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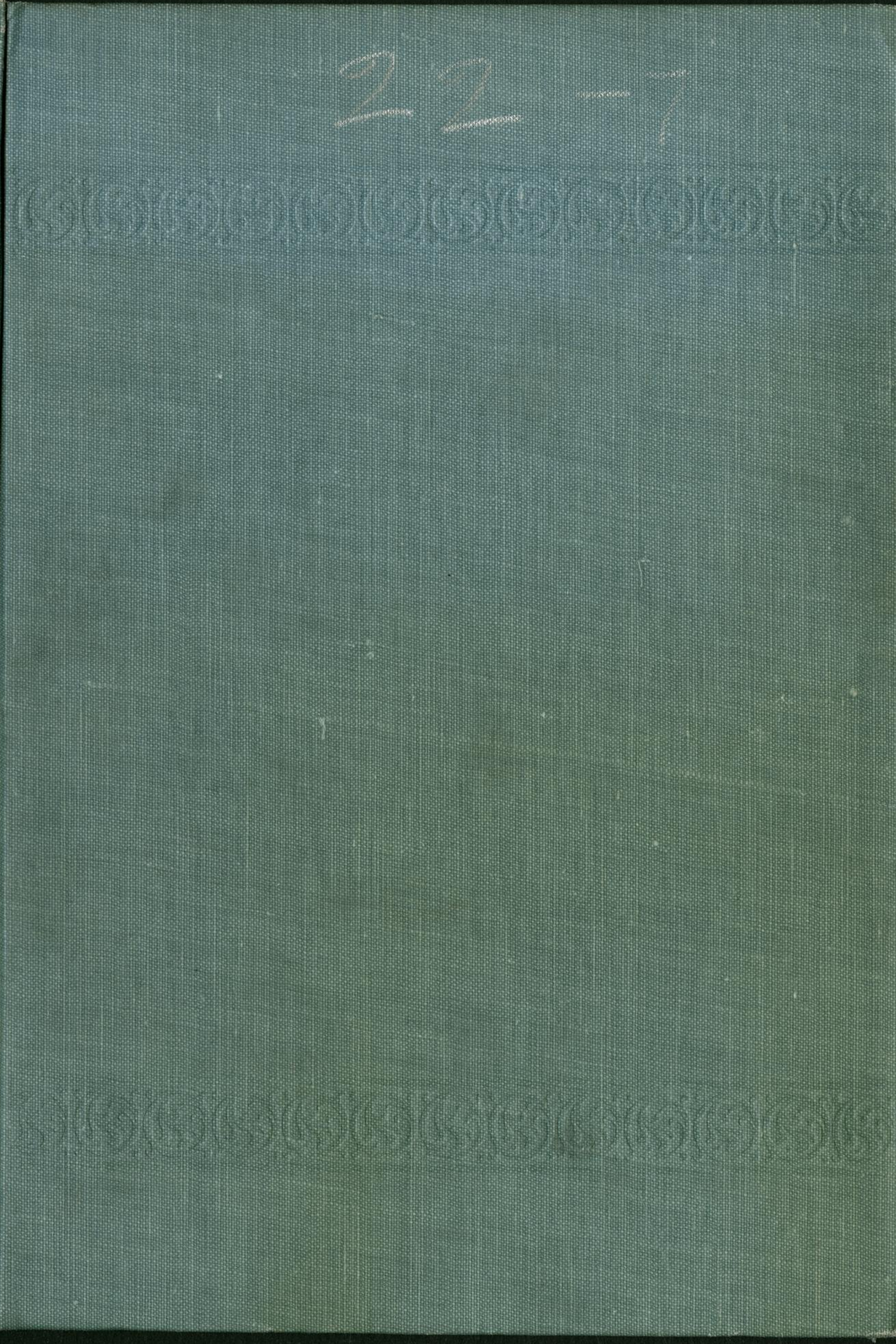

WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY.

Edw. A. BIRGE, Director **Wm. O. HOTCHKISS, State Geologist**

BULLETIN NO. XXII SCIENTIFIC SERIES NO. 7

THE
INLAND LAKES OF WISCONSIN

THE DISSOLVED GASES OF THE WATER
AND
THEIR BIOLOGICAL SIGNIFICANCE

BY

EDWARD A. BIRGE, AND CHANCEY JUDAY,
Director Biologist

WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

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PREFACE

E. A. BIRGE.

The investigation reported in this paper has been so long in progress and has engaged the attention of so many persons in varying degrees that a brief statement regarding it is not out of place.

In 1897 I published a paper on the crustacea of the plankton of lake Mendota,[1] in which much attention was given to their vertical distribution. I there indicated (p. 428) that the exclusion of crustacea from the lower water of lake Mendota in summer is due, in part at least, to chemical causes. I planned to ascertain the nature of these chemical conditions, but unforeseen changes in the duties of my position in the University of Wisconsin delayed the execution of this plan. In 1904 I resumed the study; I worked out the method of collecting and boiling samples of water substantially as described in this paper and also the method of securing correlated plankton catches. I had a trial apparatus made and with the aid of Professor Victor Lenher, of the department of chemistry in the University of Wisconsin, carried out several sets of preliminary observations on lake Mendota, which showed the general gas conditions found in the autumn in that lake. The chemical side of the study was then placed in charge of Dr. Lenher, who determined the practical details of the equipment and operation of a field laboratory and who, with the assistance of Dr. R. C. Benner, carried out the chemical work in the field during the season of 1905. In August, 1905, Mr. Chancey Juday returned to the Survey and at first took charge of the biological side of the work. During the next season Dr. Benner took charge of the chemistry, Mr. Juday of the biology, while, as before, I retained general supervision of the work and assisted in all parts of it.

During the seasons of 1907, 1908, and 1909, the field work of this Survey has been assisted by a grant of money from the United States Bureau of Fisheries; and the extension of our studies to the lakes of

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[1] Transactions Wis. Acad. Sciences, Vol. 11, pp. 274–451.

northeastern and northwestern Wisconsin has thus been made possible. This valuable assistance is acknowledged with thanks.

Chemical work has been done also by Dr. R. D. Hall and Dr. G. I. Kemmerer, who have very efficiently taken charge of field parties. Several other persons have assisted in field work. In the wearisome counting of plankton catches, Mr. Juday has been aided by Mrs. Effie R. Michener.

Mr. Juday has taken an increasing part in the execution and supervision of the work. From the first he has been responsible for the biology, and in later years for the chemistry also. He took full charge of the field parties in 1908 and 1909, when I was in the field for a short time or not at all; and the entire task of writing the report (except the introduction) has been done by him. Both of us are, however, responsible for the results as I have given almost daily attention to the work and have constantly reviewed it in all stages of progress.

Professor Lenher has continued to look after the analytical work in chemistry and the gravimetric analyses of Dr. H. B. North and Mr. E. B. Hall were made under his care, as were the analyses of the residual gases by Mr. M. E. Diemer. We should also make special acknowledgment of the assistance of Dr. R. C. Benner, who gave much thought and care to the problems of the lakes, particularly those of the dissolved carbonates. He contributed greatly to the appreciation of these problems and to their solution so far as this has been reached.

In the progress of these studies a great amount of chemical and biological data has accumulated which has not been used in this paper and remains as part material for future studies.

During the course of the investigation I have published six addresses and papers based in part on the material here reported. These are:

The Thermocline and its Biological Significance; Trans. Amer. Micros. Soc. Vol. XXV. 1903.

The Oxygen dissolved in the Waters of Wisconsin Lakes; Trans. Amer. Fish. Soc. Vol. XXXV. 1906.

The Respiration of an Inland Lake; Trans. Amer. Micros. Soc. Vol. XXXVI. 1907.

The Gases dissolved in the Waters of Wisconsin Lakes; International Fisheries Congress, Washington, 1908; Bulletin U. S. Bureau of Fisheries. Vol. XXVIII. 1910.

The Evidence for Temperature Seiches.

An Unregarded Factor in Lake Temperatures. Both published in the Trans. Wis. Acad. Sciences. Vol. XVI, Part 2. 1910.

Mr. Juday has published the following paper:

Resumé of recent Work on Lakes by the Wis. Geol. and Nat. Hist. Survey; Internat. Rev. Gesamt. Hydrobiol. u. Hydrographie. Vol. I, 1908.

The following papers (published in the Trans. Wis. Acad. Sciences. Vol. XVI, Part 1) deal with certain phases of the relation between animal life and dissolved gases; their results are summarized, with additions, in parts of chapter VI of this report:

A Summer Resting Stage in the Development of *Cyclops bicuspidatus* Claus; E. A. Birge and C. Juday.

Some aquatic Animals that live under anaerobic Conditions; C. Juday.

Dissolved Oxygen as a Factor in the Distribution of Fish; C. Juday and G. Wagner.

Attention should also be called to a paper by Mr. Juday:

The Diurnal Movement of the Plankton Crustacea. Trans. Wis. Acad. Sciences. Vol. XIV. 1904.

This paper was among the first to call attention to the variety and complexity of the biological problems offered by lakes, even in cases where the problems appeared at first sight to be capable of relatively simple solution, and to show the necessity of studying the biology of plankton animals in their natural environment rather than in the laboratory.

Reference should also be made to the following publications of the Wisconsin Geological and Natural History Survey:

Lakes of Southeastern Wisconsin, by N. M. Fennemann. Bulletin No. VIII, second edition. 1910.

The Plankton of Lake Winnebago and Green Lake, by C. Dwight Marsh. Bulletin No. XII. 1903.

Ten hydrographic maps have been published, covering the principal lakes and lake districts of southeastern Wisconsin.

A bulletin is now in preparation which gives in detail the data pertaining to the hydrography of the lakes in southeastern Wisconsin that have been surveyed, and which also gives such facts on the hydrography of the lakes in the northeastern and northwestern parts of the state as were obtained during the progress of these studies.

A large amount of literature has been consulted in the preparation of this report, but comparatively little has been found which relates to the particular phases of the subject that are presented here. This accounts for the small list of references, because only those papers which have a direct bearing on the subjects discussed, have been cited. For more general lists, the reader is referred to "Das Süsswasser" by K. Knauthe and to "Planktonkunde" by A. Steuer.

INTRODUCTION

The following report deals with the dissolved gases of the inland lakes of Wisconsin. It reports the distribution of these gases in numerous lakes and the cause of variations in distribution due to depth and season. In this introduction we purpose to sketch briefly the principles which are more fully stated and illustrated in the succeeding pages.

The lakes studied are not large, as the area does not exceed 40 sq. km. (15 sq. mi.); nor are they very deep, since the maximum depth is 73 m. (237 ft.). They are glacial lakes, usually placed in drift basins; with low banks; and are either fed from the ground water or have relatively small affluents. They are covered with ice during several months of the winter and the surface temperature ordinarily reaches a maximum of 27°–30° during the summer.

The cycle of the seasons induces a corresponding cycle of physico-chemical changes in the water of these lakes, chiefly conditioned by temperature. The lake starts in spring with a uniform temperature below 4°, when complete circulation of the water is possible. The advance of summer quickly checks circulation by warming the surface water, and soon produces a permanent thermal stratification. This leads on to the formation of an epilimnion,[1] sharply separated from the cooler water by the thermocline. This situation may be developed in small lakes as early as the opening of May; in larger lakes it may not be completed before the first of July. The epilimnion thus formed varies in thickness, in midsummer, from 3 m. in small lakes, to 10 m.–12 m. in large ones. After the epilimnion is established circulation is confined to this stratum of the lake and is very imperfect even there so long as the lake is gaining heat. As autumn comes on the lake cools. the epilimnion increases in thickness; finally the lake

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[1] By *epilimnion* is meant the upper stratum of water found in summer, above the thermocline, and whose temperature is nearly uniform. The region below the thermocline may be called the *hypolimnion*. See Birge. On the evidence for temperature seiches: Trans. Wis. Acad. Sciences, vol. XVI, pt. 2, p. 1006; 1909.

"turns over" and becomes homothermous; and the fall period of full circulation begins. This happens at a time which varies from late September to December, according to the area and depth of the lake. It lasts until the lake is frozen, which may occur in late November or early in January, varying with lake and season. Circulation then ceases until spring.

Thus during the greater part of the year, free circulation of water and consequent exchange of gases with the air are much restricted or wholly cut off. The lake is saturated with gases from the atmosphere in the fall and in early spring. As soon as direct thermal stratification appears, the lower water begins to be excluded from the circulation and consequently from contact with the air. This exclusion may be interrupted by violent winds which temporarily restore circulation. But it soon becomes permanent; and the stratum of circulating water becomes increasingly thinner until the thermocline appears and the permanent summer conditions are established. Thenceforward, until the overturn, only the water of the epilimnion can have direct contact with the air and only indirect exchanges are possible for the gases of the lower water. Practically, the lower water is cut off from the air.

Superimposed on this annual cycle, determined by the march of the seasons, is another series of physico-chemical changes due to the plankton inhabitants of the lake. These consume certain substances dissolved in the water, manufacture others; add some materials to the water and subtract others. This is done in the most complex fashion, varying with the kind of plankton and with many varying conditions in its life and environment.

It is convenient to group these activities, so far as they relate to gases, under two heads; those which liberate oxygen and those which consume it. A correlative classification would be into those processes that consume carbon dioxid and those which liberate it. The first class includes the photosynthetic activities of plants; the second comprises the respiratory processes and those of decomposition.

Photosynthesis consumes carbon dioxid and liberates a corresponding amount of oxygen. It demands a certain quantity of energy in the form of light. It is therefore most vigorous near the surface, and is limited to a stratum of the lake, whose thickness varies with the color and turbidity of the water. In highly colored or turbid lakes the *zone of photosynthesis* may be only 2 m.–3 m. thick; in clear lakes it may extend to the depth of 10 m. or even farther. The oxygen contents of this zone vary with the ratio of the liberated oxygen and that absorbed from the air to that consumed by respiration and decomposition. In the water below, the amount of oxygen will depend on the rate of consumption as compared with the rate of supply by diffusion from the upper stratum, or by circulation due to temperature changes or to wind.

In the zone of photosynthesis the oxygen may be present in sufficient quantity to saturate the water. It may rise above this amount, especially if circulation of the water is hindered by calms; if photosynthesis is slow the oxygen content may sink below saturation. In an opaque lake the zone may not extend to the thermocline; and in periods of deficient circulation the oxygen content of the lower part of the epilimnion may become low. In clear lakes, especially if they are small, the zone may extend below the epilimnion and so below circulation; and in these cases a large excess of oxygen may accumulate at the region of the thermocline.

In the processes of photosynthesis the carbon dioxid in the water is consumed. Its sources are four: from the air, from ground water, from the decomposition of organic matter and from respiration, and from dissolved bicarbonates of calcium and magnesium. The air seems to afford only a small supply; and the same may be said of the ground water under ordinary conditions, although this source may be important in small, spring-fed lakes.

The process of respiration consumes oxygen and sets free carbon dioxid at all depths where animal and plant life occur. Its effects on the dissolved gases can hardly be separated from those of decomposition. This process, too, goes on at all depths, consuming oxygen and liberating carbon dioxid. But as both animals and plants sink after death, most of the decomposition goes on in the deeper water, and especially, close to and at the bottom. There is ordinarily an accumulation of free carbon dioxid in the lower water increasing with the depth, and a corresponding reduction or exhaustion of oxygen. After the oxygen is used up, anaerobic decomposition continues, with evolution of carbon dioxid, methane, and carbon monoxid. The lower water of a lake forms a *zone of decomposition*, whose processes are most vigorous at the bottom and decrease in intensity upward. It should be observed that this term is applied to the region where decomposition is the predominant process and where most, though by no means all, of the decay occurs; while the zone of photosynthesis includes the stratum where all the photosynthesis occurs.

Thus the vertical distribution of gases in a lake is indicative of fundamental biological facts. The quantity of life which the limnetic region of a lake can support is in general a function of the amount of green plants which it can produce. This in turn is limited largely by the quantity of carbon dioxid available for photosynthesis. If a lake is so shallow that the whole of the water is circulated, the zones of photosynthesis and decomposition overlap and the carbon dioxid can readily be used over and over again with correspondingly vigorous growth of plants. If, however, an epilimnion is formed, none of the carbon dioxid liberated below it can be used in the upper water until circulation extends downward. Thus much of the carbon dioxid may be locked up in the lower water until late in the fall, when the period of growth has passed. In lakes containing much plankton a large share of it may be decomposed under anaerobic conditions, yielding in part methane and peaty products which are not available for further use in the lake.

The zone of photosynthesis is, under ordinary conditions, subject to a continual loss of part of its stock of carbon dioxid by the sinking of dead and dying planktonts. This is only very partially replaced from the air or other sources. Since this is the case, the form of the lake-basin is of importance in the economy of the lake. A lake with shoal margins, offering a chance for much decomposition above the thermocline will produce—other things being equal—more plankton than a lake of similar area, but with steep slopes and deep water. In the latter case, almost all matter manufactured near the surface is decomposed in deep water below the region of circulation; and therefore is more or less permanently withdrawn from the possibility of being used again.

Under these conditions, the carbon dioxid available for plants in the dissolved bicarbonates becomes a valuable supply. Lakes containing a large amount of these substances possess a source of carbon dioxid lacking in soft-water lakes, and can therefore support a larger population of plankton. The reduction of the bicarbonates to monocarbonates gives an alkaline reaction to the upper stratum of the lake. These monocarbonates must take up the carbon dioxid liberated in the upper water by respiration and decomposition, and more will be absorbed from the air than is possible if free carbon dioxid is already contained in the water. Thus the presence of an abundance of dissolved carbonates increases the supply of carbon dioxid for plant use, both directly and indirectly; directly, by the original stock of half-bound carbon dioxid in the bicarbonates; indirectly, because the monocarbonates take up more carbon dioxid from the air than would be absorbed without their aid, and also absorb that liberated in the upper water by respiration and decay. Much of this last would escape into the air, especially at night, if not so absorbed.

In such lakes the epilimnion is permanently alkaline during the summer, which shows that more carbon dioxid is withdrawn from the bicarbonates than is supplied to them from other sources, and more than is made good at night. The process goes so far that monocarbonates, especially calcium carbonate, are precipitated, to be redissolved by the free carbon dioxid in the lower water or to accumulate in the mud at the bottom.

The preceding paragraphs must not be understood to affirm that the productivity of a lake is wholly determined by the amount of available carbon dioxid. Many other factors, physical and chemical, are concerned and but little is yet known about them. It is certain, however, that all chemical substances which contribute to determine the amount of plankton are subject to reduction by sinking of the dead plants and animals and to limitations on repeated use, due to deficient circulation, just as is the case with carbon dioxid.

The inhabitants of an inland lake form a closed community in a stricter sense, perhaps, than the term can be applied to any other non-parasitic assemblage. The number of species living under these conditions is small and closely similar in different lakes. Only small additions are made to the food supply from without and these come slowly. The lake is dependent on its own stock of green plants for the stock of organic matter available for food of other organisms; and the possible amount of green plants is limited by the raw material supplied for photosynthesis from the lake itself. The critical factor then, in the economy of a lake with small in-and outflow of water, is the provision for the vertical circulation of the water in the lake. But this circulation is very imperfectly effected at best, and is often wholly absent for most of the water.

