidity of cooling of the surface; Second, The summer temperature of the bottom; Third, The amount and direction of the winds, especially of gales. In 1895 and 1896, the "turn over" came in the last week of September; in 1894 the distribution of the crustacea shows that it did not come until the first week of October, and it was equally late in 1897. In the year 1894 no observations were made in the first half of September, but the distribution in the latter part of September of that year closely resembles that in the early part of the month in 1895, and in the latter part of August, 1896. The distribution in the first half of October, 1894, is not very different from that two or three weeks earlier in the preceding years.

The leading general feature of distribution during the late summer and autumn is the progressive occupation by the crustacea of the deeper strata of the lake as the thermocline moves downward through August and September, and the coincident rise in number of the crustacea toward the fall maximum. It is a fact which was wholly unexpected by me that the 0–3 m. level shows little or no increase in the number of its crustacea after the early summer maximum in early June or late July. In 1895 its numbers steadily declined, or at best were stationary, after July 15th. (See Figs. 22, 23.) In 1896 there was considerable variation in numbers, but on the whole there was no increase except a sharp temporary rise in late October, due to the occurrence of great swarms of young *Daphnia hyalina* at that time. In 1894 the numbers in the upper level rose in the autumn, as would be expected, since they were at an abnormally low level in July, owing to the peculiar condition of the vegetation of the lake in that year.

The crustacea between 3 and 9 meters show also the same relation in their summer and autumn numbers; while those below 9 meters show a great increase, beginning in the 9–12 m. level, as the thermocline moves downward through it in August. The increase steadily proceeds to the the lower levels of the lake. It is very rapid in September and early October, and continues until the storms of late October, when the population decreases in all levels of the water. This result is the sum from 5 to 7 species of crustacea, and of course it does not hold accurately for each species. It is also true that since the broods of young appear in the upper level, they may temporarily increase the number of a species there, but this excess of one species is balanced by a deficiency in another, and often for the single species the semi-monthly averages agree pretty well with the general law.

A good example of the effect of age upon distribution can be seen from the case of *Daphnia hyalina* in the latter part of October, 1896, when great numbers of young appeared on several occasions, and when the old animals were nearly all full grown, so that there were very few half developed individuals. This is given on p. 398.

During November and December the population of the lake falls off pretty uniformly in all levels, more rapidly in November than later, and at this time the distribution of the animals may be more even than at any other period. If *Daphnia pulicaria* is present it rises toward the surface in December and increases the population of the upper strata. This occurred in 1895. In all years the distribution in November is more uniform than that of December, in which month the population of the lower levels of the lake seem to decline more rapidly than that of the upper stratum.

TABLE XXXI.—*Average percentile distribution Oct. 1—Dec. 31.*

	Average No.	PER CENT. IN EACH 3 M. LEVEL.					
		0-3 m.	3-6.	6-9.	9-12.	12-15.	15-18.
1894	595,000	25.8	18.8	16.0	15.7	14.0	9.8
1895	436,000	29.7	18.3	14.3	14.9	12.2	10.6
1896...............	759,000	25.9	21.0	15.3	13.9	12.4	11.4

Figures 22 and 23 represent the total population of each of the 6 levels into which the lake was divided. The scale is 100,000 crustacea to each vertical interval. If the scale be divided by 3 the same diagrams will serve to show the population of each level per cubic meter. The relations of the increase and decrease of the population in the several levels are shown very plainly from these diagrams. For instance in 1895 it will be seen that while the two upper levels began to increase during the latter part of April, the population of the lower levels scarcely changed from the winter condition until about the first of May. The population of the three upper levels reached its maximum in the latter part of May, while in the lower part of the lake the population went on increasing, or at least remained stationary, until near the middle of June. The 6–9 m. level hardly shared in the rise to the early summer maximum until two weeks after the 0–3 m. level, while in the lower part of the lake the population declined, or remained stationary throughout July. In August the crustacea of the 9–12 m. level increased in number as the thermocline moved downward into that level, while no increase was perceptible in the population of the lake below 12 m. until after the middle of September; after which date the numbers rapidly increased.

No increase of population was seen in the upper levels of the lake after the month of July; and if this diagram is compared with Fig. 6 which shows the changes in the total population of the lake, it will be seen that the autumnal maximum, which is clearly indicated, comes entirely from the increase of population in the lower water of the lake.

The same general facts appear in the diagram for 1896, but, if possible, in a form even more striking. The 0–3 m. and 3–6 m. levels follow each other closely, while the spring increase in population comes later in the lower levels of the lake. In the 9–12 m. level the population remains stationary during May, when that of the upper levels is rapidly falling, and at the same time the crustacea in the water below 12 m. are increasing in number; more rapidly in proportion to increased depth. In the 0–3 m. level at the first of June the population was substantially stationary, while that in the water below was falling rapidly. This condition was brought about by the new broods of *Chydorus*, which nearly made up for the loss in numbers of other species.

In 1896 the thermocline moved downward much more rapidly than in the preceding year and as a result of this movement, the crustacea in the lower water began to increase in numbers at an earlier date. (See Figs. 3, 4, 26, 27.) A marked increase occurs in August in the 9–12 m. level and begins about two weeks later in the levels below. As in 1895, so also in 1896, the fall maximum is caused by the increase in the population of the lower water, with the exception that in late October of 1896 there was a great increase in the number of the crustacea in the 0–3 m. level, due to the appearance of great broods of *D. hyalina* at this time. These soon disappeared, so that the crustacea in this level fell off in number even more rapidly than they had increased — so rapidly, indeed, that no effect was produced by these broods upon the population of the water below 3 m., except perhaps to check in some degree the rate of decrease toward the winter minimum. There was also a small rise in December in the 0–3 m. level, caused by the increase of *D. pulicaria*.

It would seem from these facts that there is a maximum population per cubic meter beyond which the crustacea are unable to multiply and which differs in different seasons. It is difficult to see what it is that sets a limit to this population in the autumn. At this time the food is in enormous abundance as compared with the number of the crustacea, and it would be expected that the numbers in all levels of the lake would increase together. I am quite unable to give a reason for their failure to do so, but the fact recurred exactly in all three years of my observations, making allowance for the peculiar conditions in the early summer of 1894.

Fig. 28 represents the average percentile vertical distribution of the crustacea for Oct. 1–15, 1896, March 1–15, 1895, August 1–15, 1896. The corresponding figures are given in Table C, appendix. In the diagram each horizontal space represents 10 per cent. of the crustacea and each vertical space, 3 m. On each 3 m. line is platted the percentage of crustacea found below it, and these points are connected by a line which extends from 100 per cent. at the surface to 0 at the bottom. From the intersection of these curves with the vertical lines can be seen approximately the percentage of the crustacea above and below the depth indicated at the intersection. If the distribution were uniform there would be 16.6 per cent. in each vertical space and the percentile distribution would be marked by a straight line running from corner to corner of the diagram. The curve for October approximates very closely to this, the percentage being larger in the surface stratum and somewhat smaller below 12 m., but, in general, the line lies very closely parallel to the diagonal. The distribution for March is almost equally uniform, but here the bottom level has an excess, due to *Cyclops*, and the 0–3 m. level is slightly below the average.

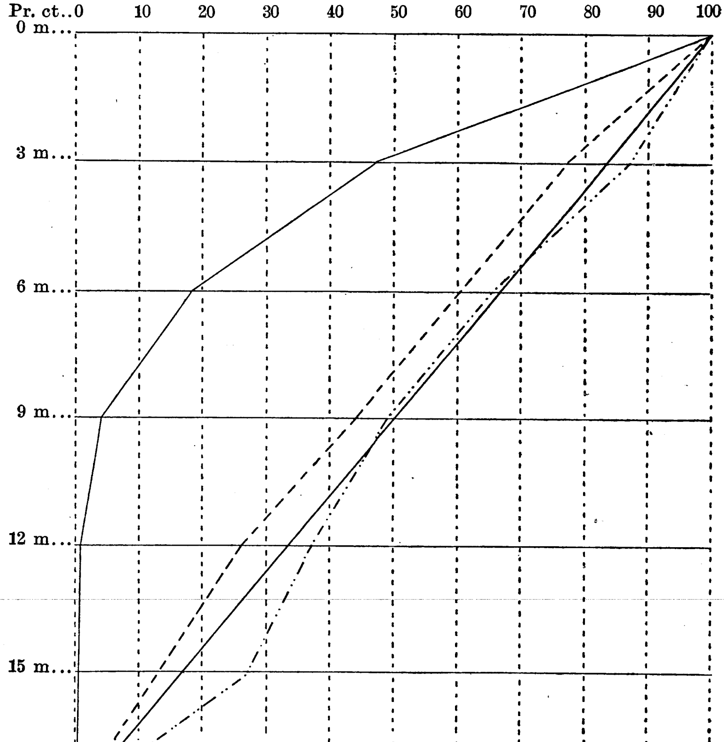
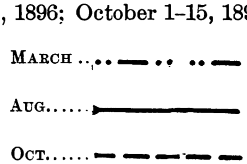


FIG. 28.—Percentile vertical distribution of crustacea, March 1–15, 1895; August 1–15, 1896; October 1–15, 1896. See p. 390.



In October the distribution of all of the species of crustacea is approximately equal. In the winter the equality of distribution is brought about by the excess of *Daphnia* and *Diaptomus* in the upper strata, nearly balancing the excess of *Cyclops* near the bottom. (See Fig. 30.) The curve for August shows a very large percentage in the upper 3 meters and a very small number in the lower water. It is a characteristic distribution for middle summer.

THE VERTICAL DISTRIBUTION OF THE INDIVIDUAL SPECIES.

After this full discussion of the vertical distribution of the total crustacean population I do not intend to describe that of the individual species in similar detail, but I shall confine myself to pointing out the individual peculiarities of each species, devoting more space to those which depart in a marked way from the average vertical distribution. One general law holds for nearly all the species, as already stated: the broods of young appear first in the upper water of the lake and the increase of population extends downward, becoming approximately uniform at all depths as the species reaches its maximum, and later in its life becoming more numerous in the deeper water of the lake. To the first part of this rule the only exception is *Daphnia pulicaria* during summer. There are, however, several factors which prevent the full carrying out of the latter part of the rule. The most important of these is the formation of the thermocline, by which all of the crustacean life is confined to the upper waters of the lake during that period when the development of several species is going on actively. In the late autumn also the numbers of the crustacea decline so rapidly after the fall broods appear that it is not easy to find any accumulation at any low level of the lake. The downward movement of the older forms is shown most clearly by *Cyclops* and *Daphnia hyalina* during the spring, and by the accumulation of *Cyclops* in the deeper water of the lake during the winter, by the disappearance of *D. hyalina* and *D. retrocurva* in autumn. Similar, though less striking, illustrations can be found in all of the species of limnetic crustacea.

Each species of crustacea, also, has individual peculiarities of distribution, which recur from year to year with surprising similarity and which are independent of the absolute number present. These peculiarities appear when the average of any species is taken, although of course it is entirely possible that the distribution should depart widely from this average at any single observation. In general it may be said that the summer distribution of the crustacea follows very closely the figures which are given in my former paper (Birge, '95), and that the variations in the distribution which have been found during the two years and a half succeeding the observations reported in that paper, have been of the same type and in general of the same degree as those which were found during the single month of our first study. It seems to me, therefore, unnecessary to point out again these variations in detail for each species.

In order to show the resemblances and differences in the percentile distribution of the crustacea during the summer months, when their numbers are great and the distribution is most characteristic, I have averaged this distribution for the summers of three years: 1894, 1895, 1896. I have included the three standard representatives of the limnetic crustacea which are regularly present in full numbers during this time; *Diaptomus, Cyclops, D. hyalina.* The period included is from the middle of June to the middle of September, in 1895 and 1896; and July and August of 1894. It will be remembered that no observations were taken in 1894 before July or during the first part of September, but as the summer conditions were thoroughly established at the first of July of that year and continued until the first of October no noteworthy difference would appear in the averages had it been possible to extend the period. It will be seen from these averages that the distribution of *Cyclops* in the three years in question varies surprisingly little; the percentile difference in the 0–3 m. level being less than 1.5. This close correspondence in distribution exists in spite of the fact that the numbers of the genus were very different in the three years. The same general agreement is seen in the tables of semi-monthly distribution. Compare July, 1894 and 1896 in Table C, Appendix.

TABLE XXXII—*Percentile distribution. Summer—Diaptomus.*

	Average No.	PER CENT. IN EACH 3 M. LEVEL.					
		0-3 m.	3-6	6-9	9-12	12-15	15-18
1894	226,000	49.2	29.3	16.6	4.1	0.5	0.3
1895	172,000	42.7	29.0	20.9	6.1	0.7	0.6
1896	188,000	52.6	27 4	12.4	5.9	1.9	0.5
			Cyclops.				
1894	138,000	40.7	28.4	20.1	9.4	1.7	0.3
1895	183,000	39.3	25.2	19.0	10.0	3.1	3.4
1896	290,000	40.2	27.1	15.6	10.1	4.8	2.3
			Daphnia hyalina.				
1894	27,000	41.9	23.8	21.4	6.7	1.0	0.3
1895	210,000	52.3	20.8	17.6	6.6	1.3	1.2
1896	145,000	44.7	22.2	16.1	11.7	4.7	1.3

The variations in the distribution of *Diaptomus* are greater, although its numbers were more nearly constant, but in each year the same characteristics are shown. The percentage of the population found below the middle of the lake is 7.5 or less, while in the case of *Cyclops* the number ranges from 11.5 to more than 17 per cent. *Daphnia hyalina* also varies more in the upper strata, but is in general intermediate in its distribution between the other two genera. The older individuals of *Daphnia hyalina* are much more apt to accumulate in the lower part of the water accessible to them than is the case with *Diaptomus*, and consequently the lower levels are apt to contain a larger percentage of this species. On the other hand the species does not extend to the thermocline in numbers anything like as great proportionately as does *Cyclops*, so that the lower part of the inhabited water always contains a larger proportion of *Cyclops* than of any other species.

The vertical distribution of *Daphnia hyalina*, therefore, differs very considerably in different years. If the species is present in large numbers and the young are constantly appearing, a very large percentage of the population is found in the upper level of the lake and even in the upper meter. This was the case during the summer of 1895, when this species was the dominant member of the limnetic crustacea throughout the entire summer. Under these circumstances its vertical distribution approximates very closely to that of *Diaptomus*. On the other hand, if the species is declining and the young appear in small numbers, there is a much larger proportion of the species in the lower levels of the lake. This was the case in 1896. In August of that year the numbers of *Daphnia* rapidly declined, so that in the latter part of the month there were present less than half as many as in the latter part of July, and in connection with this decline the population of the three upper levels was nearly equal. In this year the vertical distribution of *Daphnia hyalina* approximated very closely to that of *Cyclops*.

The vertical distribution of *D. hyalina* illustrates very strikingly the dependence of distribution on specific habit rather than on number.

The illustration given in my former paper (Birge, '95, plate VIII) fairly illustrates the characteristic differences in the summer distribution of the different genera, and the percentage diagram, Fig. 29, given herewith indicates the difference in distribution during the summer of 1896.

Diaptomus Oregonensis Lillj.

Figure 29.—Table D, Appendix.

In general *Diaptomus* is more abundant in the upper strata of the lake than in the lower at all seasons of the year. There is rarely less than 70 per cent. of the species in the upper half of the lake even in the winter, and the only times when the average distribution approaches equality are in late fall and at the period of the minimum numbers of the species in the latter part of April, or early in May. The other extreme of distribution is reached when the new broods appear and as their appearance is somewhat irregular the distribution is correspondingly variable. The maximum average number in the 0–3 m. level was reached in the latter half of May, 1895, where the average

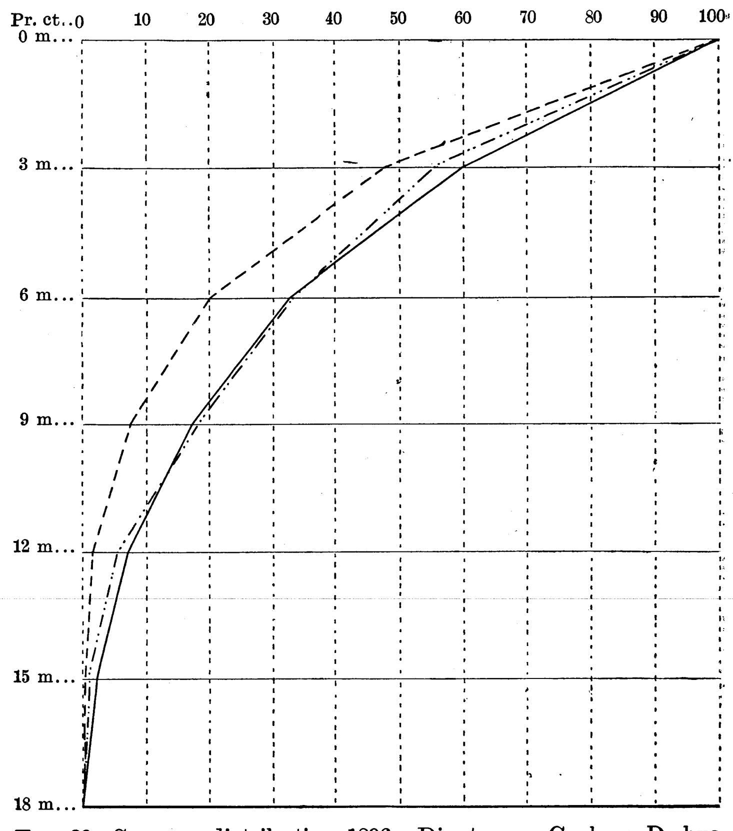
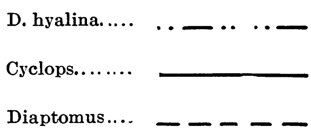


FIG. 29—Summer distribution, 1896. Diaptomus, Cyclops, D. hyalina. See p. 394.



was 61.5 per cent.; and in June, 1896, where the average for the whole month was 69 per cent. Each of these numbers is higher than the average for July, 1894, which was less than 53 per cent., and higher than the highest average per cent. for any period of July, 1894, which was 63 per cent. in the second period. The variations which are found in the percentile distribution are substantially like those which are recorded in my former paper. (Birge, '95, p. 455.) In no case do the older individuals of this species show a tendency to accumulate in the deeper water of the lake but as the broods which appear in the spring, or later, become older and the water becomes more crowded, they migrate progressively into the deeper levels, but appear to prefer to stay near the surface.

Marsh ('97, p. 194) finds that the vertical distribution of *Diaptomus* in Green lake is uniform throughout the year. This is entirely different from the facts as I find them, since the upper three meters in summer contain more than twice as many of the species as they do in winter. Apstein ('96, p. 80) finds that *Diaptomus* was chiefly in the deep water from January to April. Here again his observations differ from mine, since there was hardly a trace of a descent of the species in lake Mendota. Apstein thinks that this descent in winter on the part of *Diaptomus* and *Cyclops* may be due to their desire to seek the warmer water at the bottom of the lake. This motive cannot hold in the case of lake Mendota, where the temperature of the water is almost the same at all depths during the winter. The aggregations of *Cyclops* in the deeper water are apparently composed of feeble individuals, which do not rise again to the surface.

Cyclops.

Figures 29, 30.—Table E, Appendix.

Of all the limnetic crustacea *Cyclops* seems to be most independent of external influences in its vertical distribution. The maximum percentage in the upper levels is reached when the spring or summer broods appear. While the absolute numbers of these broods in the spring are much greater than in summer, multiplication goes on so rapidly in May that the animals are quickly forced to move toward the deeper water of the lake, and, since the entire lake is accessible to them in spring, there rarely occurs as great a percentage in the upper stratum as is the case in summer. The highest average per cent. in the 0–3 m. level, reached in the spring of 1895, was 42.7 in the first part of May; and 35 per cent. was the average in the latter part of April, 1896. In July of each year the percentage in the upper stratum rose to about 50, owing to the coincidence of swarms of young in the upper water while the lower strata contained a very scanty population. The fall rise in numbers does not cause any noteworthy increase in the percentage in the upper strata, since at this time the entire lake is accessible to the animals and food is abundant at all levels, and the autumnal gales aid to distribute the species through the lake.

In the winter there is a strong tendency of *Cyclops* toward the bottom and as many as 50 per cent. may be found in the lower three meters, and as many as 70 per cent. in the lower six meters of the lake. Illustrations are given on page 379. Since many of the older representatives of the species die during the winter and the new individuals appear towards spring in the upper water, the population of the lower levels decreases in the early spring, both absolutely and relatively. Diagram 30 shows the percentile distribution of *Cyclops* in the first part of March, 1895, and in the latter part of July of the same year, in which the extremes of its distribution were found.

The spring broods of *Cyclops* show exceedingly well the progressive occupation of the water of the lake by the increasing numbers of the species; the way in which the numbers of a declining species disappear first from the upper waters of the lake, where they first appeared; and the equality of distribution during the decline. The following table shows the spring history of *Cyclops* during 1896. The story for 1895 would be substantially the same.

TABLE XXXIII.—*Cyclops, 1896. Number per cubic meter stated in thousands.*

Depth, meters.	0-3.	3-6.	6-9.	9-12.	12-15.	15-18.
April 1-15	17.2	11.7	18.9	20.3	12.8	15.0
April 16-30	109.4	84.1	52.5	28.8	18.8	9.6
May 1-15	190.2	124.9	117.4	84.5	52.9	42.7
May 16-31	37.0	37.3	34.3	35.2	42.1	64.8
June 1-15	20.5	13.7	7.6	6.7	5.7	14.1
June 16-30	59.2	32.4	17.9	13.4	6.7	9.5

Marsh ('97, p. 204) finds that *Cyclops fluviatilis* is present in great numbers near the surface. Its distribution, therefore, agrees more nearly with that of *Diaptomus* than it does with *C. brevispinosus.* The latter species is present in Green lake in very small numbers apparently in and below the thermocline in summer.

Daphnia hyalina.

Figure 29.—Table F, Appendix.

There are two facts which give the peculiarities of vertical distribution of *Daphnia hyalina* and the allied species *D. retrocurva.* These are: First, a decided tendency of the young animals to accumulate in the superficial strata of the water, frequently in the upper meter. Second, a tendency on the part of the older animals to settle toward the bottom. These species, therefore, show a very high percentage in the upper levels of the lake in periods when they are increasing, and especially at those times when the broods of young appear. On the other hand, when the species is declining in numbers, and in the intervals between the appearance of broods, the distribution may be comparatively equal throughout that part of the lake inhabited by the species. As examples, compare the table on page 398, and the detailed figures of Table F, Appendix.

The percentage in the upper level rarely falls below 25, even in the winter. In May, when the spring broods appear, the average number in the 0–3m. level ranges from 45 to 55 per cent., and the same ratio is found during the summer when the species is increasing in numbers. On the other hand, when the species declines in numbers, as it sometimes does in August, the percentage in the lower levels may be nearly, or quite, as great as in the 0–3 m. level. (See August, 1896.) At the time of the fall maximum great numbers of young often appear at once. At this time the brood sacs of the females contain from five to nine eggs. There are very few half-grown animals, and the eggs may all hatch in the course of a week. At such a time it is not difficult to determine the difference in distribution of the young and old, and the following tables show these relations in the latter part of October, 1896:

TABLE XXXIV.—*Daphnia hyalina, per cubic meter.*

Depth.	October 26, Noon.		October 27, 8 A. M.	
	Young.	Adult.	Young.	Adult.
0-3m.	122,200	0	30,400	1,200
3-6	27,500	250	13,300	760
6-9	15,800	380	1,900	6,300
9-12	1,600	4,100	2,500	3,800
12-15	0	2,500	2,500	8,900
15-18	....	950	1,300	19,000

After the production of the young in late October or early November, the old females die off rapidly; some few remaining as late as the first of January. In the latter part of May, or the early part of June, according to the progress of the season, those individuals that have lived over winter become weak, are attacked by various diseases, caused by fungi, bacteria, and microsporidia, settle toward the bottom of the lake and die. This downward movement of the older and weaker individuals causes an increase of the number in the lower part of the lake, which was quite conspicuous in June, 1895, and in the latter part of May, 1896.

Shortly after this date the crustacea begin to disappear entirely from the lower water, and during the remainder of the summer the life of the species goes on, like that of the other crustacea, in the region above the thermocline.

The vertical distribution of this species does not appear to have been carefully studied by other authors.

Daphnia pulicaria.

Figures 30–32.—Table G, Appendix.

The vertical distribution of this species is so peculiar that it demands a somewhat more detailed account than has been given to the other species. The history of the species begins ordinarily in the early part of July of the odd numbered years. During the first part of July it has been present only in very small numbers, but in the second part of July, 1895, its numbers were so large that it appears in the lists. At that time more than 50 per cent. of the species was found between 6 and 9 meters, in the region of the thermocline, and nearly all of the remainder was found between 9 and 15 meters. In August the species moved downward, following the downward movement of the thermocline, and continued in this position until the coming on of the autumnal homothermous period in late September and October. During October the species was distributed with approximate uniformity through the water of the lake. In November, as the lake cooled, the animals began to move toward the surface, and in late November and December a period of active reproduction began. The young animals were found in the upper level of the lake, most numerously in the upper meter, and as the result of this distribution, the numbers in the upper level were far greater than those in any other portion of the lake. This relation continued throughout the winter of 1895–96, during which time reproduction also continued, although more slowly, until in March and the early part of April reproduction nearly ceased and the numbers of the species declined somewhat rapidly. At this time the distribution was uniform, or such irregularities as were present seemed to be accidental. In the latter part of April the spring period of reproduction began and an enormous number of young were produced in the upper water. At this time as many as 80–85 per cent. of the species were found in the upper level; a larger proportion than has been found there of any other species except *Chydorus*. In the early part of May a reproductive pause occurred, during which the animals were pretty evenly distributed through the water;

the largest number being found in the bottom stratum. A second reproductive period came on in the latter part of May, in which the upper water was again crowded, although the numbers increased so rapidly that the population of all the upper levels of the lake was greatly increased. During the early part of June the distribution became once more equal, with the largest number again in the bottom level, and during the latter part of the month the population rapidly declined, falling off most in the upper levels. At this time more than 60 per cent. of the species was found below the 12 m. level and less than 2 per cent. in the upper level.

Late in June the species began to move away from the bottom water, or perhaps it would be more correct to say that the individuals at the bottom of the lake died off more rapidly than those in the levels immediately above, so that in the early part of July nearly 60 per cent. of the species was between 12 and 15 meters and only 6.5 between 15 and 18 meters. As the species declined in numbers the decline took place chiefly in the lower levels of the lake, so that in July and August the few representatives of the species that were left were concentrated in the region of the thermocline, thus occupying the same position that they had held in the corresponding months of the preceding year. The following table shows the numerical relations.

TABLE XXXV.—*D. pulicaria, 1896. Population per cu. m. of each level stated in thousands.*

Depth, meter.	0-3	3-6	6-9	9-12	12-15	15-18
April 1-15.	1.0	1.5	3.2	2.5	1.3	0.6
April 16-30	41.6	5.2	0.4	0.7	0.9	0.2
May 1-15..	10.4	12.8	15.5	9.2	13.3	17.8
May 16-31.....	55.4	33.7	37.4	28.8	19.8	23.4
June 1-15.........	10.3	5.9	8.8	12.5	5.9	10.9
June 16-30........	0.4	1.5	2.8	3.7	10.9	4.4
July 1-15	....	0.1	1.1	3.5	7.3	0.8
July 16-31.	....	....	3.2	1.7	0.1	0.1

Fig. 31 shows the movement of *D. pulicaria* during the late summer and autumn of 1895. Points were established indicat-

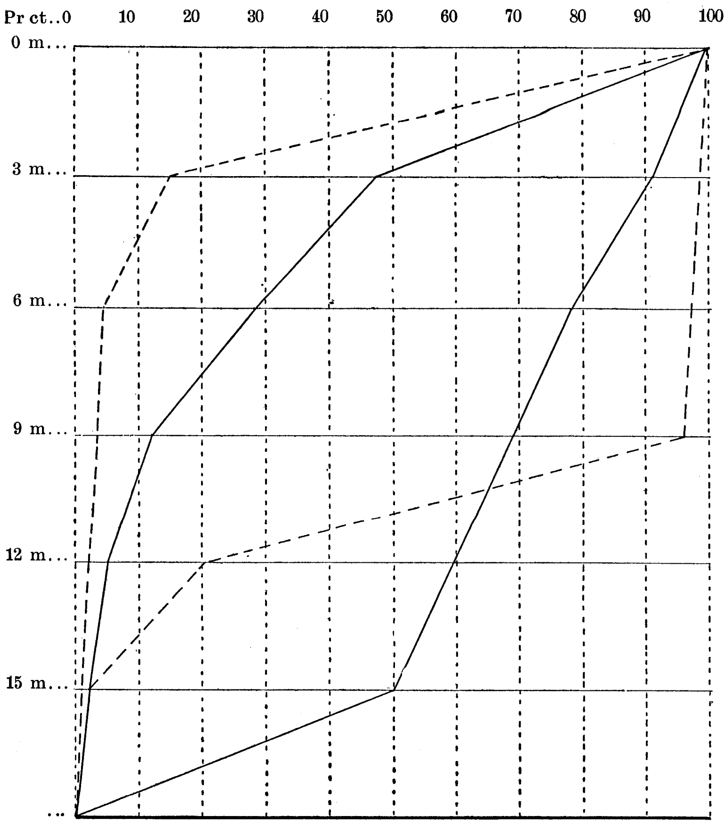


FIG. 30.—Cyclops, March and July, 1896; D. pulicaria, August, 1895, and April, 1896. See pp. 396, 399.

Cyclops..... ————

D. pulicaria — — — —

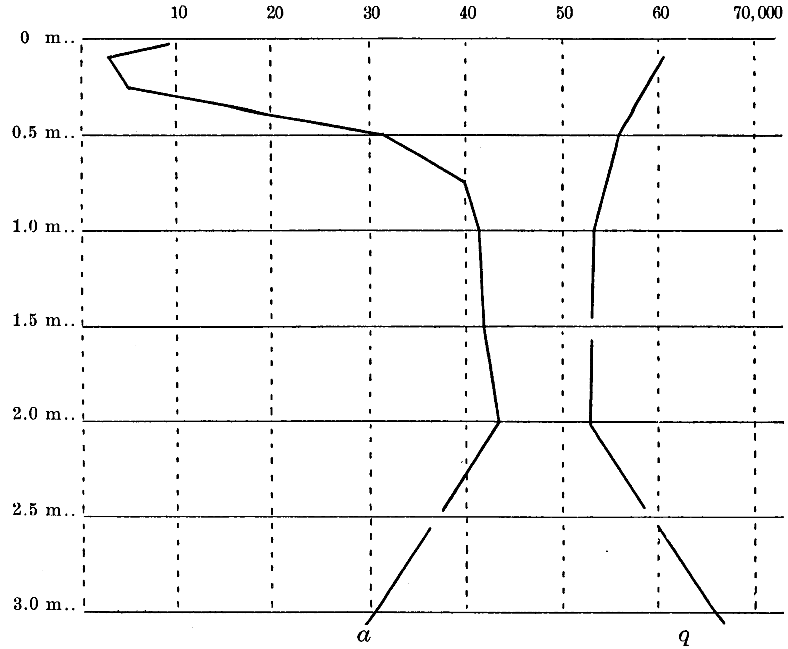


FIG. 31.—Distribution of crustacea, 0-3 m., Sept. 13, 1896, 2 p. m. (*a*), and 9 p. m. (*b*). Scale, 1 horizontal space = 10,000 crustacea per cu. m. The lines are interrupted at levels where no observation was made. See p. 413.

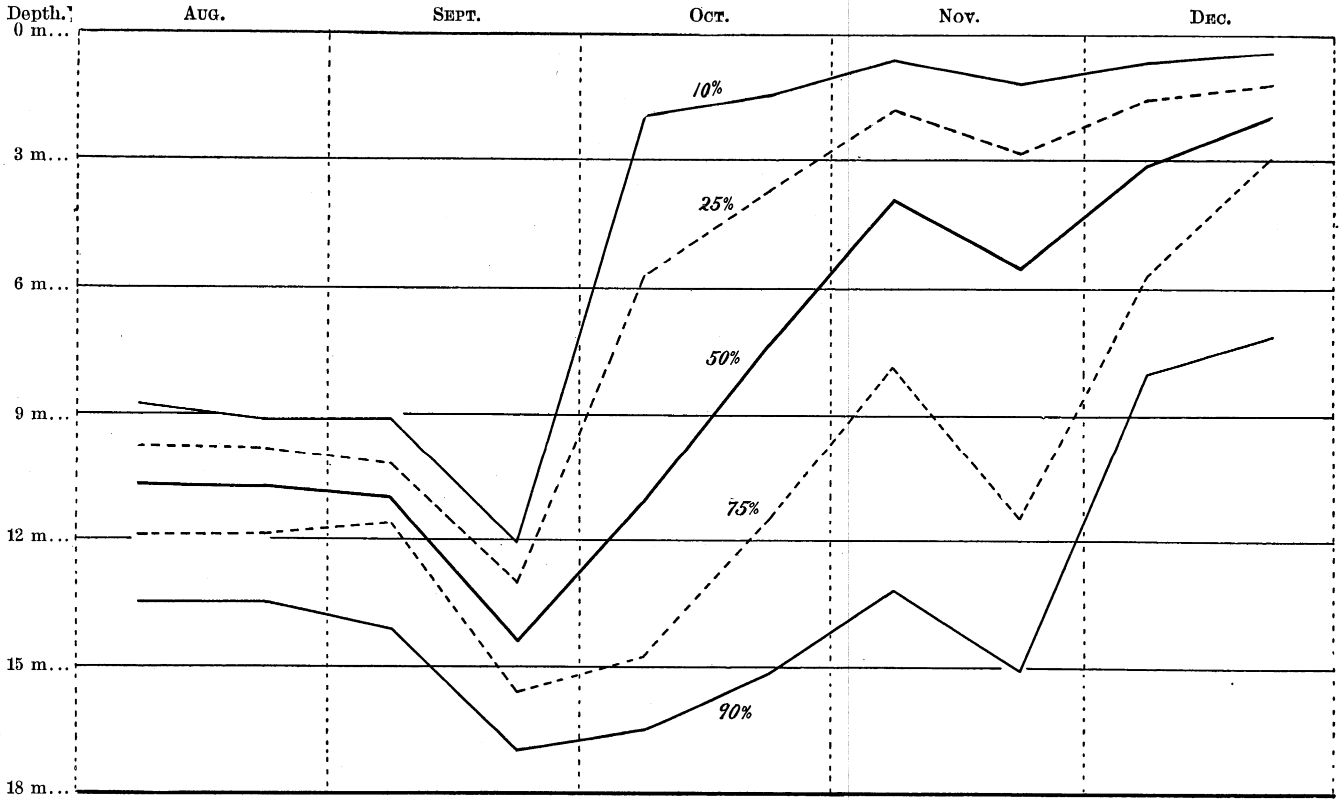


FIG. 32.—Percentile vertical distribution of D. pulicaria, August-December, 1895. See p. 401.

ing the level below which the respective percentages of the species were found and these were connected by lines. The distribution is based on assumption that the individuals of the species were uniformly distributed throughout the 3 m. level in which they were found. This assumption is peculiarly incorrect for *D. pulicaria,* since the species is limited to the region of the thermocline. It is often confined within a space of 1 meter, or even less, yet it often passes beyond these narrow limits, as is indicated by the fact that not inconsiderable numbers may be found in two or even three levels. While, therefore, the diagram spreads out the distribution of the species during the summer more than is correct, the general relations are well enough indicated by its lines. It will be seen that in the latter part of August more than 65 per cent. of the species was found between 9 and 12 meters and that the species moved downward during September as the thermocline moved down. In October, after the breaking up of the thermocline, the distribution was much more nearly equal. The center of population rose rapidly and regularly from the latter part of September to the middle of November, lying near 14 meters in late September and at 4 meters in the first part of November. After a small fluctuation in the latter part of November, it rose once more, and in the latter part of December lay about two meters below the surface, where it remained during the early part of the winter, until the decline in numbers came on in March or April. If this diagram were reversed it would serve fairly well to indicate the downward migration of the species in the spring.

In Fig. 30 are given curves for the percentile distribution of *D. pulicaria* for April 16–30, 1896, and August 16–31, 1895, showing the extreme variation of its average distribution. The diagram is similar to that described on p. 384.

I have not found any other case recorded of a *Daphnia* which in summer remains at or below the thermocline. At least one other species of the genus has the same habit in this region. A form which I have identified as *D. longiremis* Sars, belonging to the *cristata* group, is regularly confined to the region below the thermocline in some of the lakes of the Oconomowoc system and in lake Geneva.

Daphnia retrocurva Forbes.

Table H, Appendix.

This species belongs to the periodic crustacea and is present in the lake from July to December. Its numbers during July are small and the proper history of the species does not begin until the latter part of this month, or the early part of August. In 1896, indeed, the numbers were very small until the decline of *D. hyalina* in the middle and latter part of August gave an opportunity for the presence of this species.

In vertical distribution this species agrees very closely with *D. hyalina*, as would be expected. In the early part of periods of increase, from 45 to 60 per cent. may be found in the upper level. This was the case in the latter part of July, 1895. It was also true in late September and early October, 1896, although the crustacea moved rapidly downward so that the two-week averages do not disclose the fact. In the old age of the broods, as the numbers are declining, they are found chiefly in the lower water of the lake. This was especially obvious in late November and in December, 1895, when the species disappeared quite slowly and lingered latest in the lower waters of the lake. In 1896 the formation of the ephippia was nearly simultaneous on the part of all of the females and the species disappeared rapidly and completely in the early part of November, so that this phenomenon of the old individuals lingering in the lower water did not appear.

Marsh (97, p. 210) finds the distribution of *Daphnia Kahlbergiensis* in Green lake very similar to that of *D. retrocurva* in Mendota. He finds, however, a marked difference between the vertical distribution by day and night, which I have not seen. The fact, however, that *D. retrocurva* descends to a somewhat greater depth during the day than does *D. hyalina* seems to indicate a greater sensitiveness to light than that of its congener, although this sensitiveness does not lead to as great movements as Marsh's observations would indicate for Green lake.

Diaphanosoma brachyurum Sars.

Table I, Appendix.

This species belongs to the periodic crustacea, its active development extending from the first of August to the middle of October. It is provided with very large antennæ and is one of the most powerful swimmers among the limnetic crustacea. It is also positive in its relations to light. In both these respects it resembles *Diaptomus* and its vertical distribution very closely agrees with that of the latter genus, although its numbers are very much smaller. In the early history of the species 50 to 70 per cent. of the whole number are found in the upper stratum of the lake. The distribution becomes more equal during the decline of the species and at no time is there found any aggregation of individuals in the lower waters of the lake. The distribution of the small numbers present in the decline of the species is, however, quite irregular and the number in the upper part of the lake becomes smaller than that in the lower water.

Marsh ('97, p. 216) suggests that the vertical distribution of *Diaphanosoma* is controlled by light rather than temperature. He finds it negative to light and thinks that it prefers cool water. In the laboratory *Diaphanosoma* moves toward the light along with *Diaptomus*, so that my observations would indicate that it is positive in its relations to light. I find also uniformly a larger percentage of adult animals in the upper meter by day than I find of the species of *Daphnia*. There is, therefore, nothing in my observations to confirm the idea that the species is negative in its relations to light. Since, however, the absence of crustacea from the upper centimeters of the lake when the light is most intense, indicates a certain negative relation on the part of nearly all forms, it may well be that this species finds the light in the clear water of Green lake too strong, and responds to it more definitely than in lake Mendota.

Chydorus sphaericus.

Table J, Appendix.

This species belongs properly to the littoral crustacea and its presence in the limnetic region depends apparently on the presence in abundance of *Anabaena* and allied forms. Since these plants tend to aggregate in the upper water of the lake, *Chydorus* shows an equal tendency in the same direction and the percentage of this species which may be found in the upper levels exceeds that of any other of the limnetic crustacea. It is true, however, for this species, as for all others, that the largest numbers are found in the upper level at the time when the numbers are rapidly increasing, and that when the numbers are declining the distribution may be more equal, or may vary in an accidental fashion. During the periods of rapid increase from 50–80 per cent. of the individuals are found in the 0–3 m. level. These high percentages have been reached in September, 1894, July, 1895, and June and August, 1896.

In October and later the species becomes quite equally distributed through the water, but it showed no marked tendency to aggregate in the lower water at times when it is declining, until the numbers became very small in late winter, 1896. It is very abundant during the day in the upper meter and, like *Cyclops*, is one of the last forms to disappear at the thermocline.

The fact that *Chydorus* is relatively very abundant near the surface is noted by Apstein ('96, p. 80).

Leptodora.

The number of *Leptodora* caught is so small and so variable that it is difficult to give any positive general conclusions regarding its vertical distribution. The following table shows the average distribution for the months of July, August, and September, 1895, with which that of 1896 closely agrees.

TABLE XXVI.

1895.	Total Number taken.	PER CENT. IN EACH 3M. LEVEL.					
		0-3m.	3-6.	6-9.	9-12.	12-15.	15-18.
July	285	33.3	34.4	24.6	7.4	0.3	0.0
August	680	41.0	28.8	19.5	8.5	1.9	0.2
September	156	34.0	28.2	17.3	9.6	9.6	1.3

This table shows that the average agrees very closely with that of the other limnetic crustacea. During this season a considerable number of observations were made after nightfall, but neither in 1894, nor in this year was there any evidence of a movement of *Leptodora* toward the surface at night, as measured by the three meter intervals. The species is nearly, or quite absent from the upper meter or so during the day, but comes to the surface again with the other crustacea after nightfall.

In August, 1895, the number caught in the 0–3 m. level, ranged from 1 to 43 individuals; in the 3–6 m. level, from 1 to 33; and in the 6–9 m. level, from 0 to 46. Below this level, of course, few, or no individuals were obtained. With this range of variation, the percentages might easily be altered greatly by a single observation.

Nauplii.

Figure 33.

The vertical distribution of the nauplii has been very variable, as may be seen from the following facts: On July 17th 50 per cent. of the very large number taken were caught between 6 and 9 meters and only 7 per cent. in the 0–3 meter level. On the 18th the distribution was substantially the same, while on the 20th 38 per cent. were found between 0 and 3 meters, and 31.5 per cent. between 6 and 9, and on the 21st 49 per cent. were found in the upper level and only 19 per cent. between 6 and 9 meters. On the 5th of August 90 per cent. were found between 6 and 12 meters, and on the 8th 23 per cent. between 9 and 10 meters, and 50 per cent. between 6 and 10.

These observations were all made in the day and under substantially similar conditions of weather and temperature. During August and September, 1897, numerous observations were made by means of net and pump and in nearly all cases the great majority of the nauplii were found in the lower part of the inhabited water, although a considerable number was also found in the surface levels. On the 13th of September a very large number of nauplii were found in the upper half meter, by far the largest number being found at the surface itself. (See Table XXXVIII, J.) The number very rapidly declined from the surface, reaching a minimum at about 1 meter. They began to increase again at about 5 meters and reached a great number in the lower levels, substantially as shown in Fig. 33. The nauplii in the upper water were well developed and apparently about to change into the form of the immature Copepods, while the great number lying between 10 and 13 meters was composed of very young individuals. It seems probable, therefore, that the nauplii during their younger life dwell in the lower part of the inhabited water and move toward the surface when they are about to leave the nauplius stage. The immature forms, both of *Diaptomus* and *Cyclops*, are present in large numbers in the upper strata of the water and the egg-bearing individuals are present in larger numbers in the lower strata, although they are never absent from the upper water. In all the lakes which I have examined in summer the great majority of the nauplii have been found in the region of the thermocline; either just above it, or immediately in and below it. I infer, therefore, that this distribution is a common one.

In October and later the distribution becomes uniform and so continues until late in the winter. In March, as the larvae begin to change into *Cyclops* forms, they approach the surface.

Apstein ('96, Table IV.) does not appear to have found the nauplii more abundant in the deeper water than near the surface.

THE DISTRIBUTION IN THE UPPER METER, AND THE DIURNAL MOVEMENT.

Figures 32, 33.

The observations recorded in my former paper showed uniformly that there was no general diurnal movement of the crustacea and no movement at all which could be detected by the use of three-meter intervals. This conclusion has been confirmed by all of the observations which I have since made. During 1895 and 1896 considerable attention was paid to the distribution of the crustacea in the upper meter, with the design to determining whether or not there was a diurnal movement of the limnetic forms within narrower limits than three meters. A large number of observations were made in 1896 in order to determine the relative number of crustacea in the upper meter and the remainder of the 3 m. level. These observations were begun early in August and continued until the last of November; twenty sets of observations being made in all. In some cases the crustacea were taken meter by meter and the numbers compared. In other cases the crustacea of the upper meter were caught and their numbers compared with those obtained from the entire depth. A single illustration of the former method is given; partly in order to show the results, partly also to illustrate the amount of agreement and difference between the three catches of one meter each and that made through the entire distance of three meters.

TABLE XXXVI.—*Number of crustacea caught August 24, 1895. 6 P. M.*

Depth, meters.	Diaptomus.	Cyclops.	D. hyalina.	D. retrocurva.	Diaphanosoma.	Chydorus.
0-1................	700	360	2,120	280	140	100
1-2.............. ...	340	360	2,060	200	140	120
2-3................	460	370	1,150	160	50	50
Total.........	1,500	1,090	5,330	640	330	270
0-3................	1,780	1,050	4,250	475	350	375

As would naturally be expected, the ratio between the c
tacea of the upper meter and those of the entire level varies

very greatly. On some occasions the catch of certain species from the upper meter was larger than that obtained by a second catch from the entire three meters. Such instances were due to the presence of very large numbers of young in the upper meter, with a somewhat irregular distribution, so that the catches varied considerably. Upon the whole, however, the average number derived from these twenty observations agreed surprisingly in all the species. It was found that the upper meter contained an average of 43 per cent. of the entire catch of *Diaptomus* from the upper three meters; 47 per cent. of *Cyclops;* and 50 per cent. of *Daphnia hyalina.* These catches were made during the day and may be taken as fairly indicating the relative number of crustacea in the upper meter during the daylight hours. It will be seen that these observations fully justify the statement made in my former paper (Birge, '95, p. 479) that "a general movement of the crustacea as much as one meter would have been detected," and indicates that at no time is the population of the upper meter of the lake notably deficient. The minimum percentages were very irregularly distributed and depended more upon the presence or absence of young individuals than upon any influence of light, weather, or wind.

These observations also indicate the extent to which the lines of Figs. 29 and 30 should be altered in the upper three meters in order to express the average distribution within that level.

During 1897 observations were made with a view of determining the exact distribution of the crustacea in the upper meter. They were made by two methods: First, a net with an opening ten centimeters in diameter was supported so that it could be drawn horizontally through the water for a known distance at an uniform rate of speed. The crustacea so obtained were counted and the number present at a given level was thus determined. Second, a pump was taken out in the boat, by whose aid the water of the lake was pumped through a hose and strained by the plankton net, the mouth of the suction hose being placed at the successive levels. Water was taken from the surface at a depth varying from two or five centimeters in calm weather, to ten when the lake was agitated by the wind; at one-half meter; at one, two, and three meters, and sometimes deeper. The results of these two methods were the same and can be stated in general as follows:

1. On calm sunny days the upper ten centimeters of the lake may be almost devoid of crustacea, as was the case on August 1st, 2d, and 25th. At a depth of half a meter, however, the numbers become considerable and may be very great. On August 25th the total population of the water at this depth was at the rate of nearly 70,000 crustacea per cubic meter, without including the nauplii, which numbered 18,000 more. At one meter the population was nearly 200,000 per cubic meter and below that depth the numbers rapidly declined. A large number of similar observations were made on other days, and in one of the cases where the observations with the pump were extended throughout the inhabited water the results have been diagramed and are shown in Fig. 33.

2. The population of the upper meter is largely composed of immature crustacea, the percentage of young varying in different species. It is most marked in *Diaptomus*, *Daphnia hyalina*, and *D. retrocurva*. Great numbers of young are found in the upper meter, as was the case on August 25th, and especially on September 8th, and the adults may be entirely absent. At the depth of a half meter a very few half-grown individuals are present, while they are fairly numerous at one meter and at the same depth the adults begin to appear. Below one meter by far the most conspicuous part of the population consists of adults, although the young may be present in numbers as great as the comparatively few adults. A similar relation of distribution holds for *Daphnia retrocurva*, although the proportion of this species in the upper meter by day seems to be smaller than that of its congener. The adults of *Diaphanosoma* approach nearer the surface when the sun is bright, than those of *Daphnia*, but at least 75 per cent. of the individuals found between the half meter level and the surface are immature. The same statement is true for *Diaptomus*. *Cyclops* shows the least difference; females carrying eggs being regularly found in considerable numbers at half a meter, or even above that level, coming to the surface on cloudy days and occasionally in sunshine. Yet

while it is not easy to determine the exact proportions of young, it is very obvious that the majority of the immature *Cyclops* are near the surface.

3. A far larger proportion of *Cyclops* is usually obtained from the upper five or ten centimeters than comes from any of the other forms of limnetic crustacea, and it may be present at the very surface on hot, calm, sunny days, as on Sept. 13.

4. The nauplii are found in considerable numbers in the upper water during the day and frequently extend to the very surface, yet ordinarily the number at the surface is only a third, or even a smaller fraction of that found at one-half meter. Older nauplii may be found in large numbers at the surface and confined to the upper one-half meter.

5. In windy and cloudy weather the crustacea approach nearer to the surface, the numbers of *Diaptomus* and *Cyclops* being especially increased by the change in the condition of the sky. *Daphnia hyalina* also may come nearer the surface. But the numbers of these species during the day in the upper ten centimeters are always decidedly smaller than at one-half meter, so far as my observations extend.

6. At night the population of the upper meter changes in character. The young, instead of being concentrated in swarms in this layer, become more evenly distributed, and the adults which were found below the one-meter level rise toward the surface. *Leptodora* and larval *Corethra* have been regularly taken at the surface in considerable numbers at night. During the day these animals are rarely, if ever, found close to the surface, although they may be abundant enough above the three meter line. It would appear, therefore, that these animals move toward the surface at night, together with the crustacea on which they feed. *Epischura* seems to have the same habit.

TABLE XXXVII.—*Typical catches from the upper water giving the rate of population in thousands per cu. m. at the depth specified.*

	Depth, meters.	Diaptomus.	Cyclops.	D. hyalina.	Diaphanosoma.	D. retrocurva.	Total crustacea.	Nauplii.	Leptodora.	Gloiotrichia.	Conochilus
A. Aug. 1. Noon. Light north breeze. Net drawn horizontally 20 meters.	0-0.1	......	......	......	......	......	......	1.2	......	26.0	......
	0.5-0.6	22.5	2.5	......	......	......	25.0	12.0	......	5.0	......
	1.0-1.1	43.8	5.7	11.7	2.2	......	63.4	9.2	......	2.0	......
	1.5-1.6	14.0	2.4	14.8	1.6	0.4	33.2	2.4	......	2.2	......
B. Aug. 2. 5 p. m. Light clouds. Calm. Net drawn 15 meters.	0-0.1	8.2	2.2	1.4	0.1	......	11.9	1.4	......	1.4	......
	0.5-0.6	9.2	7.8	12.0	1.4	......	30.4	11.6	......	1.6	......
	1.0-1.1	11.6	9.2	18.4	2.2	......	41.4	3.6	0.04	0.04	0.08
	2.0-2.1	9 6	10.4	9.6	2.8	......	32.4	5.6	......	0.04	0.08
	3.0-3.1	20.0	8.6	9.0	2.4	......	41.0	5.0	......	0.02	0.02
C. Aug. 6, 2 p. m. light clouds, light S. E. breeze. Pump.	0.05	......	0.4	0.6	0.6	......	1.6	40.2	......	12.2	......
	0.5	22.5	4.1	0.75	0.4	......	7.8	56.2	......	8.6	......
	1	12.0	9.0	6.0	5.0	......	32.0	77.2	0.05	7.5	......
	2	22.5	15.0	23.7	12.2	......	73.4	8.2	......	s	0.2
D. Aug. 25, noon, calm, clear. Pump.	0.05	......	1.0	......	0.5	......	1.5	6.0	......	113.0	......
	0.5	18.5	12.7	4.5	31.5	......	67.2	18.0	0.1	10.5	......
	1.0	61.5	21.7	51.7	63.5	......	198.4	5.2	......	3.7	......
	2.0	45.7	18.7	8.7	8.2	......	81.3	6.0	......	2.0	4.5
	3.0	10.0	6.0	6.5	4.5	2.0	29.0	1.5	......	2.0	3.0
E. Aug. 27, 5 p. m. clear, fresh N. W. breeze. Pump.	0.1	6.5	12.0	13.0	......	12.0	43.5	4.5	......	......	......
	0.5	9.0	15.7	50.3	1.8	13.0	90.0	......	0.2	......	......
	1.0	8.0	17.5	17.0	......	9.5	51.0	......	0.1	......	......
	2.0	9.0	24.0	12.0	......	11.5	56.5	......	0.1	......	......
F. Aug. 28, 11 a. m. Cloudy, fresh S. W. breeze. Pump.	0.1	5.6	10.4	3.2	14.8	......	34.0	13.2	......	......	......
	0.5	10.8	14.0	27.6	12.8	......	65.2	19.2	......	......	......
	1.0	16.2	17.4	26.4	12.6	......	72.6	17.4	......	......	......
	2.0	12.0	24.6	17.3	13.8	......	67.7	16.8	......	......	......
	3.0	15.6	40.8	4.8	9.6	1.8	72.6	12.6	......	......	......
	4.0	7.6	20.0	5.6	6.4	......	39.6	18.4	......	......	......
	5.0	6.4	12.0	5.2	1.6	......	25.2	7.2	......	......	......

TABLE XXXVII.—Continued.

	Depth, meters.	Diaptomus.	Cyclops.	D. hyalina.	Diaphanosoma.	D. retrocurva.	Total crustacea.	Nauplii.	Leptodora.	Gloiotrichia.	Conochilus.
G. Sept. 6. Noon. Clear, fresh. S. W. breeze. Pump.	0.1	3.5	5.0	4.5	4.0	......	17.0	27.5	......	......	......
	0.5	1.0	6.0	6.0	6.5	......	19.5	29.0	......	......	......
	1.0	6.0	14.5	10.5	5.0	......	36.0	25.0	......	......	......
	2.0	5.0	13.0	10.5	4.0	5.0	37.5	25.5	......	......	......
	3.0	5.4	10.4	3.4	2.0	......	21.2	13.2	......	......	......

The preceding tables show the results of some of the more important observations of this kind made in 1897. The figures of these tables express the rate per cubic meter found at the given depths, not the actual population between certain depths as is done in the tables based on the vertical net.

In most of these lists, the preponderance of *Cyclops* in the upper stratum is striking. In A, all of the *Diaptomi* at 0.5 and 1 m. were young. The same was true of *D. hyalina* at 0.5 m., and above. In all catches 85–95 per cent. were young at 1 m. on sunny days. The effect of cloud is plainly visible in B, C, and F, and of wind in E and G. The tendency of *Gloiotrichia* to aggregate at the surface is well seen in D.

In the following tables the record for two more complete observations is given, together with one illustration of a night distribution. In the latter there were almost no nauplii, an exception to what has usually been found at night. The population for the given depths in the catch of September 8th has been platted in Fig. 33, and Fig. 32 shows the upper three meters of the two sets of observations on September 13.

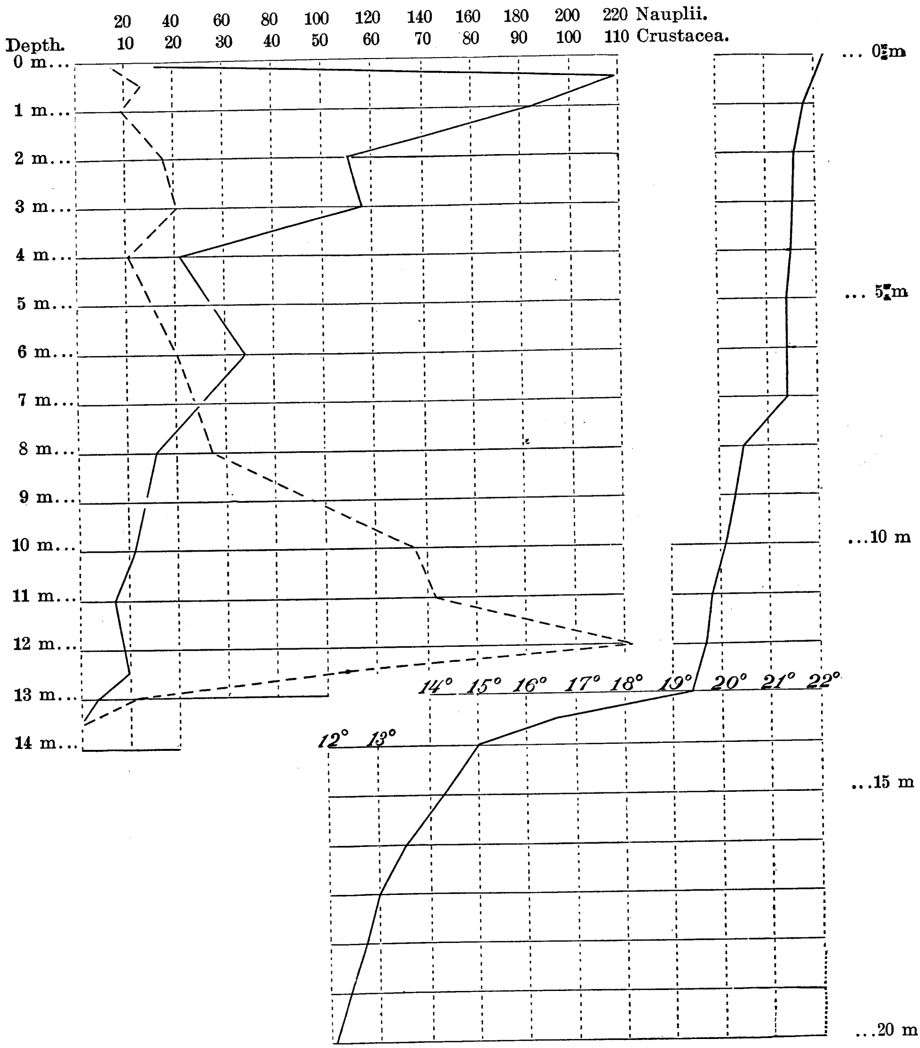


FIG. 33.—Vertical distribution of crustacea, nauplii, and temperature, Sept. 8, 1896, noon. Scale, crustacea (full line), 1 horizontal space = 10,000 per cu. m.; nauplii, 1 space = 20,000; temperature, 1 space = 1 degree. See p. 413.

TABLE XXXVIII.—*Typical catches with the pump from the entire depth. The numbers are stated in thousands per cu. m., and give the rate of the population at the depth specified.*

	Depth, meters.	Temperature.	Diaptomus.	Cyclops.	Adult D. hyalina.	Young D. hyalina.	D. retrocurva.	Diaphanosoma.	Ergasilus.	Total crustacea.	Nauplii.
H. Sept. 8, noon, clear; light S. W. breeze; pump. See Fig. 33.	0.1	22.2	1.5	3.8	......	9.3	......	2.0	......	16.6	15.5
	0.5	......	6.0	12.0	......	78.0	......	10.5	......	106.5	27.0
	1	21.8	15.0	15.7	7.5	44.5	5.3	5.3	......	93.3	19.5
	2	21.6	11.3	16.5	5.3	8.3	5.2	5.3	......	51.9	55.5
	3	......	12.5	23.5	8.0	7.5	3.5	3.0	......	58.0	40.5
	4	21.5	3.0	12.5	4.3	1.0	1.2	0.5	......	22.5	21.0
	6	21.4	3.5	16.0	7.5	3.5	......	......	3.5	34.0	50.2
	8	20.5	2.8	8.2	2.2	2.5	0.7	......	0.5	16.9	55.0
	10	20.1	1.8	3.7	1.2	4.5	......	......	1.0	11.2	135.0
	11	19.8	0.9	4.2	0.9	1.3	0.2	......	0.5	8.0	143.0
	12	19.7	......	3.8	......	2.3	......	......	2.8	10.9	225.0
	12.5	......	0.3	6.6	......	1.4	0.1	0.2	1.0	10.2	108.0
	13	19.4	......	2.1	......	......	......	......	......	2.1	22.5
	13.5	16.6	......	0.4	......	......	......	......	......	0.4	......
	15	14.3	......	......	......	......	......	......	......	......	......
	23	11.8	......	......	......	......	......	......	......	......	......
I. Sept. 13, 2 p. m.; clear, calm; pump. See Fig. 32.	0.02	26.5	0.5	9.0	......	0.05	......	......	......	9.55	141.0
	0.10	......	0.3	2.1	......	0.5	......	......	......	2.9	95.0
	0.25	......	1.0	3.2	......	0.6	......	......	......	4.8	65.0
	0.5	......	4.5	6.0	......	17.5	2.0	1.5	......	31.5	19.5
	0.75	......	3.0	5.0	......	25.0	3.5	3.5	......	40.0	16.0
	1.0	24.9	8.5	7.0	2.5	11.5	10.5	1.5	......	41.5	19.5
	1.5	......	5.5	18.0	4.0	7.0	3.0	1.5	......	39.0	18.5
	2	23.8	6.5	24.5	1.5	3.5	2.0	1.0	1.5	40.5	22.5
	3	22.2	3.5	22.0	2.0	......	0.5	......	......	28.0	33.5
	5	21.8	4.5	22.5	4.0	......	3.0	......	2.5	36.5	51.0
	7	21.3	1.0	17.0	0.3	......	0.1	0.1	......	18.5	112.0
	9	20.2	0.5	7.5	2.0	......	......	......	3.0	13.0	122.0
	11	19.3	1.3	11.2	1.0	......	......	......	1.3	14.8	259.0
	13	18.7	0.2	10.5	0.9	......	0.1	......	0.5	11.7	246.0
	15	17.8	......	10.0	0.1	......	......	......	0.2	13.0	52.0
	16	15.6	......	0.3	0.05	......	0.05	......	......	0.4	2.0
	18	13.2	......	0.05	......	......	......	......	......	0.05	......
	20	12.4	......	......	......	......	......	......	......	......	......

TABLE XXXVIII—Continued.

	Depth.	Temperature.	Diaptomus.	Cyclops.	Adult D. hyalina.	Young D. hyalina.	D. Retrocurva.	Diaphanosoma.	Ergsailus.	Total crustacea.	Nauplii.
J. Sept. 13. 9 p. m.	0.1	......	10.5	22.0	3.5	4.5	2.5	12.5	......	35.5	......
	0.5	......	7.5	13.5	5.5	12.5	10.0	11.5	......	60.5	......
	1.0	......	6.0	20.5	7.0	3.5	1.0	14.5	......	53.5	......
	2.0	......	12.5	11.5	6.0	3.5	5.0	13.5	......	52.0	......
	3.0	......	7.5	11.0	6.0	4.5	6.0	32.0	......	67.0	......

These observations (and I could adduce many more) show that there is a clearly marked diurnal movement of the crustacea in lake Mendota but that it is confined within the narrow limits of the upper meter, or meter and a half. The day population of the upper centimeters, especially in bright, calm weather, is very small, but the number at one-half meter, even under such conditions, is nearly or quite as large as that at any greater depth, and may be the maximum number. The day population of the upper meter consists chiefly of young and immature crustacea; most of the older individuals of all species being found at greater depths. This relation of age to distribution is most marked in the *Daphnias* and *Diaptomus* and least marked in *Cyclops*. At night the population of the upper meter agrees in general character with that of the water below, the older individuals ascending, and the younger descending. I have found no evidence of an aggregation of adult crustacea close to the surface at night, but my observations have been confined to the hours before midnight.

In general, these conclusions regarding the diurnal movement of the crustacea agree with those of Francé, ('94, p. 35), with the important difference that while the movements described by him are measured by meters, those which I have observed take place within the narrow limits of the upper meter, or even within a smaller distance. There are, however, some noteworthy exceptions to the agreement. I do not find that the

Cladocera aggregate at the surface at night, but find that the upper water, in the early part of the night at any rate, is tenanted by a larger proportion of Copepoda than of Cladocera and that a smaller fraction of adult Cladocera is found among those present at this level than at the depth of half a meter, or more. I do not find that a strong wind brings about an even distribution of the crustacea, although it assists in doing so. In moderate winds the crustacea approach somewhat nearer the surface than in quiet, sunny weather, and during violent winds the distribution in the upper three meters is more uniform than in cloudy weather, but in case large numbers of young are present, there is always a high percentage in the upper meter.

THE DISTRIBUTION AT THE THERMOCLINE.

During the latter part of the summer of 1896 observations were made with the net, in order to determine more exactly the distribution of the crustacea at the thermocline. The net was raised from the bottom of the lake to the bottom of the thermocline and then closed and drawn to the surface. After washing out the collection it was lowered to the depth at which it was closed, opened, raised through one meter and closed again. In this way the population was determined by single meters for the two or more meters including the thermocline and the water immediately above. Great care was taken that the movement of the net should be regular, and the messenger was sent down the line in such a way as to close the net immediately on its reaching the upper level of the meter under investigation. The results show that the crustacean population usually passes into the thermocline and often toward its lower part, but that here it ends often with great abruptness. If the temperature conditions are such that the thermocline is spread out over two or three meters the population ends less abruptly than when the thermocline is concentrated into a meter or a half meter. The observations showed a population per cubic meter of only a few hundred below the thermocline, while in it and above it the population might range from 40,000 to 60,000 per cubic meter. As these observations agree in general with the more exact results reached by the pump in 1897, the details will not be given.

In 1897 similar observations were made by the aid of the pump; 40 liters of water being ordinarily pumped from each level. The results were substantially the same, although the number of crustacea found in and above the thermocline was smaller, since the population of the lake was smaller in 1897 than in the preceding year. The following table shows the results of some of the observations. It will be noticed that the abruptness with which the crustacea stop is evidence that the pump did not draw water from any considerable distance from the mouth of the suction hose.

TABLE XXXIX.—*Typical catches from the thermocline stated in thousands per cubic meter. See also Table* XXXVIII.

	Depth, meters.	Temperature.	Diaptomus.	Cyclops.	D. hyalina.	D. retrocurva.	D. pulicaria.	Diaphanosoma.	Ergasilus.	Leptodora.	Total crustacia.	Nauplii.	Corethra.
A. Aug. 17. Surface temperature, 21.8°.	9	21.6°	8.7	7.6	6.8	0.2	......	4.8	0.8	0.05	50.5	4.1	0.05
	10	21.5	6.0	8.8	8.7	1.5	......	5.3	1.3	0.05	53.1	3.2	......
	11	17.5	......	4.8	1.8	0.5	......	0.3	......	0.02	24.7	11.8	0.1
	12	15.9	......	4.0	......	......	8.7	......	......	......	28.6	5.8	0.15
	13	15.1	......	......	......	......	......	......	......	......	......	......	0.2
B. Aug. 25. Surface temperature, 22.7°.	11	20.6	1.0	5.0	5.0	......	......	4.3	......	......	15.3	9.2	......
	12	19.0	1.0	5.0	2.8	......	......	1.5	1.8	......	12.1	10.0	......
	13	15.0	......	0.1	......	......	......	......	......	......	0.1	......	0.08
C. Aug. 27. Surface temperature 21.5°.	11	21.3	10.2	8.4	3.0	......	......	3.0	......	......	24.6	11.4	......
	12	21.2	7.8	13.8	7.2	0.6	......	3.9	......	......	23.3	11.1	......
	12.5	20.4	2.4	29.3	1.6	......	......	......	1.2	......	34.5	16.5	......
	13	16.2	......	0.1	0.1	......	......	......	......	......	0.2	......	0.05
	14	15.0	0.05	0.05	0.05	......	......	......	......	......	0.15	......	0.05
D. Aug. 28. Surface temperature 21.2°.	10	20.5	1.4	7.8	5.0	......	......	......	2.5	......	16.7	19.5	......
	11	20.4	2.5	9.2	8.2	......	......	......	2.5	......	22.4	42.5	0.05
	12	17.6	1.3	13.2	1.0	......	10.0	......	......	......	25.5	34.4	0.15
	13	15.6	0.05	0.1	0.02	......	......	......	......	......	0.17	......	0.15
	14	15.0	0.05	0.1	0.1	......	......	......	......	......	0.25	0.2	......
	15	13.0	......	......	......	......	......	......	......	......	......	......	......

The distribution of the nauplii at the thermocline is especially noteworthy. During the period of the observations there were frequently found enormous numbers of larval Copepods in the lower water. The numbers began to increase at ten or even eight meters, at a point several meters above the level at which the temperature began to fall, so that this distribution does not seem to depend on temperature. The number of nauplii rose to a maximum rate of more than 300,000 per cubic meter in and above the thermocline, but ended with very great abruptness. This termination of the population often took place within the space of half a meter.

The number of algae also declines very rapidly at the thermocline and those which are obtained below this level are dead or dying. The amount of algae thus obtained is, however, far greater than the number of crustacea; indeed the algae below the thermocline are many times more abundant in relation to the number of crustacea present than is the case in lakes like those of the Oconomowoc system, in which there is a large crustacean population in the lower waters. It is obvious, therefore, that the exclusion of the crustacea from these deeper waters is not due to the absence of food.

The algae at times appear to accumulate above the thermocline, and to pass it, as they settle, only after considerable delay. I have attempted to discover whether this delay was due to the greater density of the water, occasioned by the diminution in temperature. A large glass tube, six centimeters in internal diameter and about two meters long, was filled with water and the lower half meter placed in a vessel of ice-water. After a few hours a very marked thermocline was formed, the temperature falling some 6° C. in the space of about 10 cm. Water containing algae, chiefly diatoms, was introduced at the top of the tube and the algae gradually sank through the water. On reaching the artificial thermocline they paused for a few minutes, but rapidly acquired the temperature of the water, as would be expected, and then sank to the bottom of the vessel. The delay at the thermocline could not have amounted to more five minutes for an individual alga. It seems probable from these experiments that temperature does not cause the accummulation of algae often found above the thermocline. Their death and consequent rapid sinking in the deeper water account for their small numbers below the thermocline.

In this region *Cyclops* is the least sensitive of the limnetic crustacea to the influences which exclude them from the lower water. *Chydorus* is close to it in this respect when present in large numbers. A larger proportion of these species than of any others is found in the water immediately above the thermocline, and of the few crustacea which are found below that level by far the greater portion is composed of these genera. When *Chydorus* is extremely abundant more individuals of this species than of any other may be found below the thermocline. At one time nearly 70 individuals were taken by the net between eleven meters and eighteen, more than four times as many as all the other crustacea together. An examination showed that all, or nearly all of these individuals were in the process of moulting and had apparently become in some way entangled in the shell, so that their presence in this deeper water was an evidence of injury or weakness. The crustacea below the thermocline are, however, not dead or dying when brougnt to the surface.

The larvae of *Corethra* are found in considerable numbers below the thermocline and seem to be the only limnetic animal which normally inhabits these waters. Not infrequently the numbers of *Corethra* are far greater than the total number of the crustacea obtained. Indeed this is regularly the case when *Corethra* is present in any considerable numbers. Since *Corethra* can carry a stock of air in its breathing tubes it is easy to understand the possibility of its living in the water below the thermocline. It is less easy to see why it should go there unless it retains in lake Mendota the habits which it has in the far more numerous lakes whose lower waters are habitable by crustacea.

FACTORS DETERMINING VERTICAL DISTRIBUTION.

The following factors contribute to determine the vertical distribution of the limnetic crustacea.

1. Food.
2. Temperature.
3. Condition of the water in respect to dissolved oxygen and other substances.
4. Light.
5. Wind.
6. Gravity.
7. The age of the members of any given species.
8. Specific peculiarities.

Food.

Food influences the distribution of the crustacea both by its amount and its quality. As a general proposition, the crustacea should be most numerous where food is most abundant and least numerous where food is least plentiful. Since, therefore, the reproduction of the limnetic algae goes on most rapidly in the upper strata of the lake, it is natural that the crustacea which feed upon these algae should also be most numerous there. Yet this simple relation of food and eater does not at all cover the facts of vertical distribution. The amount of the algae in lake Mendota is in general so great in proportion to the number of crustacea that the quantity of food is rarely the predominant factor in vertical distribution. In early spring the crustacea, and especially *Cyclops*, increase more rapidly than does the food. But after the opening of summer the food appears to be almost always in excess of the crustacea, and their distribution, therefore, does not follow variations in its distribution.

For example, it is well known that the limnetic algae appear in what may be called successive waves of development. A single species rises to a maximum, predominates for a short time, then declines and nearly disappears, and its place is taken by another species. During the period of decline, especially in the case of diatoms, there is a time when the algae are sinking and when they are more abundant in the deeper strata of the water than near the surface. At such times the crustacea do not follow the food downward, but retain their normal summer distribution. Again, in the autumn there is a period, beginning a little before the first of October and extending to the freezing of the lake, when the algae are present in immense quantities, and are distributed with approximate equality through the whole mass of the water. Yet the crustacea are not by any means as uniform in their distribution, and at times some species are as closely aggregated near the surface as in summer. Their position depends on age and other factors rather than on food.

The position of *Daphnia pulicaria*, also, cannot be determined by the food. It may be added that the crustacea in the deeper strata of the water are usually less numerous in comparison to the food present than they are in the upper strata.

On the whole, while the quantity of food accounts for many of the larger facts of vertical distribution, it leaves wholly unexplained most of the details of the distribution of all of the species. It entirely fails to account for the position of *Daphnia pulicaria*, or for the absence of crustacea from the deeper water in summer.

The quality of the food at different depths is of some importance in the distribution of the crustacea. *Anabaena*, *Aphanizomenon*, and allied genera of algae are found in larger numbers in the upper strata of the water, while the diatoms, with their siliceous shells, tend to be more evenly distributed and never accumulate at the surface. *Anabaena* and allied forms, also, being small in size and devoid of skeleton, are more readily eaten by the young crustacea than the diatoms, while the diatoms in turn can be very readily eaten by the older and larger crustacea. There is, therefore, a tendency for the young of nearly all species of limnetic crustacea to seek the algae in the surface strata of the lake, and the difference in the distribution of the algae is no doubt one of the factors which keep so high a percentage of the young near the surface.

The fact that the crustacea in the 0–3 m. level do not rise above a certain number (p. 387) shows that food is not the only regulating factor, since the amount of food in that level in autumn is more than sufficient to support the total crustacean population.

Temperature.

Temperature may be considered under three heads: (1) the rise and fall of the average temperature of the water from spring to late autumn, (2) the diurnal variation of temperature, (3) the vertical distribution of temperature.

I have not been able to discover that the warming or cooling of the water in spring or fall affects directly the vertical distribution of any species except *Daphnia pulicaria.* The movements of this species are undoubtedly determined by the rise or fall of the general temperature of the water. It is a sub-thermoclinal species in plankton-poor lakes and in summer it keeps as near as possible to the cool water in lake Mendota.

The diurnal variation of temperature has no noticeable direct effect on vertical distribution.

The most striking fact in the vertical distribution of temperature is the formation in the lake during summer of the thermocline which forms the lower limit of the crustacea from July on. The crustacea follow accurately the position of the thermocline. This layer has a vertical oscillation of two or even three meters, being affected by the direction of the wind. In every case the lower limit of the crustacea oscillates with the position of the thermocline and follows it downward as it gradually descends during the summer.

The statement made in my former paper (Birge, '95, p. 481) that "during July, only the upper twelve meters are tenanted by crustacea, and over ninety per cent. are in the upper nine meters" should be modified so as to read, that ninety-five per cent. or more of the crustacea are found above the thermocline, which in July is situated from nine to twelve meters below the surface. Yet, close as is this correspondence between crustacea and thermocline, the temperature is not the fact which limits their downward extension. This will be shown under the next head.

I have no doubt, however, that the thermocline is always an important factor in determining the position of the crustacea. *Diaphanosoma* is pre-eminently a summer form and flourishes only when the temperature of the water is at or above 20° C. It would hardly extend its range into the cold bottom water. In Pine lake and Oconomowoc lake, in both of which many crustacea extend freely through the thermocline, *Diaphanosoma* is confined to the region above it. Marsh states that *Epischura* occupies the same position in Green lake, in which lake also most of the crustacea extend far below the thermocline.

In all small lakes whose deeper water is habitable it will probably be found that the limnetic crustacea (and the rotifers also) can be divided into three sets:

1. Those permanently above the thermocline, including *Diaphanosoma, Epischura* (Marsh, '97, p. 195), and probably some forms of *Daphnia hyalina* and *Ceriodaphnia.*

2. Those below the thermocline, including *D. pulicaria* and *longiremis* and *Limnocalanus* (Marsh, '97, p. 201).

3. Those which are found on both sides of the thermocline, including *Diaptomus*, *Cyclops*, and others. These forms are named on small evidence in most cases, and the list must be regarded as suggestive only. The thermocline and the upper meter or two are certainly the two important strata in vertical distribution.

Above the thermocline there are no differences in temperature which could determine the distribution of the crustacea. There is rarely a difference exceeding two degrees between the top of the thermocline and the surface of the lake, and the variations in the vertical distribution of the crustacea above this layer must depend on other causes than temperature.

After the first of October, lake Mendota is nearly homothermous. Differences exceeding one degree are rarely found, and only in the warmer parts of bright and calm days. This condition is assumed while the temperature is fairly high—16° to 18°—and so early in the autumn that the development of the crustacea goes on actively for a month or more. During this period, therefore, other factors than temperature or food must determine the vertical distribution. Uniformity of distribution, however, is not attained until the decline in numbers of the several species of crustacea. So long as the crustacea are multiplying, the higher strata may contain as high a percentage as they do in summer. (Cf. p. 398.)

One indirect effect of temperature should be noticed. A higher temperature increases the sensitiveness of the limnetic crustacea to light, and thus aids in driving from the upper strata those species which are negatively affected by light, es pecially *Daphnia hyalina.*

Chemical relations of the water.

The abrupt limitation of the downward extension of the crustacea in lake Mendota by the thermocline is not due to the change in temperature. This is shown by the fact that in lakes which are poor in plankton the crustacea extend far below the thermocline and in many cases the colder water is the more densely populated part of the lake. The crustacea are excluded from the lower water by the accumulation in it of products of the decomposition of the plankton plants and animals. Thes accumulate in the stagnant water below the thermocline and their decomposition finally, and in lake Mendota rapidly, fills the water with decomposition products and exhausts the oxygen.

The State Board of Health of Massachusetts in 1889 and 1890 made elaborate examinations of the condition of the deeper water of numerous ponds in that state. It was found (Drown, '90, p. 554) that in the deep water there was "an accumulation of intermediate products of decomposition of nitrogenous organic matter, the hydrogen compounds of carbon, sulphur, phosphorus, and nitrogen, which, owing to the exhaustion of the supply of free oxygen, cannot be further oxidized." It was found also that "in foul water of this character the varieties of animal and vegetable life which we find in water nearer the surface are almost, if not altogether, absent." In 1891 investigations were made of the amount of oxygen in the bottom water, showing (Drown, '91, p. 373) a rapid decline in the dissolved oxygen below the thermocline and its total disappearance from the bottom water of the ponds. It is not possible to state positively whether it is the absence of the oxygen or the presence of the decomposition products which excludes the crustacea from the lower water, in the absence of more exact investigations on the subject.

In lake Mendota the lower water is always clear, but the whole region below the thermocline rapidly becomes unfit to support life, so that the life in the lower waters ceases very shortly after the formation of the thermocline. In lakes with a smaller amount of plankton the bottom water may become unfit to support life in late summer, although the plants and animals extend far below the thermocline. In Pine lake on September 5, 1896, *Cyclops* was by far the most abundant crustacean in the cold water, and numbered 21,000 per cubic meter between 12 and 15 meters, and 3,000 between 15 and 18 m. It was practically wholly absent between 18 and 24 m., only 8 individuals being taken by the net within that distance, and no other forms of crustacea were taken. In Okauchee lake the crustacea are numerous to a depth of 24 m. in September, but between 24 and 27.5 m. they were very few. In lake Geneva, Wisconsin, the crustacea in September extend to the bottom at a depth of more than 42 meters. This lake is extremely poor in plankton. The statistics given by Marsh for *Cyclops* and *Diaptomus* ('97, p. 191, 204) may indicate a partial exclusion of the crustacea from the lower water of Green lake in late summer and autumn.

While the plants and animals of the upper water are excluded by this means from the lower part of the lake, animal life is by no means entirely wanting. Worms are found in the mud at the bottom, as also is *Cyclas*, in considerable numbers. There must, therefore, be oxygen enough in the water to support some life.

Cyclops and *Chydorus* are the least sensitive of the limnetic crustacea to these injurious influences. As shown by the tables on page 416, they always predominate in the lower strata of the inhabited water and form almost the entire population of the water below the thermocline.

It is possible that the exhaustion of the oxygen from the lower strata of the water is the cause of the death of *Cyclops* and *Daphnia hyalina* at the bottom in spring and early summer. I have, however, no positive evidence on this point and in the case of the latter species a great majority of the old animals are so affected by various diseases as to need no other explanation of their death.

Undoubtedly the condition of the water in summer causes the rise of the survivors of the spring broods of *D. pulicaria* from the bottom to the region of the thermocline.

Light.

In lake Mendota the direct effect of light is confined to the upper meter or two, within which distance it has a powerful influence in determining the position of the crustacea.

Laboratory study shows that the relation of the crustacea to light differs in different species. *Daphnia* in all of the limnetic species has a strongly negative movement. *Diaptomus*, *Diaphanosoma*, and *Chydorus* are strongly positive while *Cyclops* is, on the whole, positive, but is not very strongly affected either way. Yet the vertical distribution of these species is not very different when studied in the lake by three-meter intervals. Compare Fig. 30, and the percentage tables on p. 393 *Diaptomus* and *Daphnia* show an especially close correspondence in spite of their opposite relation to light. These species, placed in a glass vessel near a window, will segregate, *Diaptomus* collecting near the surface and toward the light, while *Daphnia* goes to the bottom and to the side furthest from the light. This movement away from the light is not shared by every Daphnia present; some may move toward the light, usually not more than one per cent. of the adult or half-grown individuals. Young *Daphnias*, especially the newly hatched, are attracted by the light. The adult individuals of *Diaptomus* are found in a higher level of the lake than those of *Daphnia*.

The young crustacea have a monopoly of the upper half-meter, or thereabouts, during the day. It is easy to see the advantage of this arrangement to the species. In the upper meter, plant-life is most abundant, and is represented chiefly by small forms like *Anabaena* which are especially adapted as food to the small crustacea. On the other hand, the adult crustacea find an abundance of food suited to their size and masticatory organs, in the diatoms, which are more uniformly distributed in the water. The young, therefore, are freed in part during the daytime, by the action of light, from the competition of most of the older forms of the same species for the food which is especially adapted to the young.

On August 26th, 1895, there was an alternation of cloud and sun, which made the day especially favorable for the study of the relation of light and the vertical distribution of *Daphnia.* It was found by numerous observations that the adult and half-grown Daphnias were approximately one meter below the surface during the sunny periods, but rose to about one-half meter during the cloudy intervals. The rise immediately followed the obscuring of the sun and the return was as prompt when the sun again shone. It was as though the Daphnias were depressed by a force against which they were contending, and they rose when the sun disappeared with the promptness of a compressed spring when relieved of weight.

In laboratory experiments *Diaptomus* and young Daphnias move quite to the light end of the box in which they are placed. If sunlight is reflected by a mirror, they still move toward it and find no light too strong which can thus be sent to them. It would seem, however, that the direct sunlight of the open lake is too strong for them, or they would be present in larger numbers in the upper centimeters of the lake. If the warmth of the water repelled them we should expect this stratum to be tenanted as the lake cools in the fall, and should also expect that the young crustacea would gradually withdraw during the day as the surface warms. Neither in autumn nor in early morning, however, do we find the crustacea close to the surface. The withdrawal from the upper quarter meter or so continues at least until the first of November, and the crustacea descend from the surface very promptly after sunrise. As already stated, the old nauplii are the only crustacea which I have found in large numbers immediately at the surface on calm, bright days. A high temperature, however, increases the negative action of light and a low temperature lessens or reverses it. In early winter when the ice is transparent, *D. pulicaria* and *D. hyalina* may often be seen in large numbers immediately below the ice. This is especially noticeable in the case of the former species.

The position of *D. pulicaria* must be controlled by temperature. I have never been able to detect any noteworthy difference between *Daphnia pulicaria* and *Daphnia hyalina* in their relation to light, by means of laboratory experiments. Nor have I as yet been able to find any difference in sensitiveness to light between Daphnias brought from a depth of three meters and those from a depth of twelve or more meters.

The conclusion is, therefore, that in the upper meter and perhaps within a range not exceeding two meters from the surface, light is an extremely important factor in determining the vertical position of the crustacea. Below this depth, however, there are no effects which can be definitely ascribed to light. I am not at all inclined to deny that, in lakes whose water is more transparent than that of Mendota, light may influence the crustacea to a greater depth. During the summer the water of lake Mendota is always turbid with vegetation, which cuts off the light very rapidly. My brass-topped dredge can rarely be seen to a depth greater than two meters, and frequently disappears between one-half and one meter. Vegetation, also, is especially effective in cutting off the violet and blue rays, on which the action of the light chiefly depends. In lakes whose water transmits these rays more freely, light may be a far more important factor in controlling distribution.