All of these factors cooperate to produce an annual cycle in the distribution of the dissolved gases, whose fundamental features are the same, but whose details differ endlessly in different lakes. The general story and its more important variants are shown in the following chapters.

Many details of the story, however, are not completely explained by these general principles and much more work must be done before they are fully understood. Our experience has led us to expect that certain individual peculiarities will recur in certain lakes. These closed assemblages of plants and animals have lived together, in a limited environment, since a time which goes back nearly to the glacial period. It seems as if they had acquired certain habitual actions and reactions upon each other and on the environment, whose details differ in individual cases—physiological variations in the assemblage and its units not unlike the morphological variations seen in the forms of *Daphne* from different lakes. The observations here recorded show many cases of this sort, at present unxplained, which wider study may place under general laws or in special categories.

The animal plankton has not shown any close correlation with th dissolved gases, considered either with reference to kind or quantity. These gases seem to have no chemotactic effect on the zooplankton, nor do the gaseous products of decomposition, as they exist in lakes, appear to have any unfavorable effect on the animals, such as might determine their distribution in the water of the lake. The zooplankton is excluded from water whose supply of oxygen is too small; but sensitiveness to deficient oxygen does not appear until the supply of the gas is much reduced. These animals do not begin to withdraw from water until the oxygen supply is reduced to 0.2 cc. or 0.3 cc. per liter—a very small percentage of the normal amount. Few animals remain in water which has less than 0.1 cc. Thus the whole phenomenon of response to declining oxygen takes place within very narrow limits in the quantity of the gas. It has been possible, therefore, to give only broad and general conclusions in this matter and we have not been able to work out exact correlations for the various species or other groups.

As our work has progressed we have been increasingly impressed by the complexity of the questions involved. This has become more and more manifest as our experience has extended to numerous lakes and to many seasons. If this report had been written at the close of the first or second year's work, it would have been much more definite in its conclusions and explanations than is now the case. The extension of our aquaintance with the lakes has been fatal to many interesting and at one time promising theories. The result is that in the report many chemical and biological problems are only partially solved and some are barely indicated. Such are questions connected with the excess oxygen at the thermocline and especially the relations existing between the amount of dissolved carbonates and that of the plankton.

It may not be out of place to state briefly our view of the results of this investigation, and also of some of the unsolved questions on which it touches. It is a study in the statistics of lakes and from that point of view must be judged by the quantity of observed facts which underlie it and by the way in which the facts are handled. But the facts also represent the effect of processes which go on within the lake, and the report should show the relations between the changes in dissolved gases and these other processes.

We believe that judged from the first point of view this report gives a reasonably full account of the dissolved gases in the waters of Wisconsin lakes. It sets forth in sufficient detail the facts of the kinds, the amount, and the variation of these gases; of their vertical distribution; of the effect of the seasons and the plankton on quantity and distribution; we have been able to distinguish the different types of lakes which result from these facts.

But even though we may feel that this investigation is reasonably adequate from the statistical point of view, we are sure that no reader of the paper is more keenly conscious than ourselves of its essentially fragmentary character, when judged on another and much more important side. This study is fundamentally concerned with one aspect of the physiology of a lake, and therefore with a yet almost wholly undeveloped science. Perhaps the chief interest which our work has had for us has been the fact that its progress has revealed to us the existence of physiological processes in lakes as complex, as distinct, and as varied as those of one of the higher animals. The processes which we have studied are intricately bound up with physical, chemical, and biological processes of every kind, of which limnologists are still in large measure ignorant. If the story of the dissolved gases is to be adequately told, there is needed a quantitative knowledge of the chemical results of the vital processes of the plankton plants and animals; a knowledge of which we possess hardly a beginning. We need a similar knowledge of the processes of bacterial decomposition in lakes, whose accurate study still belongs to the future. In spite of this ignorance, we have not hesitated to put forward our conjectures regarding the meaning of various changes in the gases and their relation to other processes; fully expecting that many of these conjectures will prove erroneous, and sure that future knowledge will render all of them inadequate. But we know of no better way to direct attention to problems which need study than to indicate the probable, or possible, connection of the changes which we have found in the dissolved gases with other processes of lake physiology.

Various papers which have been recently published on the problems of limnology show that the science is passing from the initial stage of the collection of more or less disconnected facts to that of the establishment of principles. It is becoming clear that the duty of limnological stations is primarily with biological questions, with the study of organisms in their natural environment. Wesenberg-Lund, in his recent statement of limnological problems[1] justly emphasizes this point. The origin of the fauna of our lakes, the nature of the "species," the relations of the several members of the plant and animal plankton to their environment and to each other; all these and many other questions of limnology have great interest and great scientific importance. But there is another aspect of the subject, as yet little considered by limnologists but which our studies have impressed upon us. This is the physiology of the lake as a whole—the physical and chemical processes in the lake, which result from the influence of its environment and from that of the organisms living in it. These processes differ in different lakes, for reasons partly external to the lakes and partly internal. The area, depth, and shape of the lake; the chemistry of its water supply; the number and kind of organisms that it contains; these and many other matters affect the lake in a complex fashion, and cause it to pass through a series of changes which may not improperly be called physiological. In preparing this report we have studied more than 150 lakes, not widely separated in distance or greatly different in climatic or topographic conditions. They are of substantially the same age, all dating from the close of the last glacial period. Their fauna and flora do not differ widely in range of forms. It might, therefore, be expected that the story of the dissolved gases in the several lakes would be similar.

Yet there are the widest differences in the process which we have studied and which may fairly be called the respiratory processes of the several lakes. These in turn are the reflection of differences—qualitative and quantitative—in the amount and nature of other processes, due in part to the substances dissolved in the water of the

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[1] Bathymetrical Survey of Scottish Fresh Water Lochs. Vol. I, p. 374. 1910.

several lakes and in part to the amount and the activities of the plankton and the reaction of its several members on each other and their environment. We find unexpected individuality in the story of the gases of each lake, and also a grouping of lakes into classes which agree in the essentials of the type of respiratory processes. Thus it seems to us that it is possible to study not only the biology of the several plankton species but also the physiology of lakes, both in its relation to external conditions and internal processes. It seems also that this study will yield results of great scientific and practical interest. One general question may be named, whose answer is as yet almost wholly outside of our knowledge and yet is of great importance in every way. Why is it that different lakes differ so widely in productivity or in ability to support a population of plankton? The lakes are equally old; they may have the same species of plankton; their temperature may not differ widely; the chemistry of their water is not greatly different; they have had apparently the same chance for development; yet the results are very unlike. This is a problem whose solution will demand the answer of many subsidiary questions. These will concern not only the biology of the several plankton species but the study of the relation of the collective plankton to the lake and of the interrelations of its members. Such matters, for instance, as the food supply of the algae in the lakes as influenced by the inorganic and organic substances dissolved in the water, by the area and depth of the lake, and the form of the lake basin; the effect of the several crops of algae on their successors, by withdrawing certain substances from the zone of photosynthesis and adding others; these are examples of questions whose solution demands not merely a knowledge of the biology of the several species of algae, but also the study of the several lakes as physiological individuals of a higher order. This point of view we have tried to keep in mind in our investigations.

Our knowledge of these matters is still so fragmentary that we cannot believe that we have contributed greatly to their ultimate solution, but they have been very vigorously impressed on our minds by the study of the dissolved gases, and we hope that we have succeeded, at least, in indicating some of the questions which have been raised and some of the lines along which study may be profitably directed.

"So bietet sich also eine Fülle von unerlegten Fragen dar, sobald man daran geht, die Schicksale des im Wasser absorbierten Sauerstoffs näher ins Auge zu fassen; aber wir dürfen die Kenntnis der Verteilung des Sauerstoffdefizits in den verschiedenen Wasserschichten als den ersten Schritt ansehen auf dem Wege, der zur Erkenntnis der Vorgänge führt, welche sich durch das Leben der Organismen im Wasser von Seen und Meeren vollziehen."

Hoppe–Seyler, 1895.

THE INLAND LAKES OF WISCONSIN

CHAPTER I.

SCOPE AND METHODS OF THE INVESTIGATION.

Preliminary work for the purpose of testing methods and perfecting apparatus for these investigations was begun in 1904, but the regular observations on which this report is based did not begin until August 1, 1905. The primary object was to make a general survey of lakes situated in various parts of Wisconsin in order to ascertain the status of the physical, chemical, and biological conditions which exist in them. Climatic and other conditions in the northern part of the state are very different from those in the southern part and it seemed desirable to ascertain the effect of these differences on limnological conditions. It was also the purpose to obtain data for comparisons between lakes belonging to the same group, or between lakes not widely separated, which would thus be subject to the same general climatic conditions. This general survey has now been substantially completed and, as it is the present plan to take up special problems, it is thought best to give the more salient results that have been obtained during the general survey.

During the progress of this work observations have been made on 156 lakes. Of this number, 151 are located in Wisconsin, 1 in Michigan and 4 in Indiana. The lake which is situated in Michigan will be considered along with a Wisconsin group since it in reality forms a part of this group but the Indiana lakes will be discussed as a separate group. Roughly speaking, the Wisconsin lakes that have been visited belong to three groups: (a) 25 are more or less widely scattered in the southeastern quarter of the state; (b) one large group lies in northeastern Wisconsin; and (c) another group is situated in the northwestern part of the state. (See sketch maps, figs. 1 and 2.)

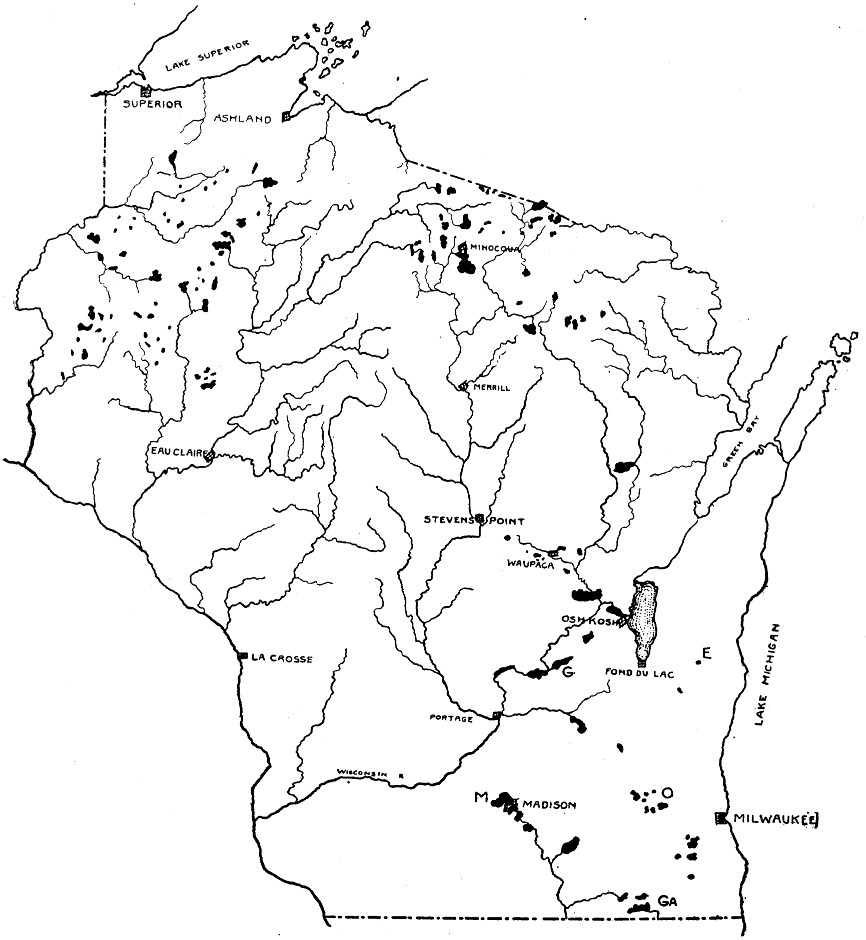

Fig. 1.—Sketch map of Wisconsin showing location of principal lakes and lake districts. Ga = lake Geneva; M = lake Mendota; O = Oconomowoc-Waukesha lakes; G = Green lake; E = Elkhart lake. Approximate scale, 1 inch = 70 miles, or 1 mm. = 4.5 km.

During the first two years the investigations were confined to the lakes in southeastern Wisconsin. Out of the total number of lakes visited, some of the more important ones were selected and studied more fully during the different seasons, especially in spring, summer, and autumn in order to obtain as adequate an idea as possible of the various physical, chemical, and biological changes which take place during these seasons. The results obtained on these lakes also furnished a basis for the interpretation of results obtained on others, which for various reasons it has not been possible to visit more than once or twice. During the month of August in 1907, in 1908, and in 1909, through aid received from the U. S. Bureau of Fisheries, it was possible to make investigations on a number of lakes belonging to the groups in northeastern and northwestern Wisconsin. The lakes in these two districts which have been visited from one to three times each, number 122, only eight of which, however, have been visited more than once.

The lakes vary widely in size, ranging in area from about 0.05 sq. km. in the smallest to 39 sq. km. in the largest. In depth there is also a wide variation, ranging from 3 m. or 4 m. in the shallowest to 72 m. in the deepest; 37 do not exced 7 m. in depth; 30 have a depth of 8 m. to 10 m.; 31 are between 10 m. and 15 m.; 26 between 15 m. and 20 m.; 17 between 20 m. and 25 m.; 10 between 25 m. and 30 m.; and 5 are more than 30 m. deep, of which one is 72 m., one is 43 m. and the other three 31 m. to 33 m.

With one exception all of these occupy basins in glacial drift and their shores, of course, are composed for the most part of the usual drift material. In general the shores of the lakes in southeastern Wisconsin are composed of coarser and more gravelly material, while the shores of the lakes in the northeastern and northwestern parts of the state are composed chiefly of sand.

During the five years in which this work has been carried on, a total of nine hundred series of dissolved gas determinations, more especially of the oxygen and carbon dioxid, have been made on these lakes. All of these observations have been taken into account in the preparation of this report but a very large part of the data is not shown by diagrams, nor in the tables of the appendix, because much would be substantially a repetition of results that are given. In fact, it will be noted that there are marked similarities between many of the sets of results that are shown either in the diagrams or in the tables, but they were selected largely for the purpose of emphasizing this very point. In the selection of the data to be published a two-fold purpose has been kept in mind. In the first place, it has been the aim to choose such material as will give a good notion of the more general changes which the lakes of a certain type pass through in their seasonal and annual cycles and in this way to indicate what may be called the generic changes in the various types of lakes. In the second place, material has been selected for the purpose of showing the individual peculiarities or specific characteristics exhibited in a more or less marked degree by all lakes, but especially marked in some at certain times, such as Beasley and Knights lakes.

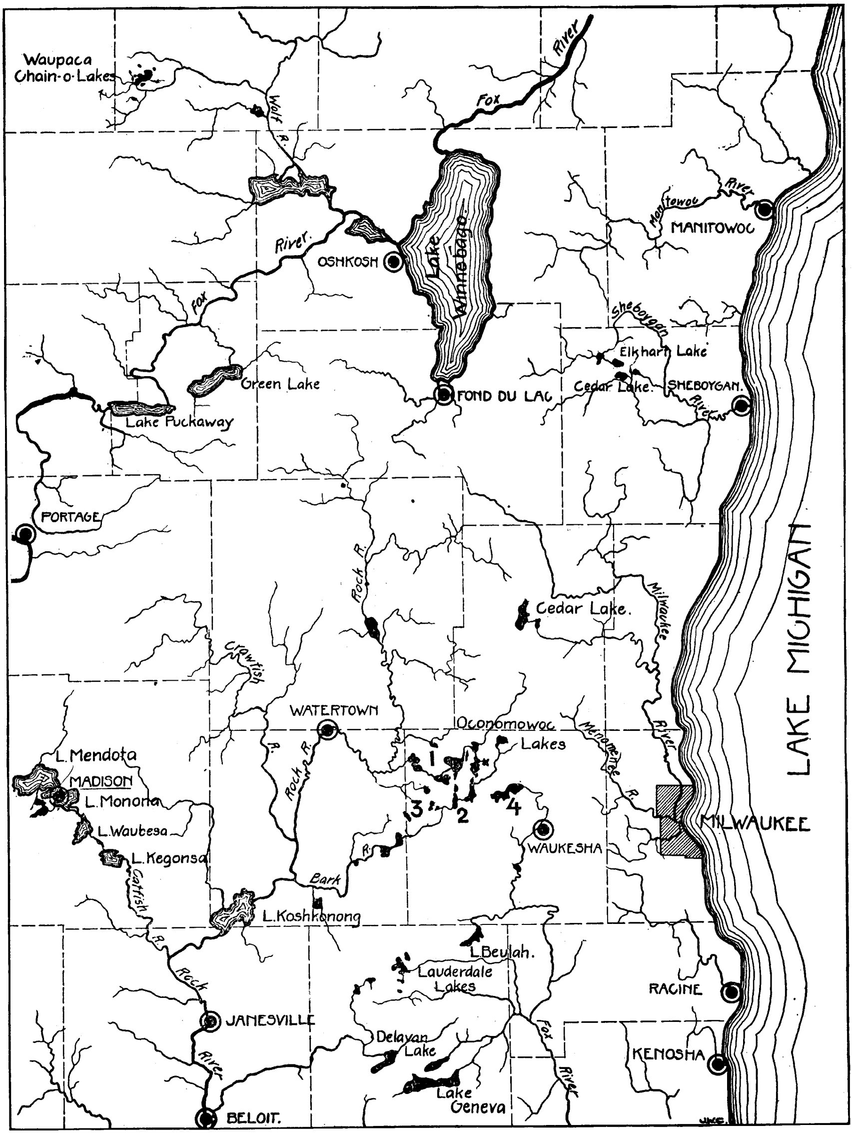

Fig. 2.—Sketch map of southeastern Wisconsin showing location of principal lakes and lake districts in this quarter of the state. In the Oconomowoc group of lakes, Lac la Belle lies west of 1, Okauchee lake east, and Oconomowoc lake almost south of 1. Nagowicka lake is northeast of 2, with Pine and North lakes continuing the chain to the north. Pewaukee lake is marked 4.

METHODS OF DETERMINING THE AMOUNT OF DISSOLVED OXYGEN.

During the first year the oxygen dissolved in the water was determined by the boiling method. In order to meet the demands of a field campaign, a special type of container for the samples of water was designed. It was desirable to have a sample container which could be readily handled in a boat or on shore without danger of being broken, and also one which could readily be packed and shipped from lake to lake. To meet these requirements, copper cans holding about three liters each were used. Some idea of the general shape and structure of these cans may be obtained from fig. 3. The can proper (A) is about 30 cm. high and the stop-cock and tube add about 8 cm., making the total height about 38 cm. The body of the can is 13 cm. in diameter. The two tubes in the cone-shaped top of the cans are fitted with adjustable brass stop-cocks so that they can be kept air tight. In order to determine whether the seams of the cans and the stop-cocks were air tight the cans were tested occasionally by forcing air into them with a large bicycle pump while they were immersed in water. The tube at the apex of the can (C, fig. 3) is attached flush with the top of the can while the side tube (B, fig. 3) extends to the bottom. At the outer ends these tubes bear threads so that pieces of rubber hose can be readily attached to them by means of couplings. In obtaining a sample, the water is taken into the can through the side tube (B) and passes out through the apex tube (C). This insures a complete flushing of the can and consequently the removal of all water that may enter the can from some depth other than that at which the sample is desired.