The diurnal movement of the crustacea, which is clearly present during summer within the narrow limits of the upper meter, is chiefly due to light. Wind or calm alter the conditions of movement but during summer can hardly be considered factors in causing it.

Wind.

On the whole, wind has only a small influence on the vertical distribution of the crustacea, although its effect varies greatly with the season and with the condition of the several species of crustacea. The action of the waves prevents the formation of the dense swarms of young crustacea which are apt to be near the surface during calm weather. These young crustacea seek the algae which on calm days accumulate near the surface. When the lake is rough the algae are distributed to a greater depth, and the crustacea follow them to some extent; although, even when the wind blows with considerable force, the young crustacea still form the chief population of the upper meter of the water. I have not been able to discover any descent of the crustacea during windy weather, but, on the contrary, have always found the upper meter fully occupied by them even when the lake was so rough as to make it very difficult to go out with a row-boat.

The wind may affect the vertical distribution, also, by creating currents in the water. These are either lateral or vertical; we are concerned only with the latter. During the summer the vertical currents can penetrate no deeper into the water than the thermocline; that is, from six to fifteen meters, according to the time of year. These currents, however, seem to produce very little effect on the distribution of the crustacea — at any rate, at a distance of 850 m. from the shore, where my observations have been made. In the next section it will be shown that crustacea must be able to move through a distance of at least 100 meters vertically per day, and that the larger individuals move through four or five times that distance. There is, therefore, no difficulty in their maintaining any position in the water they may choose to occupy, against the somewhat slow vertical currents produced by the wind. Indeed, the wind affects the vertical distribution of the limnetic algae much less than would be expected. I have frequently collected after severe gales, and, in summer, have never failed to find the algae of the upper three meters far more numerous than those from lower levels. I have never been able to detect vertical currents, produced either by wind or sun, which were capable of distributing the algae uniformly through the mass of water in summer, and of course the active crustacea are far more independent of these currents than are the algae.

In the autumn the entire mass of water in the lakes is put into somewhat active circulation by the autumnal gales. The algae are at a maximum and are pretty uniformly distributed through the water. Neither the quantity nor the quality of the food, therefore, give any reason to the crustacea for moving to any particular level. The effect of light, also, is lessened by the declining temperature of the water. Hence the crustacea are far more apt to yield to the action of wind and gravity than they do in summer, and become more evenly distributed through all levels of the water.

In the spring a similar distribution occurs immediately after the breaking up of the ice, when the lake is homothermous, and the crustacea and the algae have not yet started their spring development. Very soon, however, the surface strata contain much more food material than those below, and the young crustacea tend to remain near the surface until crowded down by the swarms of newly-hatched forms. The lake, too, rapidly becomes heterothermous and the circulation of the water in late April and early May is by no means as complete as it is during the long homothermous period of the autumn.

A slight effect is also produced by the wind on the vertical distribution of the crustacea, since it causes the thermocline to oscillate through one or more meters. In general, it may be said that the on-shore wind tends to depress the thermocline, piling up the warm water on top of it; while the off-shore wind tends to raise it by stripping off the warm water of the surface. This general law, however, is subject to many modifications owing to the irregularities in the outline of the lake and in the conformation of its bottom. Whatever effect however, the wind produces on the thermocline it also exerts, of course, on the lower limit to which the crustacea extend.

Gravity.

The action of gravity has more influence on the position of crustacea than I had supposed on beginning this investigation. Its effects are most plainly seen in *Daphnia*, and least in *Diaptomus*. Gravity does not act as an accelerating force upon the movements of the crustacea, and yet their ordinary movements are adjusted with some reference to it. If Daphnias are watched in an aquarium, it will be seen that they usually remain at about the same level, permitting themselves to sink and then with a few strokes of the antennæ resuming their former position. In this way they pass up and down through the water utilizing the material available for food. After a time the animal may swim off to a new place, but soon begins to repeat these alternate movements. The movements of *Diaptomus* are far less regular, yet it, too, keeps at about the same level, unless some attraction causes it to move up or down. *Cyclops*, which hunts for food of all sorts, and is decidedly a more predacious animal than either of the first two named, is far less regular in its movements, and *Leptodora*, as a true carnivore, swims actively in all directions.

The amount of energy required of the crustacea in order to maintain their position in the water is not inconsiderable, and is doubtless the main muscular labor demanded of them. They are all of them heavier than water, and sink at a rather rapid rate, which very quickly becomes uniform. The full-grown *Daphnia*, 3 to 4 millimeters long, sinks at the rate of 20–30 centimeters per minute even with expanded antennæ. Small, newly-hatched individuals, one millimeter or less in length, have a rate less than one-third as great, from 5 to 10 centimeters per minute. The specimens experimented upon almost always fell edgewise through the water, with the head down, if the antennæ were folded, and with the head up, if the antennæ were expanded. *Diaptomus* sinks at about the rate of about 12 cm. per minute, and medium-sized adult *Cyclops* without eggs at a rate of 9.5 cm. per minute.

Live Daphnias sink at the same rate as those freshly poisoned, as far as the eye can determine. This is easily determined in the case of half-grown and adult individuals, but young specimens are so active that it is hard to be accurate. At the rate given, an adult Daphnia would sink through as many as 250–400 meters in a day, and must, therefore, maintain itself against the force which would cause it to fall through this distance. Of course the weight to be lifted is very small, being the excess of the weight of the animal over that of an equal bulk of water. It seems impossible that the animal should ever sleep. As the creatures become older and larger the exertion becomes greater than in the case of young individuals, and the older and, especially, the feebler animals, tend gradually to sink and accumulate in the deeper waters of the lake.

Such aggregations of *Cyclops* are often found at the bottom of the lake in winter. In March, 1895, for example, from fifty to seventy per cent. of this species were in the lower three meters. *Daphnia hyalina* shows a similar downward movement in late May and early June on the part of those individuals which have lived over winter. In late autumn, also, the adult members of this species are far more numerous in the lower strata than they are at higher levels. Since, at this time, there is a superabundance of food at all depth of the water, and, since the crustacea are relatively few in number, this distribution can hardly be due to any other cause than gravity. (See p. 398.)

Diaptomus and *Diaphanosoma* with their very powerful swim ming organs, rarely show this tendency to sink. Perhaps the large amount of fat usually present in *Diaptomus* also aids in preventing sinking.

Age.

It is a general rule that the young individuals of a species appear near the surface, When the crustacea begin to multiply in the spring, the increase appears first in the 0–3-meter level. All very exceptionally large numbers of any species obtained during the summer have been caught in the upper three meters, and usually consisted of young and half-grown animals. No similar aggregations have been found in the deeper water, except as noted for *Cyclops* in the last section.

When a species is declining in numbers, the distribution is more uniform, and as the decline goes on, the lower levels may contain a larger number than the upper. If the crustacea obeyed this law with mathematical accuracy, there would be a sort of progress of the members of a brood from the top to the bottom of the lake, the successive broods of the young continually displacing the older in the upper strata.

Good illustrations of the distribution of the young and adult individuals can be obtained from the fall broods of *Daphnia hyalina*, as stated on page 398

The nauplii of the Copepods seem to form an exception to this rule of age. During the period when the thermocline is present, the maximum numbers of nauplii usually occur in the neighborhood of this layer, although not confined to it. In Pine lake, also, the thermocline and the level immediately below it contained more than sixty per cent. of the nauplii present. In Mendota they cannot go below the thermocline, but they congregate in and above it as shown in Fig. 33. The young *Cyclops* and *Diaptomus*, however, congregate near the surface by day, yet are by no means so closely confined to the surface as is the case with *Daphnia*. In autumn and winter the nauplii are pretty uniformly distributed.

The causes of this distribution by age are to be found in the different relations of old and young to light, food, and gravity. Light and food are probably the most important factors. Certainly it is true that *Cyclops*, which, of all the limnetic crustacea, is least affected by light and most omnivorous in diet, never shows as complete a separation of old and young as do the other genera. Yet even in this case there are more egg-bearing females, in proportion to the total number, in the deeper strata than near the surface. This is possibly due to gravity, which would have a greater effect on females laden with eggs.

Specific peculiarities.

It must be remembered that these various factors affect highly organized animals, which therefore do not respond with the mechanical uniformity of bacteria or of swarm-spores. Yet, in looking over my lists for catches which would illustrate exceptions to the principles given and to the averages of the tables, I have had difficulty in finding them. A few exceptional catches of *Diaptomus* occurred in all summers, where the 6–9 m. level in perhaps half a dozen cases contained more than the 0–3 m. But even such cases are very rare and in general the several species of crustacea follow their law of distribution with the range of variation already noted.

It is in the nature of the response of the species to these factors that the specific differences usually appear, rather than in aberrations from the general law. It has been very interesting to see how these specific differences regularly presented themselves in my averages in spite of great variations in absolute numbers. Even those so small that they were at first supposed to be merely accidental recurred with great uniformity.

In conclusion I would repeat what I said in my introduction, that this discussion of general causes is to be regarded as suggestive. I shall be quite satisfied if it indicates lines of investigation to students of the fresh water plankton.

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LIST OF DIAGRAMS.

ERRATA.

Page 289, line 18, *for* April 28th, *read* April 2nd.

Page 289, line 21, *for* Dec. 29th, *read* Dec. 19th.

Page 400, line 2 from bottom, *for* Fig. 31, *read* Fig. 32.

Page 412, line 2 from bottom, *for* Fig. 32, *read* Fig. 31. Also in Table XXXVIII, I.

Page 425, line 17, *for* Fig. 30, *read* Fig. 29.

In Fig. 13, *for* D. pulicaria 34, *read* D. pulicaria 3.4.

APPENDIX.—TABLE A.—*Dates on which collections were made.*

	1894.		
	No. of days.	No. observations.	Dates.
July 1-15	4	9	7, 10, 11, 14.
July 16-31	7	38	16, 17, 18, 19, 27, 28, 29.
Aug. 1-15	4	12	1, 2, 3, 4.
Aug. 16-31	3	3	23, 24, 25.
Sept. 1-15	....	....	
Sept. 16-30	7	12	18, 19, 20, 21, 22, 27, 29.
Oct. 1-15	4	7	6, 9, 11, 15.
Oct. 16-31	8	11	16, 17, 20, 22, 23, 27, 30, 31.
Nov. 1-15	5	5	1, 3, 6, 8, 14.
Nov. 16-30	....	....	
Dec. 1-15	3	10	3, 5, 7.
Dec. 16-31	1	2	19.
	46	109	

	1895.			1896.		
	No. of days.	No. observations.	Dates.	No. of days.	No. observations.	Dates.
Jan. 1-15	4	12	1, 2, 6, 9	4	4	7, 8, 14, 15.
Jan. 16-31	1	3	16	2	3	16, 20.
Feb. 1-14	1	3	14	3	4	4, 5, 14.
Feb. 14-28	3	10	15, 19, 23	1	1	24.
Mch. 1-15	4	11	6, 7, 11, 12	....	....	
Mch. 16-30	3	8	16, 18, 23	3	5	16, 21, 28.
Apr. 1-15	2	5	12, 15	3	4	4, 11, 14.
Apr. 16-31	4	13	18, 23, 25, 30	5	8	18, 20, 22, 27, 30.
May 1-15	4	9	4, 7, 10, 12	5	7	2, 6, 9, 11, 15.
May 16-31	6	11	16, 18, 20, 22, 27, 30	7	7	17, 18, 20, 21, 24, 26, 29.
June 1-15	6	12	1, 3, 6, 10, 12, 14	7	10	1, 3, 5, 6, 10, 13, 15.
June 16-30	8	14	17, 18, 20, 22, 24, 27, 29.	7	9	17, 19, 22, 24, 26, 27, 29.
July 1-15	10	18	1, 3, 4, 5, 6, 9, 10, 11, 13, 15	6	6	1, 4, 7, 9, 11, 13.
July 16-31	5	5	17, 19, 22, 24, 27	10	10	16, 17, 18, 20, 21, 24, 25, 27, 29, 31.
Aug. 1-15	7	8	2, 5, 7, 9, 12, 14, 15	7	7	2, 4, 5, 6, 8, 10, 12.
Aug. 16-31	8	8	17, 19, 21, 22, 23, 27, 29, 31	7	7	17, 19, 24, 26, 27, 29, 31.
Sept. 1-15	5	5	2, 4, 7, 9, 13	7	8	4, 8, 9, 10, 11, 12, 14.
Sept. 16-30	6	6	16, 18, 22, 25, 27, 30	7	7	17, 18, 20, 22, 24, 25, 28.
Oct. 1-15	5	5	3, 4, 8, 11, 14	8	8	1, 2, 3, 5, 7, 8, 10, 12.
Oct. 16-31	5	5	17, 20, 23, 26, 30	7	7	16, 20, 22, 24, 26, 27, 28.
Nov. 1-15	5	5	1, 5, 10, 11, 14	7	7	1, 3, 6, 9, 11, 13, 15.
Nov. 16-30	3	3	18, 20, 28	5	5	17, 19, 22, 24, 30.
Dec. 1-15	4	4	1, 9, 11, 14	5	5	1, 9, 11, 13, 15.
Dec. 16-31	3	4	18, 21, 23	3	5	21, 22, 24.
	110	187		126	144	

TABLE B.—*Average number of crustacea per cubic meter in each three meter level, 1895, 1896.*

See Figs. 22, 23.

Depth.	1895.						1896.					
	0–3	3–6	6–9	9–12	12–15	15–18	0–3	3–6	6–9	9–12	12–15	15–18
Jan. 1-15..	6.9	5.0	4.7	5.2	2.6	2.6	41.7	20.6	17.4	8.4	11.9	13.7
Jan. 16-31...							23.8	9.2	9.3	5.6	5.5	11.8
Feb. 1-14....	5.2	8.7	6.6	5.3	14.1	14.1	29.9	11.5	8.3	9.1	8.9	12.9
Feb. 15-28..							20.5	10.8	7.7	7.8	7.8	9.1
March 1-15...	5.7	8.4	6.1	5.0	3.7	10.8	......	......	......	......	......	......
March 16-31..	12.4	11.7	5.2	5.2	10.1	10.1	23.9	12.3	18.3	11.5	8.0	5.7
April 1-15....	10.3	5.8	3.7	3.1	4.1	4.2	26.5	19.6	33.9	35.5	21.2	21.0
April 16-30....	36.1	21.7	12.6	7.6	6.1	9.0	159.2	97.1	58.5	43.5	22.1	11.4
May 1-15......	134.0	76.8	41.1	22.4	14.1	20.7	254.4	179.6	154.3	98.2	69.3	62.2
May 16-31.....	188.0	90.7	64.4	38.4	38.8	47.1	197.8	118.7	117.2	94.4	81.1	99.6
June 1-15.....	148.4	83.3	59.9	45.0	36.0	46.6	188.1	69.0	30.4	24.0	12.9	30.6
June 16-30....	84.4	41.3	30.3	13.3	9.2	17.5	252.2	106.8	43.8	24.2	18.8	15.0
July 1-15.....	142.1	61.4	46.0	14.2	4.2	2.2	230.4	135.2	56.8	25.1	20.9	2.6
July 16-31....	119.0	75.8	67.8	10.9	2.1	1.4	127.2	76.9	47.5	9.7	0.8	0.3
Aug. 1-15.....	101.1	61.8	34.7	27.5	4.1	0.5	163.0	82.7	42.6	11.2	1.2	0.2
Aug. 16-31....	87.1	45.0	38.4	32.7	3.5	0.6	119.9	118.6	62.9	49.8	6.9	0.5
Sept. 1-15.....	89.4	60.4	44.8	21.4	6.5	1.7	150.6	111.9	84.8	70.5	47.0	14.4
Sept. 16-30....	93.7	62.6	45.8	34.6	42.0	24.1	107.0	61.1	50.1	51.9	53.2	47.1
Oct. 1-15......	76.8	39.3	38.2	35.8	36.6	33.9	105.7	84.1	81.3	63.6	61.3	59.8
Oct. 16-31.....	41.6	23.9	23.8	25.4	20.8	21.1	192.0	66.9	51.2	41.9	42.5	43.6
Nov. 1-15.....	29.1	22.9	17.1	21.2	17.5	14.0	56.1	47.1	30.9	36.8	28.9	28.2
Nov. 16-30....	23.9	19.3	17.3	18.5	14.1	13.2	52.2	29.8	24.7	27.9	22.7	19.6
Dec. 1-15.....	33.2	28.2	17.0	10.6	8.5	6.5	26.5	38.2	15.9	24.6	22 0	23.2
Dec. 16-31.....	45.6	16.3	10.0	15.4	9.8	7.2	14.6	27.5	22.0	10.3	10.3	10.4

TABLE C.—*Average number and percentile vertical distribution of the crustacea.*

	Av. No.	PER CENT. IN EACH 3 M. LEVEL.					
		0–3.	3–6.	6–9.	9–12.	12–15.	15–18.
1894.							
July 1–15	306.2	45.7	29.5	16.9	5.5	1.9	0.5
July 16–31....	472.3	51.2	30.6	12.3	4.9	0.8	0.1
Aug. 1–15....	401.1	43.4	27.3	21.6	7.6	0.1	0.1
Aug. 16–31 ...	382.2	42.6	29.0	21.1	7.2	0.1	0.0
Sept. 1–15....	....	No observations.					
Sept. 16–30...	691.6	46.2	26.0	14.5	9.8	3.2	0.3
Oct. 1–15.....	820.8	28.6	20.8	16.2	14.4	11.1	8.9
Oct. 16–31....	757.1	21.0	19.5	17.6	15.8	16.4	9.8
Nov. 1–15.....	571.4	20.7	18.6	15.8	19.8	16.3	8.8
Nov. 16–30....	....	No observations.					
Dec. 1–15.... Dec. 16–31....	219.9	32.8	16.2	14.4	11.8	12.4	12.4
1895.							
Jan. 1–15.... Jan. 16–31...	81.1	25.5	18.5	17.4	19.2	9.6	9.6
Feb. 1–14.... Feb. 15–28....	166.9	9.6	16.3	11.9	9.8	26.1	26.1
Mch. 1–15....	118.7	14.2	21.1	15.6	12.6	9.2	27.2
Mch. 16–31....	164.5	22.9	21.3	9.5	9.5	18.4	18.4
Apl. 1–15....	94.3	32.8	18.4	11.7	10.0	13.5	13.7
Apl. 16–30....	229.4	38.7	23.3	13.5	8.3	6.6	9.6
May 1–15.....	940.2	43 5	24.8	13.3	7.2	4.5	6.7
May 16–31....	1,419.5	40.2	19.4	13.8	8.2	8.2	10.0
June 1–15....	1,256.6	35.4	20.0	14.3	10.7	8.6	10.9
June 16–30...	610.7	43.0	21.6	15.5	6.8	4.7	8.4
July 1–15....	817.6	52.6	22.8	17.0	5.3	1.5	0.8
July 16–31....	837.9	42.9	27.4	24.4	3.9	0.7	0.5
Aug. 1–15....	689.1	44.0	26.9	15.0	12.0	1.8	0.2
Aug. 16–31....	622.8	42.0	21.7	18.4	15.8	1.6	0.3
Sept. 1–15....	669.7	39.8	26.9	20.0	9.6	2.9	0.8
Sept. 16–30...	928.1	30.9	20.7	15.1	11.4	13.9	7.9
Oct. 1–15.....	767.8	29.5	15.1	14.6	13.7	14.0	13.0
Oct. 16–31....	478.5	26.6	15.2	15.2	16.2	13.3	13.5
Nov. 1–15....	391.5	23.8	18.8	14.0	17.4	14.3	11.5
Nov. 16–30....	331.8	22.6	18.2	16.3	17.3	13.2	12.4
Dec. 1–15....	320.8	31.9	27.1	16.3	10.2	8.1	6.2
Dec. 16–31....	313.1	43.7	15.6	9.6	14.7	9.4	6.9
1896.							
Jan. 1–15....	294.1	36.6	18.0	15.2	7.4	10.5	12.2
Jan. 16–31....	240.9	36.5	14.1	14.1	8.6	8.6	18.1
Feb. 1–14....	219.0	37.1	14.3	10.0	11.3	10.1	17.0
Feb. 15–29....	191.7	32.2	17.1	12.1	12.1	12.1	14.3
Mch. 1–15....	....	No observations.					
Mch. 16–31 ...	281.6	29.7	15.4	22.7	14.1	10.0	8.1
Apl. 1–15....	480.4	16.8	12.4	21.5	22.5	13.4	13.4
Apl. 16–30....	1,184.3	40.6	24.6	14.9	11.2	5.7	2.8
May 1–15....	2,398.2	31.1	21.9	18.9	12.0	8.4	7.6

TABLE C.—Continued.

	Av. No.	PER CENT. IN EACH 3 M. LEVEL.					
		0–3.	0–6.	6–9.	9–12.	12–15.	15–18.
May 16-31....	1,901.3	27.9	16.7	16.5	13.3	11.4	14.1
June 1-15....	844.8	53.0	19.4	8.5	6.7	3.6	8.6
June 16-30....	1,265.0	54 7	23.1	9.5	5.3	4.1	3.2
July 1-15....	1,314.2	48.9	28.7	12.1	5 3	4.4	0.6
July 16-31....	776.5	48.4	29.2	18.1	3.7	0.3	0.12
Aug. 1-15....	960.4	54.2	27.4	14.2	3.7	0.4	0.0
Aug. 16-31....	1,073.3	33.4	33.1	17.5	13.9	1.8	0.1
Sept. 1-15....	1,440.9	31.3	23.3	17.7	14.7	9.8	3.0
Sept. 16-30 ...	1,112.3	28.6	16.2	13.4	13.9	15.3	12.4
Oct. 1-15....	1,368.4	23.0	18.4	17 8	14.0	13.4	13.1
Oct. 16-31....	1,314.8	43.9	15.2	11.7	9.6	9.7	9.9
Nov. 1-15....	684.8	24.6	20.7	13.5	16.1	12.7	12.4
Nov. 16-30....	537.7	29.5	16.8	14.0	15.8	12.8	11.1
Dec. 1-15....	365.8	18.0	25.7	11.0	16.6	14.9	15.8
Dec. 16-31....	285.0	15.4	29.0	23.1	10.8	10.8	11.0

TABLE D.—*Diaptomus. Average, maximum, and minimum numbers. Percentile vertical distribution.*

	Av.	Max.	Min.	PER CENT. IN EACH 3 M. LEVEL.					
				0–3.	3–6.	6–9.	9–12.	12–16.	15–18.
1894.									
July 1-15 ..	242.2	290.6	178.0	48.9	31.6	15.6	3.1	0.4	0.4
July 16-31 ..	298.9	553.3	155.8	53.6	31.2	13.0	2.1	0.07	0.06
Aug. 1-15 ..	218.7	394.3	126.5	45.5	26.8	20.9	6.5	0.2	0.1
Aug. 16-31 ..	87.4	117.9	43.8	49.7	27.6	17.4	5.0	0.2	0.1
Sept. 1-15 ..	......	......	......	......	......	......	......	......	......
Sept. 16-30 ..	54.6	84.5	10.8	58.1	20.4	12.2	8.0	1.0	0.3
Oct. 1-15 ..	67.2	92.8	38.9	38.5	23.2	13.1	11.4	10.1	3.4
Oct. 16-30 ..	38.3	72.0	3.6	25.4	20.3	17.2	14.7	15.9	6.3
Nov. 1-15 ..	44.0	95.4	26.0	28.6	17.6	16.1	16.9	13.0	7.8
Nov. 16-30 ..	......	......	......	......	......	......	......	......	......
Dec. 1-15 ..	23.9	43.2	16.5	} 28.2	15.2	12.5	13.0	16.2	14.9
Dec. 16-31 ..	16.7	......	......						

TABLE D.—Continued.

	Av.	Max.	Min.	PER CENT. IN EACH 3 M. LEVEL.					
				0-3.	3-6.	6-9.	9-12.	12-15.	15-18.
1895.									
Jan. 1-15 ..	17.5	28.9	8.0	28.2	23.1	20.2	17.4	5.5	5.5
Jan. 16-31 ..	15.9	22.9	13.3						
Feb. 1-14 / Feb. 15-28	28.0	47.7	16.5	22.6	23.1	21.3	12.0	10.5	10.5
Mch. 1-15 ..	28.3	55.6	23.8	......	......	......	......	......	......
Mch. 16-31 ..	34.7	70.5	27.1	22.7	25.6	20.0	14.7	9.3	7.7
Apl. 1-15 ..	14.0	23.5	10.8	28.1	19.0	13.5	13.5	12.9	12.9
Apl. 16-30 ..	20.6	52.7	0.2	32.7	32.1	13.3	9.6	5.5	6.8
May 1-15 ..	34.4	45.1	17.2	58.2	22.6	12.0	3.3	2.0	1.9
May 16-31 ..	207.9	284.2	49.6	61.5	21.7	11.3	3.6	1.1	0.8
June 1-15 ..	285.0	459.8	178.1	57.3	24.1	9.6	3.3	2.6	3.1
June 16-30 ..	190.6	396.9	95.4	51.1	24.9	14.9	5.7	1.3	2.1
July 1-15 ..	187.4	397.5	105.5	41.4	30.1	22 6	4.8	0.8	0.3
July 16-31 ..	217.8	366.3	127.8	31.1	24.9	36.5	6.7	0.5	0.3
Aug. 1-15 ..	110.5	169.8	61.7	47.2	29.9	13.8	8.3	0.5	0.2
Aug. 16-31 ..	101.3	264.5	45.2	45.3	27.7	19.2	7.1	0.5	0.2
Sept. 1-15 ..	224.6	311.6	69.3	40.4	36.4	18.4	3.8	0.8	0.3
Sept. 16-30 ..	331.5	586.3	152.0	40.3	26.1	15.8	10.1	5.4	2.3
Oct. 1-15 ..	148.4	323.1	101.7	27.4	15 4	15.6	13.4	17.2	11.8
Oct. 16-31 ..	79.7	115.1	42.6	22.1	17.7	14.8	17.1	14.5	13.6
Nov. 1-15 ..	55.8	71.8	42.6	13.2	14.7	19.3	20.5	20.1	12.1
Nov. 16-30 ..	46.0	54.1	43.8	12.8	19.8	16.6	17.9	17.5	15.3
Dec. 1-15 ..	33.6	47.1	22.8	13.1	20.0	23.3	20.8	13.1	9.5
Dec. 16-31 ..	58.0	67.4	22.8	25.2	21.4	13.7	20.8	12.1	6.8
1896.									
Jan. 1-15 ..	48.6	62.9	40 0	26.2	24.0	21.9	9.9	9.3	8.7
Jan. 16-31 ..	23.3	34.3	22.8	25.4	16.2	20.7	20.7	14.0	3.0
Feb. 1-14 ..	38.9	57.5	27.3	28.0	24.4	11.9	14.0	14.6	7.0
Feb. 15-29 ..	34.9	......	......	33.0	16.3	16.4	14.4	10.8	9.1
Mch. 1-15 ..	......	......	......	24.1	16.0	20.0	18.3	11.7	10.0
Mch. 16-30 ..	33.3	38.8	26.7	19 0	14.6	23.4	30.7	6.0	6.3
Apl. 1-15 ..	35.2	43.4	21.6	26.2	24.0	21.9	9.9	9.3	8.7
Apl. 16-30 ..	29.9	66.7	9.5	16.3	28.3	19.6	19.6	10.9	5.3
May 1-15 ..	102.3	388.5	38.2	48.2	31.3	17.7	1.8	0.9	0.1
May 16-31 ..	360.2	645.5	227.6	38.2	22.4	18.5	10.6	6.1	4.0
June 1-15 ..	343.5	740.9	152.6	67.9	23.7	5.6	1.8	0.4	0.6
June 16-30 ..	386.2	725.6	103.0	69.9	22.9	5.0	1.6	0.2	0.3
July 1-15 ..	202.9	319.2	178.7	49.0	28.0	16.0	5.4	1.3	0.3
July 16-31 ..	152.1	222.6	93.4	62.6	23.2	9.6	4.0	0.3	0.1
Aug. 1-15 ..	91.9	......	......	65.0	24.8	8.8	1.0	0.2	0.0
Aug. 16-31 ..	167.0	......	......	31.8	37.4	13.6	15.7	1.2	0.0
Sept. 1-15 ..	125.9	......	......	37.2	28.2	21.6	7.5	3.1	2.3
Sept. 16-30 ..	163.4	......	......	30.1	22.8	13.0	9.3	11.2	13.5
Oct. 1-15 ..	52.8	......	......	25.2	19.8	12.6	10.8	22.6	9.0
Oct. 16-31 ..	48.8	......	......	39.0	20 6	15.6	14.4	7.8	2.6
Nov. 1-15 ..	29.8	......	......	28.9	18.5	23.6	11.5	17.5	0.0
Nov. 16-30 ..	28.5	......	......	15.6	18.7	6.3	21.9	15.6	21.9
Dec. 1-15 ..	29.3	......	......	19.3	30.0	3.9	19.2	14.5	13.1
Dec. 16-31 ..	24.7	......	......	23.1	27.0	20.7	11.6	9.2	8.4

TABLE E.—*Cyclops.—Average, maximum, and minimum numbers. Percentile vertical distribution.*

	Av.	Max.	Min.	PER CENT. IN EACH 3 M. LEVEL.					
				0–3.	3–6.	6–9.	9–12.	12–15.	15–18.
1894.									
July 1–15...	39.8	63.6	11.2	37.4	24.6	21.9	11.3	4.5	0.3
July 16–31...	151.0	347.2	53.2	44.4	31.2	13.8	9.8	1.8	0.1
Aug. 1–15..	161.0	297.6	85.2	41.0	28.8	22.5	7.4	0.1	0.1
Aug. 16–31..	200.3	270.3	130.3	39.5	28.7	22.4	8.9	0.4	0.1
Sept. 1–15..	......	......	......	......	......	......	......	......	......
Sept. 16–30..	190.1	272.2	129.7	42.3	25.7	16.2	12.1	3.1	0.6
Oct. 1–15...	347.1	421.6	251.8	33.5	21.6	15.7	13.9	8.4	6.9
Oct. 16–31...	261.3	383.1	173.0	15.7	20.1	17.4	17.8	18.4	10.6
Nov. 1–15..	246.4	440.1	108.8	12.9	17.8	15.9	22.4	21.2	9.8
Nov. 16–30..	......	......	......	......	......	......	......	......	......
Dec. 1–15...	75.0	243.5	44.5	22.7	15.6	13.5	10.8	15.3	22.1
Dec. 16–31...	44.5	46.1	42.6	29.6	14.1	17.4	15.3	12.0	11.6
1895.									
Jan. 1–15...	21.5	48.3	13.3	24.8	17.2	16.0	21.6	10.3	10.1
Jan. 16–31...	40.0	50.9	32.1	5.1	8.8	25.8	25.8	17.2	17.3
Feb. 1–14 } Feb. 15–28 }	82.7	112.6	55.3	5.1	9.1	7.1	8.3	35.2	35.2
Mch. 1–15..	55.7	104.9	39.4	9.3	13.2	8.5	9.9	8.9	50.2
Mch. 16–31..	66.2	143.1	49.6	15.2	17.0	9.9	9.9	24.0	24.0
Apl. 1–15...	53.9	63.6	38.2	29.2	17.1	13.3	10.2	15.1	15.1
Apl. 16–30...	242.5	604.8	82.0	39.3	22.1	13.7	7.9	6.8	10.2
May 1–15...	864.9	1252.8	759.0	42.7	23.8	14.2	7.5	4.8	7.0
May 16–31...	944.4	1234.2	715.3	30.5	17.6	15.3	10.6	11.5	14.5
June 1–15..	616.9	966.7	231.5	21.3	17.8	17.5	13.9	12.6	16.9
June 16–30..	262.6	361.8	197.7	33.0	22.4	13.9	7.6	7.4	15.7
July 1–15...	323.6	388.0	148.2	52.5	19.3	16.2	7.0	3.1	1.8
July 16–31...	131.4	218.4	85.2	32.8	31.8	25.4	8.9	0.3	0.8
Aug. 1–15..	107.6	189.1	64.8	46.0	27.2	14.0	10.1	2.5	0.2
Aug. 16–31..	129.6	343.7	108.1	36.4	27.7	20.7	13.5	1.3	0.3
Sept. 1–15..	142.0	237.2	169.8	34.7	23.1	24.0	12.8	3.9	1.4
Sept. 16–30..	226.0	308.4	169.8	24.5	20.5	18.3	16.3	11.7	8.7
Oct. 1–15...	327.5	338.5	313.5	26.6	15.3	14.9	15.4	14.6	13.3
Oct. 16–31...	219.7	242.3	202.2	23.9	15.2	15.7	18.8	15.6	10.7
Nov. 1–15...	144.7	157.7	138.6	18.2	15.8	14.0	19.7	17.0	15.3
Nov. 16–30...	146.3	158.3	136.1	16.4	14.0	16.2	20.7	16.5	16.1
Dec. 1–15...	90.2	100.4	76.3	14.3	20.0	15.7	17.3	17.1	15.5
Dec. 16–31...	89.1	104.3	52.1	11.2	11.9	14.7	26.6	16.9	18.7
1896.									
Jan. 1–15...	111.0	131.6	78.8	16.0	12.2	13.3	10.0	21.3	27.2
Jan. 16–31...	151.0	237.8	105.5	29.2	13.3	12.6	7.4	9.2	28.3
Feb. 1–14..	91.6	108.1	75.6	12.5	10.4	13.2	17.4	16.6	29.9
Feb. 15–29..	82.0	......	......	22.4	13.3	11.6	13.9	14.7	24.0
Mch. 1–15..	......	......	......	......	......	......	......	......	......
Mch. 16–31..	212.5	239.4	74.4	30.4	15.1	21.1	15.0	11.0	7.5
Apl. 1–15...	400.7	763.2	183.1	17.7	12.0	19.5	20.9	14.3	15.6
Apl. 16–30...	1011.2	1607.8	543.7	34.9	26.8	16.9	12.3	6.0	3.1
May 1–15...	1858.4	2359.6	1071.6	30.6	20.7	18.9	13.6	8.5	7.8
May 16–31...	705.9	1294.8	176.8	14.8	14.9	13.7	13.8	16.8	26.1

TABLE E.—Continued.

	Av.	Max.	Min.	PER CENT. IN EACH 3 M. LEVEL.					
				0-3.	3-6.	6-9.	9-12.	12-15.	15-18.
June 1-15 ..	189.5	297.6	139.2	30.0	20.0	11.1	9.8	8.3	20.5
June 16-30 ..	358.7	716.1	223.2	42.6	23.3	12.8	9.6	4.8	6.8
July 1-15...	371.0	442.0	341.5	37.0	29.0	14.6	9.0	9.3	1.0
July 16-31...	317.5	412.1	138.0	49.5	30.0	18.7	1.4	0.2	0.1
Aug. 1-15 ..	326.8	......	......	48.8	25.2	20.8	4.8	0.3	0.0
Aug. 16-31 ..	209.0	......	......	30.0	32.7	10.8	24.0	2.0	0.5
Sept. 1-15..	157.1	......	......	33.8	22.5	15.8	12.6	9.9	5.3
Sept. 16-30..	228.6	......	......	29.2	13.7	14.4	18.4	14.2	10.1
Oct. 1-15...	364.8	......	......	18.3	22.6	18.7	14.3	14.3	11.7
Oct. 16-31...	469.5	......	......	27.7	20.8	15.5	12.6	12.2	11.2
Nov. 1-15 ..	267.7	......	......	18.1	19.8	12.2	19.2	14.2	16.5
Nov. 16-30 ..	173.9	......	......	25.1	13.6	12.0	15.3	12.4	11.6
Dec. 1-15...	115.5	......	......	14.3	29.2	10.7	16.0	12.6	17.1
Dec. 16-31...	93.1	......	......	6.5	20.8	19.8	13.0	17.0	22.9

TABLE F.—*D. hyalina. Average, maximum, and minimum numbers. Percentile vertical distribution.*

	Av.	Max.	Min.	PER CENT. IN EACH 3 M. LEVEL.					
				0–3.	3–6.	6–9.	9–12.	12–15.	15–15.
1894.									
July 1–15....	19.8	32.8	8.5	38.1	23.4	20.2	14.1	3.2	0.9
July 16–31...	13.3	34.4	2.7	43.4	33.5	19.7	2.5	0.9	0.0
Aug. 1–15...	16.6	33.3	9.3	43.5	26.5	23.5	6.2	0.0	0.3
Aug. 16–31..	60.7	82.7	47.8	42.7	29.0	22.2	4.2	0.0	0.0
Sept. 1–15...	No ob	servat	ions.						
Sept. 16–30..	148.4	212.7	74.4	30.6	25.2	21.1	16.3	6.0	0.8
Oct. 1–15....	207.6	461.7	117.3	32.0	26.1	17.5	9.7	6.2	8.4
Oct. 16–31 ..	252.5	531.0	96.3	31.7	19.6	17.1	11.7	11.6	8.3
Nov. 1–15....	183.1	462.6	92.2	37.1	21.3	13.9	12.2	8.9	6.6
Nov. 16–30..		No ob	servat	ions.					
Dec. 1–15.. }	121.5	154.2	78.2	41.1	16.0	16.7	12.0	8.7	5.5
Dec. 16–31 }	(48.8)	56.9	40.7						
1895.									
Jan. 1–15....	40.8	65.4	36.7	24.1	18.7	16.7	18.7	10.9	10.9
Jan. 16–31 ..	55.9	61.0	53.4	30.4	27.7	5.3	11.2	12.7	12.7
Feb. 1–14 } Feb. 15–28 }	65.8	109.4	41.9	18.1	19.9	11.0	9.8	20.6	20.6
Mch. 1–15 ..	34.7	69.3	25.6	22.9	26.9	19.2	12.4	9.1	9.5
Mch. 16–31..	63.6	102.3	39.1	28.1	22.7	8.1	8.1	16.5	16.5
Apl. 1–15....	26.4	24.2	12.7	42.7	21.0	10.1	7.5	9.3	9.4
Apl. 16–30 ..	16.3	43.8	3.2	37.5	29.7	9.4	11.3	5.1	7.0
May 1–15....	28.9	81.4	7.9	67.0	22.2	5.7	2.6	1.3	1.1
May 16–31 ..	250.7	349.8	71.2	59.1	24.3	9.9	3.0	2.3	1.4
June 1–15 ..	319.2	564.8	183.1	42.2	19.4	12.5	11.5	6.6	7.8
June 16–30..	135.6	327.5	31.8	51.0	13.3	19.2	6.6	4.3	5.5
July 1–15....	139.9	263.9	21.0	56.1	20.9	17.7	4.4	0.5	0.4
July 16–31 ..	275.3	464.3	129.7	58.3	24.1	15.7	0.9	0.2	0 8
Aug. 1–15 ..	273.0	417.2	78.2	47.6	26.6	13.8	10.7	1.1	0.3
Aug. 16–31..	252.8	428.6	143.1	51.1	17.6	17.8	12.6	0.7	0.2
Sept. 1–15 ..	202.8	349.1	169.8	49.5	23.2	21.3	4.6	1.1	0.3
Sept. 16–30..	201.6	248.0	148.1	37.0	20.8	16.9	11.4	9.6	4.3
Oct. 1–15....	180.5	253.1	123.3	36.9	14.9	12.1	12.5	10.9	12.7
Oct. 16–31 ..	76.6	111.3	54 0	37.9	15.9	15.1	13.0	10.3	7.8
Nov. 1–15 ..	56.2	72.5	38.8	32.8	21.9	12.7	14.7	10.6	7 2
Nov. 16–30..	48.2	60.4	36.2	31.3	15.8	15.0	14.8	12.8	10.3
Dec. 1–15 ..	35.0	41.9	26.4	33.9	32.7	18.7	7.3	4.2	3.2
Dec. 16–31..	44.6	52.7	11.4	38.5	29.2	9.3	12.1	9.5	1.4
1896.									
Jan. 1–15....	36.2	57.8	15.2	31.7	35.8	19.9	4.8	4.2	3.6
Jan. 16–31 ..	17.3	20.3	10.8	41.0	25.4	19.1	6.4	4.7	3.4
Feb. 1–14 ..	19.6	29.6	13.3	26.9	24.2	12.7	10.7	10.6	14.9
Feb. 15–29 ..	27.0	......	......	37.6	21.2	15.3	7.0	14.1	4.7
Mch. 1–15 ..	......	......	......	......	......	......	......	......	......
Mch. 16–31..	13.5	27.3	6.9	32.1	14.1	34.9	10.4	4.7	3.8

TABLE F.—Continued.