Two small pieces of copper (H) each perforated by a hole, are attached on opposite sides of the frustum of a cone at the bottom of the can, forming two ears into which a spring bail can be easily fastened. A small calibrated chain is attached to this bail so that the sampling can may be readily lowered to the depth from which a sample is desired. The sample is taken in the following manner. The can is first filled with surface water so that it will sink. One end of a rubber hose having an opening of 1.5 cm. is attached to the apex tube of the can and the other end of the hose is attached to a No. 1 semirotary or clock pump. After attaching the bail, the can is lowered into the water right side up and considerable water is pumped through in order to remove any air that may enter the can or hose while they are being connected. Then the can is turned upside down under water and lowered to the desired depth by means of the calibrated chain. A considerable quantity of water, usually 4 to 5 times as much as the can will hold, is pumped through in order to flush out all of the surface water. After about twice as much water as the can, hose, and pump will hold, has been pumped through, the discharge hose of the pump is placed in a plankton net and from 5 to 15 liters of water are strained for a plankton catch. The can is then raised to the surface and the stop-cocks are closed while it is still under water. It is next lifted into the boat and detached, being now ready for the boiling process.

The sample is taken while the can is upside down and raised to the surface in this position in order to prevent the loss of any gas which may be given off by the sample owing to the decrease of the pressure as the sample is brought to the surface. Should any gas be set free it would collect at the bottom of the can and would thus be saved for analysis. It was soon found, however, that the decrease in pressure did not liberate an appreciable amount of gas except in the lower water of two lakes, so that this precaution was generally unnecessary and was discontinued except in the two instances cited above. The exceptions were lakes in which the lower water contained very considerable amounts of free carbon dioxid and methane. After it was learned that the above precaution was not necessary the method of taking the samples was modified. Instead of lowering the cans, only the intake end of the hose was lowered to the desired depth, and two cans, as samples were generally taken in duplicate, were connected in series and were lowered into the water right side up only far enough to completely immerse them. Enough water was then pumped through to thoroughly flush them, and their further treatment was the same as indicated above.

The arrangement of the apparatus for the process of boiling the water and collecting the gas is shown in fig. 3. The can is placed on a plumber's torch (D) and a block tin condensing tube (E) which possesses a hose coupling at one end, is attached to the apex tube of the can. The other end of this passes under a glass receiver (F) in which the liberated gas is collected. At the upper end of the tube, there is a stop-cock (G) through which this tube and the tube of the can are filled with boiled water so as to remove all traces of air from them. The tin discharge tube is coiled at the lower end and this portion together with most of the receiver is immersed in cold water. This enables one to control the bumping resulting from the vigorous boiling and, in this way, prevents its becoming violent enough to damage the receiver. It also enables one to control the amount of steam entering the receiver. If too much steam is admitted the receiver will be filled to overflowing and some of the dissolved gases will be forced out along with the steam. During the process of boiling, the lower end of the discharge tube and the lower end of the receiver are immersed in a small basin of mercury so as to maintain a mercury seal, but the gas is collected over water in the receiver. The sample of water is boiled vigorously for about five minutes. At the end of this time the boiling is stopped, the receiver is raised out of the cup of mercury and the gas obtained is transferred from the receiver to a water-jacketed burette for analysis.

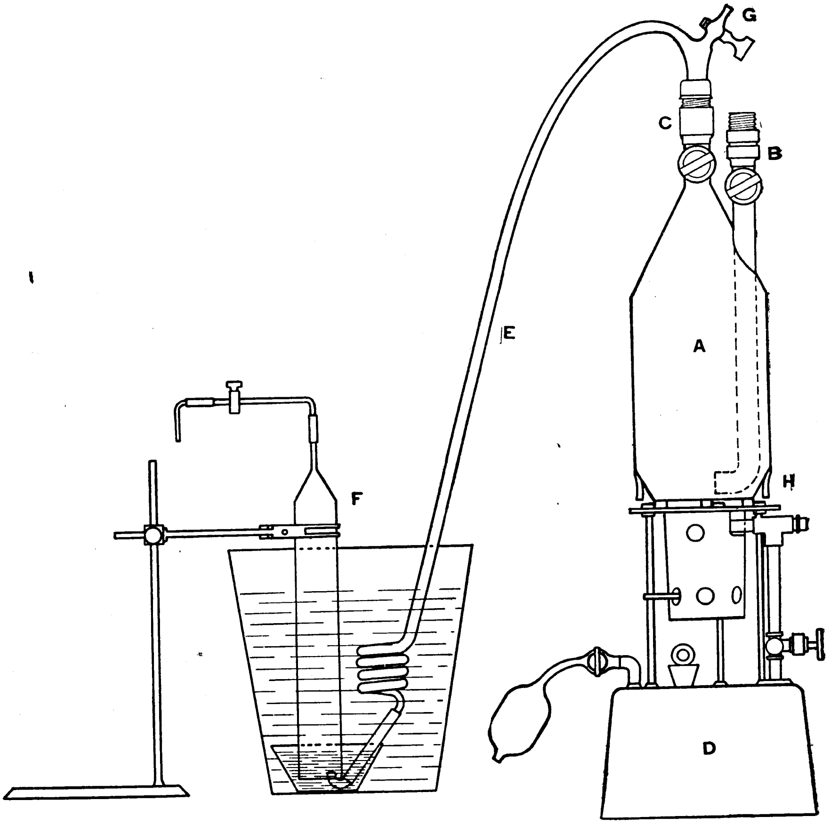

Fig. 3.—Apparatus used for boiling the sample of water and collecting the gas. D = plumber's torch, A = sample can with tubes B and C which are connected with the hose when a sample is obtained and C is connected with the discharge tube E when the sample is boiled. F is the receiver in which the gas is collected.

The quantity of this gas is then noted and it is transferred to a pipette containing a strong solution of KOH which absorbs the carbon dioxid. The residue is then returned to the burette and measured, after which it is transferred to a pipette containing either phosphorus or an alkaline solution of pyrogallic acid for the removal of the oxygen. Phosphorus was used almost entirely for this purpose as it was more convenient, requiring no attention after the gas was transferred to the pipette until the oxygen was all absorbed. The gas remained in contact with the moist sticks of phosphorus for 5 or 10 minutes. For purposes of comparison the pyrogallic acid pipette was occasionally used for the duplicate samples in order to check the phosphorus method. Occasionally also samples were obtained from which the phosphorus would not absorb the oxygen in spite of the fact that 25 to 35 per cent. of the gas was oxygen, and in such instances pyrogallic acid was used. In general the gas which remained after the removal of the carbon dioxid and oxygen was regarded as nitrogen. In some lakes, however, this residual gas from samples of the lower water contained more or less methane as will be noted later.

A small thermometer was fastened between the burette tube and the water-jacket tube and the temperature of the water surrounding the burette was noted at the time of reading the gas volumes and in the calculations this has been regarded as the temperature of the gas. The barometer readings at the Madison Station of the U. S. Weather Bureau, with corrections for the differences in elevation between the weather station and the various lakes, have been used in making the computations.

In this method of boiling the gas was driven from the sample can over into the receiver against a pressure a little greater than that of the atmosphere. This raised the question whether the gas was all driven over into the receiver during the usual period of boiling and about a dozen tests were made in order to answer this query. Two small stop-cocks were soldered into the tin condensing tube near its lower end. One of these was arranged so that the tube leading to the regular receiver could be closed at will, and opening the other connected the discharge tube with a series of three bottles as shown in fig. 4. The first bottle (C) was used as a receiver for the gas and was completely filled with boiled water still hot. The second (B) was only partially filled with water and the air space in it was connected with an exhaust pump by one tube and with the third bottle (D) by another. The third bottle contained some mercury and a barometer tube (G) which served to indicate the amount of decrease in the atmospheric pressure during the boiling process. The first and second bottles were kept under water during the experiment. A sample was boiled 5 or 6 minutes in the

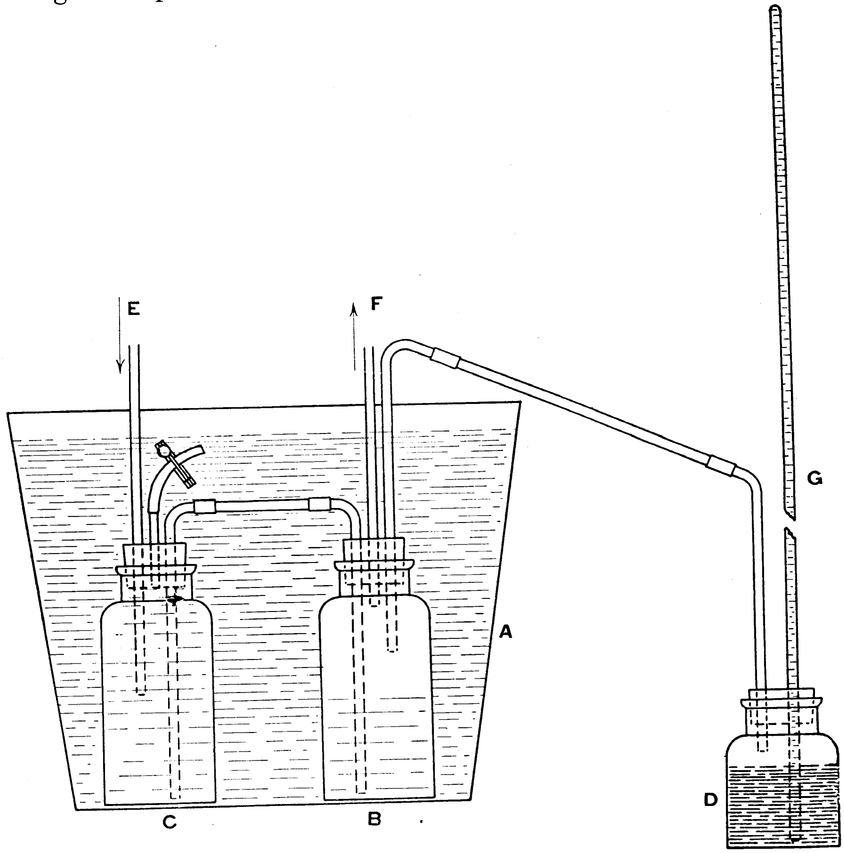

Fig. 4.—Additional apparatus used for boiling the sample of water under diminished pressure. C is bottle in which the gas is collected, bottle B is connected with an exhaust pump through tube F, and bottle D contains a barometer tube G.

usual way, that is, the gas was forced over into the receiver against a pressure slightly greater than one atmosphere. Then the stop-cock leading to the regular receiver was closed and that leading to the series of bottles was opened and the boiling was continued for 5 to 20 minutes under a pressure considerably less than one atmosphere. In one experiment the height of the mercury column in the barometer tube was only 150 mm. but in most cases it was about 230 mm. The sample container itself was so arranged that the stop-cocks could be covered with water and as many of the connections as possible were kept under water in order to prevent leakage of air during the boiling under diminished pressure. Carbon dioxid came off in considerable quantities and doubtless would have continued to do so until the water was boiled to dryness, as other observers have found. Only a very small quantity of gas was left in each experiment, however, after the carbon dioxid was absorbed. The average of several trials amounted to 0.2 cc. of gas per liter of water, the minimum being 0.06 cc. and the maximum 0.6 cc. The quantity of the residual gas was so small that it was difficult to determine whether part of it was oxygen or not but the residual gases from two experiments contained no oxygen whatever, while six other tests showed from 0.02 to 0.06 of a cubic centimeter of oxygen per liter of water. These experiments show then, that not enough gas, especially oxygen, was Two trials showed, also, that in the regular method practically all lost by the regular method of boiling to affect the results appreciably. of the gas was driven over into the receiver by a vigorous boiling lasting only 3 minutes and in another test the same amount of oxygen and nitrogen was obtained from duplicate samples, one of which was boiled 3 minutes and the other 10 minutes.

Some determinations were also made with a Tenax apparatus but the results obtained were so unreliable that the apparatus was discarded. Müller,[1] Cronheim,[2] Knauthe[3] and others, also, have found that the Tenax apparatus does not give reliable results, the oxygen generally being too low and the nitrogen too high.

The results of the first season's campaign showed that a more thorough study of the dissolved oxygen was very desirable and, as the boiling method required so much time for each sample that it did not permit the handling of a large number daily, it was abandoned and a titration method was adopted for the determination of the oxygen. This resulted, of course, in the discontinuance of regular determinations of the dissolved nitrogen, but it was felt that a more extended knowledge of its quantity and distribution was not so important as a more detailed study of the oxygen, because the former gas seems to play no appreciable rôle either chemically or biologically in the lake waters and its distribution is very similar in the differ-

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[1] Plöner Forschungsberichte, X, p. 183, 1903.

[2] Plöner Forschungsberichte, XI, p. 282, 1904. Zeitschr. Angew. Chem. XX, p. 1939, 1907.

[3] Das Süsswasser, p. 128 and 143, 1907.

ent lakes, depending apparently on purely physical factors. Some preliminary tests with both the Winkler[1] and Mohr[2] methods of determining dissolved oxygen showed that the former was more convenient for field work and gave results equally reliable, so it was adopted and has been used regularly since the first season (1905). During the summer of 1906, 69 determinations of oxygen were made in duplicate using both the boiling and the Winkler methods on samples taken at the same time and at the same depths. This was done for the purpose of determining how closely the two methods would check when subjected to field conditions. These tests were made on water which did not contain less than 0.8 cc. of dissolved oxygen per liter, nor more than 14 cc. In 15 cases out of the 69 the results were exactly the same by both methods. The following tables show the results of the other determinations.

TABLE I.—*Amount of oxygen greater by boiling method.*

Cc. per liter.	No. of determinations.
0.1	14
0.2	12
0.3	4
0.4	2
0.5	2
0.6	....
0.7	....
0.8	1
0.9	1

It will be noted that the average difference for 30 of these 36 observations in table I is only 0.16 cc.

TABLE II.—*Amount of oxygen smaller by boiling method.*

Cc. per liter.	No. of determinations.
0.1	11
0.2	6
0.3	....
0.4	1

In table II the average difference is only 0.15 cc.

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[1] Berichte der deutsch. chem. Gesellsch., XXI, p. 2843 (1888), and XXII, p. 1864. (1889).

[2] König und Krauch, Zeit. Anal. Chemie., XIX, p. 268, 1880.

Out of the 54 results shown in these tables, 43 have differences not exceeding 0.2 cc. per liter of water. Duplicate samples treated by the same method not unfrequently show greater differences than this. These 43 results together with the 15 in which the results were exactly the same constitute 84 per cent. of the total number of comparisons made (69). Only 4 determinations gave results differing by more than 0.4 cc. per liter and these larger differences were found in samples which contained not less than 6.5 cc. of oxygen per liter of water. Considering the unfavorable conditions to which the two methods were subjected in the field, the results are as concordant as could be expected, and they also show that no break in the series of observations was caused by the change in methods. The results for 5 sets of observations are given in the following table, the dissolved oxygen being stated in cubic centimeters per liter of water:

TABLE III.

Lake.	Date, 1906.	Depth.	Winkler.	Boiling.
Mendota	May 25	0 m,	7.25	7.20
		12.5	5.88	6.25
		17.5	5.88	5.90
		20	5.16	5.10
		22	4.17	4.10
	July 17	0 m.	6.30	6.40
		8	5.03	5.20
		10	2.44	2.35
		12	0.95	0.78
Green	August 14	0 m.	6.01	6.00
		10	5.20	5.21
		12	4.98	4.96
		15	4.90	4.96
		45	5.31	5.64
		66.5	0.91	1.02
Otter	August 20	0 m.	6.04	6.10
		3.5	14.73	15.12
		4.0	13.62	13.68
		5	7.23	7 47
		10.5	3.09	2.96
Garvin	June 27	0 m.	6.46	6.65
		4	6.76	7.09
		4.5	9.34	9.46
		5	6.40	6.35

Chlopin[1] concluded from his experiments in comparing the gasometric and Winkler methods that the latter gave very good results, a dozen tests on waters from various sources averaged 4.723 cc. of oxygen per liter by the former method and 4.751 cc. by the latter.

SOLUTIONS REQUIRED FOR WINKLER'S METHOD.

1. *Manganous chlorid solution.* Dissolve 200 grams of $MnCl_2$, *free from iron,* in distilled water and dilute to 500 cc.

2. *Solution of sodium or potassium hydroxid and potassium iodid.* Dissolve 180 grams of either NaOH or KOH and 75 grams of KI in distilled water and dilute to 500 cc. This solution contains more KI than the amount usually recommended which is 10 grams per 100 cc. of solution. It was found that for waters containing a large excess of oxygen, 1 cc. of the weaker solution did not contain enough iodin for 250 cc. of water. The NaOH and KOH must be free from nitrites.

3. *Hydrochloric acid,* concentrated, chemically pure.

4. *Sodium thiosulphate solution.* Dissolve 2.48 grams of chemically pure, recrystallized $Na_2S_2O_3 \cdot 5\ H_2O$ in 1000 cc. of distilled water. This gives approximately a N/100 solution. The solution gradually loses strength but the addition of 4 cc. of normal NaOH per liter will make it much more stable. If kept in a well stoppered jug, it will hold its strength for several weeks, but one should take the precaution to standardize it once or twice a week at least against a N/100 solution of $K_2Cr_2O_7$. In actual field work when considerable thiosulphate solution is being used daily, it has been found more convenient to use a solution somewhat stronger, $\frac{N}{70}$ to $\frac{N}{80}$ or even stronger.

5. *Standard bichromate solution.* Dry some chemically pure $K_2Cr_2O_7$ at a temperature of 130° for half an hour and let it cool in a desiccator. Dissolve 0.4908 g. of the dried $K_2Cr_2O_7$ in 1000 cc. of distilled water. This gives a N/100 solution and 1 cc.=0.00008 g. or 0.055825 cc. of oxygen at 0° and 760 mm. This solution is very stable and a quantity of it may be made up and kept in stock in a well stoppered bottle. The thiosulphate solution is standardized as follows:—25 cc. N/100 $K_2Cr_2O_7$ are measured into a casserole, 1 cc. of the NaOH-KI solution is added and then 2 cc. of concentrated HCl. This is now titrated with thiosulphate and from the result ob-

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[1] Arch. Hyg., XXVII, p. 18-23, 1896.

tained, the oxygen equivalent of 1 cc. of the thiosulphate solution may be determined, or the amount of thiosulphate required in the titration is substituted directly into a formula which appears on a subsequent page.

6. *Starch solution.* Mix 1 gram of good potato starch with 25 cc. of cold water and stir until the starch is all emulsified; pour slowly into about 200 cc. of boiling water, and continue the boiling for a few minutes. Allow this to stand long enough to settle thoroughly and use only the clear supernatant solution as the indicator. The solution may be preserved by adding a few drops of chloroform and shaking well.

PROCURING SAMPLES FOR THE WINKLER METHOD.

Great care must be exercised in taking samples of water in order to avoid undue exposure to the air. If the water is not saturated with oxygen, it will absorb some upon exposure to the air, or if it contains an excess, it will give up some of its oxygen upon exposure. Even for surface samples, the water should not be poured into the bottle, nor the bottle simply immersed and the air allowed to bubble out because air may be mechanically entrained in the water by such manipulations.

As already stated, the samples of water in these investigations have been obtained by means of a pump and hose. The intake end of the hose is lowered to the desired depth, enough water is pumped up to flush the hose and pump thoroughly, and then 5 to 10 liters of water are strained for a plankton catch. A short piece of gas pipe to which a small rubber tube is attached, is thrust into the outer end of the discharge hose. The outer end of the small rubber tube is placed in the bottle, extending to the bottom, and the bottle is filled by a gentle current of water. About 3 or 4 times as much water as the bottle will hold is pumped through in order to flush the bottle thoroughly and thus insure the removal of all water that has been exposed to the air. The small tube is removed from the bottle while a current of water is still passing into it and the stopper is then inserted in the bottle carefully so that no air bubbles are enclosed. Care must be exercised also to see that all connections and the pump are kept air tight. Three samples are taken from each depth, two in duplicate for the determination of the oxygen and the other for the determination of the carbon dioxid.

Heavy walled magnesium citrate bottles have been found most convenient for the collection and subsequent manipulation of samples. The stoppers of these bottles consist of porcelain or metal tops which bear rubber caps. In bottles having metal tops, the rubber caps protect the metal and prevent its coming in contact with the water and chemicals. These stoppers are wired on the bottles in such a way that an extra pressure is put upon the water when the bottles are closed. This extra pressure tends to prevent the escape of excess oxygen when the water is supersaturated, and it also keeps the water from giving up any of its dissolved oxygen when there is an increase in the temperature of the water after the sample is taken. The bottles first used had a capacity of 350 to 400 cc. but those now in use have a capacity of about 250 cc. For convenience in handling, they are kept in small wooden boxes which have compartments for 16 bottles. Each bottle bears a number so that a record of the samples can be made readily.

The exact thickness of the stratum of water from which a sample is obtained is unknown, of course. Pumping up 10 to 15 liters of water from any depth does undoubtedly cause some disturbance of the water at that depth which results in more or less of a mixture. In addition, also, the samples taken in windy weather, when the boat is being tossed by waves, would represent a mixture of a still thicker stratum of water. Generally, the change in the gas content in the water both above and below the thermocline is so gradual that this mixture makes very little if any difference whatever. In the region of the thermocline, however, there is frequently a very sudden change in the quantity of dissolved oxygen and it is very desirable to have as little mixture of the sample water here as possible and every precaution should be taken to avoid it. That the mixture is confined within narrow limits even here, is shown by the fact that very decided differences in the quantity of dissolved oxygen may be found at half meter intervals. For example, one observation shows a rise from 6.0 cc. of oxygen per liter of water to 16 cc. in half a meter; another, a drop from 16.1 cc. to 5.2 cc. in half a meter and this decreases to 0.1 cc. in the next half meter; still another shows a drop from 14 cc. to 1.9 cc. in half a meter, and several others show increases or decreases nearly as large in proportion. These results seem to show then that samples taken in this manner do not represent any greater mixture of the water than would be obtained by the other methods usually employed, such, for instance, as the water-bottle method, in which the sample represents a mixture of a stratum of water a quarter of a meter or more in thickness.

ADDING THE CHEMICALS.

The sample bottle containing about 250 cc. of water is carefully opened and 1 cc. of the $MnCl_2$ solution is added with a pipette long enough to reach the bottom. Then 1 cc. of the NaOH-KI solution is added in a similar way; the bottle is closed so as to exclude air bubbles, and shaken vigorously. The manganous chlorid reacts with the sodium hydroxid forming a precipitate which is manganous hydroxid. Some of the manganous hydroxid unites with the oxygen that is dissolved in the water to form manganic hydroxid. The manganous hydroxid precipitate is white but the color changes to brown when it is oxidized to manganic hydroxid. The bottle should be *thoroughly* shaken so that all of the water comes into contact with the manganous hydroxid precipitate. Allow the precipitate to settle for a few minutes, then open the bottle and introduce 2 cc. of concentrated hydrochloric acid just above the precipitate. Close the bottle and shake thoroughly. In the chemical reaction which takes place between the hydrochloric acid and the manganic hydroxid, chlorin is liberated and this reacts with the potassium iodid liberating iodin. The amount of iodin set free is proportional to the amount of oxygen dissolved in the water.

The sample of water should be carried thus far as soon as possible after it is collected. Usually a series of samples consisted of a considerable number and it was found rather inconvenient to add the chemicals at the time they were taken. So the whole series was obtained and taken ashore before the chemicals were added to any of the samples. This usually meant that from half an hour to two or occasionally very nearly three hours elapsed between the taking of some samples and their treatment with chemicals. The samples were not exposed to direct sunlight during this time. Some tests were made both in the laboratory and in the field to determine whether any marked changes take place in the quantity of oxygen during the time elapsing between the taking of a sample and the addition of the chemicals. Several samples were taken at the same time and from the same depth. Chemicals were added to two of them immediately after taking and the others, in sets of two, were kept for various periods of time, up to 8 hours, before they were treated with chemicals.

The results show that for a period of 5 to 6 hours after being taken, the differences between successive sets of samples are no greater than between duplicate samples which have been treated exactly alike. At the end of 8 hours, however, a distinct decrease in the quantity of oxygen was noted. This would indicate then that samples may be kept for three hours or more without any marked change in the quantity of oxygen if they are properly cared for. The following results were obtained in two tests made on surface water. Duplicates were used in each case and the results given are the average of the two samples. The time column indicates the length of time that elapsed between the taking of the sample and the adding of the chemicals, those marked zero being dosed with chemicals immediately after taking.

Experiment I.		*Experiment II.*	
September 10, 1908.		September 12, 1908.	
Time.	Cc. of O_2 per l.	Time.	Cc. of O_2 per l.
0 hrs	6.43	0 hrs	6.81
2 hrs	6.57	1 hrs	6.8
3 hrs	6.57	8.5 hrs	6.77
6 hrs	6.45		

The samples used in these experiments were allowed to stand on a table in the laboratory at some distance from a window. The temperature of the room was 25° to 26° and the temperature of the water at the time the samples were taken was 22.5°. Spitta[1] states that he did not find a very large decrease in the dissolved oxygen in most cases by letting the sample stand 24 hours.

Experiments by Gill[2], Seyler[3], and Dost[4] show that water loses its dissolved oxygen very slowly through a rise in temperature, even when more or less freely exposed to air. Seyler states that a rise of 10° is without noticeable effect on the dissolved oxygen and that the gaseous solution remains supersaturated and only parts with the extra oxygen upon vigorous shaking.

The samples may be titrated with thiosulphate in a few minutes after the addition of the hydrochloric acid, *i. e.*, as soon as all or

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[1] Archiv f. Hygiene, XXXVIII, p. 215. 1900.
[2] Tech. Quart., V. p. 250. 1892.
[3] Chem. News, LXVII, p. 87. 1893.
[4] Review in Chem. Centralbl., LXXVII, p. 1457.

nearly all of the precipitate is dissolved, or they may be kept for 24 to 48 hours without any appreciable change. But experiments have shown that the results are not very reliable if the titration is delayed much longer than 48 hours. Samples should not be exposed to direct sunlight after the addition of the hydrocholoric acid. In titrating, the sample is rinsed into a white dish, a clear white casserole serving the purpose admirably, and thiosulphate is added until the color is reduced to a faint yellow; a small quantity of the starch solution is now added; then enough thiosulphate is added drop by drop to discharge the blue color and the quantity of thiosulphate solution required is recorded.

CALCULATION OF RESULTS.

The amount of oxygen dissolved in water may be expressed in three ways: In parts per million, in cubic centimeters of gas per liter of water at 0° and 760 mm. pressure, and in per cent. of saturation.

Formulae for calculating results:

1. Oxygen in parts per million $= \frac{0.00008n \times 1,000,000}{v} = \frac{80n}{v}$

2. Oxygen in cc. per liter $= \frac{0.055825n \times 1,000}{v} = \frac{55.825n}{v}$

3. Oxygen in per cent. of saturation $= \frac{0.055825n \times 1,000 \times 100}{v \times o} = \frac{5582.5n}{vo}$

In these formulae, n = the number of cc. of $\frac{N}{100}$ thiosulphate solution; v = capacity of the bottle less 2 cc., the volume of water displaced by adding the $MnCl_2$ and NaOH-KI solutions; and O = the amount of oxygen in cc. per liter in water saturated at the same temperature and pressure.

Different strengths of thiosulphate solution have been used in these investigations and the following formula has been found more convenient for the calculations:

Oxygen in cc. per liter $= \frac{0.055825 \times 1,000 \times b \times n}{n^1 v} = \frac{55.825\,bn}{n^1 v}$

In this formula b = the number of cc. of potassium bichromate solution used in standardizing the thiosulphate, *i. e.*, 25 cc.; n^1 = the number of cc. of thiosulphate required in the standardization against 25 cc. of N/100 potassium bichromate; and n = the number of cc. of thiosulphate required for the sample of water. For example, taking an actual observation, we have, capacity of bottle = 247 cc. and this less 2 cc., the amount of water displaced by chemicals, gives 245 cc.; thiosulphate solution required for sample = 23.7 cc.; thiosulphate required for 25 cc. of N/100 $K_2Cr_2O_7$=21.65 cc. Substituting these values in the formula we have $\frac{55.825 \times 25 \times 23.7}{21.65 \times 245} = 6.23$ cc. of oxygen per liter of water. The temperature of the water at the time of taking the above sample was 21.3° and at this temperature it requires 6.13 cc. for saturation. The percentage of saturation is, therefore, 101.6.

Frequently it is desirable to calculate the percentage of saturation and the table which has been used for these calculations is given below. It is based on the one given by Roscoe and Lunt[1] for fully aerated distilled water for each half degree between 5° and 30° and for an observed pressure of 760 mm. The other fractions of degrees have been interpolated. The values below 5° are based on Whipple and Parker's[2] extrapolated results which are not strictly accurate. For water having a temperature of 0.1° Winkler[3] gives 10.14 cc. of oxygen per liter as the amount required for saturation and Pettersson and Sonden[4] give 10.1 cc. for water at 0°.

With respect to the accuracy of the results for dissolved gases, it is scarcely necessary to remark that, where the temporary field laboratory is set up in a few minutes in the shade of some tree or building, and is equipped with burettes, pipettes, boiling apparatus, and the accessories necessary for operating them, together with a few boxes for work tables, it is impossible to obtain results that are as refined and accurate as could be obtained in a well equipped, permanent chemical laboratory and no such claim is made for these results. On the other hand, however, every precaution has been taken to reduce the possibilities of errors and inaccuracies to as low a term as possible. It has been the aim to use apparatus and methods which are best adapted to meet the field conditions and which at the same time will give the most accurate results obtainable under the circumstances. Both apparatus and methods have been thoroughly tested under laboratory as well as field conditions before being finally adopted for general use and the differences in results under the two kinds of conditions were generally found to be within the limits of error of laboratory conditions.

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[1] Chem. Soc. Jour., LX, p. 569.

[2] Trans. Amer. Microscop. Soc., XXIII, p. 110. 1902.

[3] Berichte der deutsch. chem. Gesellsch., XXII, p. 1764. 1889.

[4] Berichte der deutsch. chem. Gesellsch., XXII, p. 1439. 1889.

Table IV.—*Showing the number of cc. of oxygen at 0° and 760 mm., required to saturate a liter of distilled water at temperatures between 0° and 29.90°.*

	0	1	2	3	4	5	6	7	8	9
0°	9.700	9.680	9.660	9.640	9.620	9.600	9.578	9.556	9.534	9.512
1°	9.490	9.468	9.446	9.424	9.402	9.380	9.360	9.340	9.320	9.300
2°	9.280	9.260	9.240	9.220	9.200	9.180	9.160	9.140	9.120	9.100
3°	9.080	9.060	9.040	9.020	9.000	8.980	8.958	8.936	8.914	8.892
4°	8.870	8.852	8.824	8.816	8.796	8.780	8.760	8.740	8.720	8.700
5°	8.680	8.660	8.640	8.620	8.600	8.580	8.562	8.544	8.526	8.508
6°	8.490	8.472	8.454	8.436	8.418	8.400	8.382	8.364	8.346	8.328
7°	8.310	8.292	8.274	8.256	8.238	8.220	8.202	8.184	8.166	8.148
8°	8.130	8.112	8.094	8.076	8.058	8.040	8.022	8.004	7.986	7.968
9°	7.950	7.932	7.914	7.896	7.878	7.860	7.842	7.824	7.806	7.788
10°	7.770	7.752	7.734	7.716	7.698	7.680	7.664	7.648	7.632	7.616
11°	7.600	7.584	7.568	7.552	7.536	7.520	7.504	7.488	7.472	7.456
12°	7.440	7.424	7.408	7.392	7.376	7.360	7.344	7.328	7.312	7.296
13°	7.280	7.264	7.248	7.232	7.216	7.200	7.184	7.168	7.152	7.136
14°	7.120	7.104	7.088	7.072	7.056	7.040	7.024	7.008	6.992	6.976
15°	6.960	6.946	6.932	6.918	6.904	6.890	6.876	6.862	6.848	6.834
16°	6.820	6.806	6.792	6.778	6.764	6.750	6.736	6.722	6.708	6.694
17°	6.680	6.666	6.652	6 638	6.624	6.610	6.596	6.582	6.568	6.554
18°	6.540	6.526	6.512	6.498	6.484	6.470	6.456	6.442	6.428	6.414
19°	6.400	6.388	6.376	6.364	6.352	6.340	6.328	6.316	6.304	6.292
20°	6.280	6.268	6.256	6.244	6.232	6.220	6.208	6.196	6.184	6.172
21°	6.160	6.148	6.136	6.124	6.112	6.100	6.088	6.076	6.064	6.052
22°	6.040	6.030	6.020	6.010	6.000	5.990	5.980	5.970	5.960	5.950
23°	5.940	5.930	5.920	5.910	5.900	5.890	5.880	5.870	5.860	5.850
24°	5.840	5.832	5.824	5.816	5.808	5.800	5.792	5.784	5.776	5.768
25°	5.760	5.752	5.744	5.736	5.728	5.720	5.712	5.704	5.696	5.688
26°	5.680	5.672	5.664	5.656	5.648	5.640	5.632	5.624	5.616	5.608
27°	5.600	5.594	5.588	5.582	5.576	5.570	5.564	5.558	5.552	5.546
28°	5.540	5.534	5.528	5.522	5.516	5.510	5.064	5.498	5.492	5.486
29°	5.480	5.474	5.468	5.462	5.456	5.450	5.446	5.442	5.438	5.434

Oxygen determinations have been regularly made in duplicate by the Winkler method and generally also by the boiling method, in order to check the results and the average of these two determinations has usually been regarded as the result. In making determinations by the boiling method nearly 3 liters of water were used instead of the smaller quantity usually employed, that is from 100 cc. to 1000 cc. This larger sample of water yielded a larger quantity of gas whose volume could be more accurately read in the burette and also, the errors were thus distributed over a larger volume of water, and, consequently were proportionately reduced in the subsequent calculations rather than multiplied. The gas was collected over water and water was also used in the burettes as it was found impracticable to use mercury for these purposes. Some experiments showed, however, that no appreciable amount of gas was absorbed by the water in the receiver and burettes, the water in the former very generally being kept at a high temperature so that its absorption coefficient would be low; and many determinations were made which showed no trace of oxygen, thus indicating that no oxygen was given up by the water of the receiver and burettes during the determinations. In general it may be said also that each set of observations forms such a consistent series that any serious error or inaccuracy could be readily detected when the results were platted, but only a few observations out of the hundreds that have been made, have had to be rejected on account of irregularities.

DETERMINATION OF CARBON DIOXID.

Several methods have been suggested for the determination of carbon dioxid in water. After a series of experiments in which three of the modifications of the Pettenkofer method were tested, Ellms and Beneker[1] reached the conclusion that Seyler's modification, frequently called the Seyler method, gives the most accurate results. This method has been used in these investigations. It is fully described by Seyler[2] in the Chemical News, and to this the reader is referred for more complete information.

Solutions required. For the determinations by this method four solutions are required, a standard alkali solution, a standard acid solution, and two indicators, phenolphthalein and methyl orange.

1. *Solution of sodium carbonate.* Dissolve 53.05 grams of freshly fused, chemically pure Na_2CO_3 in 1000 cc. of freshly boiled distilled water. This gives a normal solution and a weaker solution of any desired strength may be made from this by diluting with freshly boiled distilled water. The solution should be kept in a well stoppered, hard glass bottle and should be exposed to the air as little as possible as it will absorb carbon dioxid and change to bicarbonate and thus become useless for the titrations. At the time of making the solution and also occasionally afterwards, it should be standardized against an acid of known strength, $N/10$ H_2SO_4 is probably most satisfactory for this purpose.

2. *Hydrochloric acid.* A normal solution of this acid requires approximately 77.5 cc. of concentrated HCl (specific gravity 1.2) to 1000 cc. of distilled water. This solution may then be easily diluted to any desired strength. It should be standardized after dilution,

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[1] Jour. Amer. Chem. Soc. Vol. 23, p. 405. 1901.

[2] Chem. News, Vol. 70, pp. 82, 104, 112, 140 and 151. 1894.

against the standard Na_2CO_3 solution. The standard alkali and acid used for most of these investigations have been N/44.

3. *Phenolphthalein.* Dissolve 5 grams in 1000 cc. of 50 per cent. alcohol.

4. *Methyl orange.* Dissolve 1 gram of the powder in 1000 cc. of distilled water.

Method of procedure. In making a determination, 100 cc. of water are put into a 100 cc. Nessler tube or a tall beaker having a small diameter, and about 2 or 3 drops of the phenolphthalein solution are added. If the water is acid, that is contains free carbon dioxid, no pink color will appear upon the addition of the indicator. Sodium carbonate solution should then be added from a burette, care being taken to stir the sample thoroughly after each addition of sodium carbonate, until a faint pink color remains permanent for three or four minutes. If the water contains much free carbon dioxid great care is necessary to prevent its loss as the water will give it up readily upon exposure to the air. For such a water it is best to make a second titration in which nearly as much sodium carbonate as was used in the first, should be added at once after the second sample is measured out and, when the pink color has nearly disappeared, sodium carbonate should be added drop by drop until the end point is reached.

If only a very faint pink color appears when the phenolphthalein is added to a sample of water, it may be regarded as neutral. Some waters, however, will show a decided pink color which indicates that they are alkaline. In such a case enough standard acid should be added to reduce the color to a very faint pink, the sample being stirred thoroughly after each addition of acid.

For the determination of the fixed carbon dioxid, measure out 100 cc. of water, add about 3 drops of the methyl orange solution, and then enough of the standard hydrochloric acid to change the color from yellow to pink. When the water is neutral or alkaline this titration may also be made on the sample used for the phenolphthalein titration. When the end point is reached with phenolphthalein, add methyl orange and continue the titration. This may also be done with a sample which has been used for the determination of the free carbon dioxid but it is necessary to deduct the amount of sodium carbonate solution added to the water from the quantity of acid used in the titration. Generally, however, it is an economy of time to measure out a new sample of acid water for the determination of the fixed carbon dioxid, as the titration can easily be made while waiting for the end point in the titration with phenolphthalein.