	Av.	Max.	Min.	PER CENT. IN EACH 3 M. LEVEL.					
				0–3	3–6	6–9	9–12	12–14	15–18
1896.									
Apl. 1-15....	14.6	18.4	7.6	4.5	9.1	36.4	22.7	22.7	4.6
Apl. 16-30...	15.2	27.9	7.6	21.5	28.6	23.8	11.9	9.5	4.7
May 1-15....	124.6	360.0	52.1	45.0	32.9	16.4	2.5	2.8	0.4
May 16-31 ..	270.8	427.3	78.8	44.9	11.4	16.1	12.1	9.8	5.6
June 1-15 ..	55.6	156.4	6.3	59.4	20.3	12.6	5.6	1.3	0.5
June 16-30..	211.1	496.7	106.8	55.0	27.4	13.4	3.4	0.4	0.2
July 1-15 ..	319.0	783.4	132.9	56.4	26.0	13.6	3.3	0.6	0.1
July 16-31..	65.5	104.6	40.2	45.3	27.1	17.7	9.4	0.4	0.0
Aug. 1-15 ..	95.2	......	......	55.8	18.6	17.5	7.8	0.2	0.0
Aug. 16-31..	60.9	......	......	36.5	23.2	24.0	14.0	2.3	0.0
Sept. 1-15 ..	120.4	......	......	29.1	9.1	17.9	20.5	15.1	8.3
Sept. 16-30..	192.5	......	......	26.5	18.4	15.4	16.3	12.0	11.4
Oct. 1-15....	228.0	......	......	50.5	15.8	7.5	5.4	8.3	12.5
Oct. 16-31 ..	511.5	......	......	69.3	7.9	6.3	4.8	4.9	6.8
Nov. 1-15 ..	314.6	......	......	31.1	20.2	14.1	14.6	10.7	9.0
Nov. 16-30..	266.0	......	......	35.2	19.4	12.3	15.2	9.0	8.9
Dec. 1-15 ..	182.8	......	......	19.7	24.3	11.0	15.5	15.5	14.0
Dec. 16-31 ..	138.9	......	......	20.4	35.7	27.4	8.0	4.8	3.7

TABLE G.—*D. pulicaria. Average, maximum, and minimum numbers. Percentile vertical distribution.*

1895–96.	Av.	Max.	Min.	PER CENT. IN EACH 3 M. LEVEL.					
				0–3.	3–6.	6–9.	9–12.	12–15.	15–18.
July 16–31...	11.6	17.1	0.2	0.0	0.0	53.1	12.5	32.8	1.6
Aug. 1–15...	19.9	42.3	8.0	0.0	0.0	11.0	65.0	22.0	1.0
Aug. 16–31..	38.1	164.7	5.4	0.0	1.6	2.3	80.2	14.8	1.0
Sept. 1–15...	33.8	57.2	8.3	0.0	2.2	4.5	68.8	22.6	1.8
Sept. 16–30..	98.2	125.9	10.5	0.0	1.5	2.2	3.4	58.8	33 7
Oct. 1–15....	26.9	49.6	12.7	14.1	13.8	14.1	19.2	17.1	21.7
Oct. 16–31...	23.5	46.4	5.4	22.5	21.9	22.3	12.7	9.6	11.0
Nov. 1–15...	49.6	102.3	17.8	42.7	27.3	8.7	9.2	5.5	6.6
Nov. 16–30..	58.3	82.0	39.5	25.2	29.2	19.6	15.1	5.7	5.2
Dec. 1–15....	141.1	221.9	25.0	51.6	35.5	7.9	2.8	1.9	0.2
Dec. 16–31...	99.8	57.2	24.8	37.8	31.1	11.4	11.1	7.7	0.9
Jan. 1–15....	88.2	137.3	40.0	68.3	14.5	12.7	3.5	0.5	0.5
Jan. 16–31...	24.8	31.8	13.3	77.9	8.4	8.4	2.1	2.1	1.1
Feb. 1–14....	64.1	81.4	29.8	75.8	9.1	5.0	2.8	2.4	4.8
Feb. 15–29...	43.9	......	......	43.4	20.3	8.7	11.5	8.7	7.3
Mch. 1–15...	......	......	......	......	......	......	......	......	......
Mch. 16–31..	20.9	50.9	10.1	34.0	18.9	27.0	9.4	7.6	3.2
Apl. 1–15....	28.0	47.0	11.4	10.4	14.6	31.2	25.0	12.5	6.3
Apl. 16–30...	118.2	251.8	12.1	84.9	10.6	0.8	1.5	1.7	0.5
May 1–15....	284.9	683.2	85.8	13.1	16.2	19.5	12.0	16.7	22.4
May 16–31..	533.6	763.4	291.2	28.0	16.9	18.8	14.5	10.0	11.7
June 1–15...	168.6	260.7	56.6	17.5	10.0	15.0	21.3	10.1	25.8
June 16–30..	78.2	157.7	13.3	1.9	6.2	11.7	16.0	45.8	18.5
July 1–15....	39.3	52.1	19.7	0.0	0.9	8.6	27.0	57.0	6.5
July 16–31...	11.8	38.2	0.6	0.0	0.0	62.8	33.4	2.0	1.8
Aug. 1–15...	3.7	......	......	0.0	10.0	17.0	71.0	2.0	0.0
Aug. 16–31..	5.9	......	......	0.0	0.0	0.0	80.0	20.0	0.0

TABLE H.—*D. retrocurva. Average, maximum, and minimum numbers. Percentile vertical distribution.*

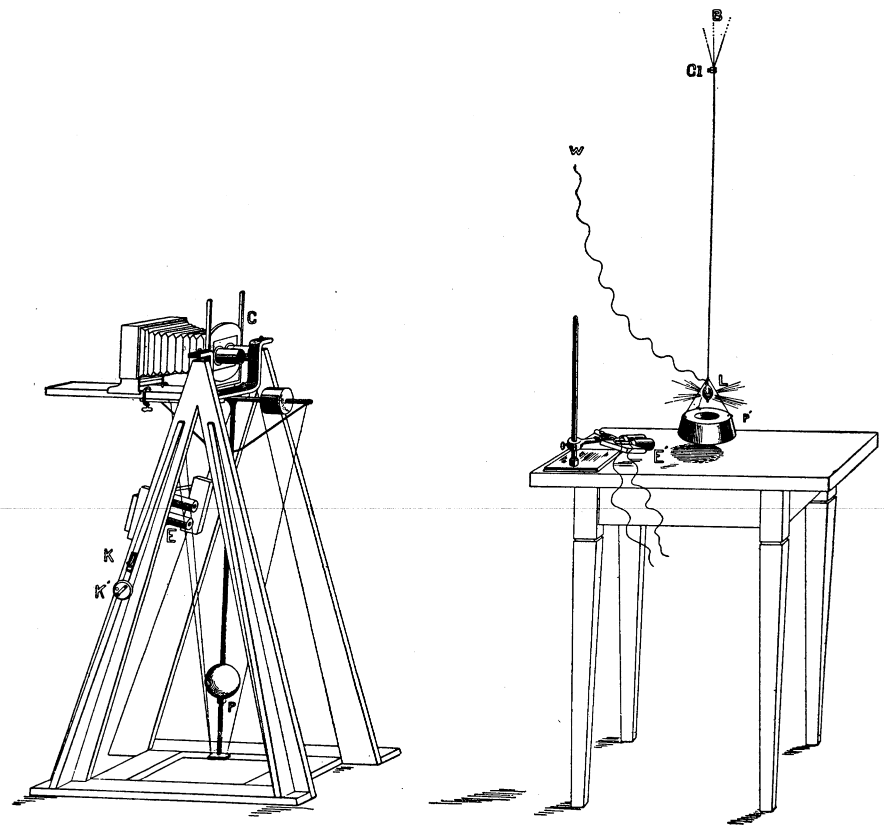
	Av.	Max.	Min.	PER CENT. IN EACH 3 M. LEVEL.					
				0–3.	3–6.	6–9.	9–12,	12–15	15–18.
1895.									
July 1-15....	9.7	14.6	0.0	47.0	25.5	13.1	14.4	0.0	0.0
July 16-31...	31.5	59.7	3.5	50.0	24.0	24.8	1.2	0.0	0.0
Aug. 1-15...	68.2	154.8	8.9	37.1	26.1	16.8	18.5	1.3	0.1
Aug. 16-31..	50.1	96.0	20.5	41.1	21.3	22.7	13.7	1.1	0.1
Sept. 1-15...	23.8	37.5	11.5	46.4	23.5	20.3	6.4	2.9	0.5
Sept. 16-30..	59.6	74.4	21.6	33.8	24.1	15.7	11.6	7.8	6.9
Oct. 1-15....	72.5	103.6	50.9	35.9	15.2	17.9	7.5	11.7	11.7
Oct. 16-31...	70.9	65.5	33.7	29.2	10.0	12.3	10.6	9.1	28.7
Nov. 1-15....	59.3	79.5	42.6	24.2	20.2	12.6	18.4	14.2	10.3
Nov. 16-30...	24.2	37.5	19.1	30.7	20.2	14.9	12.3	10.0	11.9
Dec. 1-15....	5.0	11.4	1.9	3.7	0.0	41.3	17.5	18.7	18.7
Dec. 16-31...	0.7	0.9	0.0	0.0	0.0	27.3	36.4	18.2	18.2
1896.									
July 16-31...	2.5	......	......	Irreg	ular	near	surfa	ce.	
Aug. 1-15...	27.6	......	......	59.0	32.4	8.0	0.4	0.2	0.0
Aug. 16-31..	57.1	......	......	36.5	23.2	24.0	14.0	2.3	0.0
Sept. 1-15...	157.7	......	......	26.2	17.3	19.3	19.4	12.4	5.3
Sept. 16-30..	228.6	......	......	26.5	18.4	15.4	16.3	12.0	11.4
Oct. 1-15....	199.3	......	......	26.4	20.0	14.3	10.8	13.0	15.5
Oct. 16-31...	92.7	......	......	43.5	18.8	8.8	10.8	10.4	7.6
Nov. 1-15....	9.9	......	......	29.0	30.7	0.0	0.0	13.5	26.8

TABLE I.—*Diaphanosoma. Average, maximum, and minimum numbers. Percentile vertical distribution.*

	Av.	Max.	Min.	PER CENT. IN EACH 3 M. LEVEL.					
				0-3.	3-6.	6-9.	9-12.	12-15.	15-18.
1894.									
Sept. 16-30..	19.6	68.4	6.9	50.0	29.4	8.1	7.9	4.6	0.0
Oct. 1-15....	5.2	7.8	0.7	34.1	24.4	20.7	4.9	11.0	4.9
Oct. 16-31...	3.0	5.4	0.0	0.0	25.0	43.8	0.0	25.0	6.2
1895.									
Aug. 1-15...	31.5	47.0	25.1	52.9	29.6	13.5	3.8	0.2	0.0
Aug. 16-31..	32.2	56.1	17.8	39.3	28.4	24.6	6.8	0.6	0.3
Sept. 1-15...	27.1	63.6	15.2	36.6	35.7	19.7	6.0	1.7	0.2
Sept. 16-30..	17.2	37.3	2.9	41.7	19.5	14.0	17.7	7.1	0.0
Oct. 1-16....	3.4	10.8	1.2	11.3	0.0	34.0	32.1	22.6	0.0
1896.									
Aug. 1-16...	8.9	......	......	73.5	24.1	1.8	0.6	0.0	0.0
Aug. 16-31..	147.2	......	......	45.1	28.3	19.3	6.1	1.0	0.1
Sept. 1-15...	108.3	......	......	30.7	24.0	21.0	12.4	10.7	0.1
Sept. 16-30..	32.9	......	......	31.2	20.2	11.5	13.3	11.5	12.3
Oct. 1-15....	0.4	......	......	......	......	......	......	......	......

TABLE J.—*Chydorus.— Average, maximum, and minimum numbers. Percentile vertical distribution.*

	Av.	Max.	Min.	PER CENT. IN EACH 3 M. LEVEL.					
				0-3.	3-6.	6-9.	9-12.	12-15.	15-18.
1894.									
Sept. 16-30..	278.9	440.7	96.6	55.0	26.9	10.6	5.6	2.0	0.0
Oct. 1-15....	193.3	251.2	92.8	12.3	13.3	16.4	21.6	21.6	14.8
Oct. 16-31...	202.0	304.6	82.0	14.2	17.8	18.0	18.7	19.9	11.3
Nov. 1-15....	97.9	261.3	13.3	7.3	15.5	18.6	28.4	19.3	10.8
Dec. 1-15....	9.5	15.9	3.8	16.7	20.6	13.3	16.7	18.7	14.0
1895.									
June 1-15 ...	36.7	92.8	11.1	41.9	24.9	13.0	9.4	5.0	5.6
June 16-30 ..	21.9	45.7	6.9	83.1	13.4	2.4	......	1.1	0.0
July 1-15....	156.8	271.5	13.3	61.1	25.3	11.0	2.2	0.4	0.0
July 16-31...	163.4	283.6	89.0	42.8	35.2	20.3	1.2	0.2	0.2
Aug. 1-15 ...	78.6	157.7	16.8	43.2	30.4	18.4	7.3	0.5	0.1
Aug. 16-31 ..	18.7	48.7	5.0	32.7	33.3	21.8	11.2	1.1	0.0
Sept. 1-15...	15.6	39.4	8.9	45.5	23.6	22.8	4.8	3.4	0.0
Sept. 16-30..	......	Scatte	ring	only.					
Oct. 1-15....	8.6	14.3	5.0	17.6	17.6	6.6	12.5	14.7	30.9
Oct. 16-31...	8.1	12.0	3.8	46.8	14.1	7.8	23.5	7.8	0.0
Nov. 1-15....	25.9	46.4	10.8	11.4	15.3	14.3	24.3	21.3	13.4
Nov. 16-30...	19.7	29.8	13.9	9.2	18.8	24.0	21.6	16.1	10.3
Dec. 1-15....	15.9	19.7	12.0	26.0	6.6	18.2	10.5	16.8	22.0
Dec. 16-31...	20.9	36.8	8.9	23.0	18.6	11.8	22.6	17.6	6.3
1896.									
May 1-15....	28.0	48.3	19.0	15.9	23.4	23.8	16.2	8.9	11.8
May 16-31...	30.8	68.6	13.3	34.0	23.6	15.9	19.9	4.3	2.3
June 1-15....	87.6	279.8	4.4	77.6	15.8	4.7	1.0	0.4	0.3
June 16-30..	230.8	346.0	145.6	65.0	24.4	7.0	2.6	0.5	0.3
July 1-15....	382.0	661.4	169.8	57.0	33.6	6.9	2.0	0.3	0.0
July 16-31...	245.1	465.5	129.1	43.2	34.1	20.0	2.7	0.2	0.0
Aug. 1-15....	406.5	......	......	54.8	32.0	10.4	2.2	0.5	0.0
Aug. 16-31 ..	426.0	......	......	32.4	36.2	21.0	8.5	1.7	0.1
Sept. 1-15 ..	748.6	......	......	34.9	26.7	17.0	15.2	5.6	0.7
Sept. 16-30..	263.0	......	......	25.0	14.8	14.9	12.2	18.1	14.9
Oct. 1-15....	423.7	......	......	10.3	15.0	25.8	21.0	14.5	13.4
Oct. 16-31...	191.9	......	......	16.9	18.1	17.1	12.8	16.6	18.4
Nov. 1-15 ...	62.7	......	......	18.7	22.4	13.0	13.4	12.7	19.8
Nov. 16-30 ..	69.3	......	......	21.3	12.0	26.7	17.3	10.6	12.1
Dec. 1-15....	38.2	......	......	15.0	16.2	13.4	19.1	16.2	20.1
Dec. 16-31...	28.1	......	......	12.8	25.0	15.0	17.6	19.6	10.0



B
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W
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K'
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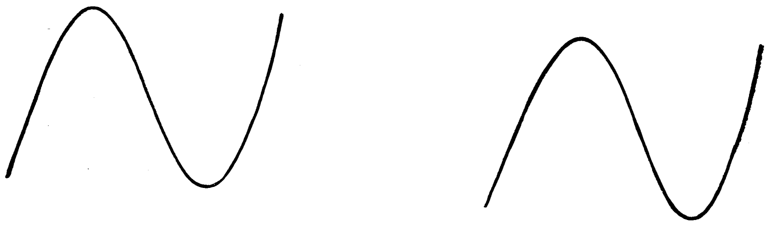

Fig. 1.—Ratio 1 : 2 : 3.

Fig. 2.—Ratio 1 : 2 : 3.

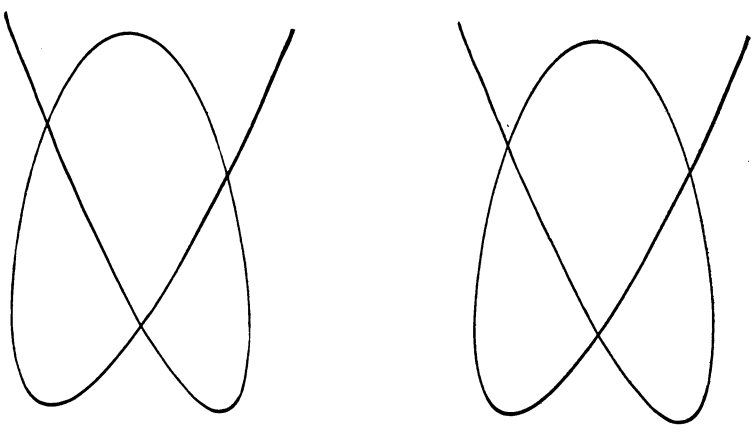

Fig. 3.—Ratio 2 : 3 : 4.
1 double point.

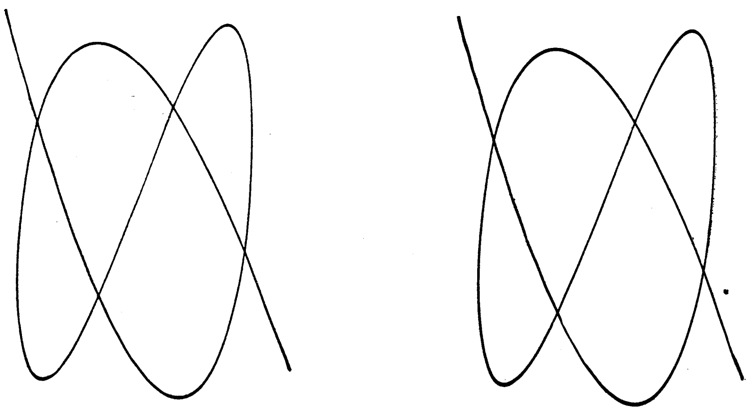

FIG. 4.—Ratio 2 : 3 : 5.

FIG. 5.—Ratio 2 : 4 : 5.
2 double points.

FIG. 6.—Ratio 3 : 4 : 5.

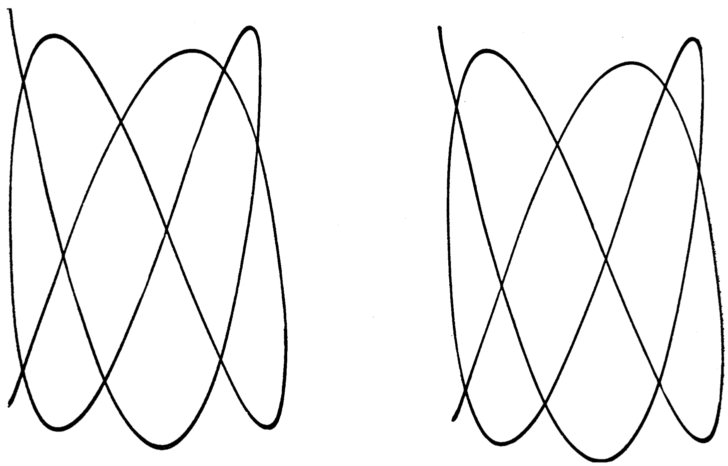

FIG. 7.—Ratio 3 : 4 : 7.

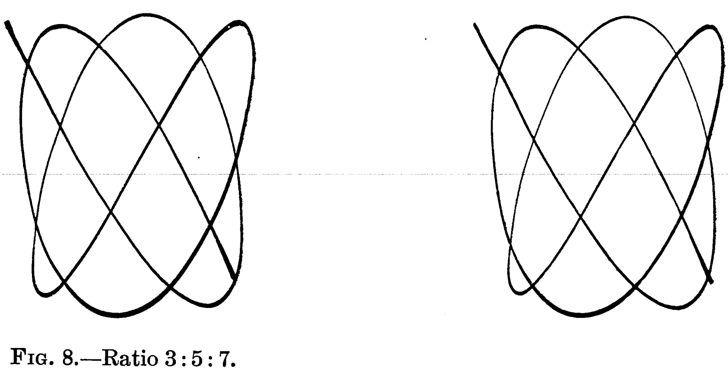

FIG. 8.—Ratio 3 : 5 : 7.

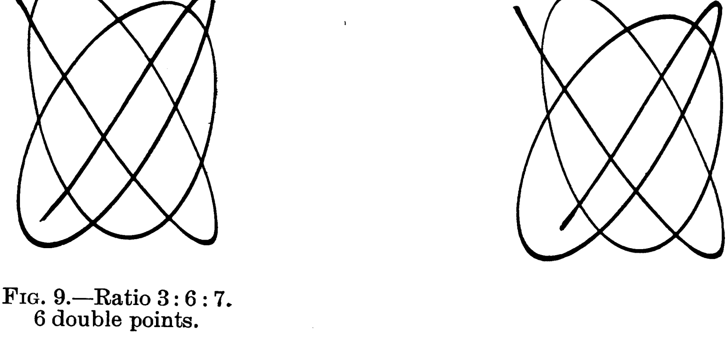

FIG. 9.—Ratio 3 : 6 : 7.
6 double points.

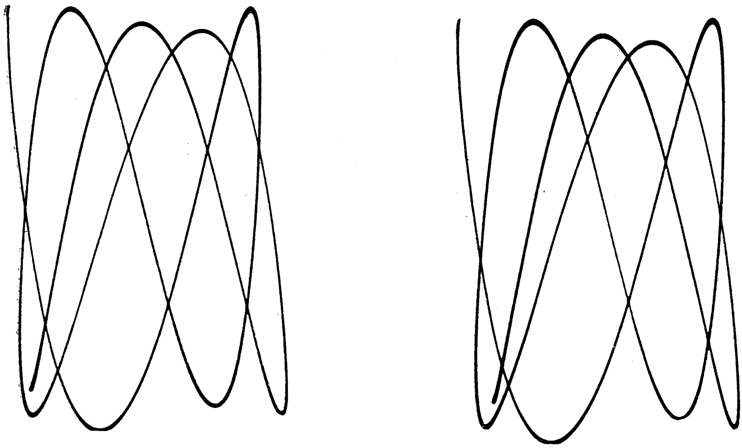

Fig. 10.—Ratio 3 : 4 : 9.
6 double points.

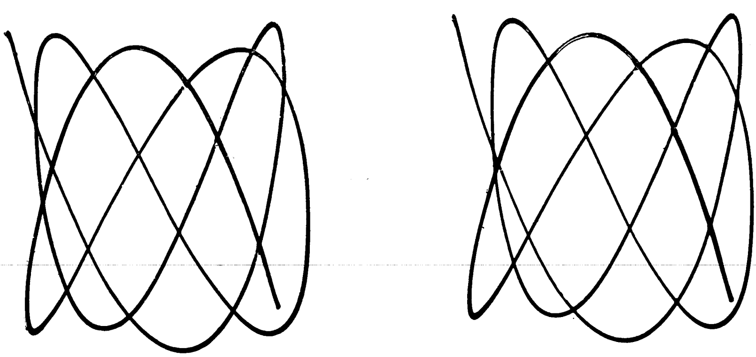

Fig. 11.—Ratio 3 : 5 : 9.
4 double points.

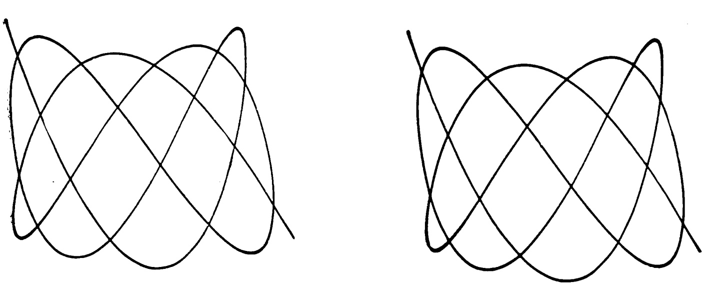

Fig. 12.—Ratio 4 : 5 : 9.

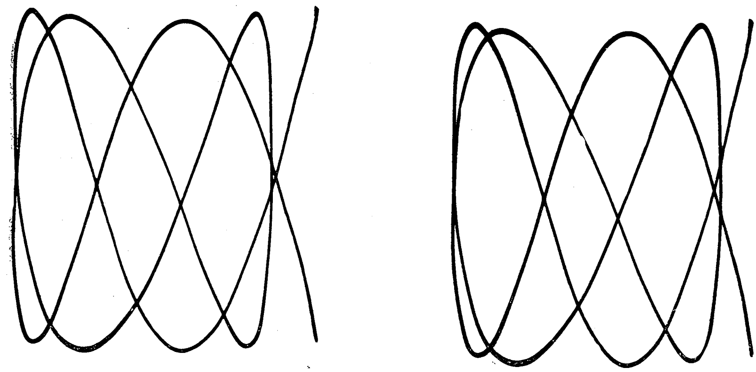

Fig. 13.—Ratio 4 : 6 : 9.
6 double points.

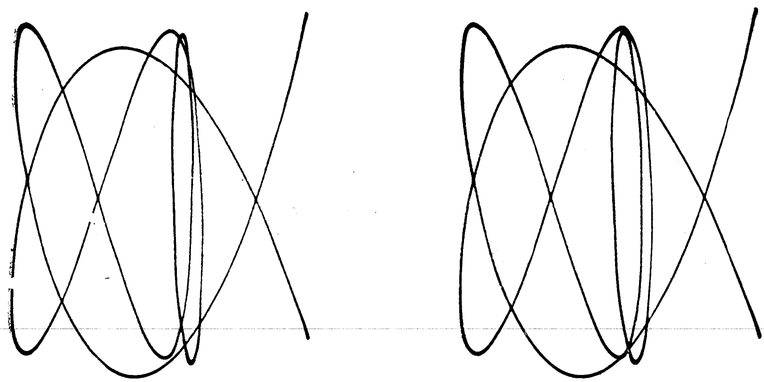

Fig. 14.—Ratio 4 : 6 : 9.
6 double points.

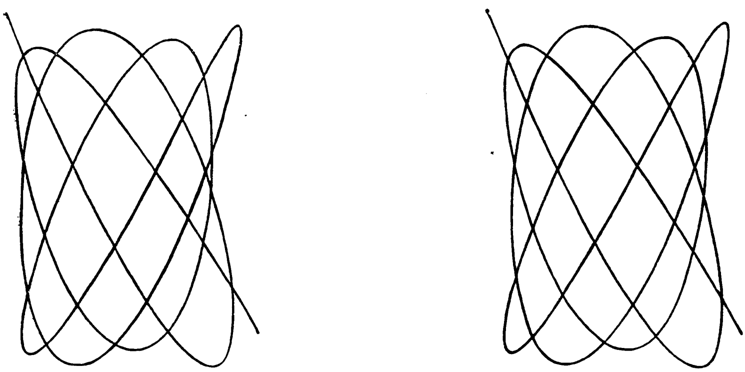

Fig. 15.—Ratio 4 : 7 : 9.

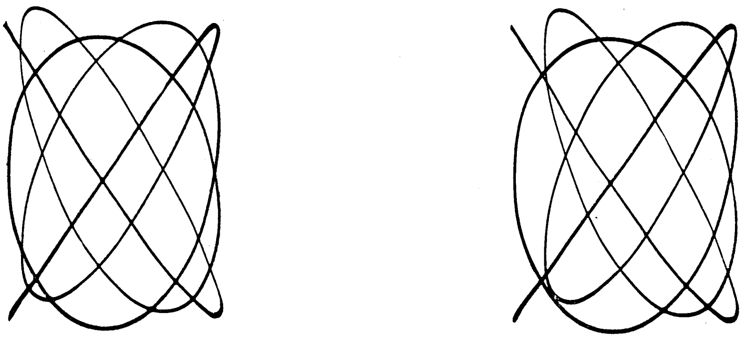

FIG. 16.—Ratio 4 : 8 : 9.
12 double points.

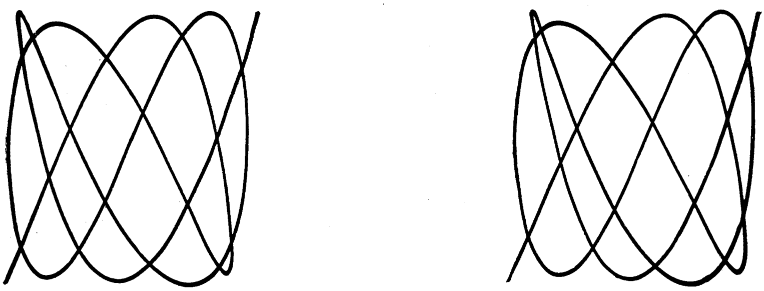

FIG. 17.—Ratio 5 : 6 : 9.
4 double points.

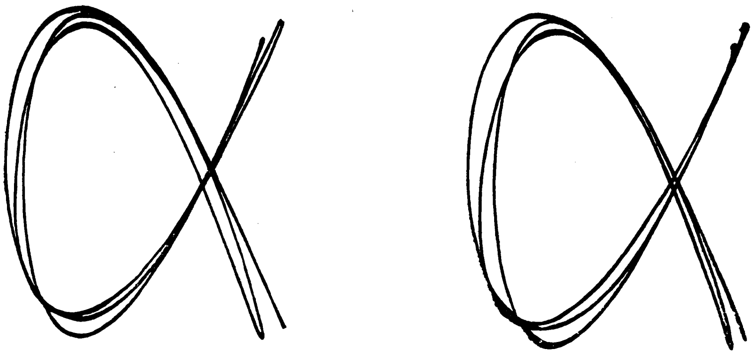

FIG. 18.—Ratio 5 : 6 : 9.
4 double points.

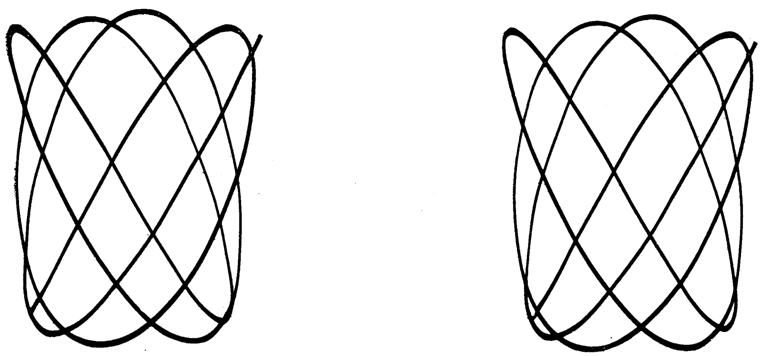

FIG. 19.—Ratio 5 : 7 : 9.

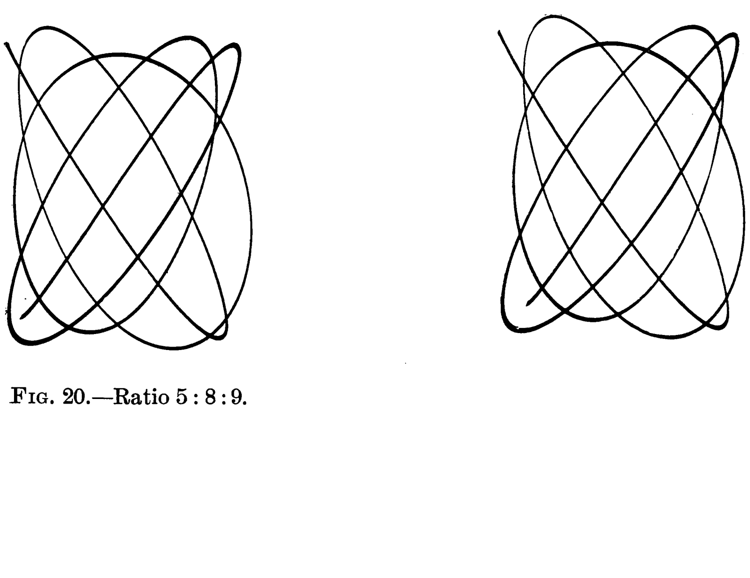

FIG. 20.—Ratio 5 : 8 : 9.

HARMONIC CURVES OF THREE FREQUENCIES.

CHARLES S. SLICHTER,

Professor of Applied Mathematics, University of Wisconsin.

Much interest attaches to the plane curves which result from compounding two harmonic motions of different frequencies at right angles to each other. This interest is doubtless due as much to the intrinsic beauty of the curves themselves as to their actual importance in physics and mechanics. Lissajous' famous memoir[1] on "L'Étude Optique des Mouvements Vibratoires" has probably contributed more to make his name known than all of the rest of his scientific work taken together. As a matter of fact, however, the path described by a particle of an elastic body is frequently not a plane curve resulting from the composition of two harmonic motions, but is a curve of double curvature in space, being the resultant of three harmonic motions in three different directions and of different frequencies. The present paper has for its object the description of a simple form of apparatus designed to give stereoscopic photographs of curves of this class. The apparatus enables one to produce stereoscopic photographs of the path of a particle resulting from compounding three harmonic motions, provided the component motions are in phase and at right angles to each other.

Plate XLIII represents the apparatus used. A Blackburn pendulum, B P′, nearly three meters long, carries a small electric pea lamp L, and can be adjusted by the clamp Cl so that the bob P′ will describe a Lissajous' curve having for its frequencies two of the three frequencies desired. A stereoscopic camera C is clamped in the Y of the pendulum shown in the left of the diagram, so that the optical centers of the lenses are

[1] Annales de Chimie et de Physique, 1857, 3e série, tome LI.

approximately in line with the two steel points which support the pendulum P. If the pendulum bob P be adjusted so that the pendulum has the third desired frequency, then when the pendulum P is vibrating, the image of the lamp L will describe upon the sensitive plate of the camera harmonic motion of the desired frequency. To secure a photograph containing a curve possessing all three of the frequencies, the bob of the Blackburn pendulum is held at one corner of the table by the electro-magnet E′ and, at the same time, the camera pendulum is held at the end of its swing by the electro-magnet E. The electro-magnets are on the same circuit and are controlled by the key K′. The key K is then pressed to illuminate the electric lamp L, and immediately afterwards the pendulums are released by the key K′. At the close of the complete period of the compound harmonic curve, the key K is released, extinguishing the light L.

There are given in figures 1–20 copies of stereoscopic photographs taken by means of the apparatus above described. The camera could be placed on either of two adjacent sides of the table and two views made of the same curve, if so desired. Figures 1 and 2, also 17 and 18, present views of the same curves taken from adjacent sides of the table. Figure 14 shows the same curve as figure 13, but is taken from a point opposite the corner of the table.

Mr. Elting H. Comstock, at that time a senior in the University of Wisconsin, succeeded in working out, by an original method, the number of intersections or double points in the plane harmonic curves, and, by the same method, succeeded in obtaining the number of double points in harmonic curves of three frequencies. The formulas obtained by him are as follows:

Let $n:r:s$ be the ratio of the periods of the component harmonic motions. Let α be the highest common factor of r and s, β the highest common factor of s and n, and γ the highest common factor of n and r. The number of double points is then given by

$$\frac{(n-1)(\alpha-1)}{2}+\frac{(r-1)(\beta-1)}{2}+\frac{(s-1)(\gamma-1)}{2}$$
$$-\frac{(\alpha-1)(\beta-1)}{2}-\frac{(\beta-1)(\gamma-1)}{2}-\frac{(\gamma-1)(\alpha-1)}{2} \qquad (1)$$

If n and r are prime to each other, this reduces to

$$\frac{(n-1)(\alpha-1)}{2}+\frac{(r-1)(\beta-1)}{2}-\frac{(\alpha-1)(\beta-1)}{2} \qquad (2)$$

If n is prime to both r and s, this reduces to

$$\frac{(n-1)(\alpha-1)}{2} \qquad (3)$$

If n, r and s are prime to each other, there will be no double points at all.

The derivation of these formulas is given in Mr. Comstock's paper, which immediately follows the present one.

Madison, Wis., Nov. 27, 1897.

THE REAL SINGULARITIES OF HARMONIC CURVES OF THREE FREQUENCIES.

ELTING H. COMSTOCK.

INTRODUCTION.

In the year 1800, Thomas Young[1] called attention to the paths traversed by any particle in a vibrating string. This led Wheatstone[2] in 1827 to study the vibrations of a rod fixed at one end. He found that if the rod was square or circular in section, the vibration of any point of the rod was in a plane passing through the axis of the rod, unless forced out by an external disturbance. When the rod was rectangular in section the path described by any point was no longer a straight line, or more properly the arc of a circle, but the point followed a complex path, depending for its complexity, upon the ratio of the lengths of the two sides of the rectangle forming the section. Lissajous,[3] in 1857, in his well known memoir on "L'etude Optique des Mouvements Vibratoires," made an exhaustive study of these curves and from that fact they are now commonly designated as "Lissajous' Curves The equations of the Lissajous' Curves are

$$x = \cos (rt + e_1) \qquad y = \cos (st + e_2),$$

t being the parameter, r/s the ratio of the number of vibrations parallel to the x axis to the number of those parallel to the y axis, and e_1 and e_2 the differences in phase.

Wilhelm Braun[4] has studied these curves from the geometri-

[1] Phil. Trans. for 1800, pp. 106–150.

[2] Quart Jour. Sci. for 1827, Vol. I, pp. 344–351; also Poggend. Annal. for 1827, Vol. X, pp. 470–480.

[3] Annales de Chimie et de Physique, 1857. 3e série, tome LI.

[4] Dissertation Erlangen. Mathematische Annalen, 1875. Band VIII, s. 567–573.

cal standpoint. He finds the algebraic equation to be of the $2r$th order (r being by supposition greater than s). He then determines the algebraic equation of the general curve. As the equation can be expressed by means of a parameter, its deficiency is zero and therefore it has the maximum number of double points, which is $(2r-1)(r-1)$. These he next locates. He then finds the class of the curve to be $2(r-s)$, which gives for the number of double tangents $2(r+s)^2 - 3(r+s)+1$. He then makes use of Plücker's formulae and finds the number of inflexions, and finally discusses the curve on a Riemann's surface.

For the curve whose phase difference is zero, he finds the number of real double points to be

$$(A) \qquad \frac{(r-1)(s-1)}{2}$$

and the number of real inflexions

$$(B) \qquad r-s-1$$

(r being greater than s).

In the work which follows I shall obtain the number of real double points of the curve $x=\cos rt$, $y=\cos st$ by determining the number of pairs values of t which make the two values of x, corresponding to these values of t, equal and also makes the values of y, corresponding to the t's, equal. The real inflexions will be found by the consideration of the conditions which can cause the second derivative to change sign between different values of t.

The object of the present paper is to determine the number of double points in the curve which results from compounding three harmonic motions, in phase, at right angles to each other. The equations to such a curve are

$$x=\cos nt \qquad y=\cos rt \qquad z=\cos st.$$

The method used for these curves of double curvature is similar to the method used in the case of the plane harmonic curves.

If n and r have a common factor ϵ, n and s a factor δ, and r and s a factor γ, I find that the number of real double points is

$$(C)\qquad \frac{(n-1)(\gamma-1)}{2}+\frac{(r-1)(\delta-1)}{2}+\frac{(s-1)(\varepsilon-1)}{2}$$
$$-\frac{(\gamma-1)(\delta-1)}{2}-\frac{(\delta-1)(\varepsilon-1)}{2}-\frac{(\varepsilon-1)(\gamma-1)}{2}$$

If ϵ is equal to unity, that is, if n and r are prime, this number will evidently reduce to

$$(D)\qquad \frac{(n-1)(\gamma-1)}{2}+\frac{(r-1)(\delta-1)}{2}-\frac{(\gamma-1)(\delta-1)}{2}$$

If ϵ is equal to unity and δ is equal to unity, that is, if n is prime to both r and s, the number reduces to

$$(E)\qquad \frac{(n-1)(\gamma-1)}{2}$$

If all three numbers n, r, and s are prime to each other, there are no double points, for then ϵ, δ, and γ will each equal unity and the formula above written reduces to zero. In each of the last three special cases the number of double points can be found by an independent method, without using the general formula.

The conditions of symmetry for both classes of curves have been found and are given for all cases that can arise. The conditions for the plane curves were given in Lissajous' original article, but I believe those for the curves of double curvature have never before been worked out.

PLANE CURVES.

§1. *Periodicity of the curve.*—

It is easy to show that the curve $x = \cos rt$, $y = \cos st$ is completed in a cycle in which t passes from 0 to π.

It is also easily shown that if $r = \delta\alpha$ and $s = \delta\beta$, (δ being the highest common factor of r and s) the curve $x = \cos rt$, $y = \cos st$ is a δ fold trace of the curve $x = \cos \alpha t$, $y = \cos \beta t$.

§ 2. *To determine the number of double points in the curve $x = \cos rt$, $y = \cos st$, r and s being considered prime to each other.*

Since, when the numbers r and s are prime to each other, the curve is traversed but once in the interval from $t = 0$ to $t = \pi$, in order that a double point may exist there must be two values of t less than π for which the corresponding values of x and y are equal. Suppose a double point occurs when $t = a\pi/b$, in which $a \ngtr b$, and a and b are prime to each other. The co-ordinates of the double point will then be

$$x = \cos \frac{r a \pi}{b}, \qquad y = \cos \frac{s a \pi}{b}$$

Of course b cannot be a factor of r or of s. If we call t' the second value of t corresponding to the double point, we know from the properties of the cosine that t' must be of such form that the co-ordinates of the double point will be given by

$$x = \cos\left(2h\pi \pm \frac{r a \pi}{b}\right), \qquad y = \cos\left(2k\pi \pm \frac{s a \pi}{b}\right)$$

Therefore t' must equal both $\left(\frac{2h}{r} \pm \frac{a}{b}\right)\pi$ and $\left(\frac{2k}{s} \pm \frac{a}{b}\right)\pi$.

Since t' can have but one value, these two values must be equal to each other, that is,

$$(1) \qquad \frac{2h}{r} \pm \frac{a}{b} = \frac{2k}{s} \pm \frac{a}{b}$$

The signs before a/b on each side of this equation cannot be the same, for if they were the equation would become $h/r = k/s$. This, since r and s are prime to each other, can only be true when h and k are equal integral multiples of r and s respectively. Let $h = er$ and $k = es$. Then t' equals $2e\pi \pm a\pi/b$ which, since by hypothesis a is less than b, would be greater than π; but t' cannot be greater than π for a single tracing of the curve. Hence h and k can never be equal integral multiples of r and s respectively, and the signs before a/b on each side of the equation (1) must differ.

Now h and k cannot be greater than $[r/2]$ and $[s/2]$ respectively, as, in case they should, $(2\,h/r \pm a/b)\pi$ or $(2\,k/s \pm a/b)\pi$ would be greater than π.

It was shown above that in the equation

$$(2\,h/r \pm a/b)\,\pi = (2\,k/s \pm a/b)\,\pi$$

the signs before a/b in each term must differ. Therefore we can change the form of the equation to

$$\pm \frac{ars}{b} = kr - hs.$$

If we assume that a/b is in its lowest terms, b must then equal rs, since $hs - kr$ is a whole number. This then gives rise to the conditions for the entrance of double points, viz.:

$$(2) \qquad \pm\, a = k\,r - h\,s.$$

in which $k \ngtr [s/2]$ and $h \ngtr [r/2]$, and k can have $[s/2]$ values and h can have $[r/2]$ values, provided no two values for $\pm\, a$ so given are equal.

To show that no two values of $\pm\, a$ given by (2) can be equal to each other, we write (2) in the form of a congruence,

$$k\,r \equiv \pm\, a \pmod{s}.$$

Multiplying each side of this congruence by $r^{\varphi(s)-1}$ and simplifying by means of Fermats' theorem, we find that

$$k \equiv \pm ar^{\varphi(s)-1} \pmod{s}$$

which shows that for a given value of $\pm\, a$, there is an interval of s units between successive values of k giving rise to the same value of $\pm\, a$. As was shown above, the values of k in (2) must all be less than $[s/2]$, so that no two values of k can differ by s units. Therefore in the series of values for $\pm\, a$ given by (2) no two can be equal.

As a result of the ambiguous sign in (2), there will be a positive and a negative value of a for every set of values of h and k. Since we are examining the curves for values of t between

0 and π only, we do not consider the negative values of a, as these would evidently give rise to negative values of t. There will be, then, $[r/2][s/2]$ values of a for which the corresponding t gives rise to one crossing, or to one double point.

If we substitute the values of the positive a, which we shall from now on denote by a, in the equation for determining t', we find that t' will equal $\pi(kr+hs)/rs$. For the sake of brevity we shall denote $(kr+hs)$ by a'.