Seyler (loc. cit. p. 104) states that these volumetric methods are based on the following facts:

1. Carbonates are alkaline to phenolphthalein, bicarbonates are neutral, and free carbon dioxid is acid.

2. Methyl orange is unaffected by carbon dioxid, hence the bases present as carbonates and bicarbonates can be titrated at once with standard acid ($Na_2CO_3+2HCl=2NaCl+H_2O+CO_2$). The bicarbonates of calcium and magnesium are neutral to phenolphthalein. From this fact the following conclusions are drawn:—

1. If a water is neutral or acid to phenolphthalein, the "half-bound" carbon dioxid is equal to the "fixed."

2. If a water is alkaline to phenolphthalein, it can contain no free carbon dioxid and the "half-bound" will be less than the "fixed" by an amount determined by titration with acid until it is neutral to phenolphthalein.

Calculation of results. The following formulae are based on N/44 solutions and 100 cc. of water:

For acid water:—
Free $CO_2 = 5$ p parts per million = 2.528 p cc. per liter of water.
Fixed $CO_2 = 5$ m parts per million = 2.528 m cc. per liter of water.
Half bound $CO_2 = 5$ m parts per million = 2.528 m cc. per liter of water.

For alkaline water:—
Fixed $CO_2 = 5$ m parts per million = 2.528 m cc. per liter of water.
Half bound $CO_2 = 5\ (m - 2p')$ parts per million = $2.528\ (m - 2p')$ cc. per liter of water.

In these formulae, p = number of cubic centimeters of N/44 Na_2CO_3; m = cc. of N/44 HCl; and p′ = cc. of N/44 HCl required to discharge the pink color from alkaline water, and the amount is doubled (2p′) because the same amount of acid corresponds to twice as much carbon dioxid with phenolphthalein as an indicator as with methyl orange.

Kaiser and Leavitt[1] and Kaiser and McMaster[2] state that the acid carbonate of calcium seems to contain more "half-bound" than "fixed" carbon dioxid. Their results agree more closely with the formulas $CaCO_3 . 1.75\ (H_2CO_3)$ and $CaCO_3 . 1.8\ (H_2CO_3)$. This means of course, about 1.8 times as much half-bound as fixed carbon dioxid. Should this prove to be the ratio, it would alter the above formulae for the calculation of the half bound carbon dioxid so far as calcium is concerned. It would mean a much higher half bound carbon dioxid

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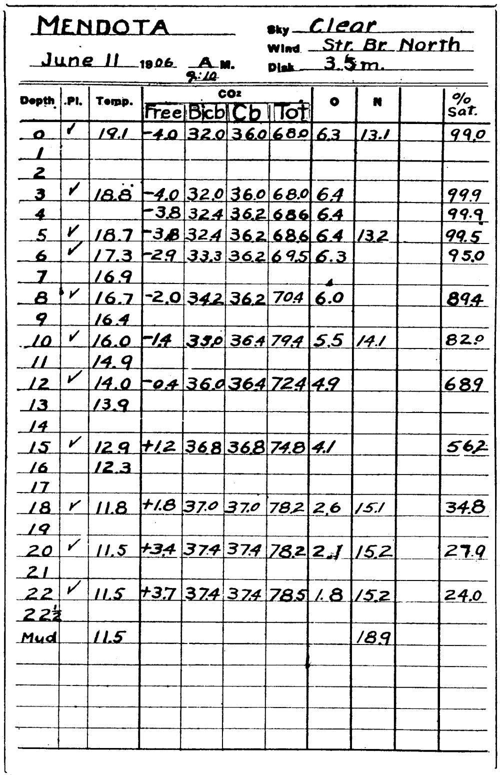
[1] Jour. Amer. Chem. Soc., XXX, p. 1713. 1908.
[2] Jour. Amer. Chem. Soc., XXX, p. 1717. 1908.

content for those lakes whose waters hold a considerable amount of calcium bicarbonate in solution. It has seemed best, however, to retain the old formula for acid calcium carbonate and the results have been computed on that basis.

The results as calculated from the field notes are recorded on cards 5x8 in. in size which can be placed in filing cases and readily referred to when occasion demands. A complete set of observations is recorded on each card and the accompanying illustration (fig. 5) shows the items indicated thereon; lake, date, weather conditions, transparency of water, depths from which samples were obtained, temperature of the water, free, half-bound, and combined carbon dioxid, oxygen, nitrogen and the per cent. of saturation of oxygen.



MENDOTA Sky Clear

Wind Str. Br. North

June 11 1906 A. M. 9:10 Disk 3.5 m.

Depth.	.Pl.	Temp.	CO_2				O	N		% Sat.
			Free	Bicb	Cb	Tot				
0	✓	19.1	-4.0	32.0	36.0	68.0	6.3	13.1		99.0
1										
2										
3	✓	18.8	-4.0	32.0	36.0	68.0	6.4			99.9
4			-3.8	32.4	36.2	68.6	6.4			99.9
5	✓	18.7	-3.8	32.4	36.2	68.6	6.4	13.2		99.5
6	✓	17.3	-2.9	33.3	36.2	69.5	6.3			95.0
7		16.9								
8	✓	16.7	-2.0	34.2	36.2	70.4	6.0			89.4
9		16.4								
10	✓	16.0	-1.4	35.0	36.4	79.4	5.5	14.1		82.0
11		14.9								
12	✓	14.0	-0.4	36.0	36.4	72.4	4.9			68.9
13		13.9								
14										
15	✓	12.9	+1.2	36.8	36.8	74.8	4.1			56.2
16		12.3								
17										
18	✓	11.8	+1.8	37.0	37.0	78.2	2.6	15.1		34.8
19										
20	✓	11.5	+3.4	37.4	37.4	78.2	2.1	15.2		27.9
21										
22	✓	11.5	+3.7	37.4	37.4	78.5	1.8	15.2		24.0
22½										
Mud		11.5						18.9		

Fig. 5.—Record card used for recording and filing results.

The depth is indicated in the first column, a check-mark in the second indicates the depths at which plankton catches are made, and the temperature of the water is recorded in the third. The carbon dioxid is shown as free, half bound or bicarbonate, fixed or carbonate, and the total. Under free carbon dioxid, the minus sign indicates alkaline water and the plus sign acid. O = oxygen, N = nitrogen, and in the last column the per cent. of saturation of the oxygen is shown. This card shows results for oxygen determinations made by both the boiling and titration methods. Those followed by results for nitrogen were made by the boiling method and the remainder by Winkler's method. The residual gas from the muddy bottom water which is recorded as nitrogen very probably contained some methane.

CHAPTER II.

OXYGEN.

A liter of water at 0° is capable of absorbing 41.14 cc. of oxygen if exposed to an atmosphere of that gas under a pressure of 760 mm., while under like conditions it is capable of absorbing 1796.7 cc. of carbon dioxid, and only 20.35 cc. of nitrogen. This difference in solubility accounts for the difference in the ratio between the oxygen and nitrogen of the air and their ratio when air is dissolved in water. By volume, air is composed of 20.96 per cent. oxygen and 79.04 nitrogen, but since oxygen is more soluble in water than nitrogen, the air that is dissolved in water consists of 34.91 per cent. oxygen and 65.09 per cent. nitrogen. The solubility of these gases is also affected by the temperature of the water, the higher the temperature the smaller the quantity of gas capable of being absorbed. At 20° for example, a liter of water will absorb only 28.38 cc. of oxygen, 901.4 cc. of carbon dioxid and 14.03 cc. of nitrogen in atmospheres of these gases at a pressure of 760 mm. as compared with the above quantities at 0°. It follows then that, when water holding these gases in solution is heated, they, being less and less soluble as the temperature rises, are given off at the higher temperature, so that boiling the water for a few minutes usually suffices to expel practically all of these gases that are merely held in solution.

A given volume of water will absorb the same volume of a gas at all pressures, but, since the volume of a gas varies inversely as the pressure, the actual volume of gas absorbed, measured at 0° and 760 mm., will be twice as much under a pressure of two atmospheres, or only half as much under a pressure of half an atmosphere. In a mixture of gases, such as the air, the absorption of each gas is independent of all the other gases present and is proportional to the pressure exerted by that gas.

LAKE MENDOTA.

In presenting the results of these investigations it seems best to give a separate account of the studies on lake Mendota for two reasons; first because these chemico-biological investigations have been carried on here longer and more thoroughly than on any other Wisconsin lake, and secondly because it is a good example of one type of lake, that is, that type whose lower water contains no free oxygen for a longer or shorter period during the summer. Mendota has an area of about 39 sq. km. and is rather irregular in outline. It has a maximum depth of about 25 m. and an average depth of 12.1 m. About 30 per cent. of the area of the lake is 18 m. or more in depth, and 16.5 per cent. is 20 m. or more. Much of the shore is rather high, reaching a maximum height of about 45 m. The bed rock of the immediate region consists of Potsdam sandstone which possesses an upper calcareous stratum known as Mendota limestone. In several places along the shore, these rocks are freely exposed in the cliffs. The drainage basin has an area of about 700 sq. km.

The relation between the thermal conditions of the water at different seasons of the year and the gas conditions is so intimate that a brief summary of the former will contribute to a better understanding of the latter. Mendota is covered with ice from 3 months to nearly 5 months each year. When the lake freezes, the temperature of the surface water is 0° but that of the bottom water varies from a minimum of about 1° in some years to 2° or 2.5° in others. The water gains some heat during the winter and early spring and by the time the ice disappears from the lake in late March or early April, the average temperature will vary from about 2° to 3°. The spring overturn takes place at the time of the disappearance of the ice or very soon thereafter. This is brought about in two ways, by convection currents and by the action of the wind. So long as the temperature of the entire body of water remains below 4°, the surface water on being warmed, becomes heavier than the water below and tends to sink. In this way convection currents are started which are more or less effective in mixing the water. Their effect, however, becomes nil, as far as the lower stratum is concerned, after the water once reaches a temperature of 4°. At night, however, when the surface stratum cools, convection currents will be produced and will play a part in mixing some of the upper water but such currents will not usually extend to the lower water.

The wind, on the other hand, is a much more important factor in bringing about the overturn and in keeping the water in circulation afterwards. A wind coming from a certain direction for a few hours tends to set the whole body of water into rotation, especially if the water is homothermous or the difference in temperature between surface and bottom is not more than 2° or 3°. The surface water will be blown across the lake and when it reaches the leeward side it must return; some of it will remain at the surface and return around the lake; but probably the greater portion will turn down and return at various depths, some of it returning along the bottom. In this way currents are started which mix the water at all depths thoroughly as long as the temperature conditions in the upper and lower water are such that the thermal resistance to mixture is not too great to be overcome by the wind.

The vernal circulation in Mendota continues more or less completely from the time of the disappearance of the ice until sometime in May or early June, the date of the termination of the period varying from year to year owing to differences in weather conditions. The temperature of the entire body of water rises to 4° within a few days after the disappearance of the ice and the increase in the temperature of the upper water beyond this point increases the thermal resistance to its mixture with the cooler water below. This results in the formation of a bottom stratum, only two or three meters thick at first, but gradually becoming thicker as the season advances, which is disturbed less and less by a mixture with the water above it. By late May or early June this mixture ceases entirely in the bottom stratum and the formation of the permanent thermocline in late June or early July prevents the mixture of any of the water above the thermocline with that below. This means that the lower water is now cut off from further contact with the air until the autumnal overturn takes place. These three strata persist during the summer. The upper one is kept in circulation by the wind and usually has a pretty uniform temperature, especially in windy weather. Its average temperature reaches a maximum of 22.5° to 25° during the summer. From the time that the thermocline becomes well established until the autumnal overturn, the temperature of the bottom water remains almost stationary, there being a rise of perhaps 1° or 2° during this period.

As autumn approaches, the sun's rays strike the water at a more oblique angle, the days grow shorter and the nights become longer and cooler. Under these conditions the upper water cools and as its temperature falls its density increases and the resistance to mixture with the lower water diminishes. The thermocline moves down and when the temperature of the upper water falls to within 3° to 5° of that of the bottom, a strong wind will bring about a complete mixture of the upper and lower water, thus producing the fall overturn. This overturning generally takes place during the latter part of September or early in October and is followed by the autumnal circulation.

Here again both wind and convection currents are involved, for the autumnal cooling takes place at the surface and as long as the tempertture remains above 4°, the cooling surface water will become heavier than the water below and will tend to sink, thus producing convection currents which will aid the wind in mixing the water. The wind, however, is directly responsible for the autumnal overturning and undoubtedly plays a much more important rôle than convection currents in producing the autumnal circulation even when the temperature of the water is above 4°. Thus it will be seen that the mere cooling of the water in the autumn tends to promote circulation until the temperature falls to 4°, but the wind alone must be held responsible for the circulation when the temperature falls below 4°. There is, then, a very important difference between the vernal and autumnal circulations. As long as the temperature of the water remains below 4° in the spring, which is a very brief period in Mendota, the warming of the surface water aids in the mixing and circulation throughout the entire depth. But as soon as the temperature of the upper water rises above 4° every increase in temperature tends to prevent the free intermixture of the upper and lower strata, for the warming takes place at the surface and the upper water becomes lighter than the lower and tends to float on it. This thermal resistance to mixture and hence to complete circulation, becomes greater and greater as spring advances and the tendency of the lower water to take part in the circulation grows correspondingly smaller and smaller. As a result the mixture of the water from surface to bottom is not so thorough in the spring after the temperature rises above 4° as it is in autumn at corresponding temperatures.

In small lakes, in fact, such as Beasley, there may be no complete overturning of the water in the spring, especially if the temperature of the bottom water rises nearly or quite to 4° before the lake loses its coat of ice. Convection currents would then play no part in dis-

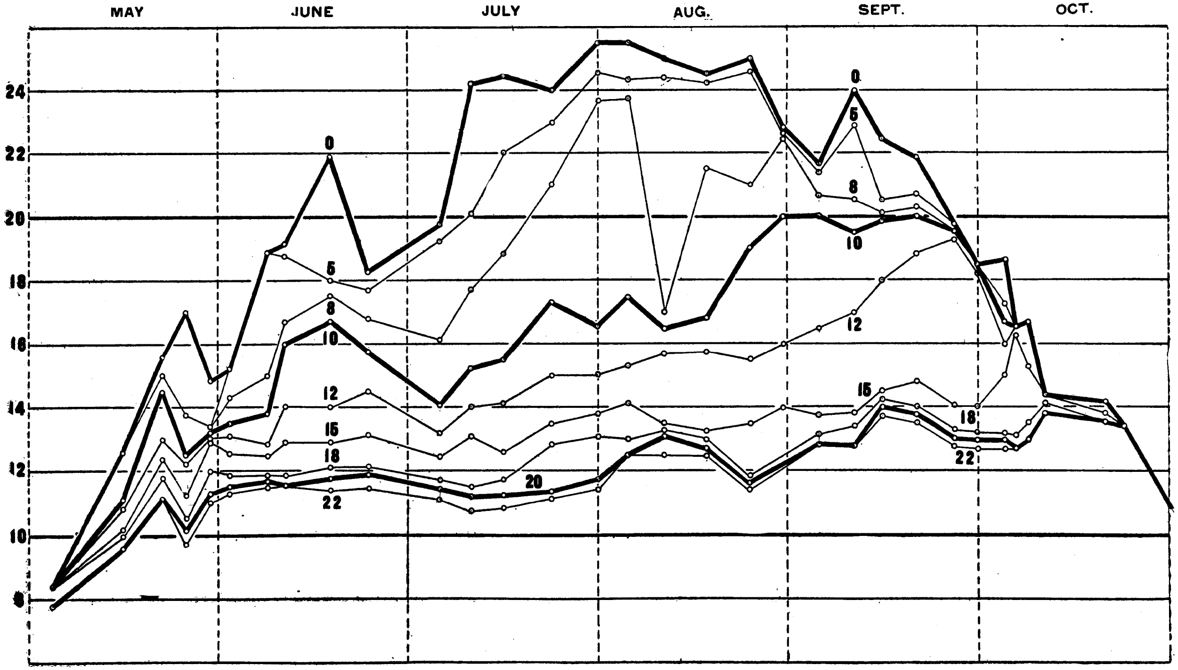


Plate I.—Temperature of the water at different depths in lake Mendota in 1906. The vertical spaces represent degrees centigrade and the figures attached to the curves indicate the depths in meters.

turbing the bottom water and a period of warm weather with comparatively little wind would soon raise the temperature of the upper water to a point where the wind would no longer be able to force this upper water down far into that below. As a consequence comparatively little, or in extreme cases none of the water above would be mixed with the bottom water and a condition either resembling or quite like that of late winter would continue until the formation of the thermocline which would insure the bottom stratum against further disturbance. During cold, windy springs, however, such lakes may experience practically a complete overturning of their waters, but the period of complete circulation will be very brief, for the bottom water will soon lag behind and assume a more quiescent condition.

Plate I shows the temperature conditions in lake Mendota at different depths during the period from early May in 1906 until the fall overturn. The heavy lines show the conditions at the surface, 10 m. and 20 m. In general there was a gradual increase in temperature at all depths until about the first of June after which the temperature of the lower water remained pretty uniform. That of the upper water continued to increase, reaching a maximum early in August. Then it declined more or less regularly until early October, when the entire lake became homothermous.

Winter Oxygen Conditions. Beginning with the conditions which obtain at the time the lake becomes completely covered with ice in early winter, we find that the water has a temperature of about zero degrees at the surface and from 1° to 2° or 2.5° at the bottom. During the autumnal circulation the water becomes thoroughly mixed from surface to bottom and as a result the gas conditions are quite uniform throughout the entire depth of the lake. It is nearly or quite saturated with oxygen. The temperature of the water is so low that the life processes which exhaust the supply of dissolved oxygen are at a very low ebb. Thus the oxygen conditions may remain almost stationary for some time after the lake freezes over. Figure 8[1] shows the conditions on Jan. 26, 1906, over a month after the lake became covered with ice.

The sheet of ice cuts off the water from direct contact with the air and protects it from the disturbing influences of the wind so that vigorous circulation soon ceases. The upper water continues to circulate more or less for some time, however, as one can readily see

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[1] See explanation of figures showing dissolved gases, p. 143.

through the ice, but the currents are not strong enough to keep the entire body of the lake in circulation. More quiescent conditions prevail in the lower water and in the course of 8 or 10 weeks there is a very noticeable decrease in the supply of dissolved oxygen in this region. (See fig. 9.)