From the symmetry of the values of the cosine, we might expect that $\pi - a\pi/rs$ would also give rise to a double point with the second crossing when $t = \pi - a'\pi/rs$. Substituting these values in the equation of the curve we get

$$x = \cos r\left(\pi - \frac{a\pi}{rs}\right), \qquad x' = \cos r\left(\pi - \frac{a'\pi}{rs}\right)$$

$$= \pm \cos\frac{ra\pi}{rs} \qquad = \pm \cos\frac{ra'\pi}{rs}$$

$$y = \cos s\left(\pi - \frac{a\pi}{rs}\right), \qquad y' = \cos s\left(\pi - \frac{a'\pi}{rs}\right)$$

$$= \pm \cos\frac{sa\pi}{rs} \qquad = \pm \cos\frac{sa'\pi}{rs}$$

which, as is easily seen from the form of a and a', are the coördinates of double points.

We have now to determine whether any of the double points given by $\pi - a\pi/rs$ are the same as those given by $a\pi/rs$. Three cases can arise: r and s can both be odd; r even and s odd; or s even and r odd.

In the first case it is evident, from the form of the equations in (3), that the coordinates of the double points for $\pi - a\pi/rs$ are all the negatives of those for $a\pi/rs$, since $\cos[(2n+1)\pi - \theta] = -\cos\theta$. If, then, no two values of $a\pi/rs$ give rise to double points, each of which has as coordinates the negatives of the coordinates of the other, and the point $x=0$, $y=0$, is not a double point given by $a\pi/rs$, the double points of $\pi - a\pi/rs$ are all distinct from those of $a\pi/rs$. To show that no double point given by $a\pi/rs$ has as either coordinate, the negative of the corresponding coordinate of another double point, given by another value of $a\pi/rs$, we suppose that $kr - hs$ gives rise to one value of a, and $k'r - h's$ gives rise to another value of a. In order for one double point to have as abcissa the negative of the abcissa of the other,

$$\cos \frac{r(kr-hs)}{rs}\pi = \cos\left[(2n+1)\pi \pm \frac{r(k'r-h's)\pi}{rs}\right]$$

or

$$\frac{r(kr-hs)}{rs} = (2n+1) \pm \frac{r(k'r-h's)}{rs}$$

which is easily seen to reduce to

$$\frac{k \pm k'}{s} = \frac{(2n+1 \mp h'+h)}{r},$$

a relation which is manifestly impossible since $k \not> [s/2]$ and $h \not> [r/2]$, and r and s are prime to each other.

In a similar manner it can be shown that no two ordinates given by $a\pi/rs$ can be the negatives of each other. As the reasoning for either abscissas or ordinates does not depend on both r and s being odd, these proofs hold equally well in the cases when r is even and s odd, and when r is odd and s even.

In order that $x=0$, $y=0$, may be a double point given by $a\pi/rs$, $\cos ra\pi/rs$ and $\cos sa\pi/rs$ must both equal zero. $ra\pi/rs$ and $sa\pi/rs$ must then be of the form $m\pi/2$. Call $ra\pi/rs$, $m_1\pi/rs$ and $sa\pi/rs$, $m_2\pi/2$; a must then both equal $m_1s/2$ and $m_2r/2$, which is impossible since $a < rs$ and r and s are prime to each other.

Therefore, when r and s are both odd, the double points given by $\pi - a\pi/rs$ are all distinct from those given by $a\pi/rs$ and the number is then $2[r/2][s/2]$ which equals,

$$\frac{(r-1)(s-1)}{2}.$$

In case r is even and s odd it is easily seen from an examination of equations (3) that $a\pi/rs$ and $\pi - a\pi/rs$ can give rise to the same double point only when $a\pi/rs$ is such that $y=0$, and that, whenever such is the case, $a\pi/rs$ and $\pi - a\pi/rs$ do give rise to the same double point.

$$y = \cos sa\pi/rs = \cos s(kr-hs)\pi/rs = \cos (k\pi - hs\pi/r) = 0.$$

only when $h = r/2$, k having any value. k has $(s-1)/2$ possible values. Therefore, for $(s-1)/2$ values of $a\pi/rs$, $a\pi/rs$ and $\pi - a\pi/rs$

give rise to the same double point. Therefore, there are, when r is even and s odd,

$$2\,[r/2]\,[s/2] - [s/2] \text{ or } \frac{(r-1)(s-1)}{2}$$

double points in the curve.

In case r is odd and s even it is easily seen that a similar reasoning holds, giving

$$2\,[r/2]\,[s/2] - [r/2] \text{ or } \frac{(r-1)(s-1)}{2}$$

double points in the curve.

Thus we see that in any case which may arise the number of double points is equal to

$$\frac{(r-1)(s-1)}{2}.$$

The examination above made has shown that the double points which are counted twice are either all on the x axis (the case in which r is even), or are all on the y axis (the case in which s is even). In case r and s are both odd, double points can exist on neither axis. In no case can double points exist simultaneously on both axes.

§ 3. *To determine the number of points of inflexion in the curve* $x = \cos rt$, $y = \cos st$.—

For convenience suppose that s is less than r.

When $t = n\pi/r$

(1) $$\frac{d^2x}{dy^2} = \frac{r^2 s \cos n\pi}{-s^3 \sin^3 ns\pi/r}$$

When $t = (n+1)\pi/r$

(2) $$\frac{d^2x}{dy^2} = \frac{r^2 s \cos (n+1)\pi}{-s^3 \sin^3 (n+1)\, s\pi/r}$$

Since the sine appearing in the denominator of the second derivative is always squared, its value will not change sign for any value of n, and the sign of the second derivative will then depend only on that of the cosine in the numerator. Now $\cos n\pi = -\cos (n+1)\pi$, so that the sign of the second derivative in (1) is the negative of that in (2), therefore the curvature changes between $t = n\pi/r$ and $(n+1)\pi/r$. It is obvious that the curvature can change but once in one of these intervals, since as t takes on values from $n\pi/r$ to $(n+1)\pi/r$, the cosines of multiples of these values of t present a continuously decreasing or increasing series of values in this interval.

There are two ways in which the second derivative, and hence the curvature, may change sign. Either the curve passes through a point of inflexion or else is perpendicular to the axis of y.

It can become perpendicular to the axis of y only when $dx/dy = \infty$. For this case

$$\frac{dx}{dy} = \frac{-r \sin rt}{-s \sin st} = \infty$$

when $\sin st = 0$.

Now $\sin st$ equals zero only when $t = m\pi/s$ and there are evidently only $s-1$ values of t of the form $m\pi/s$ between 0 and π. If r is greater than s, let $r = s + a$. There will then be $s + a - 2$ intervals between successive t's of the form $n\pi/r$ and $(n+1)\pi/r$. Now the intervals between $n\pi/r$ and $(n+1)\pi/r$ are shorter than those between $m\pi/s$ and $(m+1)\pi/s$, so that no two values of $m\pi/s$ can coexist in an interval from $n\pi/r$ to $(n+1)\pi/r$.

Now since there are $s + a - 2$ changes of sign in the second derivative and but $s-1$ of these are caused by the curve becoming perpendicular to the axis of y, there must be $a-1$ points of inflexion. Therefore there are $(r-s-1)$ points of inflexion when r is greater than s.

Similarly it can be shown that if s is greater than r the number is $(s-r-1)$.

§ 4. *The conditions of symmetry.*—

Three cases can arise, r and s both odd, r even and s odd, or r odd and s even.

In the first place let t' be a value of t giving rise to the points x', y' on the curve. If we use $\pi - t'$ we obtain $-x'$, $-y'$, as the co-ordinates of the resulting point. Therefore the curve is symmetrical with respect to the origin.

In the second case if t' gives rise to the point x', y', $\pi - t'$ will give rise to the point x', $-y'$, so that the curve is symmetrical with respect to the axis of y.

In the third case if t' gives rise to the point x', y', $\pi - t'$ will give rise to $-x'$, y', and the curve will be symmetrical with respect to the x axis.

CURVES OF DOUBLE CURVATURE.

§ 1. *Periodicity of the curve*

$$x = \cos nt \quad y = \cos rt \quad z = \cos st.$$

It is easy to see that the period of the curve of double curvature is π, the same as in the case of a plane curve. It is also easily shown that if n, r, and s have a common factor δ, the curve is a δ-fold tracing.

§ 2. *To find the number of double points in the curve*

$$x = \cos nt \quad y = \cos rt \quad z = \cos st.$$

Let us assume that n and r have a highest common factor ϵ, n and s a highest common factor δ, and r and s a highest common factor γ.

If a double point arises, suppose the first passage of the curve through the point occurs when $t = a\pi/b$. Then

$$x = \cos na\pi/b, \; y = \cos ra\pi/b, \; z = \cos sa\pi/b$$

give the coordinates of the double point.

For the second passage of the curve through the point, t must be such that the values of x, y and z will be the same for the new t as for $a\pi/b$. Call the new t, t'. Then t' must be of a form such that

$$nt' = 2h\pi \pm na\pi/b$$
$$rt' = 2k\pi \pm ra\pi/b$$
$$st' = 2j\pi \pm sa\pi/b$$

since for these values only can the two corresponding sets of values for x, y and z be equal.

The number t' will then equal

(1) $$2h\pi/n \pm a\pi/b = 2k\pi/r \pm a\pi/b = 2j\pi/s \pm a\pi/b$$

Since t' cannot be greater than π for a single tracing of the curve

(2) $$h \not> [n/2],\ k \not> [r/2] \text{ and } j \not> [s/2],$$

unless all signs in (1) before $a\pi/b$ are negative. If all the signs of $a\pi/b$ in (1) are the same we have

$$2h/n = 2k/r = 2j/s,$$

which can only be true for h, k, and j equaling respectively n, r, and s, which is impossible by (1), as t' is less than π.

The sign before $a\pi/b$ in one of the members must then differ from the other two, giving rise to the three cases:

(3) $$\begin{aligned} 2h\pi/n \mp a\pi/b &= 2k\pi/r \pm a\pi/b = 2j\pi/r \pm a\pi/b \\ 2h\pi/n \pm a\pi/b &= 2k\pi/r \mp a\pi/b = 2j\pi/s \pm a\pi/b \\ 2h\pi/n \pm a\pi/b &= 2k\pi/r \pm a\pi/b = 2j\pi/s \mp a\pi/b \end{aligned}$$

Let us consider the first case. Putting the first member equal separately to the second and third and simplifying, we obtain the relation

$$\pm\frac{a}{b} = \frac{kn - hr}{nr} = \frac{jn - hs}{ns}.$$

Since n, r, and s have no common factor, b must equal nrs in order for this relation to be satisfied.

Putting $b = nrs$ we obtain the relation $\pm a = kns - hrs = jnr - hrs$ or $k/j = r/s$. For this to be true it is necessary that $k = l_1 r/\gamma$ and $j = l_1 s/\gamma$ where $l_1 \not> [\gamma/2]$. Then $\pm a$ will be given by the relation $\pm a = l_1 srn/\gamma - hrs$ in which $l_1 \not> [\gamma/2]$ and $h \not> [n/2]$. Using a method exactly similar to that used in §(3) Plane Curves, it can be shown that, except for $(\gamma - 1)/2$ values when n is even and $(n-1)/2$ values when γ is even, double points also arise when $t = \pi - a\pi/nrs$, so that in all there will be $(\gamma - 1)(n - 1)/2$ double points.

If we use the second equation of (3) we obtain in the same way $(\delta - 1)(r - 1)/2$ double points and from the third we get $(s - 1)(\epsilon - 1)/2$. Some of the values, counted in the first case, in the $(\gamma - 1)(n - 1)/2$ values, were also counted in the second case, in the $(\delta - 1)(r - 1)/2$ values.

In the value for $\pm a = l_1 nrs/\gamma - hrs$ we should note that as l_1

passed through all values to $[\gamma/2]$, h passed through values of the form $l_2 n/\delta$. The results for $\pm a$ given by these $[\gamma/2][\delta/2]$ values were evidently again given when l_2 passed through values to $[\delta/2]$, and k was of form $l_1 r/\gamma$. The number of double points must then be diminished by $(\delta-1)(\gamma-1)/2$ if δ and γ are both odd, as in that case $\pi - a\pi/nrs$ also gives rise to $(\delta-1)(\gamma-1)/4$ double points counted twice.

If, however, δ is even, then $(\gamma-1)/2$ values were not counted twice, for these $(\gamma-1)/2$ values were thrown out above with $(r-1)/2-(\gamma-1)/2$ others. If γ is even, $(\delta-1)/2$ values were not counted twice. In either case this will give either $(\gamma-1)\delta/2-(\gamma-1)/2=(\gamma-1)(\delta-1)/2$ or $(\delta-1)\gamma/2-(\delta-1)/2 =(\gamma-1)(\delta-1)/2$.

Similarly in the first and third cases $(\gamma-1)(\epsilon-1)/2$ values must be thrown out, and in the second and third cases $(\delta-1)(\epsilon-1)/2$ values must be thrown out. This accounts for all double points counted twice, so the total number of double points in the curve of double curvature $x=\cos nt$, $y=\cos rt$, $z=\cos st$ is equal to

$$\frac{(n-1)(\gamma-1)}{2}+\frac{(r-1)(\delta-1)}{2}+\frac{(s-1)(\varepsilon-1)}{2}-\frac{(\gamma-1)(\delta-1)}{2}$$
$$-\frac{(\delta-1)(\varepsilon-1)}{2}-\frac{(\gamma-1)(\varepsilon-1)}{2}$$

γ being highest common factor of r and s, δ being highest common factor of n and s, ϵ being highest common factor of n and r.

§ 3. For the special cases when either γ, δ, or ϵ or any two or all three are equal to unity, we can derive the formulæ either by independent proofs or we can deduce them from the results obtained in the last paragraph. If γ equals unity the formula for the number of double points becomes

$$\frac{(r-1)(\delta-1)}{2}+\frac{(s-1)(\varepsilon-1)}{2}-\frac{(\delta-)(\varepsilon-1)}{2}$$

If δ and γ are both unity the formula becomes

$$\frac{(s-1)(\varepsilon-2)}{2}$$

and if all three are unity, that is if n, r and s are all prime to each other the number of double points in the curve reduces to zero.

§ 4. *To find the points, axes and planes of symmetry for the curve*

$$x = \cos nt \qquad y = \cos rt \qquad z = \cos st.$$

Divide the curves into three classes: First, those with n, r, and s all odd; second, those with two odd and one even; third, those with one odd and two even. If n, r, and s are all odd, substituting $(\pi - t)$ for t in the equations gives the x for $(\pi - t)$ as the negative of that for t, the y for $(\pi - t)$ as the negative of that for t, and the z for $(\pi - t)$ as the negative of that for t, so that the origin is a center of symmetry for the curve.

If two of the numbers n, r and s are odd, say, for convenience, n and r, and the other even, substituting $(\pi - t)$ for t, gives the x and y for $(\pi - t)$ as negatives of the x and y for t but the z for $(\pi - t)$ is the same as the z for t. Thus the curve is symmetrical with respect to the z axis.

Similarly when n and s or r and s are odd, and r or n even, the curves are symmetrical about the y or x axis respectively.

When one number is odd and the other two even, say n odd and r and s even, the curve will be symmetrical with respect to the yz plane. In this case the y and z, coordinates for $(\pi - t)$ will equal those for t, while the x for the $(\pi - t)$ will be the negative of that for t.

University of Wisconsin, June 1, 1897.

EARTH MOVEMENTS.

ADDRESS OF RETIRING PRESIDENT, C. R. VAN HISE.

The part of the world of which we have definite knowledge consists, as stated by Powell,[1] of three moving envelopes, an atmosphere, a hydrosphere, and a lithosphere. That the air moves we are aware; that the waters of river and lake and ocean move we well know; but that the rock constituting the outer part of the supposed solid earth as certainly and as continuously moves as do these envelopes of air and water, we may not understand. It is true that the majority of the greater earth movements are so slow that they ordinarily escape our observation; yet their cumulative effects are of the same order of importance as the movements of air and water. The atmosphere may be called the second hand of the world clock, the hydrosphere the minute hand, and the lithosphere the month or year hand.

Kinds of Earth Movements.— With volcanic phenomena we are more or less familiar. The majority of the important active volcanoes are located along or near the continental borders, but this statement is not applicable in the case of the several great past periods of igneous activity.

As a consequence of volcanic action material within the earth is brought to the surface. In historic times the material thus transferred has been considerable in amount, but in the past at different periods and in various regions volcanic products have buried great regions to the depth of hundreds or thousands of feet. Accompanying volcanic outbursts of material, great transfers of liquid rock from one place to another have occurred within the outer part of the earth, no evidence of which appears

[1] Physiographic features, by J. W. Powell: Nat. Geog. Mon., Vol. I, No. 1, 1895, pp. 1-23

in volcanic phenomena. It has been supposed by Russell[1] that some of the great mountain uplifts of the United States are due to the interior transfer of molten material. If this be so, the question remains as to the cause of the transfer. For such transfer reasons are later assigned. Some of the intruded igneous material, long after solidification, has reached the surface by the removal of the covering rock through epigene agencies. Probably a much greater part still remains below the surface.

That the lithosphere locally has movements which we call earthquakes is well known. It is not so well known that minor tremors continuously affect much or all of the surface of the earth,[2] but the majority of these tremors are so feeble as not to be called earthquakes, even by scientists who classify as earthquakes many very slight shocks which the senses do not detect. But even the most violent earthquakes are very insignificant rock waves, being only a few centimeters in amplitude, and the permanent effects of earthquakes upon the earth are comparatively slight. It is of course well known that in some cases volcanoes and earthquakes are most disastrous to the living things which chance to occupy the disturbed tracts.

With the exception of earthquakes and active volcanoes, we are accustomed to think of the lithosphere as motionless. Yet these phenomena are far less important than other existing earth movements. As in so many cases, the exceptional has attracted the greater share of attention, while the slow, general movements have escaped notice.

The latter earth movements may be classified into mass movements and molecular movements. The mass movements are vertical and horizontal. As a result of the vertical mass movements the continents are now above and now below the waters of the ocean. Such movements were named by Gilbert epiorogenic. As a result of the vertical and horizontal mass movements combined, mountain ranges here and there on the

[1] Igneous intrusions in the neighborhood of the Black Hills of Dakota, by I. C. Russell: Journ. of Geol., Vol. IV, 1896, pp. 23-43; On the nature of igneous intrusions, Ibid., pp. 177-194.

[2] Popular lectures and addresses, by Lord Kelvin: Vol. III, 1891, pp. 158-9.

earth, and at various times in its history, have been formed. Such movements are called orogenic movements. No sooner are mountain masses formed than they begin to be wasted away by surficial, or epigenic, forces. In many regions mountain ranges have arisen and fallen several times during the history of the earth. The molecular movements of the rocks may affect the shape and arrangement of their constituent particles, or the very composition of the particles themselves may be changed. As a result the character and structure of the rock masses affected may be wholly altered, and even under quiescent mechanical conditions the solid rocks beneath our feet may be so changed as not to contain one trace of the original minerals composing them.

It is the purpose of this paper to inquire into the character and effects of these various earth movements.

Relations of Continental Masses to Oceanic Basins.[1]—Before considering the earth movements it is necessary to recall the relations of the continental masses to the oceanic basins. The bed of the great world ocean is for the most part a continuous plain, surpassing in evenness, as it does in extent, any plain upon the continental masses. Below the general level of the plain are smaller areas called deeps, such as the Tuscarora Deep. In most cases the passage from one level to the other is very gradual. Above some of these deeps are 30,000 feet of water. One may imagine himself on the floor of the vast ocean plain, traveling toward the continental area. As he nears the continental mass a gentle but great slope rises before him. Climbing this slope, which places him 14,000 feet farther from the center of the earth than when on the ocean bed, he finds himself upon another plain, less even than the first, being broken by mountain ranges and other irregularities. This plain is the world continent. When this upper plain is reached he may still be 100 or 150 miles from the border of the continent as we ordinarily think of it, for the great land masses are fringed by shallows varying from a few miles to 150 miles in width. The lands below these shallows belong

[1] On the height of the land and the depth of the ocean, by John Murray: Scottish Geog. Mag., Vol. IV, 1888, pp. 1-41.

with the continent, are a part of it, and the continental mass must be considered as ending where the great slope begins which decends into the abyss of the ocean. Thus defined, there is but one great continent, for the Americas, Greenland, Eurasia, and Africa are connected by the continental shoals; but for convenience the word *continent* will be used in the ordinary sense. The heights of continental areas average between 2,000 and 2,500 feet above the level of the sea[1] although a number of extensive plateaus have altitudes from 5,000 to 12,000 feet, and a few mountains have altitudes between 20,000 and 30,000 feet. The total vertical distance between the deepest parts of the ocean and the tops of the highest mountains is more than 50,000 feet. But the great features of the earth are the deep-lying ocean plain and the low continental plain.

Whether or not a greater or less portion of the continental masses chances to be a few hundred feet above or below the water is a comparatively small matter, but to bring any part of the oceanic bed to the surface would involve a vertical movement of 15,000 or more feet. Vertical movements which have placed all or nearly all parts of all continents below the ocean have recurred at various times in the past. Of vertical movements which have brought extensive areas of the deep-lying bed of the ocean to the surface we have scant evidence.

The Permanence of Continents.— The continents and ocean beds alike are ever subject to omnipresent gravity. The continental masses down to the level of the bed of the ocean are plainly heavier than the water standing opposite them. This being so, two explanations have been offered for the permanent existence of the continents. Either the rocks composing them and underlying them must be strong enough to sustain their own enormous mass, upon an average 16,000 to 16,500 feet above the bed of the sea and only partly balanced by the water of the ocean, or else the rocks underlying the ocean must be heavier than those constituting the continents and their downward extensions. Geologists now believe that no such strength can be premised for the rocks as

[1]A summary of estimates is given in Text-book of Geology, by Sir Archibald Geikie: 3d ed., 1893, pp. 39-40

is involved in the first supposition, and hence we are driven to the second, i. e., that the continental and sea areas are approximately in isostatic equilbrium.[1]

In other words, the continents are mainly sustained above the level of the ocean in the same way as a ship. The hull of a great vessel rises 20 or more feet above the surface of the water, because upon the average it is lighter than the water which surrounds it. As the ship is loaded it sinks deeply into the water; when emptied, it rises higher above the surface.

Theory of Isostacy.—In many discussions of isostacy it is assumed that the level of the sea is absolute, and that its surface is a safe datum plane. However, it is evident that all shifting of earth material, either vertically or horizontally, either by deformation or by denudation, results in changing the level of the ocean in the absolute sense, that is, the average distance of its surface from the center of the earth. Thus, an important subsidence in one region may produce an apparent movement of all continental shores. If the subsidence be of the sea bed, this will result in apparent uplift of the continents. If it be of some continental region, this will result in the advance of the sea over this region, and because of the consequent absolute fall of the sea, there will be an apparent small uplift of the great undisturbed remainder of the continental masses.

Evidence of the existence of approximate equilibrium of continental and sea areas has been found in gravity determinations, and especially in recent determinations of the force of gravity by pendulum experiments made by Putnam.[2]

As a result of these we find we cannot suppose that there is any such delicate adjustment of the earth masses as might be

[1]Appendix to Babbage's Ninth Bridgewater treatise, by Sir John Herschel, 1837, pp. 212–213. A treatise on attractions, Laplace's functions, and the figure of the earth, by John H. Pratt: 4th ed., 1871. On some of the greater problems of physical geology, by C. E. Dutton: Phil. Soc. Wash., Vol. XI, 1888–91, p. 53.

[2]Results of a transcontinental series of gravity measurements, by G. R. Putnam, and notes on gravity determinations reported by G. R. Putnam, by G. K. Gilbert: Bull. Phil. Soc. Wash., Vol. XIII, 1895, pp. 31–76, Pl. V, Figs. 1–3.

implied by the illustration of the ship. The rocks have a very considerable rigidity, and in order that a readjustment shall begin, the difference in vertical stresses must be sufficient to overcome the rigidity of the rocks. The stress-difference required is probably far short of the elastic limit of rocks as determined by experiment under ordinary conditions of pressure and temperature. According to Gilbert,[1] the excess of gravity in the Rocky Mountains is measured by some 2200 feet of material. This is steadily tending to lower this area. Whether it is sufficient to cause any movement is uncertain. Wherever there is an excess of material sufficient to cause subsidence, it is probable that the movement is exceedingly slow, for nowhere is the weight of the excess known to approach the crushing strength of the stronger rocks. The excess required to give a weight sufficient to crush such rocks would be a thickness of rock material of about 20,000 feet.[2] In areas where the excess is sufficient to produce subsidence, the process would doubtless go on with decreasing speed, because of the steady decrease of the stresses. Movement resulting from excess of pressure will not continue until perfect equilibrium is reached, because it will cease the moment the stresses are unable to overcome the rigidity of the rocks. But as explained later (See p. 472), equilibrium may possibly result from loading of one area, combined with denudation of another.

As a result of the erosive action of wind, water, and ice, the continents are constantly being degraded, and the higher they stand above the surface of the seas, other things being equal, the more rapidly does the process go on. If, with a sufficient number of locomotives, all the freight cars in the United States were continuously at work carrying to the sea the earth of our continent, the average haul being taken at 1,500 miles, and no time being taken for loading or emptying, there would be carried to the sea but a little more than twice the amount of material contributed to the Gulf of Mexico by the Missis-

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[1] New light of isostacy, by G. K. Gilbert: Journ. of Geol., Vol. III, 1895, p. 332.

[2] Principles of North American pre-Cambrian geology, by C. R. Van Hise: Sixteenth Ann. Rept. U. S. Geol. Survey, Pt. I, 1896, p. 592.

sippi river.[1] It has been calculated that if the present rate of erosion continued, and no uplift occurred, North America would be reduced to sea level by erosion in 3,000,000 years, and Europe in 2,000,000 years.[2]

However, it must be remembered that as the elevation of the land areas is lessened by erosion, the rate of degradation rapidly decreases, for the speed of erosion largely depends upon the amount of precipitation and the declivity of the slopes. At a low elevation both the quantity of water in the streams and the declivity of the streams are less than at high elevations. Consequently to actually reduce the continents to the level of the sea by erosion, even if no further uplift occurs, would undoubtedly require a far longer time than indicated by calculations based upon the present rate of erosion.

However, under present conditions it is plain that as a secondary result of the movements of the atmosphere and hydrosphere there is a horizontal movement of great magnitude of earth material from the continent to the ocean, combined with a relatively small but important vertical movement. The horizontal movement is from less than a mile to thousamds of miles. The vertical movement is from less than a foot to thousands of feet. Gravity is the force which causes the transfer, both horizontal and vertical. It is to be noted that the transfer is cu-

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[1] According to the report (1894) of Messrs. Humphrey and Abbot, the engineers charged with the investigation by the United States Government, the amount of mud carried in suspension and solution by the Mississippi river is 812,500,000,000 lbs. per year. The amount rolled along the bottom is 126,360,000,000 lbs. per year. Thus the yearly contribution of the Mississippi to the Gulf of Mexico is 938,860,000,000 lbs. of mud. The number of freight cars in the United States, according to the report of the Railroad Commissioner for 1894, is 1,191,866. If each of these carry 30,000 lbs., the amount of one load of all these cars would be 35,755,980,000 lbs. A round trip of 3,000 miles, 1,500 miles each way, would be made in about 6 days, giving about 60 trips per year. The cars would thus carry in a year about 2,145,358,800,000 lbs. Thus the amount carried by the cars would be a little more than twice the amount transported by the Mississippi.

[2] Einleitung in die Geologie als historische Wissenschaft, by J. Walther: Theil III, 1894, P. 580. Text-book of geology, by Archibald Geikie: 3rd ed., 1892 , pp. 462-5.

mulative. The water that goes to the ocean or some equivalent amount is returned to the land through the atmosphere by the power of the sun. The land dumped into the sea does not return, but remains to build up a great deposit fringing the coast.

In this process of erosion two things are happening to the continental ship: its interior is being unloaded, and its periphery is being loaded. If there were isostatic equilibrium at the beginning, or at some time during the process, and erosion afterwards long continued, this would result in differential stresses between the interior and the periphery of the continents. At the first place the pressure is upward, and at the second downward. A study of the coastal features of the continents by physiographers shows beyond all question that where many of the great deposits are forming, there the border is sinking. As evidence of this subsidence, and the consequent encroachment of the ocean are the keys, estuaries, divided rivers, and other phenomena. There is also clear evidence in deformed beaches of lakes, that the interior and northern parts of the north American continent, which is being unloaded, is rising.

In order that these correlative movements shall occur, deep-seated flow of material under the continental border toward the interior must take place.[1] Such deep-seated flowage does not involve more than a slight movement of any part of the material, just as when a faucet is opened the cubic inch of water occupying the front of the pipe is the first to issue, and there is an average forward movement of but an inch all along the pipe.

The lateral transfer of material involved in denudation may work toward or from isostatic equilibrium. If the land area has an excess of material and the adjacent sea is deficient in material, the work is at first toward isostatic equilibrium, and this state may finally be attained, although it is improbable that this ever exactly occurs. When the excess of material is removed from the land, if the area is still above sea level, denudation continues, and from this time the removal of material from the

[1] The mechanics of Appalachian structure, by Bailey Willis: Thirteenth Ann. Rept., U. S. G. S., Part II, 1893, pp. 280–281.

land results in a disturbance of isostatic equilibrium, the land becoming more and more deficient in gravity. At the same time the adjacent sea area may become overloaded. Where a sea border is subsiding, and the corresponding unloaded land area is rising, this shows that there is not exact isostatic equilibrium, but a disturbing stress, which surpasses the elastic limits of the rocks under the conditions in which they exist, although the movement tends to prevent further departure from equilibrium.

The ordinary explanation offered for the sinking of the continental border and the rising of the interior is the loading of the one and the unloading of the other.

While it cannot be doubted that this is a factor in the process, it is by no means clear that this is the only or chief cause. As shown later, other forces are at work resulting in earth movements, and consequently in advances and recessions of the sea coast of the most complicated character. During these earth movements great stress-differences may be produced between the borders and the interiors of the continents, and in the same direction as those of erosion. Under these conditions the loading of the sea borders and the unloading of the interiors may give the additional force necessary to produce a vertical stress-difference greater than the rigidity of the rocks can continuously resist, and therefore inaugurate such movements as described.

Where bordering the sea an area is under stresses so great that it responds by uplift or subsidence, because of its rigidity it may carry with it a smaller adjacent area not similarly stressed, and thus shift the sea shore.

Where denudation of the continents and deposition in the adjacent sea beds are the only causes disturbing equilibrium, before movements begin a considerable slice must probably be removed from the continents, and a thick deposit be formed in the sea, in order to accumulate a sufficient stress-difference to overcome the rigidity of the rocks. How great this difference must be in order to act slowly can only be conjectured.

It is possible that successive relative uplifts may result from the contractional forces, in connection with an alternation of nearly sufficient and greatly deficient amounts of material. As just seen where as a result of erosion an area becomes deficient in material, upward movement will not begin until the deficiency is so great that this and the other forces combined, surpass the elastic limit of the rocks. The movement, once set up, would continue even if the deforming forces were less than at first, for when rigidity is once overcome less force is required to continue deformation. Relative uplift might continue faster than denudation, until the differential stresses became too small to produce further effect. Denudation would then continue its work until the area was so deficient in gravity that the differential stresses would again overcome the rigidity of the rocks, and a second uplift would occur. This is offered merely as a partial explanation for some local uplifts; for general uplifts, as explained (pp. 483–4), probably result from differential subsidence of sea beds and of continental areas or from changing rotation.

At all times and places no sooner is the land above the water than the epigene forces begin their work of denudation. At various times in many regions a land area remained so long above the ocean that the epigene forces were able to hew it nearly or quite to the surface of the water before the vertical movement came which relatively raised the area or lowered it, and in the latter case caused the sea to override the land.

If there are no differential movements of subsidence which result in relative elevation of the land, the epigene forces always conquer. The part of the continent above the sea is slowly, although surely, cut away. To illustrate, we may direct our attention to North America. It is certain that before the rocks were deposited which bear evidence of the earliest life, three times were the land masses overridden by the sea and subsequently emerged from it. Since the time of the earliest life at least three times more have the seas overridden the North American continent, and three times have the continental masses again emerged from the water. Also there have been a number of other every great differential movements which have resulted in the submergences and emergences of considerable parts of the continent. During the erosion intervals large parts of the regions were reduced nearly to sea level by subaerial erosion.

Condition of the Interior of the Earth.[1]—In order to understand how great vertical earth movements may occur, it is necessary to mention modern conclusions as to the condition of the interior of the earth. It is certain that the material deep down is highly heated. Most lines of calculation indicate that the temperature near the center of the earth must be several thousands and may be many thousands of degrees. Such temperatures as probably exist at the earth's center would at the surface make the most refractory rock as liquid as water, if indeed it did not vaporize it. However, it does not follow that under the tremendous pressures deep within the earth the material is gaseous or even liquid. It is a well known law of physics that bodies which contract on solidifying may be held in a solid condition by great pressure at temperatures which would render them liquid if under less pressure. It has been concluded by some physicists that the pressures within the earth are so great that even at the high temperatures calculated the material is held in the solid condition. Deductions based upon the tide-producing force of the sun and moon show beyond all question that the earth has an exceedingly high rigidity when subjected to great and not long continued stress. As Kelvin states it, the earth "Is not, as commonly supposed, all liquid within a thin solid crust of from 30 to 100 miles thick, but that it is on the whole more rigid certainly than a continuous solid globe of glass of the same diameter, and probably than one of steel."[2] While this conclusion is not doubted by geologists if it be confined to the rigidity shown by the earth to the daily tidal stress, their observations lead them to believe that the earth shows real plasticity when subjected to long-continued, moderate stresses. Experiments upon viscous wax show that under pressure it becomes highly

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[1] The mathematical theories of the earth, by R. S. Woodward: Am. Journ. Sci., 3rd ser., Vol. 38, 1889, pp. 337-355.

[2] Treatise on natural philosophy, by Thompson and Tait: Part II, 1890, p. 485. See also Popular lectures and addresses, by Lord Kelvin: Vol. II, 1891, p. 306, and Vol. III, 1891, pp. 189-190.

rigid.[1] Molasses candy when subjected to the sudden stress of a blow is as brittle as glass. Under slight but long continued pressure it is readily deformed without fracture. We know so little about the state of matter at the temperatures and pressures, over 3,000,000 atmospheres,[2] that must exist at the center of the earth that we could not assert that a viscous liquid would not there be as rigid as glass or steel when subjected to stress of brief duration, and thus the conclusion be reached that the liquid is a solid. But it would not be wise to apply either of the terms solid or liquid to it. We know what these terms mean in reference to matter under temperatures and pressures obtainable by experiment, but to apply them in the same sense to the material deep within the earth, which is subject to pressures and temperatures far beyond our experience, is certain to lead to misconception.

It is believed that the material of the interior of the earth is so highly heated that it would be liquid or gaseous at the surface, and that it is very rigid when subjected to stresses of short duration, but is plastic under long-continued, moderate stresses. Whether this material exists as crystallized minerals, or as highly viscous amorphous substance, or in some state of matter of which we have no knowledge whatever, or of a combination of these, cannot be asserted.

Contraction of the Earth.— How vast and varied are earth movements has to some extent been stated. The main cause ordinarily assigned for these movements is a more rapid contraction of the interior of the earth than of its exterior shell. As a result the outer part is deformed in such a way as to bring its too large outer part into adjustment with the inner part. The chief, and ordinarily the only cause given for such contraction is the loss of heat due to secular cooling. In another place[3] I discuss the various other important causes for contraction,

[1] The flow of solids, by William Hallock: Phil. Soc. of Washington, Vol. XI, 1888–91, pp. 509–511.

[2] Physics of the earth's crust, by Osmond Fisher: London, 1881, p. 33.

[3] Estimates of crustal shortening, and causes for the same, by C. R. Van Hise: Journ. of Geol., Vol. VI, Jan–Feb., 1898.

some of which may be of equal or of greater importance than secular cooling, and here therefore only summarize them.

As a result of vulcanism vast quantities of igneous rocks have been intruded within the crust of the earth, and extruded upon its surface. The extrusions lessen the volume of the interior mass, and therefore are an important cause for nucleal contraction. Moreover, the material intruded within the crust of the earth expands it, and tends to make it too large to fit the already proportionally smaller nucleus. Thus the transfer of liquid material from the interior of the earth into the outer part has a double effect in forming corrugations. The immensity of regional eruptions is considered later. It is only when the enormous volume of igneous rocks which must have been intruded and extruded during geological time is appreciated, that the importance of this cause of nucleal contraction can be understood. It is possible that it is of equal or greater importance than that due to secular cooling.

Peirce[1] and G. H. Darwin[2] have calculated that at a time in the remote history of the earth, its rate of rotation was about four times as fast as at present. As a consequence the earth then had a greater oblateness. Supposing the mass not to have changed, its surface must have been larger than at the present time, for a sphere contains a greater volume with a less surface area than any other form of solid. The difference in superficial area as a result of this change in oblateness, upon the hypothesis of a spheroid of uniform density, as calculated by Prof. C. S. Slichter at my request, is about 200,000 square miles.

Also at the time of more rapid rotation the pressures at any point within the earth were considerably less than at present, because of the greater centrifugal force at the time of rapid rotation, and the consequent lessened effectiveness of gravity, and therefore the earth in the past time could not have been so dense as at present. As the rotation decreased in speed, the

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[1] The contraction of the earth, by B. Peirce: Proc. Am. Acad. Arts and Sci., Vol. 8, 1873, pp. 106–108.

[2] On the precession of a viscous spheroid and on the remote history of the earth, by G. H. Darwin: Phil. Trans. Roy. Soc., Vol. 170, Part 2, 1879, p. 505

pressure increased to the present amount, and important con raction may have resulted from the increased pressure.

The surficial contraction due to change of oblateness and that due to increased pressure, may together be of equal and possibly of greater importance than that due to secular cooling.

Important contraction has doubtless also resulted from a change in the physical condition of a part of the earth's interior. In the change from liquid rock to a solid amorphous condition, a contraction occurs[1]. Further, more important contraction results from a change from the glassy to a crystalline condition. In the direct change from a liquid to a crystalline condition the contraction equals the sum of the contractions of the two stages mentioned. In the case of one rock, the amount of this contraction, as shown by Barus, is as much as 13 per cent. Contraction to some small extent may also have resulted by a change from a less complex to a more complex molecular structure. If physical changes of these kinds have been extensive during geological time, and this can hardly be doubted, this is an important cause for contraction. However, some of these physical changes may have been a part of the consequences of increased pressure and secular cooling, in which case these causes are not wholly independent.

Finally, the water and air now upon the surface of the earth, and possibly also gas and water which have been lost to the earth[2], may have been originally occluded deep within its interior. The escape of this water and gas from the interior would result in contraction.

The cumulative effects of these various causes for surficial contraction are possibly sufficient to explain all the observed phenomena of mountain-building, and if they are not, still other causes for contraction may be discovered in the future. Thus the objections to the contractional theory of mountain-making have far less weight than they had when only a single cause, loss of heat due to secular cooling, was assigned for contraction.

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[1] Manual of geology, by J. D. Dana: 4th ed., 1895, p. 265.

[2] A group of hypotheses bearing on climatic changes, by T. C. Chamberlin: Journ. of Geol., Vol. V, 1897, pp. 653–683.

Furthermore, it is believed, as explained in another place,[1] that some estimates of the amount of shortening of the outer part of the earth have been too great.

As a result of the contraction of the interior of the earth and its change of form, due to the causes given, and doubtless others, the outer part becomes too large to fit the inner part. Pulled down by gravity, enormous lateral stresses are set up, which could not be resisted by the rock, though it were 30 times as strong as the finest steel, or from 600 to 1,000 times as strong as granite.[2] Consequently the outer part adjusts itself to the lessened nucleus by various earth movements.

However, the above changes, so far as they occurred before the formation of the outer solid crust of the earth, can have produced no effects which would be permanently retained. After such a crust was formed they would all result in epiorogenic and orogenic crustal movements.

Origin of Continents.—Dana[3] and Gilbert,[4] assuming that the earth in the remote past was in a liquid condition, have suggested that the continental plateaus originated at places where the molten lava first began to solidify. These would probably be places of low heat conductivity. As the rock changed to the solid condition it contracted[5] and sank below the liquid surface, which in turn solidified and sank. Much of this material which passed below the surface might have been re-melted, but by the long-continued process at last a solid mass was formed, which extended from the surface far below. This solid mass being built up of successive portions of the outer part of the liquid world would be lighter than the remainder, and therefore would project above it. Even if solidifi-

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[1] Estimates of crustal shortening, and causes for the same, by C. R. Van Hise: Journ. of Geol., Vol. VI, Jan.-Feb., 1898.

[2] Some mechanical conditions of the earth's mass, by R. S. Woodward: Phil. Soc. Washington, Vol. XI, 1888-91, p. 532.

[3] Manual of geology, by J. D. Dana: 2nd ed., 1874, p. 738.

[4] Continental problems, by G. K. Gilbert: Bull. Geol. Soc. Am., Vol. 4, 1893, pp. 183-190.

[5] Report on earthquakes and volcanic action, by Wm. Hopkins: Brit. Assoc. Rep., 1847, p. 46. Treatise on natural philosophy, by Thompson and Tait: new ed., Part II, 1890, p. 483. Popular lectures and addresses, by Sir Wm. Thompson: Vol. II, 1894; p. 306.

cation of the earth began at the center, in advance of the surface, as conjectured by Hopkins,[1] this conclusion would probably hold, for it is hardly probable that consolidation did not also begin at the surface long before the earth was completely solidified. Whenever consolidation finally began at the surface the process outlined would take place. When a protruding continent had formed, and afterwards what is now the bed of the ocean had solidified, it was heavier than the continental masses, because the lightest material had already passed from a liquid condition.

Another cause for the formation of the continents is suggested by an experiment made by Daubrée.[2] He painted parts of the surfaces of an inflated rubber ball in patterns. Part of the air was then allowed to escape, and it was found that the unpainted parts of the ball contracted radially more than the painted portions, the unpainted portions thus forming synclines, and the painted portions forming anticlines. This was attributed to the greater stiffness of the painted portions. Where on the surface of the earth considerable areas of rock at first solidified, there would be greater stiffness, and hence this cause would operate, and tend to develop the continental masses and the oceanic areas. This supposed difference in stiffness of different parts of the earth's surface may not have been of great importance, but it possibly produced some effect, working in conjunction with other causes.

The above explanations of the origin of the continents are based upon the supposition that the earth was once in a liquid condition. Chamberlin,[3] however, questions the existence at any time of such a liquid earth. He suggests that the earth may have segregated from a meteoric swarm, so slowly that the temperature at the surface was at no time sufficient to liquefy the rocks. Under this theory he thinks that the continental elevations and oceanic depressions are caused by the readjustments of various kinds of the heterogeneous materials during the slow growth of the earth.

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[1] Loc. cit., pp. 45–49.