The decrease is brought about in two ways, (a) through the respiration of animals and (b) through the decomposition of organic matter. Early winter observations show that animal forms, both large and small, are generally quite as abundant in a few meters of the bottom water as at any other depth, and, in the process of respiration, these organisms use up some of the dissolved oxygen. But there are evidences which seem to show that the most important factor concerned in the depletion of the oxygen in this region is the decay of organic matter. Undoubtedly decomposition goes on very slowly at temperatures of 1° to 3°, yet when continued through a period of several weeks, an appreciable amount of oxygen is used up. The fact that the pronounced decrease takes place wholly within a stratum of bottom water only 4 m. or 5 m. thick which is generally not any more densely populated with animals than the water above, seems to indicate that decay is the most important factor. Then, too, the most rapid and greatest decrease is found in the layer of water just above the mud where the decomposable material is most abundant. Analyses show that about 40 per cent. of the dry weight of the bottom mud is organic matter. This decrease of oxygen continues during the winter and by the time the ice disappears in the spring there may be little or no free oxygen in the bottom water. On March 29, 1906, (fig. 11) for example, nine days before the disappearance of the ice, there was no oxygen at 22 m. and only 0.7 cc. per liter of water at 20 m. On March 19, 1907, five days before the lake was clear of ice, the amounts were 0.55 cc. at 22 m. and 2.2 cc. at 20 m. and on March 6, 1909, (fig. 31), a month before the ice disappeared, there was no oxygen at 22.5 m. and only 0.39 cc. at 20 m.

Drown[1] found that about 2 m. of the bottom water of Mystic lake contained no dissolved oxygen on March 8, 1893, and also that there was none in the bottom water of Jamaica Pond on January 24, 1893. He also observed that the decrease of oxygen in winter with increasing depth is not so abrupt as in summer, there being a gradual falling off. This is true also of lake Mendota and those other lakes on which winter observations have been made.

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[1] 24th Ann. Rept. St. Bd. of Health of Mass., 1893, pp. 333–42.

In the region from 1 m. to 15 m. there is not a very marked decrease in the dissolved oxygen during the winter, but the amount varies considerably in different years. In early January, 1906, the water of this region contained on an average about 9.5 cc. per liter while on March 29, the average for this region was 8.3 cc. This represented a decrease of 1.2 cc. or over 12 per cent. in about two and a half months. On January 5, 1907, there were 9 cc. of oxygen per liter of water in this region and on March 19, 8.6 cc., a decrease of only 0.4 cc. or 4.4 per cent. during this period of time.

During the winter, there are sometimes very marked changes in the amount of dissolved oxygen in a stratum of water just under the ice. If the ice is rather transparent and fairly free from snow, so that considerable sunlight passes through, the algae are able to carry on their photosynthetic processes on clear days and only a few such days are necessary for them to raise the amount of oxygen appreciably above the saturation point. The result of such favorable conditions is shown in the following table:

TABLE V.—*Sta. I, March 3, 1906.*

Depth.	Temperature.	Oxygen in cc. per l. of water.	Per cent. of saturation.
0 m.	0.6	12.5	130.6
2 m.	1.3	12.2	129.7
5 m.	1.5	10.1	107.9

More frequently, however, the changes in this layer are very different from this. During the winter there are periods in which the temperature of the air rises considerably above the melting point and remains so long enough to produce extensive thaws. Since the ground is frozen so that very little water penetrates it, much of the water of the drainage basin resulting from the thaw, soon reaches the lake. The amount of this drainage water depends upon the amount of snow and ice, the duration of the warm weather, and whether the thaw is accompanied by rain or not. These thaws may occur at any time during the winter but they are most frequent, of course, toward spring.

With respect to the thermal condition the density of the inflowing water is not very different from that of the upper half-meter or meter of lake water because they do not differ materially in temperature; but there is a difference in density which is due to the difference in the amounts of substances held in solution. The incoming water has only a small amount of dissolved salts and for that reason, it is lighter than the lake water. As a result this lighter water tends to float on the lake water so that it spreads out just under the ice forming a layer which varies in thickness from less than half a meter to perhaps a meter. The fact that it bears silt, enables one to follow its movements over the lake easily. As this drainage water is derived largely or wholly from the melting of snow and ice and reaches the lake apparently before it has had time to absorb much oxygen, it is usually deficient in this gas and the stratum which it forms just under the ice is more or less deficient in oxygen, sometimes containing less than 50 per cent. of the amount necessary for saturation.

As the drainage water spreads over the lake, it becomes mixed with more or less of the surface water and in this way it becomes stocked with algae. It generally contains much organic matter so that it serves as a good culture medium for these algae and under favorable light conditions, these plants liberate oxygen which accumulates here and causes supersaturation in part, or in some cases in all, of this stratum. From time to time the upper quarter meter of this region receives new supplies of water that is poor in oxygen so that it may be found supersaturated with oxygen at one time and again very deficient in oxygen, depending upon the amount of drainage water, or water from the snow and ice on the lake itself, which has been mixed with this stratum in the meantime. (Compare figs. 9 to 11.)

The following table shows some conditions which may be found toward spring, generally a few days before the ice disappears from the lake. At such times a larger amount of dissolved oxygen may be found in this stratum than at any other time during the winter. Most of the sun's energy which penetrates the ice is absorbed by this layer, and its temperature rises from 3° to 5° above that of the water 2 or 3 meters below. This increase in temperature doubtless accelerates reproduction in the algae and also accelerates their photosynthetic activities. As a result of these activities the quantity of dissolved oxygen soon rises above the saturation point.

TABLE VI.

April 2, 1906.

Depth.	Temperature.	Cc. of O_2.	Per cent. of saturation.
0 m	1.5	5.2	55.5
0.5 m	6.25	12.4	146.9
1.5 m	2.5	8.6	93.6

April 3, 1906.

Depth.	Temperature.	Cc. of O_2.	Per cent. of saturation.
0 m	0.6	4.6	48.0
0.5 m	5.1	13.8	159.3
1.0 m	3.0	9.8	107.9

The existence of all these peculiar winter phenomena depends primarily upon the weather and naturally there may be very noticeable differences from year to year. These phenomena for instance were much more marked in late winter in 1906 than in 1907. With respect to oxygen conditions in late winter, the lake sometimes consists of four strata. There is an upper, thin stratum just under the ice which is more or less deficient in dissolved oxygen; below this is a stratum somewhat thicker which is supersaturated; then comes a stratum about 15 m. thick which generally contains 90 per cent. or more of the amount of oxygen necessary for saturation; and lastly a bottom stratum which is markedly deficient in dissolved oxygen, the deficiency sometimes amounting to its total absence from the lower part of this stratum.

Winter oxygen conditions in Mendota are shown in figures 8 to 11, indicating results for 1906 and figures 29 to 31, 1909. (See pp. 174, 183, for figures and pp. 152, 156, for tables.)

Spring. The spring overturn takes place at the time of the disappearance of the ice, or within a very short time thereafter and it results in a pretty thorough mixing of the entire body of water. The water thus becomes homothermous and all of the dissolved gases are equally distributed throughout the entire depth of the lake. The ice disappeared on the afternoon and evening of April 7, 1906, and on April 8 (fig. 12), the water from surface to bottom was found to have a temperature of 2.3° and the oxygen was very uniformly distributed throughout the entire depth except in the bottom half meter. In 1907, the ice began to leave the lake on the afternoon of March 24, and entirely disappeared during the forenoon of March 25. A set of observations taken during the afternoon of March 25 showed that oxygen conditions had become uniform down to a depth of 15 m. and thermal conditions to 20 m. (See fig. 24.) But the water below these depths had not yet been thoroughly mixed with the upper so that it contained a smaller amount of oxygen and had a slightly higher temperature. Five days later, however, the lake was homothermous and the amount of oxygen at the bottom was only 0.4 cc. less than at the surface.

On March 29, 1906, just 9 days before the ice disappeared, the average oxygen content of the water down to a depth of 15 m. was 8.65 cc. per liter, or about 93 per cent. of the amount necessary for saturation, and from 15 m. to the bottom, it was 3.4 cc. per liter. The amount of water below 15 m. constitutes about 16.2 per cent. of the total volume of the lake so that a mixture of the water of these two regions under these conditions would have given the entire body an oxygen content of 7.8 cc. A set of observations on April 8, the day after the lake became free of ice, showed an average of 7.88 cc. of oxygen per liter of water. During the 9 days intervening between these two sets of observations, a part of the oxygen supply of the water was used up, of course, but the oxygen absorbed during the process of overturning was a little more than sufficient to make up this loss. On March 19, 1907, the water down to a depth of 15 m. contained on an average 8.5 cc. and below 15 m. it was 4 cc. A mixture of these two strata would give 7.78 cc. but a set of observations immediately after the disappearance of the ice on March 25 showed an average of only 7.5 cc. or 0.28 cc. per liter less than would have resulted from a mixture of the water five days previously. This loss is most probably accounted for by the various processes going on at this time which were exhausting the supply of dissolved oxygen.

During the 12 days immediately following the vernal overturn in 1906, the quantity of dissolved oxygen increased only 0.2 cc. per liter of water, but the percentage of saturation rose in this period from 86.7 to 92.0, largely as a result of the increase in the temperature of the water. From April 20 to May 4, the quantity of oxygen remained about the same, 8 cc. per liter of water, but, owing to the increase in temperature, the water was substantially saturated at all depths on the is most probably accounted for by the various processes going on at 7.5 cc. on March 25 to an average of 8.4 cc. on March 30, a gain of 0.9 cc. per liter of water in five days. The percentages of saturation were 82.4 and 94.4 respectively. For the total volume of water in lake Mendota this meant a net increase of about 430,500 cu. m. of dissolved oxygen in five days or 86,100 cu. m. per day, or a total increase of about 2.2 l. per square meter of surface. There was also a marked loss of free carbon dioxid during this time. (See tables, p. 155.)

In 1906 the vernal circulation of the water was fairly complete from the time of the disappearance of the ice on April 7 till early in May, and in 1907 from March 25 till about the first of June. As long as the temperature of the water was below 4°, the entire body was easily kept in circulation by the wind. But when the temperature rose above this point, the bottom water had a tendency to lag behind in the mixing process because it was cooler and thus denser than the upper water. As a result the mixture of the water from surface to bottom was not complete except when wind conditions were favorable. Whenever there was a calm period which lasted for a few days, the bottom water was not disturbed and there was soon a noticeable decrease in the amount of oxygen in this region. But a strong wind would mix the water from surface to bottom and the oxygen would thus become uniformly distributed.

As the upper water became warmer, however, with the advancing season, the thermal resistance to its mixture with the cooler water below gradually became greater, until early in May, 1906, and almost the first of June, 1907, even a very strong wind was no longer able to effect a complete mixture of the two strata. After these two periods the bottom water constantly lagged behind as is clearly illustrated by the oxygen and thermal conditions which followed. (See figs. 14, 15, and 26, pp. 176 and 182, and tables, pp. 152 and 155.)

A little later the thermocline became permanently established and this insured the complete cessation of the mixture of the water above and below this region, thus completely cutting off the lower stratum from further mixture with fully aerated water. Thenceforth the dissolved oxygen in the lower water was limited to the amount which it possessed at the time of its isolation, and when this supply was exhausted, this water remained devoid of free oxygen until the autumnal overturn.

Summer. In 1906, observations were made frequently enough to enable one to plat the results in a diagram covering the period from late spring until the autumnal overturn. These results are shown in Plate II, in which the vertical spaces represent the number of cubic centimeters of oxygen per liter of water, and the horizontal spaces show the time at which the observations were made, the months being indicated at the top. The curves represent the different depths from surface to 22 m. and show the amount of oxygen at the various depths. In most cases the quantity of oxygen indicated in the diagram is based upon a single set of observations, but, in some instances, they show averages of two or three sets of observations which were made in close succession, that is, within a period of two or three days.

The diagram begins with a set of observations on May 4. At this time the lake was practically homothermous and saturated with oxygen from surface to bottom, having 8 cc. of this gas per liter of water. Then followed a period of more than two weeks during which time the quantity of dissolved oxygen in the 0-5 m. stratum remained almost the same, but at all other depths there was a decrease. This period was succeeded toward the end of May by a rapid decrease in all of the upper water which resulted very largely, no doubt, from the decreased capacity for oxygen due to the rise in temperature.

At the close of the vernal period of circulation the lower water has a temperature of 10° to 12° and at this temperature decay will proceed rather rapidly. As a result, there is soon a marked decline in the quantity of oxygen in the lower water. By the last of June in 1906, there was only a small amount of oxygen at 20 m. and 22 m., and it entirely disappeared from the 18-22 m. stratum before the middle of July. The water at the 15 m. level possessed only a small quantity of dissolved oxygen from the middle of July until the first week in August when it disappeared entirely at this depth also, and did not reappear until after the middle of September; and then only in small quantities until the fall overturn in October. At 12 m. there was no oxygen for about 3 weeks in August and at 10 m. even, only a trace of oxygen was found in one set of observations and in others not to exceed 0.1 cc. The amount was so small that animals requiring a moderate supply of oxygen, such as fish, could not have lived at this depth during this time. The jagged appearance of the 10 m. curve beginning with the latter part of August and lasting until after the middle of September well illustrates the effect of windy and calm periods of weather at this season of year. A strong wind will disturb

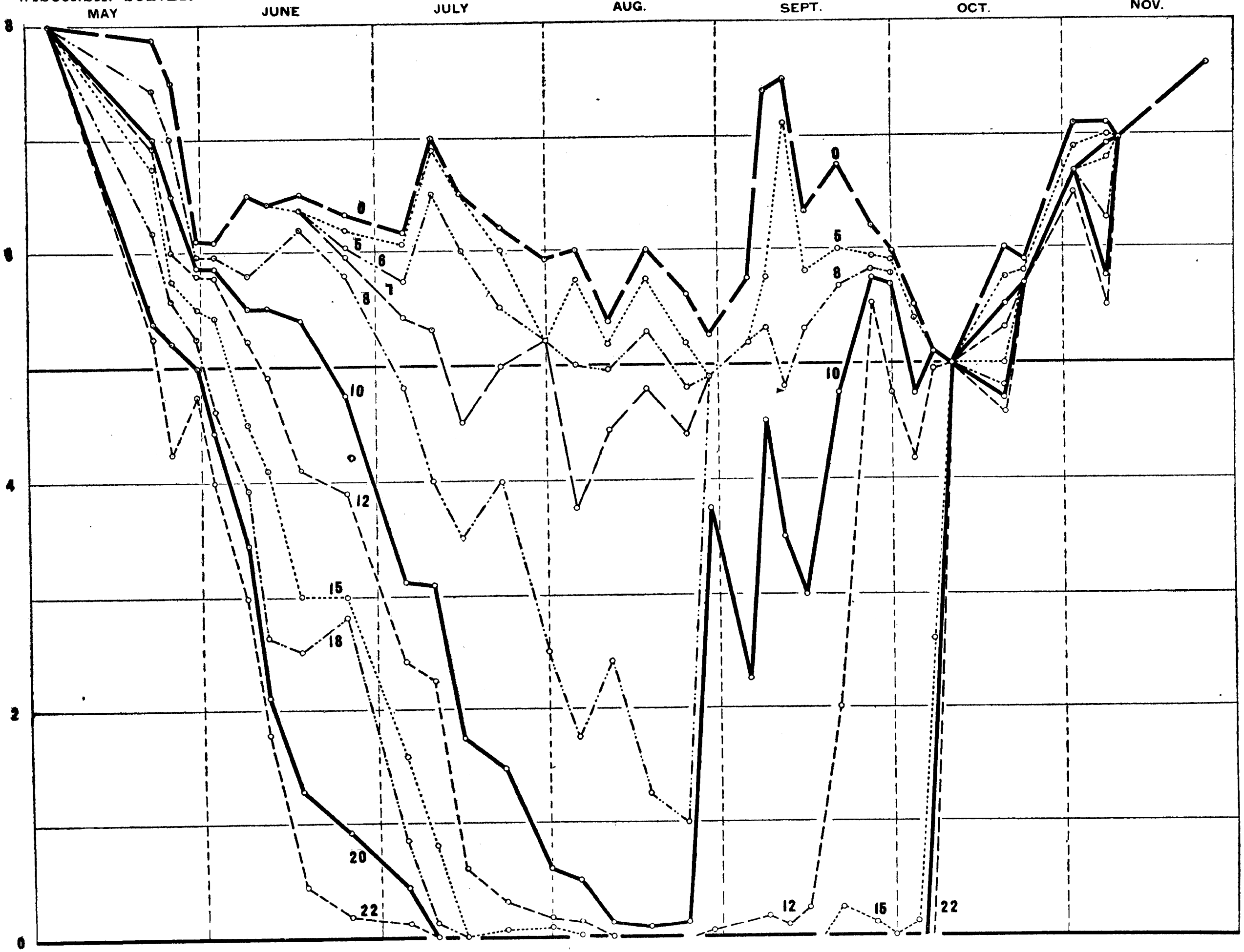

Plate II.—Dissolved oxygen at different depths in lake Mendota in 1906. The vertical spaces represent cubic centimeters of gas per liter of water and the figures attached to the curves indicate the depths in meters. See p. 36

the water down to this depth by blowing the warm, aerated water toward the leeward side of the lake, thus causing a depression of the thermocline on this side and a rise on the windward side. But during calm weather or periods of light winds, the water comes to a more stable equilibrium and the thermocline becomes practically horizontal. Hence samples from 10 m., which was in the thermocline region at this time, show very considerable differences in the amount of oxygen, depending upon wind conditions. The samples were taken at a station in the deep central portion of the lake but nearer the southern shore. Northerly winds blew the upper water toward the southern shore of the lake and depressed the thermocline on this side and at such times considerable oxygen was found at 10 m. But during calm weather, or periods of light winds the thermocline became more nearly horizontal; or during southerly winds it was tilted to the north and then some of the cool, lower water which was poor in oxygen was found at 10 m., consequently observations made when such conditions existed showed smaller amounts of oxygen at this depth.

Just after the middle of June, a gradual decrease in the quantity of oxygen at 8 m. began, and, with two exceptions when there were slight increases resulting from the disturbance of the water at this depth by winds, the decline continued until August 24, when a minimum of 1 cc. per liter of water was found. After this date the amount suddenly rose as a result of stronger winds and falling temperature which caused some of the upper water to be mixed with that at this depth, and the quantity remained high during the rest of the season.

It will be noted that the curves for the surface and 5 m. are not widely separated throughout most of their courses, joining at some points, in fact, and have the same general trend, so this region will be considered as a single stratum. The water of this stratum is kept in circulation by the wind and by convection currents during the summer and is thus freely exposed to the air. For this reason we might expect the quantity of oxygen to remain quite uniform, but such is not the case as an examination of the curves will readily show. This gas is consumed in the processes of respiration and decay and it is liberated by chlorophyl-bearing organisms in the process of photosynthesis, so that the quantity of oxygen held in solution by the water of this stratum will vary from time to time. Under conditions which favor consumption there may soon be a noticeable decrease in the oxygen and when conditions are favorable for production, the quantity may soon rise considerably above the saturation point, sometimes rising as high as 175 per cent. in parts of this stratum.