[2] Geologie experimental, by A. Daubrée: Vol. I, 1879, pp. 585-590.

[3] A group of hypotheses bearing on climatic changes, by T. C. Chamberlin: Journ. of Geol., Vol. V, 1897, pp. 670–675.

Darwin,[1] apparently also working on the hypothesis that the continents were formed after the earth became somewhat rigid, suggests that the protrusion of the continental masses is due to the tides. The secular distortion consequent upon tidal action due to inertia would result in "screwing action" upon the earth. "Now this sort of motion, acting on a mass which is not perfectly homogeneous, would raise wrinkles on the surface which would run in directions perpendicular to the axis of greatest pressure. In the case of the earth the wrinkles would run north and south at the equator, and would bear away to the eastward in northerly and southerly latitudes; so that at the north pole the trend would be northeast, and at the south pole northwest. Also the intensity of the wrinkling force varies as the square of the cosine of the latitude, and is thus greatest at the equator, and zero at the poles. Any wrinkle when once formed would have a tendency to turn slightly, so as to become more nearly east and west, than it was when first made. The general configuration of the continents (the large wrinkles) on the earth's surface appears to me remarkable when viewed in connection with these results. There can be little doubt that, on the whole, the highest mountains are equatorial, and that the general trend of the great continents is north and south in those regions. The theoretical directions of coast line are not so well marked in parts removed from the equator." He further concludes that if this be a correct explanation "The view must be held that the general position of the continents has always been somewhat as at present, and that, after the wrinkles were formed, the surface attained a considerable rigidity, so that the inequalities could not entirely subside during the continuous adjustment to the form of equilibrium of the earth, adapted at each period to the lengthening day."

As has been seen, geologists would not agree that the continental masses are sustained by their own strength. However, this tendency to produce wrinkles might work in connection with the tendency for lighter materials first to segregate, with

[1] Problems connected with the tides of a viscous spheroid, by G. H. Darwin: Phil. Trans. Roy. Soc., Vol. 170, 1879, Part 2, pp. 587-590.

the slower contraction of the continental regions than of the oceanic regions because of the lower conductivity of the former, and with the effects of changing rotation. As has been seen, as a result of decreased speed of rotation there is decreased oblateness, and increased density caused by the increased effectiveness of gravity. Both of these effects require very important adjustments of the outer part of the earth. The actual work of the tides may give a direction to these adjustments in the manner explained by Darwin, and thus the forces of changing rotation concur with the immediate stresses of tidal movements in forming differences in elevation between the oceanic basins and the continental plateaus, the two being in approximate equilibrium.

Davison[1] further suggests, in support of Darwin's theory, that "Soon after the formation of these wrinkles, that is, in the initial period of the Earth's history as a solid, or nearly solid, globe, the unstrained shell must have been very close to the surface of the Earth, and the surface of greatest stretching also so near to it that stretching by lateral tension must have affected the form of the surface features. But, owing to the pressure of the continental wrinkles, the amount of stretching under them must have been very much less than under the great oceanic areas. Thenceforward, therefore, *crust-stretching by lateral tension must have taken place chiefly beneath the ocean basins, deepening them and intensifying their character.* And, in leading to the continual subsidence of the ocean-bed, it is evidently a physical cause of the general permanence of oceanic areas: a cause, it is true, continually receding from the surface, and diminishing in intensity with the increase of time, but probably even now not quite ineffective."

The above suggestions as to the origin of the continental masses are not all exclusive of one another, but on the contrary several of them to a large extent supplement one another. However, the explanation must be considered as provisional and

[1] 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, by Charles Davison: Phil. Trans. Roy. Soc., Vol. 178, Part A, 1887, p. 241.

very incomplete. But plausible suppositions are more satisfactory than no explanation. However unsatisfactory the explanations offered, we know that for some reason, in some way, the continental masses and oceanic basins were formed. As has been seen, we further have strong evidence that the specific gravity of the continents and their downward extensions is less than that of the masses below the deep seas, so that the gravitative pressure due to the sea beds and the superjacent water is approximately the same as that of the continental areas, or in other words, the earth is in approximate isostatic equilibrium.

Submergences and Emergences of the Continents.— The various submergences of the continents by the sea, and the subsequent emergences, which by the rock records are known to have occurred, are believed to be due mainly to gravity, working in conjunction with contraction. So far as I know Prevost[1] was the earliest to see that it is unphilosophical to premise that there are active vertical forces which absolutely raise the continental masses. In a cooling spheroid of lessening rotation, the effect of gravity must ever be to steadily condense the earth. In the last analysis both vertical and lateral earth movements are due to the force of gravity. This being the case, it is impossible to believe that the result of a gravitative movement can be other than to carry the center of gravity of the masses moved nearer to the center of the earth than it was before the movement. It, however, does not follow that great masses of material may not be pushed farther from the center of the earth as a result of the earth movement, but in this case equivalent or greater masses must have moved a corresponding amount toward the center of the earth. Under these principles it is believed that the great vertical earth movements are those of differential subsidence or of elevation, the sum total of any movement, combining all its parts, being downward.

It is not to be expected that the subsidence of the outer part of the earth, due to the various causes, would be equal on every part of it. Where the subsidence of a continental mass is slightly greater than the average of that of the bed of the seas,

[1] Bull. Geol. Soc. of France, Vol. XI, 1840, pp. 183–203.

a part of the continental land sinks below the level of the water. After an area has subsided below the water, it has been supposed that for some unknown reason titanic forces below pushed up the continents against gravity, but in favor of such a supposition no adequate reason was given. As has been seen it cannot be supposed that the great continental masses have anywhere been by any forces pushed farther from the center of the earth, unless at the same time another mass approached nearer the center of the earth. However, the continents would emerge from the sea if the sea bed sank upon the average faster than the continents, as certainly as they would if the continental masses rose absolutely, and this, it is believed, is the explanation of the emergences of the continents from the sea.[1]

When a great subsidence of a sea or land area anywhere occurs, the only possible earth movement which, in the first event, would avoid elevation with reference to the sea of all of the continents an amount equal to the subsidence, and in the second event other parts of the continents, a much smaller amount, is the equal simultaneous subsidence of all the land masses at the same rate as one another, and at the same rate as the average subsidence of the sea beds. That such a remarkable adjustment should at any time occur is highly improbable, and therefore, it is to be expected that relative subsidence or elevation is at all times somewhere taking place.

If the above theory of great continental submergences and emergences by differential subsidence be true, it would follow, as just explained, that the emergence of one land area by the sinking of the sea bottom faster than the land area would be ac-

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[1] The fundamental idea involved in this explanation was stated by Constant Prevost many years ago. (Loc. cit., p. 186.) I quote Dana's translation (Am. Journ. Sci. & Arts, ii, Vol. 3, 1847, p. 179):

"Are we not then forced to admit that while the bottom of the sea has been raised above the level of the sea and made dry land, by a series of displacements, still larger terrestrial areas have disappeared from submergence; and in such a way that the depressions formed were greater than the elevations, a condition without which, I repeat it, the low parts of our existing continents could not have been emerged, a condition requiring for its fulfillment, no aid from the suppossed agent of 'soulèvement,' since this would produce a contrary effect."

companied by the emergence of all other land areas which were not under a greater depth of water, unless they too subsided more rapidly than the land area which emerged. After such land areas emerged they would be eroded. After this, as a result of their erosion or subsidence, one or more of the land areas might be submerged. The submergence of one area would not necessarily result in the submergence of all which emerged at the same time, for the subsidence of land areas may be differential. However, the land areas which emerge at the same time might finally be again submerged. If this idea of simultaneous emergence of land areas in different continents and their subsequent submergence, either simultaneously or successively, be true, it would follow that certain unconformities are intercontinental. It is to be noted that such partial continental equivalence of unconformity is producible by the initial subsidence of the sea bottom. The greater breaks in the geological succession give a certain amount of confirmation to this idea of intercontinental unconformity. Some of the great intercontinental unconformities are (1) the break at the base of the Cambrian, (2) the break between the Upper Silurian and Lower Silurian, or between the Silurian and Ordovician, and (3) the break between the Mesozoic and Paleozoic.

It is not supposed that the above general statement is complete. There are various disturbing factors which make the problem of differential subsidence, resulting in positive or negative movement of the sea shore, very complicated. One of the greatest of these disturbing elements is the lengthening day.

It has already been seen that the rate of rotation of the earth has been decreasing for millions of years. Concurrent with this, there has been a decreasing oblateness. Blytt[1] explains that the water of the ocean would adjust itself at once to the changing speed, and as a result of the lessened centrifugal force would fall at the equator and rise in the polar regions. He further argues that the rigid earth would lag behind in its adjustment, until the stresses accumulated so as to overcome the rigidity of the rocks, when movement, once begun, would take

[1] A probable cause of the displacement of beach lines, by A. Blytt: Christiania, 1889, p. 89.

place rapidly. Consequently at first land would emerge from the water in the equatorial region, and land would be submerged in the polar regions; and later a reverse effect would occur. Moreover, he finds as a result of the precession of the equinoxes and changing eccentricity of the earth's orbit, that the lessened rotation has not occurred uniformly, but irregularly, and this affords a cause for the recurrence of lagging and readjustment of the earth, the sea each time, however, adjusting itself promptly to the changing period of rotation. Uniting these factors, he thinks he finds an adequate cause for important shifting of the beach lines, first in one direction and then in the other, but at any given time in opposite directions in the polar and equatorial areas. Suess[1] and Blytt,[2] find evidence that in late geological time there have been actual shiftings of the beach lines, such as demanded by Blytt's theory. If these movements have the potency advocated by Blytt, it would follow that in the equatorial regions and in the polar regions there are two sets of more or less extensive intercontinental unconformities. However, they would be in an opposite sense. When, as a result of the ready adjustment of the sea and the lagging behind of the land, due to the changing speed of rotation, the low-lying polar land areas were submerged and therefore areas of deposition, the low-lying equatorial areas would stand above the sea and therefore be subjected to erosion. When the stresses had sufficiently accumulated, the equatorial land areas sank, and the polar land areas rose. As a result the low-lying districts formerly eroded in the equatorial regions would become areas of deposition, and the formerly low-lying areas of deposition in the polar areas would be above the water, and be areas of erosion. However, it is not supposed that these alternating intercontinental unconformities are of the same order of magnitude as those mentioned upon page 485, for which another cause is assigned.

It is to be noted that the change of the form of the spheroid as a result of lessening rate of rotation causes the polar areas to rise absolutely. This, however, is no exception to the

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[1] Antlitz der Erde, by E. Suess: Vol. II, 1888, pp. 697.

[2] Loc. cit., pp. 87–92.

general principle of gravitative adjustment already explained, for an equal or greater mass at the equatorial areas subsides a corresponding amount.

Another factor disturbing the clear-cut effects of differential subsidence is the lateral attraction between the land and sea. Where adjacent to the sea the land is high, the water is raised above the normal level. The same effect would be produced to some extent by a continental ice sheet. Woodward[1] calculates that if there were a North American ice sheet 10,000 feet thick sloping to the sea, the water would be raised several hundred feet as a result of lateral attraction.

Other important factors affecting the submergence and emergence of the land areas are orogenic movements and vulcanism. As shown later, more or less extensive elevations and depressions may result from these processes, and the sea shore thereby be greatly shifted.

Finally, it has been seen that epigene transfer of material may also produce a wide shifting of the beach lines.

But however complicated are the causes of movements and the resultant movements, the center of gravity of the entire mass moved is lower than before the movements. When the land areas subside with relative rapidity, they fall below the sea; when the sea beds sink more rapidly the water follows, leaving the land areas at an apparently higher level. Thus we have great vertical movements[2] of the surface of the earth, the effect of which is now to place large parts of the continents above the water, now below the water, the greater phenomena being the result of differential subsidence. Furthermore, there is every reason to believe that these differential vertical movements affect the continents all the time, and there is no reason to believe that any extensive area is ever quiescent. However, the movements are exceedingly slow.

Orogenic Movements. —Accompanying the vertical continental movements of the first order of magnitude, there are im-

[1] On the form and position of the sea level, by R. S. Woodward: Bull. U. S. Geol. Surv., No. 48, 1888, p. 70.

[2] The extension of uniformitarianism to deformation, by W. J. McGee: Bull. Geol. Soc. Am., Vol. 6, 1894, pp. 55–70.

portant horizontal movements in the crust of the earth, and vertical movements of the second order of magnitude. We may think of the standard illustration of the russet apple, with the smooth skin of the autumn. During the winter season there is a loss of water by evaporation, and the skin sinks to accommodate itself to the lessened bulk of the apple. The chief movements of the skin with reference to the apple are centerward, but beside this movement the skin as it sinks becomes wrinkled, and parts of it are pushed farther from the center. In this same way the greater movements of the crust of the earth are centerward. But there are local areas in which the strata of the solid rock are elevated, bent, broken, crenulated, or even corrugated. Folds, joints, faults, and secondary structures are formed. Vulcanism and earthquakes result. The total effect is to produce elevated plateaus and mountain ranges. These areas correspond to the wrinkles upon the surface of the apple.

The analogy between the orogenic earth movements and the wrinkling of the skin of an apple is only of the most general kind. The forces at work in the two cases are different, and their effects in one are much more complex than in the other.

In mountain areas, because of the corrugations and thrust fractures, the average thickness of the strata is increased, just as in the case of ice ridges upon a lake formed at a time of relative warmth and consequent expansion. The mountain masses may rise far above the elevation required for isostatic equilibrium. The only theoretical limit is the sustaining power of the rocks, and so far as gravity determinations have gone, this limit is nowhere reached. In order that there shall be local elevation, there must be regional depression. Indeed, the vertical downward forces resulting in regional depressions are partly transformed, first into horizontal thrust, and this again into upward thrust, and therefore are believed to be the cause of local elevations. As stated above, since the active force which caused both the regional depressions and the local elevations is gravity, it cannot but be that in a combined epiorogenic and orogenic movement the center of gravity of the mass moved shall be nearer the center of the earth after the movement than before, just as in the case of epiorogenic movements alone. When the time shall come, for any reason, that in any part of the earth a regional movement becomes less forceful, or altogether ceases, the excess of weight of the plateaus and mountain masses may dominate, and local subsidence, tending toward isostatic equilibrium, may slowly begin. From the foregoing we see that mountain-making movements are local disturbers of isostacy.

It seems reasonable to suppose, as above explained, that the rigidity of the rocks is sufficient to explain the uplift and to sustain the comparatively narrow mountain masses. But the question arises as to the cause of the elevation of the broad mountain systems and extensive plateaus of the earth such as those of Thibet and western America, and how they are sustained. Some of the mountain systems are tens or scores of miles across. Thibet is said to have an area of several hundred thousands of square miles, and an average elevation of 14,000 or 15,000 feet. The plateaus of western America above 6,000 feet in height are extensive. The larger plateaus are traversed and bounded by mountain ranges or systems. Many plateaus are partly composed of marine rocks of comparatively late age. Elsewhere rocks of the same age are at low levels. If the elevation of the plateaus were explained by differential subsidence alone, it would be necessary to believe that other portions of the continental areas bearing similar rocks and the bed of the sea had subsided to a far greater extent than the plateau districts. This would involve a differential subsidence amounting to several thousands of feet since Eocene time. It seems rather improbable that the surface of the sea could have been so far from the center of the earth at so recent a date, and if this were not the case, there must have been absolute elevation of the plateaus. In order to have produced absolute elevation there must have been thickening of the outer crust by plications along the mountainous areas, and deep-seated flowage of material under the non-plicated areas from other places.

In order that the crust shall be thickened by plications over an extensive area, it is necessary that the effects of the contraction of the outer part of the earth shall be largely concentrated along certain zones. We may suppose that the plications first thickened the strata along a relatively weak belt. After a time the increased thickness of material is sufficient to present a greater total resistance to deformation than the equivalent thinner layers adjacent. The stresses now deform them, and they are plicated and thickened. These areas now resist deformation, and the stresses deform the adjacent thinner belts, which in turn are thickened and plicated, and so on. In this manner various zones of plications and consequent thickening and elevation may be produced in a plateau area.

The second cause suggested for elevation, deep-seated flowage, is dependent upon the hypothesis that the rigidity of the superficial rocks is sufficiently great so that under the horizontal stresses in each region there arise a series of arches, which in a measure support themselves. Consequently the stresses are less than normal below the arches, and greater than normal upon the flanks, because of the transmitted thrusts. These stress-differences would result in deep-seated flowage from the flanks of the arches toward their central parts. This is a modification of Willis's[1] theory of competent structure. The explanation differs from his in that the broad arches are supposed to be only partly supported by the strength of the superficial rocks. If, on account of increased temperature, or because of this and decreased pressure, the deep-seated rocks are less rigid than in the superficial spherical shells, it would only be necessary for the arches to be partly supported by the strength of the rocks. The deep-seated materials, as soon as subject to stress-differences greater than their rigidity, would ever closely follow the arches and help to support them.

The character of the plateau areas accords with this explanation. As already noted, they are regions of alternating mountain chains or systems, and intervening unfolded or gently folded areas. The mountain ranges are the areas of thickening and greatest elevation. The intervening unfolded areas may be those of the arches and partial self-support. The sides of the mountain zones receive the downward thrusts of the intervening arches. These forces and the downward pressures of the mountain masses

[1] Mechanics of Appalachian structure by Bailey Willis: Thirteenth Ann. Rept. U. S. Geol. Survey, Pt. II, 1893, p. 250.

themselves, place the deep-seated materials below them under great stresses, and they flow from beneath them toward the intervening arches, where the stresses are less than normal, and thus helps to support them.

Looked at in another way, an entire plateau may be considered as a great arch of such magnitude that the strength of the rocks is insufficient to support the mass. At various zones the arch collapses. At such places the rocks are plicated and thickened and these zones are the traversing mountain ranges. This point of view does not substantially alter the principles of uplift as above given.

It may, perhaps, be doubted whether the explanation offered is adequate to account for the existence of the more extensive plateaus. But, if the causes assigned are not adequate, I am unable to suggest supplementary causes. However such plateaus may have been produced, it appears highly probable from gravity measurements, made by Putnam,[1] and discussed by him and Gilbert, that the plateaus of western America have an amount of material in excess of that of the low lands, corresponding in most cases to their elevation. Therefore it appears certain that whatever the causes of these uplifts the rigidity of the rocks is sufficient to sustain them for a long time, and it may be plausibly argued that if the rocks are strong enough to sustain the excess of material, they were strong enough to produce the uplift as suggested. Whether or not Thibet has an excess of material corresponding to its elevation is unknown. This can only be ascertained by gravity observations. Until such observations determine the excess of material in this region, we cannot tell to what extent this plateau is sustained by the rigidity of the rocks.

Returning to the mountain systems, we find they are not located by accident. The rule appears to be, as stated by Hall,[2] that where great masses of sediments are being piled up as a

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[1] Results of a transcontinental series of gravity measurements, by G. R. Putnam; and Notes on the gravity determinations reported by G. R. Putnam, by G. K. Gilbert: Phil. Soc. Wash., Vol. XIII, 1895, pp. 31-76.

[2] Contributions to the geological history of the American continent, by James Hall: Proc. Am. Assoc. Adv. Sci., Vol. 31, 1882, p. 55.

result of the erosion of the land, there future mountain ranges may be born.

We may anticipate that in the border of the Gulf of Mexico, where the sediments of the Mississippi have accumulated to a great thickness, and are still accumulating, at some future time a mountain system may exist. That Hall's law is true is shown by the vast thicknesses of sediments which are found in the Appalachians, in the Sierra Nevadas, in the Alps, in the Himalayas, and in all other great mountain systems of the earth. As shown by Willis,[1] an important cause for the location of mountain ranges in areas of great sedimentation appears to be the initial dips of the strata of the geosynclines of deposition. Further, under the stresses at work during deposition the solid rocks below the sediments are flexed. When later, great horizontal thrust comes, as a result of contraction, it finds the strata in a loaded area already somewhat bent. When a rigid mass is once slightly bent at any place it bends farther much more easily at that place than elsewhere. Furthermore, newly-formed unconsolidated sediments form an outer zone of relative weakness.[2] Hence it follows for any given period that a large part of the effects of the outer contraction of the earth is concentrated along the comparatively narrow zones of mountain-making.[3]

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[1] The mechanics of Appalachian structure, by Bailey Willis: Thirteenth Ann. Rept. U. S. G. S., Part II, 1893, pp. 249-250.

[2] Le Conte, in supposing that the rise of mountains in areas of great accumulation is due to the weakness and softness of the strata caused by the rise of the isogeotherms, altogether overlooks the fact that in regions of little or no sedimentation the rocks at corresponding depths are equally and probably more highly heated. Otherwise it would have to be supposed that complete isothermal equilibrium had been restored in the areas of sedimentation before mountain-making began. (Loc. cit., p. 557.)

[3] As suggested by Babbage and Herschel, and advocated by Reade, the localization of mountains may possibly also partly be explained by the rise of the isogeotherms. (Babbage's ninth Bridgewater treatise, with appendix by Sir John Herschel, 1837, pp. 187-197, 214-217. The origin of mountain ranges, by T. Mellard Reade, 1886, pp. 107-116. Manual of geology, by J. D. Dana, 4th ed., 1895, pp. 258, 381-383.) It has been held by Reade that if this expansion be concentrated it would be sufficient to explain the rise of mountains. Davison has pointed out (Expansion theory

In the above the contractional theory of mountain-making is accepted. However, it is a contractional theory materially modified from that proposed by Prevost, Dana, and Le Conte, in which the cause assigned was the loss of heat due to secular cooling. We have seen that there are other causes for superficial contractions, some of which may be of equal or greater importance than this. These are vulcanism, the increased density and decreased oblateness of the earth due to decreasing speed of rotation, change in part from a liquid to a solid crystalline condition, change in molecular composition, and possibly also loss of occluded water and gases.

Vulcanism.—It has been held that epiorogenic, orogenic, and epigene movements alike are gravitative, and that their resultant is ever earth-centerward. It remains to see that the same is true of vulcanism.

It is certain that vulcanism is a phenomenon attending epiorogenic and orogenic movements. The living volcanoes are in regions of known earth movements. In regions of relative quiescence there are no active volcanoes. In regions in which vulcanism has been prominent in the past, the field evidence is clear that these were also regions of simultaneous crustal movements. Moreover, it is certain that rising lava takes advantage of openings formed by earth movements. The rows of active volcanoes are presumably located along zones of faulting or jointing. The dikes intruded during ancient periods of vulcanism generally conform to the faults and joints, and in many districts

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of mountain-evolution, by C. Davison, Geol. Mag., new ser., Vol. II, 1895, pp. 308–309), that Reade does not sufficiently explain how the effects of heat are to be concentrated along mountain ranges, and more important than this, the heat causing the expansion by the rise of the isogeotherms must be derived from somewhere else, and if derived from somewhere else, there must be contraction corresponding in amount to the expansion where the mountain ranges are formed. Further the question is pertinent as to how far the expansion due to the rise of the isogoetherms is compensated for by condensation of the unconsolidated sediments also resulting from the same cause. Possibly the rise of the isogeotherms may be the real cause, among others, for the localization of mountain changes, but even if so, it is plainly but auxiliary to the contractional theory of mountain-making.

they may be seen to be arranged in definite systems occupying a portion of one or more of the systems of joints of the districts. This is nowhere more beautifully illustrated than by the numerous granite dikes which have been intruded along the joints in the Sierra Nevada granite. In the magnificent exposures of the Yosemite Valley this may be beautifully seen. The sills and laccolites have taken advantage of the partings along bedding planes.

Cause of Liquefaction.—If Mallet's[1] theory be accepted, that the heat liquefying the rock for vulcanism is produced by the mechanical crushing of orogenic movements, the formation of magma is certainly due to gravity, for orogenic movements are the direct result of gravity, or the indirect result arising from tangential thrust, which in most cases is caused, as already explained, by the general settling of the outer part of the earth. However, even if this theory were accepted as adequate to explain the source of magma for local volcanic action such as now exists, few would regard it as sufficient to account for the vast regional extrusions and intrusions of great periods of volcanic activity such as those of the pre-Cambrian (Keweenawan) of the Lake Superior region; the Silurian of Great Britain; and the Tertiary of India, New Zealand, Abyssinia, Great Britain, and western America. The volcanic material of this last period surpasses in quantity that of any previous period. But this does not show that the extrusives of the remote volcanic periods were less extensive; for the further back the eruption, the greater the proportion of the igneous rocks which have been transformed into sedimentary rocks by the epigene agencies. The predominant lavas of regional eruptions appear to be of an intermediate or basic character.

If the liquid rock is not produced from the crystallized crust by mechanical crushing alone, it must be supposed to be residual liquid material of the earth or to be produced from highly heated rigid or potentially liquid rock, held in the solid state by great pressure. If as a result of the release of pressure due to

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[1] Volcanic energy; an attempt to develop its true origin and cosmical relations, by Robert Mallet: Phil. Trans. Roy. Soc. London, Vol. 163, 1873, p. 167.

denudation, or the uprise of an arch of rigid rock supported in part by its limbs, or to deep-seated fractures, or to all of these combined, the rock below changes to a less rigid condition than normal for a given depth, or possibly into a liquid condition, this modification of form is due to gravity, for it has already been seen that all of these processes in the final analysis are gravitative. In this change it is entirely possible, perhaps probable, that the heat of dynamic action, as suggested by Mallet, may be an important factor, although this factor does not have the dominating value which he attributed to it.

Rise of Lava Caused by Gravity.— The plastic or liquefied rock, whether original or produced, is ready to take advantage of any crack, whether it be called joint or fault, and may begin to rise, exactly as water rises in a fractured sheet of ice nearly to the surface, a relatively large mass of the rock, like the ice, settling a small distance, to compensate for the considerable uprise of a small amount of liquid material. The rise of ice and lava alike are therefore gravitative. Probably, however, or at least possibly, liquid rock is upon the average somewhat heavier than the superjacent solid material, just as water is heavier than ice. In this case it would not rise to the surface. However, if the solid material were supposed to be in an amorphous, or crystalline condition, the change to the liquid condition would lessen the specific gravity, for a given mass of liquid rock occupies more space than an equivalent mass of glass of the same character (in the case of diabase 3 per cent.[1]), and in the amorphous solid condition occupies more space than in the crystalline condition (in the case of diabase about 10 per cent.[1]) The average specific gravity of the known solid crust of the earth is about 2.7. That of diabase glass, a rock fully as basic and heavy, as the average of extrusives, is 2.717.[1] The specific gravity of fused diabase at ordinary pressures is about 2.635. Furthermore the development of steam bubbles may greatly lessen the specific gravity of the magma. It therefore appears probable that upon the average the liquid rock cannot be supposed to be heavier than the subjacent solid material. Locally the magmas

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[1] High temperature work in igneous fusion and ebullition, by C. Barus: Bull. U. S. Geol. Survey, No. 103, 1893, pp. 26, 38.

may be more basic than the average, and such undoubtedly have a greater specific gravity than the average of the known crust. Also, in many places the crust has a lower specific gravity than the average. At localities where either or both of these conditions obtain this would be unfavorable to the rise of the magma to the surface. Furthermore, the friction of viscous magma upon the walls of the orifices and within itself, during uprise, is great. Because of the approximate balance in density between magmas and the known crust, because of friction, and because many of the openings entered by magma do not extend to the surface, by far the larger part of the material which starts on an upward movement is probably stayed before it reaches the surface. The amount of material which does reach the surface is indeed vast, but this amount is believed to fall far short of the simply enormous quantity of igneous material which stops within the upper crust of the earth as great batholites, laccolites, sills, and dikes.

It has been said that a part of the magma does reach the surface. During regional eruptions it wells forth in enormous quantities from numerous long fissures or from throat-like orifices and floods the country. The amount thus poured forth at various periods and in different regions has been sufficient to bury thousands or tens of thousands of square miles to a depth of thousands of feet.

Although the absolute amount of material emitted by active volcanoes is very large, it is indeed small compared with regional extrusions. The material extruded in late Tertiary time is probably far greater than the amount that would be thrown out during an entire era at the present rate. During the regional eruptions great numbers of volcanic mountains, similar to those now in action, are also built up, and in a manner similar to the present volcanic mountain building. This is especially the case in the last epoch of a period of regional volcanic activity. In the Cascade region it was at this stage that the great volcanic mountains, such as Rainier, Hood, Helens, Three Sisters, Jefferson, Adams, and others were piled up.

As already explained, it is believed that the dominant force which is behind the great regional extrusions of igneous material, is gravity. Further it has been noted that these extrusions are contemporaneous with great crustal movements. The phenomenon may be considered under the headings of, vulcanism in connection with regional compressive movements, vulcanism in connection with regional tensile movements, and local vulcanism.

Vulcanism in Connection with Regional Compressive Movements. During regional compressive movements the effects of great lateral forces are concentrated along certain belts, and there the rocks are thickened, plicated, and broken. Broad anticlinal mountain ridges are separated by wide synclinal depressions. The heaping up of the material gives sufficient pressure to cause the magma to reach the surface at the lower levels by gravitational adjustment, just as in a lake covered by a thick layer of ice, where on the depressed areas adjacent to expansion ice ridges which form during times of rising temperature, water rises to the surface of the lighter ice and floods it. Under this theory the material would be extruded through cracks in the depressed areas, or from the flanks of the folds, in which case it would flow toward the depressions. If the magma passes through cracks in the depressed area, it must be supposed that the mechanica movements or the local release of pressure at the cracks, or both, suffice to soften the deep-seated rock so that it rises.[1]

If the passage of the magma be through the flanks of the folds, in addition to the factors already mentioned tending to soften the rocks, there is still another: Such places are adjacent to the anticlinal ridges. There, because of the partial transmission of the load along the limbs of the arches, under the principle of competent structure, the deep-seated material is under less pressure than the average, and this also tends to make it plastic or liquid.

When once the extrusion of material has begun, its weight must be added to the load of the solid rock, and if deformation continues tending to depress the synclines and to raise the anti-

[1] Geikie thinks that cracks are not necessary, but that the magma may drill its way "through rocks independently of faults." (Ancient volcanoes of Great Britain, by Sir Archibald Geikie, Vol. II, 1897, p. 473.)

clines, the extrusion of magma may continue until a great thickness of volcanic material is accumulated.

If the force behind the magma be sufficient to drive it to the surface, it may be sufficient to force it along the partings between the layers, or other fractures or planes of weakness, and thus form sills, laccolites, batholites, or other intrusive masses. As stated by Gilbert[1] this is especially likely to be the case if the magma has a greater specific gravity than the upper part of the solid crust; for, disregarding the forces necessary to flexure the rocks overlying the intrusive, the work required to introduce a given quantity of magma below the surface is less than that required to carry it to the surface. In either case the boundary between the rock and air is at the same level, but if intruded, the center of gravity of the sill or laccolite and the overlying solid rock is lower than the center of gravity of this same mass of solid rock and the extruded lava spread over an equivalent area of the surface. Because of this principle it happens in many regions that after the forces are too feeble to press the magma to the surface, vast quantities may still be intruded into the rocks near the surface. This is illustrated by the ancient vulcanism of Great Britain.[2]

To some extent the expansive force of the dissolved waters known always to be contained in the magma may assist in the process of regional eruptions.[3] A portion of the water is probably original. Another part may be derived from underground

[1] Geology of the Henry mountains, by G. K. Gilbert: Rept. U. S. Geol. Survey, 2nd ed., 1880, pp. 66–74.

[2] Loc. cit., p. 474.

[3] It is not my purpose to here only discuss the source of the water. It is probable that an important source is by percolation through the surface rocks. This is especially true of local volcanoes. In regional extrusions it, however, appears highly probable that the occluded water has been held largely by the magma from the first. The gas pressure resulting from its presence would depend upon the quantity of water occluded per unit mass and the temperature of the occluding rock. Since both of these factors are unknown, it is useless to speculate upon the resulting pressure, but unless the amount of water be assumed to be great, and the temperature be assumed to be very high, there is no doubt that the pressure of the superincumbent rock would vastly surpass that of the gas pressures resulting from the water contained, except at very superficial depths.

waters of superficial origin. If this water were superheated before absorption it might help to give liquidity to the magma,

When the magma nears the surface a part of the occluded water may separate as steam bubbles. The energy spent in the formation of steam bubbles, and consequently in expanding and lifting the lava, is derived from the heat of the rocks solid or liquid. So far as this heat is mechanical, as suggested by Mallet, its source is gravity. If the heat be derived from the stores within the earth, its source is as certainly gravity, only in this case a very long time interval has elapsed between the accummulation of the heat during the segregation of the earth by gravity, and its transfer to the water. Thus in any case the energy of the steam used in vulcanism is indirectly obtained from the force of gravity.

In the process of steam bubble development in magma the volume is increased, and the specific gravity of the liquid mass is thereby lessened. Consequently the magma may reach the surface at places where gravitation would not have carried it but for its decreased density. It is well known that some intrusive rocks are amygdaloidal. Moreover, such rocks are known in regions which have undergone considerable denudation since the intrusions occurred,[1] thus showing that steam bubbles may begin to form at considerable depths, and therefore may greatly help the magma to reach the surface. The importance of the phenomenon doubtless largely depends upon the quantity of water occluded. If it be supposed that this process of deep steam bubble formation does extensively occur, great outflows of lava might take place rather high upon the ridges, and inundate large areas of a region.

The facts in some of the great lava regions of the world correspond with the above explanation. Geikie[2] has shown that the great Silurian, Carboniferous, and Tertiary regional eruptions in the British Isles mainly occurred through comparatively low-lying fissures. Corresponding with this rule, the vast masses of lava of the Keweenawan of Lake Superior seem

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[1] Ancient lava flows of Great Britain, by Sir Archibald Geikie: Vol. II, 1897, pp. 31 and 130.

[2] Loc. cit., p. 468.

to have been poured out over a depressed area. Moreover, these extrusions and those of the Tertiary of Britain[1] are very largely amygdaloidal. The cavities resulted from steam separation, and the specific gravity of the magmas was considerably lowered. That this change partly or largely took place after the extrusions is highly probably, but it is not unlikely that the formation of bubbles occurred somewhat extensively at a considerable depth, and if so, as already explained, it was an important factor in the eruption of the lavas. Whether the bubbles were originally formed before or after the extrusions, they made their way toward the upper and lower surfaces of the lava flows before solidification. Many of the bubbles which once existed may have escaped. Only those which were retained in the solidified lava furnished cavities for the formation of amygdules.

Whether or not in the lavas of the other areas of regional vulcanism amygdaloidal lavas are abundant, I have been unable to ascertain from the literature.

Vulcanism in Connection with Regional Tensile Movements.—It is believed that the same principle of gravitative rise, perhaps through the assistance of steam is also applicable to regions in which the deformation is largely that of tension. The plateau region of the western United States belongs to this class. As explained by Gilbert and others this is a region of normal faulting and block tilting. The fractures are believed in such cases to be due to tension. If this be so, it is favorable to their extension to a great depth. The fractures are generally not exactly vertical. In the case of the rock masses upon opposite sides of a given inclined fracture, the base of the overhanging mass carries a greater weight per unit area than the average of the region, and the base of the opposite mass a less weight. The deep-seated rock is therefore under greater stress than the average for the region, in the first place, and under less stress, in the second place. As a consequence, the mass on one side sinks, and on the other side rises. This necessitates flowage from below one mass to below the other. The potentially liquid rock far below the surface is largely released from pressure

[1] Loc. cit., p. 187.

at the immediate place of fracture, and to a less extent under the mass giving less than the average pressure per unit area. Where the pressure is lessened, as a result of this cause, and perhaps as a result of mechanical movement, the rock is softened and it begins to rise and overflow the subsiding area. The process once begun, the weight of the ejected material must be added to that of the overhanging block, and thus tends to continue the process. Furthermore, as in the case of regional eruption by crustal compression, the formation of steam bubbles may be an important assistance in the uprise of the lava. It is not supposed that the disturbed gravitative equilibrium is entirely compensated for by extrusions. It is partly compensated for by the movements of the blocks in opposite directions. The position of the extensive lava fields and cones at various places in the plateau country of western America appears to accord with this explanation. The lavas have flowed from fissures and in many places they also built up rows of cones. On one side of each fissure there probably has been depression, and upon the other side equivalent uprise. However, a part of the subsidence of the great basin blocks have been compensated for by extrusions of the lavas.

During tensile movements, exactly as in the case of compressive movements, much or all of the magma formed or moved may be intruded instead of extruded, and thus dikes, sills, laccolites and batholites be produced.

Local Vulcanism.—In the case of volcanoes such as now exist, it may be supposed that the expansive force of steam is a relatively more important factor than in regional eruptions. In most districts of living volcanoes, as a consequence of various eruptions, volcanic mountains have been built. In such a case the weight of the mountain is to be added to that of the adjacent crust. The total stress is sufficient to raise the lava part way up the funnel. If as a result of earth movements fissures form on the flank or at the base of a mountain, gravity may be sufficient to cause an extrusion. When any considerable quantity of lava is extruded during a given eruption, it is generally through low-lying fissures. Through them lava may easily escape. However, many extrusions are over the lower lips of the craters. It is not to be expected that the downward pressure of the solid material is sufficient to raise the dense lava to the place of overflow, and nowhere does this appear to be the case. However, as the lava becomes porous as the result of the formation of steam bubbles, it becomes lighter and may rise to the top. The process once begun, the steam bubbles may form rapidly, in which case there is an explosive eruption. They may form rather uniformly, and be evenly distributed through the lava, in which case the lava quietly overflows. After an eruption of a given volcano there is ordinarily a period of relative quiescence, during which time the slow formation of steam bubbles may continue until the density of the lava is sufficiently decreased so that another eruption may occur.

Thus, even in the case of ordinary vulcanism the direct action of gravity is given a dominant place among the causes. The frequent inward sagging of sedimentary rocks observed about ancient volcanic necks is important evidence in favor of this view.

I would not underestimate the power of steam in vulcanism, but that its expansive power is the chief force in the transfers of liquid material within the earth seems to me to be wholly unproved. The dominating force as explained is believed to be that of gravity. In these earth movements, as in others, the resultant of the gravitative movements is earth-centerward.[1]

Growth of Continents.—I shall now consider the joint effects of epigene transfer of material by erosion, of the compensating transfer of deep-seated flow toward the continents, of differential subsidence, and of vulcanism, upon the growth of continents.

[1] The outline of the processes of vulcanism above given is largely independent of other authors. However a comparison with the writings of Hopkins, Prestwich, Geikie and Russell will show that to a greater or less degree these authors have expressed views similar in various respects to those given.

Researches in physical geology, by Wm. Hopkins: Phil. Trans. Roy. Soc., 1842, Pt. I, p. 53.

Chemical, physical, and stratigraphical geology, by Joseph Prestwich: Vol. I, 1886, pp. 210-211.

Ancient volcanoes of Great Britain, by Sir A. Geikie: Vol. I, 1897, pp. 12 and 13.

Volcanoes, by I. C. Russell: 1897, pp. 297-326.

It has been a very general belief among geologists that the continental masses are gradually expanding, or that they grow.

By erosion the rock materials above the water are transferred to the borders of the continental platform, and are there deposited in the shallow water and upon the slope. To some extent deep-seated inland flow may compensate for this.

However, it has been seen that where great thicknesses of sediments are formed, there land areas or even mountain masses may subsequently be found, and thus the continents may grow.[1] No sooner do the land areas rise than erosion begins, and a large part of the material is transported seaward and thus still farther builds out the continental platform. This statement remains true even if in some cases still greater masses of material are transported to a mediterranean sea, as may have been the case at the time of the deposition of the sediments of the Alleghany mountains. The continuation of this process, provided no other forces were at work, would finally result in extending the continental border at the expense of altitude, for wherever the land arises above the sea, that part is cut off and transported to the continental border. Finally, if no other forces were at work except superficial seaward movement and compensatory hypogene flow, they would result in reducing the continental platform to the level of the sea and in enlarging its borders. And ultimately, as suggested by Gilbert,[2] as a result of solution, the entire continental platform would be immersed. However, it appears probable that with these forces others are at work.

How vast is the quantity of intruded and extruded rocks has already been seen. This material, stopping in the outer part of the earth or reaching the surface, becomes a prey to erosion, and like the other land materials, and in a similar manner, is distributed along the border of the continents, helping in their growth. This igneous material comes from far below. Moreover, there is no reason to believe that during the periods of regional vulcanism the volcanic regions subside an amount equivalent to the intrusions

[1] J. D. Dana: Phil. Mag., Vol. 46, 1873, p. 49.

[2] Continental problems, by G. K. Gilbert: Bull. Geol. Soc. Am., Vol. 4, 93, p. 189.

and extrusions. On the contrary vulcanism seems to be usually connected with general uplift of the volcanic districts. If this be so, the intruded and extruded material must be compensated for by the deep-seated flow from the continental areas or from the sea beds. If from the former, no additional effect is produced upon continental growth, but if from the latter, this gives a source of material for continental growth. When it is remembered that the majority of the living volcanoes are adjacent to the ocean, and that many of the ancient volcanoes have occupied a similar position, it can hardly be doubted that the compensating flow has often, in part at least, come from the sea. Where the volcanoes are beyond the main land areas, as in the case of the great line of volcanoes extending from the Aleutian through the Kurille, Japan, Phillipine and East India islands, this position is particularly favorable for continental growth, as they are almost immediately adjacent to the deep sea, and the epigene agencies rapidly transfer a part of the material to the continental slope.

In the supposed deep-seated flowage of material from the oceanic basins towards the lands areas, it is not meant to imply that any part of the material has moved all the way to the roots of the volcanoes. As already explained (p. 472), the result may be accomplished by a small continent-ward movement of a large mass, rather than by a long movement of a smaller mass. In the case of the igneous material thus fed to a volcano, the movement of any given particle would doubtless be slower, the more remote from the volcano, just as that of a particle of water in a lake remote from the outlet. However, if there be any movement of the material below the bed of the ocean toward the land, this is a real source of material for continental growth. If the continental masses formed during the partial or complete solidification of a liquid earth (pp. 479–483), it would follow that there was, and perhaps is still, a real cause for deep-seated flowage of material from the sea beds toward the land areas. It was supposed that after the continents had formed, and the first crust under the sea had solidified, the two were approximately in isostatic equilibrium. After the continents had formed, because of the greater thickness of the solidified material as compared with the sea bed, solidification would go on more rapidly at the latter place than at the former, until finally the thickness of the solidified material below the sea beds might approximate to that below the continental areas. But as rocks solidify, and especially as they crystallize, they contract a very considerable amount.[1] Barus[2] has shown this combined contraction for diabase, a rock of average composition, to be about 12 per cent. Furthermore, it has been supposed that the regions below the sea have a higher conductivity than the continents and their downward extensions. If this be so, the former regions would ever continue to cool more rapidly than the latter, and would contract more.[3] Both of these contractions would result in concentration of the rocks of the sea bed and in bringing them nearer to the center of the earth than the continental masses. Hence gravity would be more effective on the mass below the sea than elsewhere, and differential stresses would result. The quantitative value of the increased effectiveness of gravity on the mass of the sea beds should be estimated upon various numerical suppositions, but the amount of contraction in cooling, solidification, and crystallization is so great that it can hardly be doubted that its effectiveness would be considerably increased. As a result of the unequal contraction the continental ship would be no longer in isostatic equilibrium. Differential vertical movement would be set up, and material below the sea areas would tend to flow toward the land areas, and thus tend to elevate the continents, but the average of the movements would be downward. Whether the continents absolutely or relatively rise under these stresses would depend upon the average amount of contraction of the earth. It is probable that this contraction would more than counteract the tendency to uplift, and therefore that relative elevation, and not absolute

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[1] Manual of geology, by J. D. Dana: 4th ed., 1895, pp. 264-265.

[2] The contraction of molten rock, by C. Barus: Am. Journ. Sci., 3rd ser., Vol. 42, 1891, pp. 498-499.

[3] Davison expresses the idea that early in the history of the earth below the level of no lateral stress "crust stretching by lateral tension must have taken place chiefly beneath the ocean basins, deepening them and intensifying their character." (Phil. Trans. Royal Soc., Vol. 178, 1887, p. 241.)

elevation would occur. The process above outlined might continue until approximate isostatic equilibrium had again been reached. We thus have a real cause for a very long continued growth. When the hypogene forces causing more rapid subsidence of the sea beds than of the continents, and consequently relative upheaval of the continental masses, shall have finally exhausted themselves, it cannot be doubted that the epigene forces will win, and that the continental masses will be reduced to an even platform slightly below the level of the sea.

Rock Structures Resulting from Earth Movements.—Returning now to the corrugations of the earth, I would direct attention more closely to the structures and rock alterations resulting from mountain-making.

During these movements the strata are bent into great complex flexures or folds; they are faulted, jointed, and fractured; new structures are produced in them; their composition and mineral character are changed.

In the outer part of the surface where the rocks are not sufficiently loaded, numerous joints and faults are formed; very numerous parallel fractures and slight displacements may occur which break the rock up into thin leaves, these leaves being parallel to the bedding or intersecting it; and finally, the rock may be broken into irregular fragments, or even into rubble. This is the zone of rock fracture. Deeper down, where the load is great, even the most rigid rocks are bent like paper or are mashed like dough, showing no macroscopic evidence of crevice or fracture. It has been calculated that for even the strongest rocks this depth can not exceed 40,000 feet.[1] This is the zone of rock flowage. It is in this deep-seated zone that true flexure folds are produced. In the zone of fracture, folds of similar form may be developed by slight rotations of the small blocks between multiple parallel joints. The result is similar to that of an arch made of rectangular bricks, there being slight openings between the bricks on the convex side of the arch.

Folds in rocks may be compared with waves of the sea. Each

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[1] Principles of North American pre-Cambrian geology, by C. R. Van Hise: Sixteenth Ann. Rept. U. S. Geol. Survey, Pt. I, 1896, p. 592.

large wave has superimposed upon it waves of the second order; upon these are waves of the third order and on these waves of the fourth order, and so on. Moreover, running across the most conspicuous waves, at various angles up to perpendicularity, may be other waves of an equally composite character. As observed from a ship at sea, the waves of the first order are so large and have such gentle slopes that they are often overlooked, while the steeper waves of the second order are noticed, because more conspicuous. Upon account of their small size the waves of a higher order than the second are usually unnoticed, as are also the waves of all orders which are transverse to the more conspicuous set.

If when stirred by a great storm the surface of the sea could in an instant be frozen we should obtain some idea of the complexity of the waves. We should see primary elevations and depressions of circular, oval, and lenticular horizontal sections, in different sets, crossing one another in various directions, and upon these would be other sets of waves of like complexity of the second, third, and fourth orders, and so on.

The rock waves of the earth are of greater size and of equal or greater complexity than the waves of the sea. The rollers of the sea, when not wind-forced, may be compared with the long gentle folds of rock. At first sight they seem simple, but, like the rock folds, when observed closely they are found to possess secondary crenulations. At the other extreme are the highly complex waves running in various directions at the same time, formed by the shifting winds of a storm, by currents and tides, together. The sea in this condition may be compared with the rocks in which each set of primary folds has superimposed upon it folds of the second order, and upon these those of a higher order up to the *n*th order. The smaller orders of folds are microscopic. Such complexly deformed rock folds are called crumpled, plicated, or implicated.

Deep-seated, homogeneous rocks, when deformed, flow in the same way as would a flat, thick cake of dough if subjected to stresses similarly disposed. In this change no particles, small or great, weak or strong, escape the effect of the pressure. All are deformed. In extremely closely folded stratified or heterogeneous rocks, the mashing process may have gone so far as to impose on them nearly the same mass effects as in homogeneous rocks, the numerous layers being pressed until they lap back upon themselves, like the plications of a closed fan. The hardest and most brittle pebbles of quartz or of jasper may be flattened so that they are several times as long as broad, or may be pressed into thin paper-like leaflets, or even so far that their original outlines are altogether lost. During the flowage, as a result of the flattening and rotation of the particles, and of the formation of new minerals in the rock and their rotation, the rock may gain a capacity to part in one direction more readily than in others. This property is called cleavage, and is best illustrated by slates, which with a wedge may be split into thin layers. The cleavage may or may not accord with the original structure.

Rock Alterations.—But perhaps the most surprising of all the earth movements are the minute ones. By our modern method of microscopical study of rocks in thin section, we look through even the black rocks as though they were transparent, and we see that no rocks are stable. We see one mineral changing into another. We see minerals grow. We see one mineral replaced by another. In short, we see one kind of rock transformed into another kind. Minerals stable under one set of conditions may not be stable under another. No rock is so dense that water may not penetrate to its innermost part. Water, driven by gravity, is the great transporting and transforming agent of the earth, as well within the mass of the rock as upon the surface.

Wherever as a result of the forces of deformation the rocks are fractured, creviced, or brecciated, there waters freely enter. These waters may take the materials of the rocks in solution, and thus are explained the caves of the earth. Within the cracks, crevices, and openings in the rocks through which the percolating waters pass, a portion of the material in the solution may be deposited, and thus the rocks be healed of their wounds, becoming as strong as before broken. But usually differences between the original and secondary materials enables one to trace the histories of the transformations. The water deposits in rock crevices are of great interest to man, for from them are taken nearly all of the valuable metalliferous ores. Our stores of zinc, of lead, of copper, of silver, of gold, and of iron, are nearly all produced by water concentration, either in openings in the rocks or else as replacements of their materials. It is to be remembered that the original materials of the earth are igneous, and it is only rarely that these contain a sufficient quantity of the useful metals to be available.

At a given place the conditions may be such that minerals are being dissolved at one time and being deposited at another. Some minerals may be dissolved at the same time other minerals are being deposited. In the same cavity a mineral may be in the process of solution in one part and in the process of deposition in another. In the same opening a dozen different combinations of minerals may be deposited in succession. The conditions for the deposition of the later minerals may be favorable for the solution of those earlier deposited. All of these phenomena and many others are illustrated in the clefts and caves bearing lead and zinc in the southwestern part of our own state.

From the foregoing it should not be concluded that minerals have any such mobility as has life. The transformations of minerals in most cases is exceedingly slow. Where the environment remains the same as that in which the minerals developed, they may continue the same indefinitely, for under given conditions minerals form which are stable under those conditions. The meteoric stones which fall to the earth may have had the same mineral composition which they now possess since their segregation, perhaps before the history of the solar system began. But when the conditions of environment are profoundly changed, as for instance when the meteoric stones leave the interplanetary or interstellar spaces and fall to the surface of the earth, mineral transformations will begin. Within the outer part of the earth itself the most important changes in environment are those due to orogenic movements or to erosion.

At first a mineral may crystallize in a lava bed, or in a deep-seated intrusive. The physical and chemical forces may now attack it. By the physical forces, it may be mashed, and from one mineral particle may be produced a multitude of particles. The mineral may be of the kind which is capable of changing into an entirely different mineral having the same chemical composition. In this case the motions are merely molecular, and yet the mineral is fundamentally changed. It acts differently in reference to light, in reference to heat; it cleaves differently, and has various other different properties. For instance, in its original condition the filtered light from a white complex ray may emerge reddish or brownish, whereas after the transformation the light which passes through may be green or blue. The mineral may have its chemical composition changed. Certain elements may be taken from it by percolating waters, or certain elements may be added to it or both may occur, any of these changes producing a different mineral. The mineral without addition or subtraction of material may alter chemically into one or more different minerals. Finally, the entire mineral particle may be taken into solution, and its place be taken by other mineral particles.

As a result of profound erosion in a region, the rocks are gradually transferred from deep within the earth to the zone of rapid water percolation. The conditions are now favorable for change. Where, as a result of continued erosion the materials are brought above the level of underground waters, the conditions are still more favorable for rapid alteration of the mineral particles, for here they are attacked by the powerful chemical agents; they are in the zone of active disintegration, decomposition, and solution.

At last a mineral particle reaches the surface of the earth. It is then directly attacked by the forces of erosion. By them it may be altered, or be torn from its matrix, with little or no alteration. It may then be caught up by running water, and transported to the sea. If decomposed its elements will certainly be widely distributed, and if not, it may be mechanically broken into many parts, so that its distribution is scarcely less wide, but ultimately much of its material will be deposited along the continental border, and be buried under thick deposits. It is now in a position where future land areas may be formed, and thus its parts may again go through another cycle of change.

When the environment changes, different minerals behave very differently, some being capable of existing under many conditions, others under only particularly favorable ones. Such minerals as leucite, nepheline, and olivine, are changed with comparative rapidity. Quartz, or rock crystal, upon the other hand, is comparatively permanent.

This mineral is one of the commonest ones in the abundant rock granite. Granite crystallizes from a molten magma far below the surface of the earth. When a quartz individual below the surface passes through a mountain-making period, it is recrystallized, or crushed into numerous granules, but in either case the material is of essentially the same character as the original. At the surface, weathering agencies have little effect upon quartz, except very slowly to dissolve it. However, they may break the quartz from its setting. The particles may be ground against one another as they are carried down the river, or they may beat against one another on the sea shore until they are rounded. These dirt-covered grains may be deposited in a sand bed and become deeply buried by newer deposits. Through the pores of this sand-rock later solutions may pass, bearing the material out of which quartz can be made. The mineral particles, notwithstanding all the vicissitudes through which they have gone, notwithstanding their millions of years of age, are able to take material like themselves and add it to themselves, and build up new, perfect crystals.

The total effects of the interior alterations of minerals and the transportation of mineral material by underground waters are enormous. If one looked only at the result, and thought not of the vast time it took to accomplish the work, he would conclude that such refractory minerals as quartz are as soluble as sugar. In the cementation of a great sand-rock formation to a quartzite, thousands of cubic miles of quartz are deposited from the mineral-bearing solutions. This almost incredible statement is fully justified when the extensiveness of the quartzite formations, and the amount of material required for the cementation of the original sandstones are considered. Some of the single quartzite formations cover thousands of square miles, and are several thousands of feet thick. If the original sandstones from which these quartzites were made be assumed to have been composed of spherical grains of uniform size, the amount of quartz required to fill the spaces would be .26 of that of the original grains of sand.[1] The minute interspaces are so well filled and the grains so firmly cemented that a quartzite breaks across the original particles rather than around them, giving a smooth conchoidal fracture like glass. But the change from sandstone to quartzite is a comparatively simple one. Far more profound changes have occurred on as great a scale in many countries. In some regions great igneous formations thousands of feet in thickness have been transformed into rocks which do not now contain a discoverable vestige of any original mineral. In other regions in which orogenic movements of the crust have occurred, the deeper seated rocks throughout have been completely recrystallized.

It is to be finally noted that as a result of the work of underground solutions the transferred material is on the average carried to a lower level. In the upper zone and especially that of weathering, material is dissolved, to be deposited deeper down in the earth, or to be brought to the streams for transportation to the sea. It is well understood that the underground waters may carry material upward, but it is certain that a much more than equivalent amount is carried downward. Thus the work of underground waters, like that of the surface agencies, is gravitative.

The Power of Gravity.— Summarizing, we have seen that differential subsidence slowly but surely causes the continental masses to rise or fall with reference to the surface of the sea. As a result of the subsidence of great areas, smaller areas, such as the plateaus and mountain ranges and systems, may be elevated. The horizontal stresses, thickening the strata along the zones of plication and producing the mountain systems and plateaus, are but incident to the larger movements of subsidence. By vulcanism vast masses of magma are introduced into the outer part of the crust of the earth, or spread over its surface. The continental areas, wherever they are above the sea, are being de-

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[1] R. S. Woodward: Bull. Geol. Soc. Am., Vol. I, 1890, p. 220.

graded by the wasting forces of water, ice, and wind. Concurrent with these movements is deep-seated flowage. As a result of these movements it is possible that the continents may grow. The remote cause to which continent-making, differential subsidence, mountain-making and attendant phenomena, epigene transfer, vulcanism, and deep-seated compensatory flow, are due, is the force of gravity persistently working upon a plastic contracting mass; and therefore the center of gravity of the various masses moved, is nearer the center of the earth as a result of the movements.[1]

Furthermore gravity is ever working toward isostatic equilibrium, but the rigidity of the rocks ever prevents its perfect accomplishment. The limit of excess or deficiency maintained by the strength of the rocks in any district is measured by the elastic limit of the rocks deformed, under the varying conditions of deformation. Some of these varying conditions are the magnitudes of the masses, the character of the rocks, the temperature of the rocks, the water content of the rocks, and the rapidity of the deformation. The greater the length and breadth of the mass moved, the less the thickness of the excess or deficiency which may be

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[1] This generalization is in accord with that which Prevost urged many years ago, as is shown by the following quotation from the Bull. of the Geol. Soc. of France, Vol. XI, 1840, p. 186:

"1. Que le relief de la surface du sol est le résultat de grands affaisements successifs, qui, par contre-coup, et d'une manière secondaire, ont pu occasioner accidentellement des élévations absolues, des pressions laterales, des ploiements, des plissements, des ruptures, des tassements, des failles, etc.; mais que rien n'autorise à croire que ces divers accidents ont été produits par une cause agissant *sous les sol*, c'est-à-dire, par une force soulevante;"

"2. Que les dislocations du sol sont des effets complexes de retrait, de contraction, de plissement et de chute;"

"3. Que les matières ignées (granites, porphyres, trachytes, basaltes, lavas,) loin d'avoir souleve et rompu le sol pour s'eschapper, ont seulement profité des solutions de continuité qui leur ont été offertes par le retrait et les ruptures, pour sortir, *suinter* et s'épancher audehors."

As proof of this paper is passing through my hands, through the generous courtesy of Major J. W. Powell I am in receipt, in advance of publication, of his manuscript on An Hypothesis to Account for Earth Movements (to be published in the Jan.–Feb. number of the Journal of Geol.

maintained. The greater the depth of the mass moved, the greater the thickness of the excess or deficiency of the mass which may be maintained. The harder the rocks, the greater the thickness of the excess or deficiency which may be maintained. The higher the temperature, the less the thickness of the excess or deficieny which may be maintained. The greater the water content, the less the thickness of the excess or deficiency which may be maintained. The more rapid the deformation, the greater the thickness of the excess or deficiency which may be maintained. All of these statements are sufficiently self-explanatory except the last. Where rocks are deformed rapidly, the elastic limit is higher than where deformed slowly. Also during uplift of the continental areas, erosion works in the opposite direction. The more rapid the uplift, the more effective is erosion. As the elevation becomes great, erosion becomes very rapid, and uplift slow, because the elastic limit of the rock is neared. Therefore the actual limit of uplift is less than that which could be temporarily sustained by the strength of the rocks.

Conclusion.—I hope this paper has made it clear that in the part of the earth we know there is movement everywhere; that the forces are constantly at work re-shaping, re-making the world. Even within the rocks themselves, porous or apparently

ogy, Chicago). The central thesis of this paper is that the modulus of compression of rocks varies under pressure in various ways under different conditions. As illustrative of his applications, erosion may be taken. Because of the shifting of material by epigene agencies to the sea shore, there is additional weight, and consequent compression, which results in subsidence. The denudation of the land removes load, which results in expansion, and therefore elevation. If Major Powell's hypothesis be accepted, it seems to me to accord with the law above advocated, that is, the sum-total of the movements are gravitative. For the compression is compensated for by expansion, and the lateral transfer is accompanied by downward movement.

I would make gravity explain the phenomena of deformation "of the earth's crust as the law of gravity explains the constitution of the celestial systems." (Powell.) Indeed, the geological history of the geoid is the part of the astronomical history which has been studied in detail. The geoid continues to be controlled in its deformation through geological time as it has in pre-geological time, and as are other worlds and the suns, —by the force of gravity.

solid, are everywhere forces producing movement and change. Moreover there is abundant reasons for believing that these forces are still as potent and their resultant transformations as rapid as in the past. The earth is not finished, but is now being, and will forevermore be re-made.

I am keenly aware that I have failed to give any adequate idea of the constancy, universality, and complexity of earth movements. Whatever the degree of complication which any of us may grasp, we may be absolutely certain that the facts are indefinitely more complicated. It is ever so in nature. The explanation first offered of a complex set of phenomena is always exceedingly imperfect. In succession, year after year, as new facts and principles are discovered, new statements, nearer the truth, are made. If the first work was good the explanation offered was not false,—it was incomplete. The later, larger explanation includes and adds something to the previous imperfect one. Each succeeding generation brings the explanation nearer completion, nearer perfection. This principle is well illustrated by the multiplicity of causes now assigned for the contraction of the earth, this being at first wholly attributed to secular cooling.

It is often remarked that it is scarcely worth while to learn the scientific theories of today — they will be changed tomorrow. By certain people, because of this, we are frequently warned not to place confidence in the conclusions of science. However, the change in science is its chief merit. Science is ever moving nearer the truth. If we would know the secrets of the world, the only way is to learn science as it is today, and move forward as it moves. The subject in which ideas are fixed, in which theories do not change, is dead.

We may be certain that all who hold a light opinion of science because its theories change lack a grasp of the methods of science. They may know some of its facts,—of little or no value, without at least a partial understanding of the underlying principles which control them,—but they are as ignorant of the real teachings and merits of science as is the savage The latter may see the electric car move, driven by an invisible power. He may be wonder-struck by many other phenomena of science. He, at least, has the feeling that here is profound mystery, while to the average civilized person it does not even occur to marvel, much less to try to understand the significance of the phenomena of the Universe in which he lives. He has ears to hear, and yet hears not. He has eyes to see, and yet is as if born blind. He has a reason to understand, but yet is as the ox that lies in the field and chews his cud in contentment. A being that lives in this world without a desire to know the meaning of the phenomena of the Universe cannot lay just claim to the name of man. He who has a desire to know, and ceases to strive until he has attained as much of an understanding of the Universe as his mind is capable of, is a sloth. But, however the mightiest intellect may labor, it may never hope to have more than an incomplete understanding of the simplest thing. Complete knowledge of the constitution of, and forces at work within, even a grain of sand can be obtained only through infinite capacity.

MEMORIAL ADDRESSES.

JAMES J. BLAISDELL.

James Joshua Blaisdell was born in Canaan, New Hampshire, February 8th, 1827. In 1834 his family removed to Lebanon, New Hampshire, where he grew up. He spent a few months in the Kimball Union Academy, entered Dartmouth College in 1842, and graduated in 1846, fifty years ago last Commencement. In speaking once of the formative influences of his life, Professor Blaisdell said that among them he recognized especially his honorable ancestry, his grandfather being a revolutionary soldier and a member of one of the early Congresses of our country, and his father an eminent member of the New Hampshire bar, of whom he always spoke with great veneration and love; his rearing amid scenes noble in landscape of mountain and river; and the fact that those among whom he was brought up were strenuous and plain people, doing their work thoroughly and fearing God. After leaving college he taught a year in Montreal. He then studied law between two and three years with his father, but during the study of the law his thoughts turned toward the work of the ministry, and leaving his father's office he went to Andover, Massachusetts, and there spent three years in the study of theology, graduating in 1852. He was pastor of the Third Presbyterian Church, Cincinnati, Ohio, from 1852 to 1857. In 1853 he married Miss Susan A. Allen, who had been brought up near him, under like influences, and who has been to a rare degree the companion of his home, of his thought, of his work. In 1859 he was called to Beloit College to the chair of rhetoric and English literature. In 1865 he was transferred by his own desire to the chair of mental and moral philosophy, those themes being especially germane to his own thinking. He was chaplain of the 40th Wisconsin Volunteers during their one hundred days' service in the vicinity of Memphis; "an ideal chaplain," Col. (now Bishop) Fallows called him. He traveled in Europe in 1869 and 1870. In 1873 he received the degree of Doctor of Divinity, both from Knox College and from Dartmouth, his *alma mater.* He was sought for the presidency of two of our leading western colleges, but in each case decided to remain in Beloit and to make his work as a teacher center there and in Wisconsin. He died on the 10th of October, 1896.

Between the lines of these simple statements we of the Academy and all who knew him, read the record of a noble and memorable life. Professor Blaisdell was a marked man as a thinker. You knew him in the breadth, the catholic range of his thinking. He loved best the great thinkers, but he found those great thinkers in many lands and ages. Isaiah and Paul and the seer of Patmos, Plato and Aeschylus, Dante and Aristotle,— these were men with whom he loved to hold converse. Of Puritan stock, he had the Puritan predilection for high themes and for wrestling with great problems of human destiny. In such society he found his chosen companionship; and with great men of recent years he also was in close touch and fellowship. Anyone who thought deeply on any line found in Professor Blaisdell an interested and sympathetic fellow-thinker. While certain lines were dearest to him, there could be no profound thought anywhere that did not attract him and tempt him to follow it. His library was the library of a man who thought widely, and whose sympathies were wide; and this was part of the charm of his personality to those who knew him. We all of us are aware that the distinguishing trait of his thinking was its spiritual quality. A Puritan, austere in appearance and serious and strenuous in his thinking and his life, he was also a mystic, loving the subtle, spiritual qualities of thought, and absolved from the limitations of any age or condition. With him all nature was intensely spiritual. Behind the physical manifestation shone the spiritual, as a light shines through an alabaster vase. He sunk himself deeply in these spiritual relations of mind and matter. He loved to soar on strong wings into spiritual ranges of thought and feeling, and lift with him the thought of others. He could well have said

"I have felt
A presence that disturbs me with the joy
Of elevated thoughts; a sense sublime
Of something far more deeply interfused,
Whose dwelling is the light of setting suns,
And the round ocean, and the living air,
And the blue sky, and in the mind of man;
A motion and a spirit, that impels
All thinking things, all objects of all thought,
And rolls through all things."

As a teacher Professor Blaisdell has had a marked place in the life and history of Wisconsin. For thirty-seven years he has been an instructor of young men in this state, and by voice and pen in wider circles. He was not a conventional teacher. He was not in some respects a modern teacher. He had little interest personally in the laboratory method of teaching. He shrunk from it with a sense that somehow it reduced study to a mechanical or dead thing. I have thought that he gave too little weight and value to certain current methods. But in his own method he was easily a master. With him every pupil was an individual, spiritual personality. And while he believed profoundly the things he taught, he used these truths not for their own sake so much as for the developing power there might be in them for the minds with which and upon which he worked. He sought to know each individual student intimately, in his modes of thought, in his modes of living. He was not content unless he could in some genuine way come into personal, vital, throbbing touch with each pupil. This attempt of his, instinctive and deliberate, was almost always crowned with a remarkable degree of success. His students he grappled to himself with hooks of steel. Men would look forward for years to reaching that part of their course where they would come under his influence, and they went forth from the college impressed with his personality, molded by his thinking, and yet empowered by him in a remarkable degree to be individual thinkers and actors in a living world. It was this that made him what I may term the Thomas Arnold of Wisconsin. And what Matthew Arnold said of his father may very properly be said of Professor Blaisdell:

> "But thou wouldst not alone
> Be saved, my father; alone
> Conquer and come to thy goal,
> Leaving the rest in the wild.
> Still thou turnedst and still
> Beckond'st the trembler, and still
> Gavest the weary thy hand.
> Therefore to thee it was given
> Many to save with thyself;
> And in the end of thy day,
> O faithful shepherd, to come
> Bringing thy sheep in thy hand."

Perhaps not less marked was Professor Blaisdell's relation to the commonwealth of Wisconsin as a citizen. The fact that his life was that of a thinker and teacher never in the least tempted him to excuse himself from the life of a practical man of affairs devoted to the welfare of his state. He loved Wisconsin. He had a generous pride in her citizens, in her resources, in her history, in her future. Any fruit that was grown in Wisconsin was interesting to him. The forests of the state were dear to him and he lifted his voice for their conservation. The hills of Wisconsin were hardly less dear to him than those higher hills of his own Granite State. A mystic, he was yet clear-sighted and resolute. He studied, and as far as man could do it, he solved the problems of civic life and of the life of the commonwealth, and his counsel was sought by men of affairs. The mayor of Beloit would come to him for counsel, and he would go to the mayor of Beloit with suggestions as to the city's civic welfare. He was the President of the Wisconsin Children's Home Society, in whose development he felt the keenest, the most glowing interest, believing that by this method of taking children out of unhopeful environments and placing them in families of character we may undercut the forces of evil and save our commonwealth. He was President of the Wisconsin Home Missionary Society and gave in the last two or three years of his life a vast amount of effort to the cherishing of the Christian work of feeble churches in our state. He was chairman of the committee on Reformatories and Penitentiaries of the State Conference of Charities and Corrections, and wrote reports in this capacity which may become classic in the literature of the care of dependent classes. In all of these ways and in the countless influences that went forth from him as a citizen and as a man, he aided this commonwealth in the effort to produce and maintain a noble life.

It seemed to us that in his seventieth year he was at the summit of his power. His intellectual activities never seemed more clear and keen nor the wings of his imagination more strong for flight. His hold upon his students never was more absolute, in their confidence in him, and devotion to him; and we hoped that for many years to come he might be spared to do the work that was given him to do in Wisconsin. And yet during the past few months we detected in him a feverish eagerness which was, it seemed to us, somewhat ominous. He could not give due thought to the question of the limitations of his power. It was as if, seeing the westering sun, he felt that he must work with growing intensity and the more rapidly as the time grew short. And so at the end of the last college year, and after meeting his college class of fifty years ago and pouring out his spirit with them in reminiscence and in hope, he came home spent. He went to seek rest beside the great lake, but the balance of his powers could not be renewed; the harp of his spirit, so delicately strung, sounded chords that were strange and bewildering, and in a moment of conflict in which we cannot follow him save with awe and fear, he passed from life. It was as when a warrior falls in the front line of the charge. As the soldier, seeing the greatness of his country's need, puts his life in jeopardy and reckons not the chances of its sudden end, so Professor Blaisdell, realizing with deepening intensity the need of mankind, the need of the commonwealth, flung himself so without reserve upon the hosts of evil that he fell wounded to death.

On an October day, such as he himself so greatly loved, when the air was full of mellow haze and the sun shone with softened radiance and the brilliant leaves were dropping to the ground, we passed from the college chapel, where throughout the morning he had lain, that students and friends might look again upon that face, so strong, so peaceful, so natural. The Grand Army, who loved him and shared his love, bore the precious burden from chapel to church; from the church the Seniors and Juniors of the college by turn bore him the half mile to the cemetery; and there, gathering about the grave, while flowers were dropped upon the casket from the hands of students, and soldiers, and children, with hushed breath and upturned faces we looked whither he had gone for higher thought and larger service. A great citizen of the republic of letters, a great citizen of our commonwealth, a loyal citizen of the kingdom of God, has passed out of the life of our state and become a part of its enduring memory and wealth.

EDWARD D. EATON.

Beloit, Wis.

GEORGE P. DELAPLAINE.

George P. Delaplaine was born in Philadelphia, September 23, 1814. His father, Joseph Delaplaine, projected and in 1815 had in part executed an extensive work, "Repository of the Lives and Portraits of Distinguished American Characters." This enterprise seems to have been undertaken at too early a date to secure the needful patronage, and only three volumes of it were issued. His lineage was traceable to Nicholas de la Plaine, a Huguenot who came from France to New York about 1672. His mother was a Livingston, and connected with the Jay family so prominent in early New York and in making the first treaty between the United States and Great Britain.

At the death of his father in 1824 he was separated from his mother either at school or when employed as a store-boy. But his vacations of all sorts were spent among his Jay kindred at the Jay mansion in Bedford, Westchester Co., New York, where Chief Justice Jay was still surviving. His death was in 1829. Through contact there with people of such high culture and refinement his ideals of life and scholarship were elevated, and he was roused to life-long aspirations and endeavors for self-improvement. The names Ann *Jay* and Blanche *Livingston* which he gave his daughters show how fondly he remembered those early haunts.

His coming to reside at Madison in 1838 was only one year after the first settlers had arrived, and at his death, April 29, 1896, he had outlived all but one of those who had made their homes there before him. In 1837 he had seen the Madison pioneers start from Milwaukee. Still earlier, in 1835, he had been a rodman under Capt. Garret Vliet, United States surveyor in that region, until thrown out of business by an order from Washington suspending the work. Then, with one Joseph Green from Rutland, Vt., a schoolmate of the present writer, he roved about the unknown country in quest of mill-sites. In October, 1836, these prospectors came to Madison where they saw Fourth Lake ridge covered with Winnebagoes who were gathering in a harvest of fish for winter — the braves spearing fish, the squaws spreading the captures to dry on frames, children bringing up the scaly store, and pappooses hanging up near by. The Indian summer was at its height and the scene fascinated Delaplaine with a first love which he never forgot. His companion and he were, however, afraid to lodge among the fishers, and fled as far as possible before nightfall. Their fear was of losing at least their single pony. This incident was related to the writer by Mr. Delaplaine nearly forty years ago.

Mr. Delaplaine served the first three Wisconsin governors as private secretary. He is described in 1846 by General Hobart, who was then in the territorial council, as "the life and soul of Governor Dodge's office. If there was anything to be looked up or any information to be secured he was the man we went to. He was withal the wittiest man in the State in those times and his wit was of a refined nature." Another councilman says, "His fund of anecdote has never been equalled in my experience."

For many years our associate held offices in the State militia. In the civil war he became engineer-in-chief with the rank of brigadier general, and did efficient service in making troops ready to take the field. As Park commissioner he was largely instrumental in getting trees planted alongside Madison's streets, indeed, many of those earliest planted he had set out with his own hands.

In 1870 he was a charter-member of the "Wisconsin Academy of Sciences, Arts and Letters." As its first treasurer and long afterward his coöperation was valuable. In all his relations he may be best described as a *humanitarian.* Hence, as a boy in Ohio, he became a sort of conductor on the underground railroad. He was a champion of women's rights;—before Dr. Berg was heard of he had "regarded the life of his beast." He was a good Samaritan to many who had fallen helpless by the wayside, and whom priest and levite, despairing of lifting up, had passed by on the other side.

In regard to religion while his faith was small his hope and charity were large. He never ceased to be a seeker of light concerning the spiritual, eternal, heavenly and divine. "The world is my country and to do good is my religion" was a saying often in his mouth.

While diligent and successful in his business as a dealer in real estate he was never so buried in it as to have no leisure hours for the best books of the best authors in widely devious paths of literature.

The immediate cause of his death was heart failure, which followed after chronic asthma and insomnia during six previous months. It was in the last half of his eighty-second year

> "When, like a clock worn out with eating time,
> The weary wheels of life at last stood still."

JAMES D. BUTLER.

Madison, Wis.

SIMEON MILLS.

Our late associate Simeon Mills was born February 14, 1810, and died June 1, 1895. His birth was at Norfolk in the state of Connecticut, but he was brought up in northeastern Ohio, to which his parents removed in his infancy. In the fall of 1836 he went west on an exploring tour and was in Belmont during the legislative session there when, on November 28, Madison was decided upon as the site of the territorial capital.

He came to Madison the next season. On June 10th, 1837, he walked alone from Janesville to the site where Madison was to be built, and found there the thirty-seven first comers,— the pioneers who had arrived on the morning of that day from Milwaukee, having been eleven days on the way.

He worked on the first house there built, was employed in the first store, was the first deputy post-master, and the first mail-contractor. He was a footpost to and from Milwaukee, crossing rivers by ferries but oftener by fording. The mail-matter was never cumbersome.

He was an original member of the Board of Regents of the State University — and their treasurer for half a dozen years. During his service in this capacity the University largely paid its running expenses by buying city lots and selling them. At one time its acreage amounted to a square mile or about double its present extent. But before 1856 this area had shrunk to about fifty acres.

The State Historical Society, from its start in 1849, had the favor and assistance of Mr. Mills. He may be called a *pre-*charter member of it. From 1854 he was one of its curators and from 1878 till his death a vice-president. In early years he offered to give an eligible site for a building that would show and safeguard its collections. This present the Society was then too weak to stretch out its hands for receiving. Knowledge that a fire-proof edifice would make it sure that the historic treasures shall not perish from among men, was a solace to him in the chronic languishing of his last illness.

Our associate outlived all save one or two of the forty first founders of Madison. The sabbath of his years was spent in full view of the spot where he had stepped ashore into the forest from the Indian canoe, and in the midst of the city which was more to him than all the world beside.

Had Mr. Mills been taught chemistry he would have done something to extend the area of that science. He was an original thinker in many lines, and printed his views not only in newspapers but in several little books which he published.

Mr. Mills early became a member of the Academy. He furthered its researches by excavations in aboriginal mounds, and read papers on various themes at its meetings.

JAMES D. BUTLER.

Madison, Wis.

NEWTON STONE FULLER.

Newton Stone Fuller, son of Leonard F. and Mary I. (Hunt) Fuller, was born February 9, 1860, in Providence, R. I. His preparation for college was made in the High School of his native city, and he graduated from Brown University in 1882. He taught in Colby Academy, at New London, N. H., for a year after his graduation, and in a private academy at Poughkeepsie, N. Y., during the second year. In 1884 he was elected Professor of Latin in Ripon College, which position he occupied for ten years, resigning it in 1894 on account of his health which had been such as to require his absence in Colorado during the preceding year. He died of consumption at Colorado Springs, May 8, 1895. He married, June 29, 1886, Miss Harriet Peirce who, with their two daughters, survives him.

Professor Fuller's first years in Wisconsin were so fully occupied by the immediate duties of the position to which he had been called at an early age that he had little opportunity for other work; so that, although he had previously attended one or more meetings of the Academy, he became a member only two years before his failing health forbade further efforts; and therefore the fidelity which was the marked characteristic of his life was little known beyond the narrow circle of his intimate associates, who have placed on record their testimony that "as a man of scholarship, strong character, cultivated tastes, skill in instruction, gentleness combined with firmness, and steadfast devotion to duty, he made himself a place of usefulness and effective service rarely surpassed."

CHAS. H. CHANDLER.

Ripon, Wis.

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MERRELL, Edward Huntington, Ripon.
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MERRILL, Mary Ellen, (Mrs. S. S.), 3355 Grand av., Milwaukee.

MEYER, Balthasar Henry, 311 Brooks st., Madison.
L. B., Ph. D. (Wisconsin). Instructor in Sociology, Extension Lecturer in Economics, Secretary of Extension Department, University of Wisconsin.

MIDDLETON, Perry H., Milwaukee.

MILLER, William Snow, 615 Lake st., Madison.
M. D. (Yale). Assistant Professor of Vertebrate Anatomy, University of Wisconsin.

MITCHELL, Andrew Stuart, 436 Milwaukee st., Milwaukee.
Ph. G. Analyst and Teacher of Chemistry; Chemist, State Dairy and Food Commission, Madison.

MOOREHOUSE, George Wilton, Wauwatosa.
L. B., L. M. (Wisconsin); M. D. (Harvard). Massachusetts General Hospital (until Jan. 31, 1899).

MORRIS, William Augustus Pringle, 240 Langdon st., Madison.
A. B. (Hamilton). Attorney at Law.

NADER, John, 302 W. Main st., Madison.
Architect and Civil Engineer.

NEHRLING, Henry, 254 Twenty-first st., Milwaukee.
Curator Public Museum.

NICHOLSON, Dexter Putnam, 524 John st., Appleton.
S. B., S. M. (Lawrence). Professor of Natural History, Lawrence University.

Norton, Richard Greenleaf, 110 Monona av., Madison.
Mechanician.

Noyes, George Henry, 204 Prospect av., Milwaukee.
A. B., LL. B. (Wisconsin). Attorney; Ex-Judge Superior Court.

O'Connor, Charles James, 1242 E. Dayton st., Madison.
A. B. (Wisconsin). Teacher.

O'Shea, M. Vincent, 431 Lake st., Madison.
L. B. (Cornell). Professor of the Science and Art of Teaching, University of Wisconsin.

Owen, Edward Thomas, 614 State st., Madison.
A. B. (Yale). Professor of the French Language and Literature, University of Wisconsin.

Pabst, Fred, Milwaukee.

Parker, Fletcher Andrew, 14 W. Gilman st., Madison.
Professor of Music and Director of School of Music, University of Wisconsin.

Pereles, James M., 529 Astor st., Milwaukee.
LL. B. Lawyer. Ex-President Public School Board; President Public Library.

Pereles, Jennie W. (Mrs. J. M.), 529 Astor st., Milwaukee.
Treasurer Wisconsin Training School for Nurses; Secretary Milwaukee Flower Mission and Mission Kindergarten.

Pereles, Nellie W. (Mrs. T. J.) 535 Astor st., Milwaukee.

Pereles, Thomas Jefferson, 535 Astor st., Milwaukee.
LL. B. (Wisconsin). Attorney at Law (Nathl. Pereles and Sons). Commissioner of the Public Debt of Milwaukee. President High School Alumni.

Preusser, Christian, 289 Knapp st., Milwaukee.
Jeweler; President Milwaukee Mechanics Fire Insurance Co.

Plantz, Samuel, Appleton.
Ph. D., D. D. President of Lawrence University.

Porter, William, 735 College st., Beloit.
A. B., A. M., D. D. (Williams). Professor of Latin and Dean, Beloit College.

Post, Harriet L., 525 Cass st., Milwaukee.
M. D. (Woman's Medical College of New York Infirmary). Teacher of Biology, East Side High School.

Pretts, W. W., Monroe.

Puls, Arthur John, 116 Mason st., Milwaukee.
L. B. (Wisconsin); M. D. (Heidelberg). Physician.

PUTNEY, Frank Howell, 105 Park av., Waukesha.
Attorney at Law.

RAINEY, Frank Lewis, 4122 Vincennes av., Chicago.
S. B. (Purdue). Teacher of Biology, Harvard School.

RAMSEY, Robert Craig, Peshtigo.
Superintendent of Schools.

RANKIN, WALTER L., 201 East av., Waukesha.
A. M., Ph. D. (Princeton). President, Carroll College.

REUL, Miss Matilda E., Baraboo.
S. B., S. M. (Wisconsin). Teacher, Baraboo High School.

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B. M. E., M. E. (Wisconsin). Assistant Professor of Experimental Engineering, University of Wisconsin.

ROESELER, John Samuel, Sauk City.
L. B. (Wisconsin). County Superintendent of Schools.

ROGERS, Augustus J., 318 Ogden av., Milwaukee.
Ph. B. (Cornell). Principal of East Side High School.

RUENZEL, Henry Gottlieb, 753 Third st., Milwaukee.
Ph. G. (Wisconsin). Pharmacist.

RUSSELL, Harry Luman, 1532 Univ. av., Madison.
S. B., S. M. (Wisconsin); Ph. D. (Johns Hopkins). Professor of Bacteriology, University of Wisconsin.

SALMON, Edward Payson, 618 Church st., Beloit.
A. M. (Beloit). Congregational Minister.

SANBORN, John Bell, 210 Langdon st., Madison.
L. B., L. M. (Wisconsin). Graduate Student, University of Wisconsin.

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L. B. (Wisconsin); A. B. (Harvard). Instructor in History and Civics, State Normal School.

SAUNDERS, Arthur Percy, Ottawa, Ontario.
A. B. (Toronto); Ph. D. (Johns Hopkins).

SAUNDERSON, George William, Ripon.
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SCOTT, William Amasa, 251 Langdon st., Madison.
A. B., A. M, (Rochester); Ph. D. (Johns Hopkins). Professor of Economic History and Theory, University of Wisconsin.

SECRIST, Henry Thomas, Roxbury District, Boston, Mass.
Minister, Unitarian Church.

SHARP, Frank Chapman, 27 Mendota Court, Madison.
A. B. (Amherst), Ph. D. (Berlin). Assistant Professor of Philosophy, University of Wisconsin.

SIMONDS, William Day, 15 West Dayton st., Madison.
Pastor, Unitarian Church.

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S. B. (Howard). Professor of Natural Sciences, State Normal School.

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SLICHTER, Charles Sumner, 636 Francis st., Madison.
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SMITH, Erastus Gilbert, Beloit.
A. B., A. M. (Amherst); A. M., Ph. D., (Göttingen). Professer of Chemistry and Mineralogy, Beloit College.

SMITH, Leonard Sewell, 939 University av., Madison.
B. C. E., C. E. (Wisconsin). Assistant Professor of Topographical Engineering, University of Wisconsin.

SMITH, Thomas Alexander, 1023 Chapin st., Beloit.
A. B., A. M. (Muskingum); Ph. D. (Yale). Professor of Mathematics and Physics, Beloit College.

STARR, William J., Eau Claire.
LL. B. (Columbia). Commissioner of Fisheries, Wisconsin.

STUART, James Reese, 245 Langdon st., Madison.
Artist.

TELLER, Edgar E., 3303 Cedar st., Milwaukee.

THWAITES, Reuben Gold, 260 Langdon st., Madison.
Secretary State Historical Society.

TRUE, Rodney Howard, Wingra Park, Madison.
S. B. (Wisconsin); Ph. D. (Leipsic). Assistant Professor of Pharmacognosy.

TURNER, Frederick Jackson, 629 Francis st., Madison.
A. B., A. M. (Wisconsin); Ph. D. (Johns Hopkins). Professor of American History, University of Wisconsin.

UIHLEIN, August, Milwaukee.

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S. B., S. M., D. D. (Lawrence). Pastor, First Congregational Church.

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Professor of Natural Sciences, State Normal School.

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Ph. G., Ph. M. (Wisconsin). Pharmaceutical Chemist, Kremers and Urban Co.

WALKER, Milo S., Racine.

VAN VELZER, Charles Ambrose, 134 W. Gorham st., Madison.
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Superintendent of Schools and Principal of High Schools.

WEIDMAN, Samuel, 911 W. Johnson st., Madison.
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S. B., Ph. B. (Christiania); S. M. (Wisconsin). Assistant Professor of Agricultural Chemistry, University of Wisconsin.

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Ph. B. (Illinois Wesleyan); A. M. (Charles City). Principal Seventeenth District School.

ZIMMERMANN, Oliver Brunner, 622 Otjen st., Milwaukee.
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CORRESPONDING MEMBERS.