Following a supersaturation on May 22 and May 25, which amounted to 114 and 111 per cent. or 7.9 cc. and 7.6 cc. respectively, there was a very rapid decrease in oxygen to only 84 per cent. of saturation, or 6 cc. on May 29. No good explanation has yet been found for this unusual decrease so far below saturation. There was a very strong wind on May 28 which apparently disturbed the water throughout its entire depth, as a marked increase in oxygen was noted at 22 m. on May 29, but not enough of the lower water which was much poorer in oxygen, was mixed with the upper to account for such a large decrease of oxygen in the upper water. The oxygen remained low for two or three days after May 29 and then gradually rose to 6.5 cc. or the saturation point on June 6, after which this stratum remained substantially saturated until early July. During a few calm, clear days the second week in July the algae produced enough oxygen to raise the amount to 6.5 cc. and 7 cc. or 115 to 120 per cent. of saturation. Succeeding this were two periods in which the oxygen decreased somewhat, going noticeably below the saturation point at the surface. But for the most part the surface remained near the saturation point until September. After the middle of July the surface and 5 m. curves become more widely separated. The maximum difference was 0.7 cc. on July 30, the amount of oxygen at 5 m. during this period varying from 6.1 cc. in two July observations to 4.7 cc. on August 30. Two factors were responsible for the difference in the amount of oxygen at the surface and at 5 m. (1) During this period, the number of algae was small so that very little oxygen was contributed to this stratum by them. Under such a condition the chief source of oxygen for this water was the air. (2) During periods of calm weather, the circulation of the water in the upper stratum was incomplete, consequently the water at 5 m. was not exposed to the air frequently enough to replenish the quantity of oxygen which was used up in the processes of respiration and decay. The surface water, however, could readily obtain oxygen from the air to replace that which was lost. Such conditions would produce the results obtained in the observations.

About the middle of September there were periods of clear, calm weather which were favorable both for the activities of algae and for the accumulation in the upper water of the oxygen set free by them. As a result the entire 0–5 m. stratum was found to be supersaturated occasionally, the most marked supersaturation being found on Sept. 11, when the surface water contained 7.5 cc. and the 5 m. water 7.1 cc. of oxygen, the saturation percentages being respectively 128 and 119. In most of the observations, however, the supersaturation was confined to the upper 2 or 3 m.

Autumn—As the epilimnion cools during the latter part of August and in September, its temperature approaches that of the water in the upper part of the thermocline and the thermal resistance to mixture decreases. For this reason the wind is now able to set into circulation a stratum of water which gradually increases in thickness. In other words the thermocline gradually moves down to a greater and greater depth. This is well illustrated in figures 19 to 21. In early August, the upper part of the thermocline lay at a depth of 7 m. to 8 m.; by the last of August it had moved down nearly to 10 m.; by September 27 to 12 m.; and on October 8, just before the autumnal overturn, to 14 m. As the water at 8 m. and 10 m. was added to the circulating portion in the latter part of August, we find a rapid rise in the quantity of dissolved oxygen at these depths. During the first half of September, the amount of oxygen at 10 m. rose and fell corresponding to the alternate periods of calm and windy weather, but in the latter half of the month there was a gradual rise until it closely approached surface conditions. From the last of August until the middle of September, a small quantity of oxygen was found at 12 m., after which there was a rapid rise followed by equally as great a decline just before the overturn. A small amount of oxygen was found at 15 m. the latter part of September and the first week in October but the quantity remained very small until the overturn. Below 15 m. there was no dissolved oxygen in the water until the overturn took place on October 9 and 10, which was caused by a heavy north-west wind. The conditions which existed on October 8 and 11 are shown in figures 21 and 22 (p. 180) and in the tables on pages 153 and 154.

As autumnal conditions advanced, the dissolved oxygen in the upper water gradually decreased in amount. Three factors were in all probability chiefly responsible for this decrease. (1). At this season conditions became more unfavorable for the summer forms of the phytoplankton and they declined; their photosynthetic activities decreased also, resulting in the production of less and less oxygen and the rising crop of autumnal algae, consisting of diatoms, was not yet active enough in the process of photosynthesis to make good the loss of oxygen. (2) Decay was proceeding vigorously at this time in the upper water and more oxygen was being consumed in this process and by the various organisms in their respiration than was supplied to this water by the algae or obtained by it from the air. As a result the quantity fell below the saturation point. (3). As the thermocline was gradually moving down at this time, more and more of the lower water which had little or no free oxygen was being mixed with the upper, thus lowering the relative amount of this gas in the upper strata.

Between September 20 and October 8, the decrease in oxygen in the 0–5 m. stratum amounted to a little more than 1 cc. per liter. On October 8 the average amount of oxygen for the entire depth of the lake was about 4 cc. On October 11, it was 4.61 cc. or only 65 per cent. of the amount required for saturation. Thus the water gained about 0.6 cc. of oxygen per liter during the process of overturning which meant an increase of 287,000 cu. m. in the dissolved oxygen supply of the entire body of water. Between October 11 and 20, the increase amounted to 411,400 cu. m. so that, in 12 days, the lake added 698,400 cu. m. of oxygen to the supply which it already possessed, or an average of 58,200 cu. m. per day, which was a daily increase of about 1.5 liters per square meter of surface.

After the autumnal overturn, the oxygen conditions which obtain in the lower water for a few days or perhaps a week, depend very largely upon the weather. If the wind is not strong enough for a few days to keep the entire body of water in circulation, there will soon be a noticeable decrease in the dissolved oxygen in the lower water. This water reaches its annual maximum temperature at this time and decomposition will therefore be most vigorous, so that oxygen will be used up rather rapidly in this process. At the same time, the upper water upon exposure to the air and to some extent also through the photosynthetic action of the algae will be increasing its supply of oxygen, so that there will be a marked difference between surface and bottom in a few days if there is little or no wind.

On October 20, 1906, just nine days after the autumnal overturn, the dissolved oxygen showed a distinct decrease in amount in the lower water. (See table p. 154.) This was followed by a period during which the winds were stronger, so that the water was pretty thoroughly mixed and gas conditions became almost uniform from surface to bottom (see table, p. 154 for Oct. 23) and remained so until November 2. This was then succeeded by a calm period during which there was again a noticeable decrease in dissolved oxygen in the 18–22 m. stratum. (See fig. 23). On November 10, gas conditions were quite uniform from surface to bottom and remained so until the lake was covered with ice.

As the temperature of the water falls during the autumnal period of circulation, the capacity for oxygen increases, so that there is a tendency for the oxygen to remain below the saturation point. The rapidity with which the water gains oxygen after the overturn depends upon two factors chiefly, the wind and the photosynthetic activity of the algae. If the winds are strong enough to keep the entire body of water in circulation, all of the water is exposed to the air from time to time where it may obtain more oxygen. Under favorable conditions, also, the algae become active and liberate oxygen which may be absorbed by the water. In 1906, the average gain per liter of water at all depths between October 11 and November 2 was 2.2 cc. or an increase of 0.1 cc. per day. That is, the amount rose from an average of 4.6 cc. on the former date to 6.8 cc. on the latter. In the next 22 days, the increase amounted to only 0.8 cc.; that is, on November 24, the water contained 7.6 cc. of oxygen per liter, which amounted to 88.5 per cent. of saturation. But by the time the lake became covered with ice on December 18, 1906, the amount of oxygen had risen to 9.1 cc. Figures 8 to 23 show the seasonal changes in oxygen in 1906 (pp. 174 to 181.) (See tables pp. 152 to 154.)

CONDITIONS IN 1905 AND 1907.

The spring decrease in oxygen in 1905 was more gradual than in 1906. The surface water had 8.1 cc., which was 95.4 per cent. of saturation, on April 22, and this amount steadily declined to 5.8 cc.,—86.8 per cent. of saturation—on June 10. From this time until July 29, the amount varied from 5.4 cc. as a minimum to 6.1 cc. as a maximum. The early summer decrease in the lower water was much the same in 1905 as in 1906. No observations were made in August, 1905, with the exception of August 31. Between this date and the autumnal overturn in early October, conditions were substantially the same as during this period in 1906. At the completion of the overturn the water contained on an average 5.1 cc. of oxygen per liter, or 71.8 per cent. of the amount required for saturation at the observed temperature, 14.1°.

In general the changes in the amount of dissolved oxygen during the winter of 1905–6, were very much like those found during the winter of 1906–7. Changes were noted in a thin stratum just under the ice both years but they were not so marked in the latter as in the former winter. Also in the former winter (1905–6) the ice did not disappear from the lake until April 7, while in the latter (1906–7) it disappeared on March 25, 1907, so that the lake was covered with ice practically 2 weeks later in the spring of 1906. Thus decomposition continued about 2 weeks longer in the spring of 1906 and resulted in the complete exhaustion of the dissolved oxygen from the bottom water. In 1907, however, just six days before the lake became free of ice, the bottom water still contained 0.5 cc. of oxygen per liter.

On March 30, 1907, or 5 days after the disappearance of the ice, it was found that the water contained on an average 8.4 cc. of oxygen per liter at all depths. This represented a gain of 0.9 cc. per liter in 5 days or a daily gain of 0.18 cc., which was a gain of about 86,100 cu. m. of oxygen per day for the total volume of water, or 2.2 liters per square meter of surface. The quantity of oxygen gradually rose to a maximum average of 8.8 cc. on April 14, and thereafter it began to decrease owing to the increase in the temperature of the water. Up to May 16, the time at which the diagram on Plate III figure A begins, the amount had fallen to an average of 7.9 cc. in the 0–15 m. stratum and 7.7 cc. below this depth.

Plate III, figure A, shows that the spring decrease in oxygen in the upper water was much more gradual in 1907, than in 1906; the rapid decrease which was noted during the latter part of May, 1906, not being represented at all in 1907. The entire body of water was kept in circulation somewhat later in 1907 and, as a result, it will be noted that the lower water contained much more oxygen in mid-June, 1907, than on that date in 1906. In fact, oxygen conditions were about the same by the middle of June, 1906, as they were on July 1, 1907, but by August 1, they were substantially the same in both years. Only two sets of observations were made after August 1, 1907, one on September 6 (fig. 28) and the other on September 18, but they showed nothing essentially different from results obtained on September 5 and 17, 1906. (See tables pp. 153 and 156.)

Only a single set of observations was made in 1908 prior to Sep-

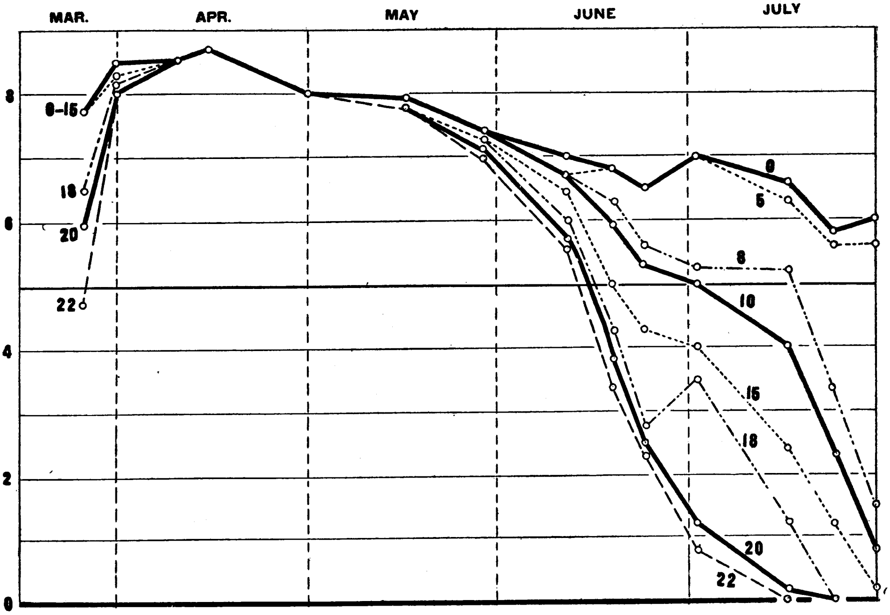

Plate III, Fig. A.—Dissolved oxygen at different depths (0 m. to 22 m.) in lake Mendota in 1907. The vertical spaces represent cubic centimeters of gas per liter of water.

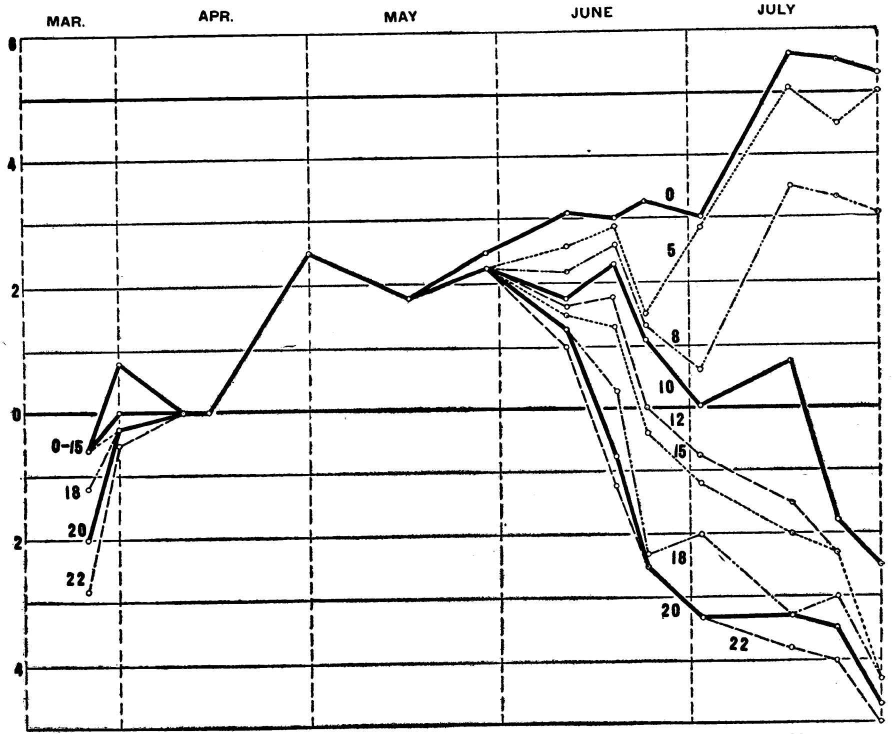

Plate III, Fig. B.—Free carbon dioxid at different depths (0 m. to 22 m.) in lake Mendota in 1907. The vertical spaces represent cubic centimeters of gas per liter of water. Spaces above th zero line show negative carbon dioxid or the alkalinity and spaces below, the acidity.

tember. This was on July 25 and oxygen conditions were found to be substantially the same as in the three previous years at this time. Two sets of observations in September showed about the usual conditions in the lower water, but some unusually favorable weather conditions were responsible for marked differences in the 0–5 m. stratum. This region was well populated with algae and at different times during this month, there were periods of clear, calm weather which made light conditions favorable for the photosynthetic activities of the algae and also permitted the oxygen liberated during these activities to accumulate in the upper water, resulting in a supersaturation. The following table shows some results obtained during one of these clear, calm periods.

TABLE VII. *September, 1908.*

Day.	Hour.	Temperature.	Depth.	Oxygen in cc. per liter.	Per cent. of saturation.
20.....	4:40 P. M....	24.1	0.0	8.7	149.1
			0.5	8.7	147.5
		23.0	1.0	9.4	158.2
			1.5	10.5	175.5
		22.0	2.0	9.2	152.2
	4:55 P. M....	21.3	3.0	7.5	122.2
21.....	6:05 A. M...	21.8	0.0	8.5	140.0
			1.0	8.6	142.0
			1.5	8.7	144.2
		21.8	2.0	8.6	142.0
	6:20 A. M...	21.25	3.0	6.0	97.7
21.....	4:45 P. M....	25.1	0.0	8.5	147.6
		25.0	0.5	8.6	149.1
		23.7	1.0	9.2	156.6
		22.9	1.5	10.0	167.8
		22.3	2.0	9.8	163.0
	4:55 P. M....	22.0	3.0	9.3	154.0
22.....	6:20 A. M...	21.8	0.0	8.6	141.6
		21.8	1.0	8.6	141.6
			1.5	8.7	143.3
		21.8	2.0	8.5	140.0
		21.3	3.0	7.4	120.7
	6:40 A. M...	21.1	4.0	6.5	105.8

It will be noted that the maximum amount of dissolved oxygen was found at a depth of 1.5 m. and that the increase at this depth between the morning and evening observations on September 21 was

1.3 cc. per liter. If we may assume that the amount of oxygen at this depth was about the same on the morning of September 20 as on September 21, then the increase during the former day was about 1.8 cc. The morning observations were taken just about sunrise, or before the algae became active in the production of oxygen. As the surface water cooled at night, convection currents were set up which mixed the water thoroughly down to a depth of 2 m. as shown by the morning temperatures, and the results show that the oxygen became practically uniformly distributed throughout the upper 2 m. But, in spite of the circulation and mixture which took place, the quantity of oxygen remained considerably above the saturation point. In this connection, also, it is interesting to note that the transparency of the water was such at this time that a Secchi's disc just disappeared from view at a depth of 1.75 m., the transparency being thus rather closely associated with the depth of maximum oxygen. No definite correlation between transparency and the region of high oxygen has been noted in other lakes.

OXYGEN—IN OTHER LAKES.

It has already been noted that the 156 lakes that have been studied cover a wide range of conditions. There are marked differences in the size and depth of the various lakes, in their exposure to the action of the wind, in the amount of the decomposable material found in the water, and also in climatic conditions. In addition to these general differences, it may be said that almost every lake possesses some individual characteristics which affect more or less markedly the gases dissolved in the water, more especially the oxygen. In view of this diversity of conditions, then, it is not surprising that the quantity of oxygen dissolved in the waters of the various lakes and its distribution therein, should show marked differences, because this oxygen is subject to the influence of so many factors. Not only do the different lakes show important differences in oxygen conditions but there may be annual variations in the same lake. These are due, in a large measure perhaps, to variations in weather and also to annual variations in the biological factors, such for instance as the abundance or scarcity of phytoplankton.

On the basis of thermal and gas conditions in the lower water during the summer, the lakes fall readily into two groups. The first group includes those which are shallow and whose area and exposure to wind are such that the entire body of water is kept in circulation during the summer. Only 27 lakes, however, belong to this class and they vary in depth from 3 m. to 10 m. As a result of the complete circulation of the water, thermal and gas conditions were found to be substantially the same from surface to bottom. The lakes of this group contained various amounts of oxygen dissolved in their waters as a result of differences in the amount of decomposition going on and differences in the abundance and photosynthetic activities of the algae, but in each lake the oxygen conditions were generally the same at all depths. The results show that, during periods of clear, calm weather, the upper 2 m. to 3 m. of water may become supersaturated with oxygen owing to the action of the algae and that the dissolved oxygen of the bottom water may decrease appreciably as a result of the decomposition going on there, but a brisk wind would soon restore uniform conditions. These lakes showed no other characteristics which require further consideration. (See fig. 110, p. 220 and tables, p. 164.)

The second group of lakes includes those in which the entire body of water was not kept in circulation during the summer but in which a more or less pronounced thermal stratification was found. Some of the 129 lakes belonging to this group did not differ very widely from those of the first group, since the bottom stratum which did not take part in the circulation was not more than a meter or a meter and a half thick. This condition was found only in the shallower lakes of this class. In the others the cool, lower stratum of water which was not kept in circulation by the wind, varied in thickness from a very few meters to as much as 60 m., depending upon the depth of the lake. This group is characterized by the fact that there is a more or less pronounced decrease in the dissolved oxygen in this lower stratum of water during the summer. The amount of the decrease varied very much in the different lakes. In some the bottom water contained 75 to 80 per cent. as much oxygen as the surface which was freely exposed to the air; while in others a layer of bottom water of varying thickness was entirely devoid of free oxygen.