ABBOTT, Charles Conrad, Trenton, N. J.

M. D. (Pennsylvania). Biology, Archæology, Literature.

ANDREWS, Edmund, 65 Randolph st., Chicago, Ill.

A. B., A. M., M. D., LL. D. (Michigan). Professor of Clinical Surgery, Northwestern University; Surgeon of Mercy Hospital; Consulting Surgeon Michael Reese Hospital and Illinois Hospital for Women and Children.

ARMSBY, Henry Prentiss, State College, Pa.

S. B. (Worcester Polytechnic); Ph. B., Ph. D. (Yale). Director of Experiment Station.

BASCOM, John, Park st., Williamstown, Mass.

A. B., A. M. (Williams); D.D. (Iowa); LL. D. (Amherst). Professor of Political Science, Williams College.

BENNETT, Charles Edward, 1 Grove Place, Ithaca, N. Y.

A. B. (Brown). Professor of Latin Language and Literature, Cornell University.

BRIDGE, Norman, { 217 S. Broadway. Los Angeles, Calif. Oct. and Nov. each year, Rush Medical College, Chicago, Ill.

A. M. (Lake Forest); M. D. (Northwestern, Rush). Prosessor of Clinical Medicine and Physical Diagnosis, Rush Medical College.

CAVERNOR, Charles, Boulder, Colorado.

A. M. (Dartmouth); LL. D. (California). Pastor Congregational Church.

COULTER, John Merle, Chicago, Ill.

A. B., A. M., Ph. D. (Hanover); Ph. D. (Indiana). Head Professor of Botany, University of Chicago.

CROOKER, Joseph Henry, Troy, N. Y.

Minister, Unitarian Church.

DAVIS, Floyd, 317 Iowa Loan and Trust bldg., Des Moines, Ia.

Ph. B., C. E., M. E. (Missouri); Ph. D. (Miami). Analytical and Consulting Chemist.

DE VERE, Maximilian Freiherr Schale, University Station, Charlottesville, Va.

Ph. D. (Greifswalde); J. U. D. (Berlin). Professor of Modern Languages, University of Virginia.

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Smithsonian Institution, Washington, D. C.
S. B., A. M. (Washington); S. D. (Pacific); LL. D. (Wisconsin and Columbia). Astronomer.

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A. B. (Harvard).

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M. D. (Western Reserve). Physician; Chief of Staff, Mercy Hospital.

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LEVERETT, Frank, Denmark, Iowa.
S. B. (Iowa Agricultural). Assistant Geologist, U. S. Geological Survey.

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A. M. Consul General for Liberia; Consul for Paraguay, Uruguay, and Australia.

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MARX, Charles David, Stanford University, Calif.

B. C. E. (Cornell); C. E. (Carlsruhe). Professor of Civil Engineering, Leland Stanford Jr., University.

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RAYMOND, Jerome Hall, Morgantown, W. Va.

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SAFFORD, Truman Henry, Williamstown, Mass.

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SAWYER, Wesley Caleb, Belmont, Calif.

A. B., A. M. (Harvard); A. M., Ph. D. (Göttingen). Professor of German and French, Belmont School.

SHIPMAN, Stephen Vaughn, 269 Warren ave., Chicago, Ill.

Architect.

SOMERS, Amos Newton, Lancaster, N. H.

A. B. (Roanoke). Clergyman.

STEELE, George McKendall, 19 Chalmer Place, Chicago, Ill.

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STUMP, I. W Oswego, N. Y.

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A. B., A. M. (Williams); F. R. A. S. Assistant Actuary, Mutual Life Insurance Co.

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TOLMAN, Herbert Cushing, Nashville, Tenn.

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TOWNLEY, Sidney Dean, 755 E. University ave., Ann Arbor, Mich.

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TRELEASE, William, Botanical Garden, St. Louis, Mo.

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VAN DE WARKER, Ely, 404 Fayette Park, Syracuse, N. Y.

M. D. (Albany Medical and Union). Surgeon Central New York Hospital for Women; Consulting Physician St. Ann's Maternity Hospital.

VAN VLECK, Edward Burr, Middletown, Ct.

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VERRILL, Addison Emory, 86 Whalley av., New Haven, Ct.

S. B. (Harvard); A. M. (Yale). Professor of Zoology, Yale University.

WINCHELL, N. H., 120 State st., Minneapolis, Minn.

A. M. (Michigan). State Geologist of Minnesota.

YOUNG, Albert Adams, P. O. Box 326, Harvey, Ill.

A. B., A. M. (Dartmouth). D. B. (Andover). Clergyman.

MEMBERS DECEASED

SINCE THE ISSUE OF VOLUME X.

BLAISDELL, James J., D. D., Professor of Philosophy, Beloit College, Beloit.

FULLER, Newton S., Professor of Latin, Ripon College, Ripon.

MEACHEM, John G., Sr., M. D., Racine.

ORTON, Harlow S., LL. D., Ex-Chief Justice Supreme Court of Wisconsin.

CONSTITUTION OF THE WISCONSIN ACADEMY OF SCIENCES, ARTS, AND LETTERS.

[As amended in *Article VII* at the regular meeting of December, 1897.]

Article I.—Name and Location.

This association shall be known as the Wisconsin Academy of Sciences, Arts, and Letters, and shall be located at the city of Madison.

Article II.—Object.

The object of the Academy shall be the promotion of sciences, arts, and letters in the state of Wisconsin. Among the special objects shall be the publication of the results of investigation and the formation of a library.

Article III.—Membership.

The Academy shall include four classes of members, viz.: life members, honorary members, corresponding members, and active members, to be elected by ballot.

1. Life members shall be elected on account of special services rendered the Academy. Life membership in the Academy may also be obtained by the payment of one hundred dollars and election by the Academy. Life members shall be allowed to vote and to hold office.

2. Honorary members shall be elected by the Academy and shall be men who have rendered conspicuous services to science, arts, or letters.

3. Corresponding members shall be elected from those who have been active members of the Academy, but have removed from the state. By special vote of the Academy men of attain-

ments in science or letters may be elected corresponding members. They shall have no vote in the meetings of the Academy.

4. Active members shall be elected by the Academy and shall enter upon membership on the payment of an initiation fee of two dollars and the annual assessment of one dollar. The annual assessment shall be omitted for the president, secretary, treasurer, and librarian during their term of office.

Article IV. — Officers.

The officers of the Academy shall be a president, a vice-president for each of the three departments, sciences, arts and letters, a secretary, a treasurer, and a custodian. These officers shall be chosen by ballot, on recommendation of the committee on nomination of officers, by the Academy at an annual meeting and shall hold office for three years. Their duties shall be those usually performed by officers thus named in scientific societies. It shall be one of the duties of the president to prepare an address which shall be delivered before the Academy at the annual meeting at which his term of office expires.

Article V.— Council.

The council of the Academy shall be entrusted with the management of its affairs during the intervals between regular meetings, and shall consist of the president, the three vice-presidents, the secretary, the treasurer, and the past presidents who retain their residence in Wisconsin. Three members of the council shall constitute a quorum for the transaction of business, provided the secretary and one of the presiding officers be included in the number.

Article VI.— Committees.

The standing committees of the Academy shall be a committee on publication, a library committee, and a committe on the nomination of members. These committees shall be elected at the annual meeting of the Academy in the same manner as the other officers of the Academy, and shall hold office for the same term.

1. The committee on publication shall consist of the president and secretary and a third member elected by the Academy.

They shall determine the matter which shall be printed in the publications of the Academy. They may at their discretion refer papers of a doubtful character to specialists for their opinion as to scientific value and relevancy.

2. The library committee shall consist of three members and shall include the librarian.

3. The committee on nomination of members shall consist of five members, one of whom shall be the secretary of the Academy.

Article VII.— Meetings.

The annual meetings of the Academy shall be held between Christmas and New Year, at such place as the council may designate; but all regular meetings for the election of the board of officers shall be held at Madison. Summer field meetings shall be held at such times and places as the Academy or the council may decide. Special meetings may be called by the council.

Article VIII.— Publications.

The regular publication of the Academy shall be known as its Transactions, and shall include suitable papers, a record of its proceedings and any other matter pertaining to the Academy. This shall be printed by the state as provided in the statutes of Wisconsin. All members of the Academy shall receive gratis the current issues of its Transactions.

Article IX.— Amendments.

Amendments to this constitution may be made at any annual meeting by a vote of three-fourths of all the members present; *provided*, that the amendment has been proposed by five members, and that notice has been sent to all the members at least three months before the meeting.

PROCEEDINGS.

SECRETARY'S REPORT.

THIRD SUMMER MEETING.

MILWAUKEE, JUNE 6-8, 1895.

THURSDAY, June 6th.

EVENING SESSION.

The Academy was called to order in the hall of the North American Gymnasium Union, at 8 o'clock by President C. R. Van Hise. An address of welcome was made by Geo. W. Peckham, President of the Natural History Society of Wisconsin.

President Van Hise replied briefly on behalf of the Academy.

The Chairman of the Local Committee made announcements regarding excursions and other matters.

The opening address was then delivered by Charles Kendall Adams, President of the University of Wisconsin, on "Reforms in Germany after the Napoleonic wars."

FRIDAY, June 7th.

MORNING SESSION.

The morning session was opened at 9 A. M. in the German American Academy rooms, the President in the chair.

The minutes of the Twenty-fifth annual meeting were read and approved.

The following papers were then read:

1. The relation of pooling to some phases of the transportation question. *A. M. Simons.*

2. The forms spontaneously assumed by folk-songs. *J. Comfort Fillmore.* This paper was illustrated by Indian songs reproduced by graphophone and piano. The paper was discussed by various persons.

3. Negro suffrage in Wisconsin. *J. G. Gregory.* Discussed by various members.

4. The union of the Free Soil and Whig parties in Wisconsin, 1853–5. *Theo. C. Smith.* Discussed.

5. The Booth case and Wisconsin nullification sentiment. *Vroman Mason.*

6. State making in the West, 1774–89. *Frederick J. Turner.*

7. The legal aspects of trusts. *Edgar F. Strong.* Read by title.

The Committee on Membership reported, recommending that the following named persons be elected active members. The report was accepted, and the Secretary instructed to cast the ballot for them; which was done and they were declared elected:

Paul S. Reinsch, Madison.
D. E. Roberts, Milwaukee.
Mrs. D. E. Roberts, Milwaukee.
C. P. Cary, Milwaukee.
Dr. A. J. Burgess, Milwaukee.
Ernest Bruncken, Milwaukee.
Geo. B. Bergen, Milwaukee.
C. F. A. Zimmerman, Milwaukee
Wm. Whitnall, Milwaukee.
Mrs. Wm. Whitnall, Milwaukee.
R. C. Spencer, Milwaukee.
Geo. B. Ferry, Milwaukee.
Geo. Merwin Browne, Oshkosh.
Samuel Plantz, Appleton.
Jerome H. Raymond, Chicago.
Milo S. Walker, Racine.
A. M. Simons, Cincinnati, O.
Edgar F. Strong, Madison.
Theo. C. Smith, Madison.

After announcements by the Local Committee the Academy adjourned.

AFTERNOON SESSION.

The afternoon of Friday was spent in an excursion to the railroad shops of the C. M. & St. P. R. R., at West Milwaukee and the famous cement quarries which are located in the only Devonian rocks in the state and are of great interest. The C., M. & St. P. R. R. courteously placed a special train at the disposal of the Academy.

EVENING SESSION.

In the evening, at 8:00 o'clock at the Athenaeum, a reception was tendered by the citizens of Milwaukee to members and visitors of the Academy.

SATURDAY, June 8th.

MORNING SESSION.

The Academy was called to order by the President, at 9:10 o'clock, in the rooms of the German-American Academy.

The following papers were read:

8. Some observations on the lateral moraines at Devil's Lake. *D. P. Nicholson.*

9. Geology of Mts. Adam & Eve, Orange Co., N. Y. *G. L. Collie.* Read by title.

10. Certain uses of topographical maps. *G. L. Collie.*

11. The production of electrical energy directly from carbon. *A. J. Rogers.*

12. A contribution to the mineralogy of Wisconsin. *Wm. H. Hobbs.*

13. Some new occurrences of minerals in Michigan and Montana. *Wm. H. Hobbs.*

14. On a diamond from Kohlsville, Wis. *Wm. H. Hobbs.*

15. From pinene to carvacrol. *Edw. Kremers.*

16. A dredge for collecting crustacea at different depths. *C. Dwight Marsh.*

17. Method of determining the coefficient of a plankton net. *E. A. Birge.*

18. The pelagic crustacea of Lake Mendota during the winter and spring of 1894–95. *E. A. Birge.*

19. The biological history of Daphnia Hyalina, Leydig. *E. A. Birge.*

20. The periodic system as a didactic basis. *Edw. Kremers.* Read by title.

21. Observed and computed precession. *D. P. Blackstone.* Read by title.

22. The dells of Wisconsin. *C. R. VanHise.*

The local secretary, Prof. A. T. Rogers, announced the details of the afternoon excursion.

The Committee on Membership reported the following names of persons for election as active members. The Secretary was directed to cast the ballot for them and they were declared elected:

Dr. U. O. B. Wingate, Milwaukee.
Dr. Wm. F. Becker, Milwaukee.
P. H. Middleton, So. Milwaukee.
Mrs. S. S. Merrill, Milwaukee.
Mrs. J. B. Estee, Milwaukee.
Mrs. W. E. Anderson, Milwaukee.
S. C. Emery, U. S. Signal officer, Milwaukee.
Julius H. Pratt, Milwaukee.
Wm. J. Desmond, Milwaukee.
J. M. Pereles, Milwaukee.
T. J. Pereles, Milwaukee.
Mrs. J. W. Pereles, Milwaukee.
Mrs. N. W. Pereles, Milwaukee.
Dr. Harriet L. Post, Milwaukee.
M. D. Kimball, Milwaukee.
J. F. Burke, Milwaukee.
Rev. H. T. Secrist, Milwaukee.
Miss L. Haessler, Milwaukee.
Henry Krueger, Milwaukee.
Mrs. R. B. Mallory, Milwaukee.

The Committee on Membership also recommended that the following be elected honorary members:

Dr. D. C. Gilman, President of Johns Hopkins University, Baltimore, Md.

Dr. W. T. Harris, U. S. Commissioner of Education, Washington, D. C.

Dr. N. S. Shaler, Professor of Geology, Harvard University, Cambridge, Mass.

The Secretary was directed to cast the ballot for these as honorary members. It was done, and they were declared elected.

The Secretary presented the following resolutions, which were adopted as expressing the feelings of the Academy:

Resolved, 1. That the Academy desires to express its high appreciation of the labors of the Local Committee of Arrangements (particularly of the chairman, Prof. A. J. Rogers), and the Ladies' Reception Committee, in providing so completely for the meetings and social entertainment of the Academy.

2. That the thanks of the Academy be returned to the citizens of Milwaukee, for their cordial and generous hospitality in the entertainment of the Academy.

3. That the Academy recognizes gratefully the liberality of the C., M. & St. P. R. R. through Chief Engineer D. J. Whittemore, General Manager A. J. Earling and Superintendent W. B. Underwood, in placing a special train at the disposal of the Academy, for the visit to the cement quarries and its West Milwaukee Shops; where the courteous attentions of Mr. Geo. Gibbs, Mechanical Engineer, and Mr. Barr, Superintendent of Motive Power, were much appreciated.

The kindness of Mr. Bartlett and Superintendent Berthelot of the cement quarries is also gratefully acknowledged.

The Academy then adjourned *sine die.*

C. R. Barnes,
Secretary.

The afternoon was spent in inspecting the plant of the Pabst Brewing Co. and the private museum of the late Daniel Green.

TWENTY-SIXTH ANNUAL MEETING.

MADISON, DECEMBER 26–27, 1895.

THURSDAY, December 26th.

AFTERNOON SESSION.

The Academy was called to order at 2:45 o'clock in the rooms of the Horticultural Society at the Capitol, by Vice-president J. J. Blaisdell.

The meeting was opened with prayer by Dr. J. D. Butler.

The minutes of the Third Summer Meeting were read and approved.

The report of the Treasurer was read and referred to an Auditing Committee consisting of Messrs. W. W. Daniells, D. P. Blackstone and J. H. Clements.

The Treasurer tendered his resignation on account of his removal to Green Bay. The resignation was reluctantly accepted. Mr. L. S. Cheney was elected Treasurer to fill the unexpired term.

The report of the Secretary was presented informally showing that since the last annual meeting 39 new members have been added to the Academy and Volume X of the Transactions has been published. The report was accepted.

The report of the Librarian was read and accepted. The report included his resignation on account of special and pressing duties at the University. The nomination of a Librarian to fill the unexpired term was referred to the Committee on Membership.

The Secretary for the Committee on the Bill for Natural History Survey, reported the mode of campaign adopted by the Committee in presenting this bill to the Legislature and the failure to secure a favorable report of the same from the Committee on Ways and Means, which killed the bill for the present. The report was accepted. The thanks of the Academy were returned to the Committee for its energetie efforts, and the Committee was discharged.

The following papers were then read:

1. The poisonous action of dissolved salts and their electrolytic dissociation. *Louis Kahlenberg* and *R. H. True.*

2. The scientific importance of more complete vital statistics in the state of Wisconsin. *U. O. B. Wingate.*

It was then voted that during the remainder of the session no departure from the order of the published program be allowed without unanimous consent of the Academy.

The following papers were then read:

3. Some uses of the low potential alternating current in the chemical laboratory. *Milo S. Walker.*

4. The floral structure of some Gramineae. *Herman F. Lueders.*

5. Some native hybrid verbenas. *H. F. Leuders.*

6. The periodic errors of the right ascensions of the fundamental stars. *Geo. C. Comstock.*

7. Recent criticism of the Newtonian law of gravitation. *Geo. C. Comstock.*

The chair announced that in place of Messrs. Birge, Rogers and Marsh of the Committee on Membership, who were absent, he would appoint Messrs. H. W. Hillyer, H. F. Lueders and G. L. Collie, pro tem.

The academy then adjourned until evening.

EVENING SESSION.

At 8 o'clock Vice-president J. J. Blaisdell delivered an address upon " The methods of science as being in the domain of logic." No business was transacted.

FRIDAY, December 27th.

MORNING SESSION.

The Academy was called to order by the secretary at 9:45 o'clock, neither President nor any Vice-president being present.

Dr. J. D. Butler moved that the Secretary preside. The motion was put by him and it was so voted.

The Auditing Committee reported that the Treasurer's accounts were correct and that the funds of the Academy (a bond for $1,000 and a check for $206.25) had been placed in the hands of the Treasurer elect.

The following papers were then read:

8. Some stages in the development of rivers as illustrated by Deer river, Michigan. *J. Morgan Clements.*

9. The adjustment of railroad rates in Prussia. *B. H. Meyer.*

10. The development of the English system of convict transportion. *Mrs. Helen F. Bates.*

11. English convicts shipped to colonial America. *Jas. D. Butler.*

12. The freehold qualifications for suffrage with especial reference to Connecticut. *Florence Robinson.*

13. The importance of round numbers in estimating wages. *Edward D. Jones.*

The Academy adjourned to 2:30 o'clock.

AFTERNOON SESSION.

The Academy was called to order by the Secretary at 2:45 o'clock.

The report of the Committee on Membership was read, recommending that the following named persons be elected active members:

Linnaeus W. Dowling, Madison.	Edw. D. Jones, Madison.
B. H. Meyer, Madison.	A. G. Laird, Madison.
Mrs. H. F. Bates, Madison.	Chas. E. Buell, Madison.
J. H. Hamilton, Madison.	Fannie Grant, Milwaukee
Charles F. Smith, Madison.	W. W. Pretts, Monroe.

The Secretary was directed to cast a ballot for these persons, who were thereupon declared elected.

The Committee further reported the name of G. L. Hendrickson, as Librarian. He was thereupon elected to fill out the unexpired term (one year).

The following papers were then read:

14. Discussion of poetic and Ionic influence in Thucydides. *Chas. F. Smith.*

15. Notes on Attic vocalism. *A. G. Laird.*

The following papers in the absence of the authors were read by title:

On the composition of water from an artesian well at Marinette, Wis. *W. W. Daniells.*

Note on Wittstein's method of estimating carbon in graphite. *W. W. Daniells.*

The origin of conglomerates. *G. L. Collie.*

Money and prices. *W. A. Scott.*

Proposed emendation in Lucretius. *G. L. Hendrickson.*

The rationale of tolerance. *H. J. Desmond.*

The Secretary announced that the annual supper placed upon the program would be omitted because of the small attendance of members outside of Madison.

The Academy then adjourned *sine die.*

C. R. BARNES,
Secretary.

TWENTY-SEVENTH ANNUAL MEETING.

MILWAUKEE, DECEMBER 28-30, 1896.

MONDAY, December 28th.

EVENING SESSION.

The Academy assembled in the State Normal School building at eight o'clock, together with members of the Wisconsin Teachers' Association and of the general public, and listened to an address by Professor Rollin D. Salisbury of the University of Chicago, on "Greenland."

The address was illustrated with the lantern and was complimentary to the members of the Wisconsin Teachers' Association.

TUESDAY, December 29th.

MORNING SESSION.

The meeting was called to order by President C. R. Van Hise at 9:15 o'clock in the State Normal School building.

The minutes of the Twenty-sixth annual meeting were read and approved.

The report of the Secretary was read and accepted.

This report included the following:

Vol. XI. (1896-97) of the Transactions is in press, 150 pages having been printed and authors' separates mostly distributed.

The membership of the Academy is now constituted as follows: Honorary 6, Life 9, Active 162, Corresponding 47. Total 224.

One resignation has been sent; Mrs. Clarissa T. Tracy, Ripon.

The following deaths have occurred since the last Annual meeting:

Professor James J. Blaisdell, Beloit College, October 10, 1896.

Professor Newton S. Fuller, Ripon College, May 8, 1895.

The report of the Treasurer was read and referred to the Auditing Committee, consisting of Messrs. A. S. Mitchell, C. S. Slichter, J. S. Roeseler.

The President appointed the following members as a committee on nomination of officers: Messrs. C. R. Barnes, Chas. H. Chandler, G. W. Peckham.

A communication was read from the President of the Gelogical Society of America, regarding the Pasteur Monument Fund, requesting the co-operation of the Academy in this movement. The Treasurer was appointed to receive and transmit in the name of the Academy any subscriptions which might be made.

A communication was read from F. A. Bather, Secretary of the British Association Committee on Zoological Bibliography and Publication, regarding various *desiderata* of publication. The Secretary was directed to reply that the Academy already complied with the recommendations of the Committee, except that author's separates are distributed in advance of general publication; and that the Academy deems it necessary to continue the practice inasmuch as a volume of the Transactions can be published only once in two years. The Secretary was further directed to add to the date of publication already printed on the separates the words, "In advance of general publication."

The following papers of the program were then read:

1. Aluminium alcoholates. *Orin E. Crooker.* Discussed by A. S. Mitchell.

Papers 2–5 were postponed owing to the absence of the authors.

6. Some distillations from spirits of pine tar. *W. S. Leavenworth.* Read by title only.

7. The Berlin and Utley quartz porphories and Waushara granite. *Samuel Weidman.* Discussed by E. R. Buckley and C. R. Van Hise.

8. The pre-Cambrian volcanic rocks of the Fox river valley.

W. H. Hobbs, *C. K. Leith* and *W. W. Pretts.* Discussed by E. R. Buckley and C. R. Van Hise.

9. Glacial phenomena of the Baraboo district. *Rollin D. Salisbury.* Discussed by C. R. Van Hise.

The next paper on the program was postponed on account of the absence of the author.

11. Experiments with road-building materials of Southern Wisconsin. *Ellsworth Huntington.*

12. Relations of faults, complex fractures, fissility and cleavage to lengthening and shortening of the crust of the earth. *C. R. Van Hise.* Discussed by W. H. Hobbs, A. S. Mitchell and R. D. Salisbury.

5. The addition products of nitrosyl chloride, nitrosyl nitrite, and nitrosyl nitrate to unsaturated hydrocarbons. *Edward Kremers.*

After announcements by the President the Academy adjourned until 2 o'clock.

AFTERNOON SESSION.

The Academy was called to order at 2:15 o'clock by the Secretary.

The following papers of the program were presented:

13. Transcendental space. *Charles H. Chandler.* Discussed by C. S. Slichter and C. R. Van Hise.

The next paper was passed over on account of the absence of the author due to illness.

15. Photographs of three dimensional curves. *C. S. Slichter.* Discussed by W. H. Hobbs and C. R. Van Hise.

16. Some problems in the theoretical investigation of the motion of ground waters. *Charles S. Slichter.* Discussed by W. H. Hobbs and C. R. Van Hise.

17. On the flow of viscous liquids. *P. E. Doudna.* Read by title only.

18. Habits and instincts. *George W. Peckham.* Discussed by Harriet B. Merrill, L. S. Cheney and others.

The following two papers were read by the Secretary:

19. On the limnetic Crustacea of Green Lake. *C. Dwight Marsh.*

20. Forces determining the vertical distribution of the limnetic Crustacea. *Edward A. Birge.*

The Academy adjourned at 5:40 o'clock.

EVENING SESSION.

President C. R. Van Hise called the Academy to order at 7:30 o'clock and introduced the subject of the advisability of again presenting before the State Legislature the bill for a geological and natural history survey of the state.

The discussion which followed was participated in by Messrs. C. S. Slichter, J. G. Gregory, Chas. H. Chandler, C. Dwight Marsh, G. L. Collie, and C. R. Barnes. All of the speakers agreed in the desirability of presenting the bill again to the legislature.

It was voted that the Council be directed to appoint a committee to present and push the bill which was drafted last year, the committee to have power to modify the bill as seems necessary.

President Edward D. Eaton of Beloit College then read a memorial address on the late Professor James J. Blaisdell, a Vice-president of the Academy.

The Secretary read memorial notices of the late General Geo. P. Delaplaine and Mr. Simeon Mills, who were members of the Academy.

These memorials were prepared by Dr. James D. Butler.

The Academy then adjourned.

WEDNESDAY, December 30th, 1896.

MORNING SESSION.

The Academy was called to order at 9:10 o'clock by the President, C. R. Van Hise.

The regular program of the meeting was resumed and the following papers were read:

23. Codfish: its place in American history. *James D. Butler.*

The following two papers left over from the preceding session were next read:

21. The relations of Daphnia hyalina to light. *John Arbuthnot.*

22. What is bark? *C. R. Barnes.*

Also the following paper not on the printed program was read: Nerve endings in the eye of Aulostomum. *Harriet B. Merrill.*

24. The usefulness of parties in municipal government. *Ernest Bruncken.*

25. The qualifications of voters. *John G. Gregory.* Discussed by F. J. Turner and C. H. Chandler.

26. Influence of research and criticism on history. *H. J. Desmond.*

27. The projected French expedition of George Rogers Clark against Louisiana. *Frederick J. Turner.*

28. The quantity theory. *William A. Scott.* Read in the absence of the author by B. H. Meyer.

29. The Scandinavian immigrant. *John H. Bille.* Read by title only.

30. The need of a medical faculty in connection with the State University. *Arthur J. Puls.* Discussed by A. S. Mitchell, W. W. Daniells, Edward Kremers, C. R. Van Hise, C. S. Slichter.

Professor A. S. Mitchell exhibited two diamonds found at Burlington and Schlesingerville, both in Wisconsin.

The report of the Committee on Membership was read recommending the following persons for membership:

Ellsworth Huntington, Beloit.
Howard S. Brode, Beloit.
H. A. Allen, Milwaukee.
Alice A. (Mrs. Hugo) Bremer, Milwaukee.
Mrs. H. F. Whitcomb, Milwaukee.
J. I. Jegi, Milwaukee.
Daniel Fulcomer, Milwaukee.
S. A. Hooper, Milwaukee.
August Uihlein, Milwaukee.
W. D. Frost, Madison.
George Gibbs, Milwaukee.
Fred Pabst, Milwaukee.
N. A. Harvey, West Superior.
E. W. Clark, Ripon.
F. M. Erickson, Ripon.
F. M. Lillebridge, Ripon.
F. H. Putney, Waukesha.
W. L. Rankin, Waukesha.
Chas. N. Gregory, Madison.
M. S. Slaughter, Madison.
Richard Fischer, Madison.
S. E. Sparling, Madison.

The Secretary was instructed to cast the ballot of the Academy for the persons named. This was done and they were declared elected as active members.

The report of the Auditing Committee was read and adopted.

The report of the Committee on Nomination of Officers was read recommending the following as officers for the regular term of three years:

President: C. Dwight Marsh, Ripon.

Vice-Presidents: Harriet B. Merrill, Milwaukee; E. D. Eaton, Beloit; F. J. Turner, Madison.

Secretary: A. S. Flint, Madison.

Treasurer: L. S. Cheney, Madison.

Librarian: W. S. Marshall, Madison.

Curator: H. F. Lueders, Sauk City.

Committees.

On Library: The Librarian; W. S. Leavenworth, Ripon; R. G. Thwaites, Madison.

On Membership: The Secretary; D. P. Nicholson, Appleton; A. S. Mitchell, Milwaukee; A. L. Ewing, River Falls; J. J. Davies, Racine.

On Publication: The President; the Secretary; J. G. Gregory, Milwaukee.

The Secretary was directed to cast the ballot of the Academy to elect as officers the persons named. This was done and these officers declared elected.

The Committee on Membership also recommended the following for election to be corresponding members:

Chas. F. McClumpha, Minneapolis, Minn.

Geo. L. Hendrickson, Chicago, Ill.

Edward B. Van Vleck, Middletown, Vt.

David Kinley, Urbana, (Champaign), Ill.

AFTERNOON.

The Academy adjourned for the afternoon in order to attend the meeting of the College section of the Wisconsin Teachers' Association.

EVENING SESSION.

The Academy assembled at 8:30 o'clock with friends from the public and listened to the address of the retiring President, Professor Charles R. Van Hise of the University of Wisconsin, on "Earth Movements."

This closed the Twenty-seventh Annual meeting of the Academy.

All sessions were held at the State Normal School building.

CHAS. R. BARNES,
Secretary.

NOTE:— The following amendment to the Constitution was proposed at some time in the meeting of December, 1896:— To add after the word "year" in the first sentence of Article VII concerning meetings the following words:—"or at such other place as the Council may designate."

TWENTY-EIGHTH ANNUAL MEETING.

MILWAUKEE, WIS., DECEMBER 27-29, 1898.

PRELIMINARY REPORT OF THE SECRETARY.

The printing of Vol. XI (1896-7) of the Transactions is nearly completed, 460 pages having been printed and nearly all of the authors' separates distributed.

The following resignations from active membership have been received:

W. A. Eckels, Baltimore, Md.

W. S. Leavenworth, Ripon.

C. W. Pearson. Beloit.

Mrs. D. E. Roberts, Milwaukee.

Dr. J. H. Hamilton, Syracuse, N. Y.

The membership, of the Academy at present is as follows: Honorary 6, Life 9, Active 186, Corresponding 50. Total 251.

The resignations reported were accepted. On recommendation of the Committee on Membership the following were elected active members:

G. A. Tawney, Beloit College.
Amelia McMinn, Milwaukee.
E. H. Merrell, Ripon College.
H. C. Wolff, Madison.
O. B. Zimmerman, Milwaukee.
Isidor Ladoff, Milwaukee.
J. B. Sanborn, Madison.
E. T. Owen, Madison.
H. C. Legler, Milwaukee.
Henry Nehrling, Milwaukee.
E. H. Comstock, Milwaukee.
E. F. Chandler, Ripon.
G. F. Lane, Ripon.
William Starr, Eau Claire.
A. C. Clas, Milwaukee.
Mary C. Harwood, Ripon.
Herman Schlundt, Milwaukee.
Rosalia A. Hatherell, River Falls
Edgar E. Teller, Milwaukee.
Mary F. Hall, Milwaukee.
M. V. O'Shea, Madison.
Geo. B. Ferry, Milwaukee, (Elected also in June, 1895).

The following having been active members, but removed from the state, were elected corresponding members:

F. L. Lurton, Monticello, Minn.

S. D. Townley, Ann Arbor, Mich.

J. H. Raymond, Morgantown, W. Va.

W. A. Eckels, Baltimore, Md.

Jos. P. Iddings, Chicago.

The following were elected life members, on account of special services to the Academy:

Chas. R. Van Hise, Madison.

Chas. R. Barnes, Madison.

Samuel D. Hastings, Green Bay.

The following amendment to the Constitution was adopted:

To add after the word "Year" in the first sentence of Article VII, concerning meetings, the following words: "or at such other place as the Council may designate; but all regular meetings for the election of officers shall be held at Madison."

On recommendation of the Committee on Nomination of Officers, Chas. H. Chandler was elected to fill the vacancy on the Library Committee made by the resignation of W. S. Leavenworth.

A. S. Flint,
Secretary.

LIBRARIAN'S REPORT, 1895.

MADISON, Wis., Dec. 25, 1895.

To the Wisconsin Academy of Sciences, Arts, and Letters:

Your Librarian begs leave to submit the following report concerning the conduct of his office during the past year, and the present condition of the library.

The number of additions to the list of exchanges during the past year has been comparatively small. The Librarian, owing to lack of time, has not been able to give sufficient attention to the soliciting of exchanges, and regrets exceedingly that he has to report so little progress in this direction.

There have been many accessions of volumes, partially or wholly completing imperfect sets of publications, due for the most part to the efforts of Professor Van Cleef, my predecessor in office. The most notable accession is a complete set of the Memoirs of the St. Petersburg Academy, forty volumes.

Volume X of the Transactions of the Academy has been distributed to all members of the Academy, and to all correspondents. A large number of back volumes of the Transactions have been distributed to the libraries of colleges, universities and other educational institutions and to foreign correspondents.

The occupation of the library for a large part of the year by committees of the Legislature and compilers of the state census has hampered the work of the Librarian somewhat. Access to the shelves has at times been very difficult, and sometimes impossible.

The large accessions to the library during the past four years have almost completely filled the shelf room. The overcrowded condition of many cases has made a re-arrangement of sets of books necessary, so that the printed catalogue is not always a sure guide. As there is prospect of ample shelf-room in the quarters designated for our library in the new building projected for the State Historical Society, it may not be advisable to take steps for the increase of shelf room in our present quarters. It is possible, however, that something may have to be done to give temporary relief in the near future.

No cataloguing has been done in the past two years, and for this reason a large number of dissertations are at present practically inaccessible.

The number of unbound volumes is at present quite large. If the financial condition of the Academy will permit, these volumes should be bound as soon as practicable, that they may be better preserved and more easily handled.

A very important part of the Librarian's duty is the soliciting of exchanges. It has seemed to the present librarian that much more effective work in this direction might be done by a fuller co-operation with the librarians of the State Historical Society and of the State University.

The Librarian feels himself obliged at this time to resign his office. Increasing demands upon his time during the past year have seriously interfered with his conduct of this office, and further continuance in it is at present an impossibility. His resignation is hereby tendered.

Respectfully submitted,

F. G. HUBBARD,

Librarian.

REPORTS OF TREASURER.

TREASURER'S REPORT, 1895.

MADISON, WIS., Dec. 26, 1895.

To the Wisconsin Academy of Sciences, Arts and Letters:

The following is a statement of the financial transactions of the Academy during the past year:

Balance on hand as per last year's statement.........	$316 57	
Received for interest on permanent fund	73 33	
Received from initiation fees of 37 new members.....	74 00	
Received from members, annual dues...............	94 00	
Received from Librarian for Transactions sold	4 18	
		$562 08

The disbursements, upon the order of the President and Secretary, have been as follows:

1894.				
Dec.	27	S. E. Barnes, for clerical work...........	$3 68	
	27	A. Zeese, for zinc cut map	1 73	
	27	A. Zeese, for zinc cut map...............	1 28	
	27	F. G. Hubbard, for postage, etc..........	6 42	
1895.				
March	29	Tracy, Gibbs & Co., for printing.........	61 00	
	29	S. E. Barnes, for clerical work..	2 00	
April	17	A. Zeese & Co., engraving, etc...........	13 79	
	17	C. K. Leith, writing, etc.................	69 80	
	17	F. E. Morrow, drawing maps	6 00	
	17	C. R. Barnes, for postage................	2 00	
May	24	Franklin Engraving & Electrotyping Co..	27 83	
	24	Franklin Engraving & Electrotyping Co..	12 38	
July	15	C. R. Barnes, postage stamps............	2 00	
	15	F. E. Morrow, drawing maps............	22 80	
	15	C. K. Leith, clerical services	7 67	
	31	S. E. Barnes, clerical work	7 25	
	31	F. G. Hubbard, Librarian, for postage, expressage, freight, etc..................	20 65	
Aug.	19	Tracy, Gibbs & Co., printing.............	12 25	
				$280 63
		Balance on hand Dec. 26, 1895		$281 45

Owing to the fact that the property that was mortgaged to secure the $1,000 permanent fund of the Academy, was recently sold, the money was returned and the mortgage discharged.

After trying without success to find a mortgage of a thousand dollars on property in Dane county, in which this fund could be invested, after consultation with the President and Secretary of the Academy, and in accordance with their advice, the money was placed in the hands of the Savings Loan and Trust Company of Madison, Wis.; for which the Academy holds the company's debenture bond No. 1039, dated October 31st, 1895, for one thousand dollars with interest at the rate of five per cent. per annum payable semi-annually on the first of January and July at the company's office or at the First National Bank of Madison.

SUPPLEMENTARY REPORT.

Since the foregoing was written there have been receipts and disbursements as follows:

Balance brought forward		$281 45
Received for initiation fees and annual dues		11 00
		$292 45
Disbursements:		
Democrat Printing Co., for printing	$71 95	
S. D. Hastings, for postage and envelopes for 3 years	14 25	86 20
		$206 25
Balance Dec. 26, 1895		$206 25

Respectfully submitted,

SAML. D. HASTINGS,
Treasurer.

The Auditing Committee report that they have found the report of the Treasurer correct according to accompaning vouchers and check for the balance due the Academy $206.25 and bond for $1,000. All effects of the office have been turned over to L. S. Cheney, Treasurer-elect.

W. W. DANIELLS,
D. P. BLACKSTONE,
J. MORGAN CLEMENTS,
Committee.

TREASURER'S REPORT, 1896.

MADISON, Wis., Dec. 29, 1896.

To the Wisconsin Academy of Sciences, Arts, and Letters:

The following is a statement of the financial transactions of the Wisconsin Academy of Sciences, Arts, and Letters, for the year 1896:

RECEIPTS.

Dec. 26, 1895.		From retiring Treasurer	$206 25	
From Dec. 26, 1895, to Dec. 29, 1896.		Dues from members	112 00	
1896.				
Jan.	1	Check returned by Tillie Snyder	1 50	
June	9	From J. G. Gregory for printed covers	1 50	
Sept.	25	Interest on bond for 6 months, ending July 1	33 33	
Jan.	29	Stamps received as dues	1 00	
				$355 58

DISBURSEMENTS.

1895.			
Dec.	28	To C. K. Leith, for clerical work and stamps, Vr. 1	$12 60
Dec.	28	To A. S. Kingsford, for clerical work, Vr. 2	2 29
Dec.	28	To W. E. Ferguson, for cartage on vol. x Transactions, Vr. 3	7 00
Dec.	28	To F. G. Hubbard, for postage, Vr. 4	28
Dec.	28	To Tillie Snyder, for typewriting, Vr. 4	1 50
1896.			
Jan.	30	To L. S. Cheney, for postage, Vr. 5	5 00
Feb.	11	To Tracy, Gibbs & Co., for printing, Vr. 6	12 25
Feb.	16	To C. R. Barnes, for postage, Vr. 7	2 00
Feb.	18	To Mrs. S. E. Barnes, for clerical work, Vr. 8	1 06
March	2	To C. K. Leith, for clerical services, Vr. 9	2 00
March	6	To Taylor & Gleason, for printing, Vr. 10.	1 25
April	10	To Franklin Engraving & Electrotyping, Co., for plates, Vr. 11	4 95
Sept.	3	To F. G. Hubbard, for foreign postal cards, Vr. 12	10 00

Oct.	1	To Tracy, Gibbs & Co., for stationery and printing. Vr. 13	$2 75	
Oct.	1	To Franklin, Engraving & Electrotyping Co., for plates, Vr. 14	13 35	
Oct.	25	Stamps received for dues applied for use of Academy, vr. 15	1 00	
Dec.	24	To F. G. Hubbard, for balance due for expenditures, Vr. 12	75	
				$80 03

Balance cash on hand	$275 55
Debenture bond	1,000 00
Total	$1,275 55

Respectfully submitted,

L. S. Cheney,
Treasurer.

The committee appointed to audit the accounts of the Treasurer of the Wisconsin Academy beg leave to report that they have examined the books and vouchers of said officer and have found them to be correct.

Chas. S. Slichter,
John S. Roeseler,
Commtttee.

TREASURER'S REPORT, 1897.

Madison, Wis.

The following is a report of the receipts and expenditures for the year ending Dec. 28, 1897.

RECEIPTS.

Balance in treasury Dec. 29, 1896, as per report	$275 55	
Dues received from members	141 00	
Interest on bond for $1,000.00 at 5 per cent. for one year	50 00	
For binding separates	1 00	$467 55
		$467 55

DISBURSEMENTS.

Jan.	19	To C. K. Leith, for clerical services and postage, Vr. 1	$19 14	
	22	To C. D. Marsh, expenses incurred for Academy, Vr. 2	7 84	
	28	To W. J. Buckley, reporting address, Vr. 3	7 50	
Feb.	1	To L. S. Cheney, for stamps purchased, Vr. 4	5 00	
	25	To C. D. Marsh, expenses incurred for Academy, Vr. 5	20 09	
March	1	To Tracy, Gibbs & Co., for printing, Vr. 6	10 50	
	5	To C. D. Marsh, expenses incurred for Academy, Vr. 7	19 75	
June	18	To C. D. Marsh, expenses incurred for Academy, Vr. 8	3 90	
	28	To H. M. Esterley, for labor, Vr. 9	90	
Aug.	24	To Franklin Engraving and Electrotyping Co., for plates, Vr. 10	26 43	
Dec.	13	To Franklin Engraving and Electrotyping Co., for plates, Vr. 11	76 76	
	13	To W. S. Marshall, transferring books to Sci-Hall, Vr. 12	17 78	
	13	To Mrs. H. A. Flint, for clerical services, Vr. 13	2 25	
	13	To A. S. Flint, for stationery and postage, Vr. 14	8 44	226 28
		Balance on hand		$241 27

Respectfully submitted,

L. L. CHENEY,

Treasurer.

The report of the Treasurer for 1897 was approved by the Auditing Committee, Messrs. Ernest Bruncken, G. E. Culver, and E. R. Buckley, and adopted by the Academy, December 29, 1897.

A. S. FLINT,

Secretary.

GENERAL INDEX.

[The numbers connected with a hyphen cover several references between the pages indicated.]