The second group of lakes may be further separated into two divisions for convenience in the discussion. The first comprises those lakes in which the supply of dissolved oxygen in the lower water is not entirely exhausted during the summer, the amount varying from about 80 per cent. of that in the surface water to only a trace; the second division includes those lakes in which the dissolved oxygen is completely exhausted from more or less of the lower water. The lakes belonging to the first division vary in depth from 7 m. to 72 m. Diagrams for White Eagle lake (fig. 32) and Big Butternut lake (figs. 33 and 34) show two of the shallow lakes belonging to this group while diagrams of Green and Geneva (figs. 36–42) are examples of the deep lakes. It will be noted that there is only a comparatively thin stratum of water in the shallow lakes which shows a decrease in free oxygen, but this region is very much thicker in the deeper lakes, being thickest in Green lake which has a maximum depth of 72 m. (See tables, pp. 147, 166.)

In 56 lakes, or more than a third of the total number, a stratum of bottom water has been found which contained no dissolved oxygen for a longer or shorter period during the summer. In some lakes this condition may be found for only two or three weeks, while in others, for example Beasley and Garvin lakes, such a stratum of water may exist for a period of about five months (figs. 43–53). The stratum of water which is devoid of free oxygen may be very thin (1 m. to 2 m.) in some lakes, but in others it may have a thickness of 15 m. The dissolved oxygen always disappears first at the bottom, because there is a greater amount of decomposable material, hence a larger amount of decomposition there. This stratum then gradually increases in thickness and in some cases the free oxygen is exhausted from practically all of the water below the thermocline. In the west part of North lake, for example, only a trace of dissolved oxygen was found at 6 m., none at 7 m. and none thence to the bottom, 22 m., on August 21, 1906, so that the stratum of water which contained no free oxygen was almost 2.5 times as thick as that which did have more or less of this gas in solution. The volume of water in the upper 6 m. constitutes a little less than 45 per cent. of the total volume of the lake, hence about 55 per cent. of the water of the lake was either completely devoid of free oxygen, or practically so. Lake Mendota belongs to this class of lakes and in August the stratum which contains no dissolved oxygen may include as much as half the maximum depth of the lake, or about a third of the total volume.

It has already been pointed out that the lower water in a thermally stratified lake is cut off from further contact with the air after stratification and hence has no opportunity to obtain a new supply of oxygen from the air until the autumnal overturn. As a rule very little if any ground water ever reaches the deeper water of a lake directly and even if it did, it is generally so deficient in oxygen that very little of this gas would be contributed to the lower water from this source. Neither are conditions favorable in the lower water of a deep lake for the photosynthetic activities of the algae, so no free oxygen will be derived from this source. Hence the summer supply of oxygen in this region is limited to the amount which the water possesses at the time that it becomes stratified. When this supply is once exhausted, this water must remain free of oxygen until the autumnal overturn.

Two factors are responsible for the exhaustion of the oxygen dissolved in the lower water. The living organisms, both plants and animals, which inhabit this region use up some of this oxygen in the process of respiration. But by far the most important factor concerned is the decomposition of organic matter. A small amount is doubtless used in the direct oxidation of dead organic material but most of it is exhausted in the decomposition which results from the action of bacteria.

The decomposable matter is derived from various sources but the material which probably affects the largest volume of water is that derived from plankton forms, more especially from the phytoplankton. In general the latter reproduce very rapidly under favorable conditions and live a comparatively short time. Thus when the upper water contains an abundance of phytoplankton it will furnish a constant supply of decomposable material to the lower water. Through the floating devices possessed by these organisms, their specific gravity is reduced so that it is generally only a very little greater than that of water, some forms even being able to remain suspended for several hours in seventy or eighty per cent. alcohol. Forms which possess such a low specific gravity will sink very slowly through the cool, lower water when they die, and this will give opportunity for them to pass through at least the early stages of decay on their downward passage. In this way the supply of oxygen in the lower stratum will be affected not only at and near the bottom but throughout the entire region below the thermocline. The decomposition of a great deal of phytoplankton in the upper water also sometimes causes a material decrease in the oxygen here, in spite of its free exposure to the air.

The specific gravity of most zooplankton forms is greater than that of phytoplankton forms. Thus they sink more rapidly and their decomposition does not proceed very far before they reach the bottom. For this reason they are probably not such an important factor in exhausting the oxygen supply through decay except at the bottom.

Another important source of decomposable material is the shore vegetation, more especially the leaves of trees. Lakes whose shores are covered with deciduous trees will receive a very large amount of decomposable material in the form of leaves when these are shed in the autumn. They will be blown into the lakes and will eventually sink to the bottom. A few lakes have been found in which the bottom in the deeper portions of the lakes is literally carpeted with decomposing leaves. The decay of this material goes on more or less rapidly at all times and it is a very important factor in removing dissolved oxygen from the bottom water in lakes where it is so abundant.

The shallow water vegetation also contributes its quota of organic material to the deeper water. The larger aquatic plants are frequently torn loose from their moorings in shallow water by the action of the wind and waves, especially in the fall, and carried out to deep water where they sink, thus contributing to the supply of decomposable material on the bottom. In lakes which have very little water shallow enough for such plants, this source of material would not be of very great importance but in lakes which have large areas of shallow water, such as wide shallow margins for instance, where such plants may thrive in abundance, this would be an important source of organic material.

As already indicated, there may be no complete overturning of the water in the spring in small lakes which are well sheltered from wind. In such cases the bottom stratum receives only a small supply of oxygen at this season, or in extreme cases, none at all. This small supply will soon be exhausted and the bottom water will then remain without free oxygen until the autumnal overturn, which means a considerable period of time in some instances. In 1909, for example, there was no complete vernal overturn of the water in Beasley lake and the small supply of oxygen which reached the bottom stratum through a slight mixture with the water above was exhausted by the first of June and this stratum remained without free oxygen until early November or for a period of five months. In 1906 also, no dissolved oxygen was found in the bottom water of Garvin lake between the middle of May and the middle of October, a period of five months. (See figs. 49–53, pp. 194, 195, and tables, p. 147.)

In addition it may be said that the supply of oxygen in the bottom water of such lakes is completely exhausted in early winter so that this stratum is free from dissolved oxygen for a month or two in winter also. This means, then, that the bottom water in such lakes may be devoid of free oxygen for a period of 6 to 7 months during the year. Such a prolonged period during which free oxygen is absent from this stratum is of considerable importance from a biological standpoint, more especially with respect to the bottom fauna.

In the larger lakes, where the wind is more effective in disturbing the water, there is a complete vernal overturning which is followed by more or less of a vernal circulation. The period of time during which this circulation continues varies of course in the different lakes and in fact, varies in the same lake from year to year, depending upon weather conditions. During a cold, windy spring for example the circulation will continue for a longer period than during a warm one in which there is not so much wind. The longer the period of complete circulation lasts, the later will the consumption of the final supply of oxygen in the bottom water begin, and consequently the later will this supply of oxygen be exhausted in those lakes where the dissolved oxygen entirely disappears from this stratum in summer.

The effect of weather conditions is well shown in results obtained on Mouse lake (See table p. 157). On May 11, 1906, its bottom water contained only 0.1 cc. of dissolved oxygen per liter but on May 11, 1907, it had 6.6 cc. The bottom water of several other lakes contained more dissolved oxygen during the latter part of May, 1907, than during this period in 1906, but the differences were not so great as in Mouse lake. Generally one and a half to two times as much was found in 1907 as in 1906.

The rapidity of the decrease of the oxygen in the lower water depends chiefly upon three factors, the quantity of decomposable material, the temperature of the water, and the volume of water below the thermocline. The larger the amount of decomposable matter, the faster will the dissolved oxygen be used up. In a plankton-poor lake, the decrease will be slow on account of the scarcity of organic matter. The higher the temperature of the lower water, the faster will decomposition take place and, consequently, the more rapidly will the supply of oxygen decrease. In some lakes the bottom water does not have a temperature of more than 5° to 7° during the summer, while in others it may rise to 13° or 14°. Obviously, of course, the process of decay will proceed more rapidly in the water having the higher temperature and other conditions being the same, the dissolved oxygen will decrease more rapidly in lakes whose bottom water has a temperature of 13° to 14° than in those having the cooler water.

Likewise the rapidity of this decrease will depend upon the volume of water below the thermocline because the amount of dissolved oxygen in this water will be proportional to the volume of water. Also the extent of the oxygen decrease in the lower water, is a function of the quantity of decomposable material contributed to this region, and of the volume of the water. (See tables pp. 146, 147, 148, for results on Elkhart, Geneva, and Green lakes.)

A peculiar and interesting distribution of dissolved oxygen has been observed in a few lakes in the region of the thermocline. In a stratum from 0.5 m. to 2 m. thick situated about the middle of the thermocline, the oxygen decreases more rapidly than in the water a few meters below. This more rapid decrease in this region produces a distinct notch in the oxygen curve here as may be seen in figures 77, 84, 88, and 115. In some instances the more rapid decrease continues here until the dissolved oxygen is all used up, resulting in a separation of the lake into 4 strata with respect to oxygen. There will be an upper stratum consisting of the upper, warm water and the upper part of the thermocline which contains a considerable amount of dissolved oxygen; below this, the thin stratum in the thermocline which is devoid of free oxygen; below this, a stratum containing some dissolved oxygen, as much as 0.8 cc. per liter in some instances; and lastly, a bottom stratum in which the dissolved oxygen has been exhausted. As yet, the causes of the more rapid depletion of the oxygen in the mid-thermocline stratum are not clearly evident. Plankton crustacea are sometimes found in large numbers in this region before the dissolved oxygen is entirely exhausted, and they, of course, use up some oxygen in respiration, but it does not seem probable that the respiration of these crustacea is the sole factor involved. Indeed it seems evident that in most lakes of this type the respiration of crustacea must play only an unimportant rôle because no large aggregations of them are found in this region. Here again decomposition, it would seem, is the chief factor. The water of this stratum is much colder than the upper water, sometimes as much as 10°. The organisms constituting the phytoplankton adjust their floating devices such as oil droplets, gas vacuoles, etc., so as to enable them to remain suspended in the warmer upper water. But when they die and sink down to this region where the water rapidly becomes colder, their downward progress will be checked for a time because the density of this water is greater. Therefore it seems probable that they may remain here long enough to permit them to pass through the early stages of decomposition and in this way they may make inroads upon the supply of dissolved oxygen at this depth. It is possible also that either senile or healthy phytoplanktonts sink into this region and live here saprophytically for a time and under such conditions, they would actively consume oxygen. (See figs. 40, 77, 84, 88, 90, 100 and 115.)

Excess Oxygen.

So far only those factors have been considered which are active in using up dissolved oxygen. There are activities going on in the upper water, however, which increase the supply of oxygen in this region. These activities not only aid in keeping the water saturated with oxygen, but under favorable conditions they may result in the supersaturation of certain strata of water with this gas. A few meters of the upper water of lake Mendota may thus become supersaturated with oxygen under favorable weather conditions, and other lakes show the same phenomenon. The upper water always contains chlorophyl-bearing organisms whose numbers vary from a few hundreds per liter in some lakes to as many as several hundred thousand in others. The number found in any one lake from time to time during the summer varies very widely of course. When exposed to light, these organisms are able to carry on the process of photosynthesis in which carbon dioxid is taken up from the water and broken up into its two elements. The carbon is retained for further use in the plants and the oxygen is liberated, some or all of it passing into solution in the water so that the quantity of this gas may be raised above the saturation point.

In lake Mendota the maximum amount of excess oxygen was found at a depth of only a meter and a half; and such an accumulation of oxygen can take place only during calm weather. A breeze would set this upper water into circulation and it would all be exposed to the air from time to time where the oxygen tension would be lower and the excess would be imparted to the air. Even during calm weather, more or less of the upper water will be disturbed by convection currents on cool nights and will thus be exposed to the air, so that the excess of oxygen will be greatly reduced at least. In this upper stratum, then, the excess oxygen will not be much greater than the amount which the chlorophyl-bearing organisms can produce in a single day, for the disturbances due either to wind or convection currents will prevent the accumulation of a large amount of excess oxygen at so slight a depth. But some lakes have been found in which rather large amounts of excess oxygen accumulated in the upper part of the thermocline. Since the water at this depth is disturbed very little by wind action and not at all by convection currents, it may remain supersaturated with oxygen for a long period of time. (See figs. 43–46 and 54–62.) The transparency of the water is such in these lakes that the algae in the thermocline receive enough light to enable them to carry on their photosynthetic activities. As stated above the water of this region is affected very little by the wind, so that oxygen is removed only by decomposition, respiration, and the slow process of diffusion. When the algae are active and the light is favorable, the production of oxygen greatly exceeds the consumption, consequently it accumulates in this region until there is a large excess in some instances.

The maximum amount of oxygen was found in Knights lake on August 26, 1909. At a depth of 4.5 m., there were 25.5 cc. of oxygen per liter of water, which was 364.5 per cent. of saturation. The following table shows the results obtained on this date and a previous one.

TABLE VIII.—*Knights Lake.*

August 14, 1909.			August 26, 1909.		
Depth.	O_2 in cc. per liter.	Per cent. of saturation.	Depth.	O_2 in cc. per liter.	Per cent. of saturation.
3 m..........	6.8	109.1	3.0 m.......	7.6	123.8
4 m..........	19.2	282.5	3.5 m.......	13.4	206.5
5 m..........	23.6	321.5	4.0 m.......	20.4	301.0
6 m..........	4.9	62.8	4.5 m.......	25.5	364.5
			5.0 m.......	21.2	293.0
			5.5 m.......	6.8	89.8
			6.0 m.......	1.4	18.1

Otter lake ranks second in respect to excess oxygen. At a depth of 4 m. on August 26, 1909, the amount of dissolved oxygen was 18.9 cc. per liter of water, which was 297 per cent. of saturation and 25.0 cc. (396.2 per cent. of saturation) were found at a depth of 4.5 m. on July 25, 1910.

Several investigators have found an excess of dissolved oxygen in the waters of ponds and lakes during the summer but the maximum quantity that has generally been found at this season was about 300 per cent. of the amount required for saturation. Both Knights lake and Otter lake have shown larger amounts than this, each rising considerably above 300 per cent. of saturation, but the maximum amounts of this gas have been found at a depth of 4.5 m. in both lakes. At that depth the hydrostatic pressure is about half an atmosphere and this extra pressure would aid materially in holding the oxygen in solution. It is doubtful whether the amount of oxygen could have risen much higher without some of it being liberated in bubbles, and, in fact, it seems probable that some of it escaped in this way even under the above conditions. When this water was pumped up to the surface it effervesced very freely, so it is safe to say that the quantity of oxygen indicated in the results does not represent the entire amount that was present.

The problem of the rapidity of manufacture and accumulation of oxygen in the excess oxygen stratum has not yet been thoroughly studied; but data bearing on this question have been obtained in 4 lakes. In lake Mendota it was found that the quantity of oxygen rose as much as 1.3 cc. per liter of water per day at a depth of 1.5 m. (see p. 43) on one date and apparently a little more than this on another. During the summer of 1910 regular observations were made on 3 lakes at Waupaca. The maximum increase of oxygen in Beasley lake was a rise from 7.7 cc. per liter of water to 12 cc. at a depth of 3 m. between June 14 and June 20. This was an increase of a little more than 0.7 cc. per day during this period. In Knights lake the quantity of oxygen rose from 8.5 cc. to 14 cc. at a depth of 5 m. between June 29 and July 2, which was a daily gain of a little more than 1.8 cc. At the same depth, the quantity of oxygen rose from 2.8 cc. on June 10 to 14 cc. on July 2, a daily gain of a little more than 0.5 cc. for this long period. In Otter lake the quantity of this gas increased from 8.2 cc. on July 20 to 22.4 cc. on July 23 at a depth of 3 m., a gain of 14.2 cc. in 3 days or a daily gain of about 4.7 cc. During the same period also, there was an increase of 12.4 cc. in the quantity of oxygen at 3.5 m. and of 4 cc. at 4 m.

These gains doubtless represent by far the greater part of the oxygen liberated at these depths, because little would be lost from these strata by diffusion and little or none would escape in the form of bubbles. A portion of this gas, however, is consumed in the processes of respiration and decay but this will not represent a very large percentage of the entire amount of oxygen liberated, especially when it is being liberated at a rate of 1.5 cc. or more per liter of water per day.

With respect to the correlation in depth between the maximum amount of oxygen and the maximum number of algae, in lakes which have a stratum containing an excess of this gas, it may be said that various results have been obtained, the major portion of the data showing no very close relation between the two. In figure 138, it will be noted that the maximum number of diatoms was found at 5 m. in Beasley lake, on August 3, 1908, and the largest amount of oxygen was found at this depth; the other algae, however, reached their maximum at 2 m. In Knights lake (fig. 139) the diatom maximum was located at a depth of 2.5 m. and that of all other algae at 3 m. on August 14, 1909. But the maximum amount of oxygen was found at 5 m., or 2 m. to 2.5 m. below the maxima of algae, where the number of these organisms was small. Similar, but less marked differences were found on August 25. (Fig. 140.) On this date the diatoms reached a maximum at 4 m. and the other algae at 3 m., while the oxygen maximum was in the 4–5 m. stratum. In Silver lake (fig. 141) the largest number of diatoms was found at 7 m. on August 21, 1907, where the water was distinctly alkaline and contained the largest amount of dissolved oxygen. While the other algae showed a distinct increase in number at 7 m., yet they were most abundant at 1 m. Figure 142 shows a very different set of conditions on August 27, 1908. On this date the largest number of algae was found at 10 m. where the oxygen was about 9 per cent. below the saturation point, while the largest amount of oxygen was found at 8 m. where the water was also alkaline. It seems that the most probable explanation of this condition is that this set of observations was made soon after a crop of algae had reached its maximum development and that they were thus found in an early stage of their decline. It seems probable, however, that a more complete knowledge of this high oxygen phenomenon would reveal a much closer correlation in depth between algae and excess oxygen.

In the smaller lakes, where the excess oxygen stratum lies within 4 m. to 5 m. of the surface, the large plants growing in shallow water may contribute oxygen to this stratum during their photosynthetic activities. In Otter lake, for example, much of the bottom is covered with *Chara* to a greater depth than the high oxygen stratum, so that some of the excess oxygen might be liberated by this plant. But several sets of observations made in August, 1906, gave no evidence that such is the case. In two larger lakes, Elkhart and Okauchee, several observations having this same end in view, gave negative results.

Some European observers have noted very marked diurnal changes in the amount of dissolved oxygen in small, shallow bodies of water, especially fish ponds, and attention has been called to such changes in the upper water of lake Mendota in September, 1908 (p. 43). In Mendota, the excess oxygen stratum comprised only the upper two or three meters which were readily disturbed by wind and by convection currents. Thus there was a pretty thorough mixture of this upper water at night so that the oxygen became uniformly distributed in this stratum. As a consequence, there was an appreciable decrease in the quantity of oxygen in the layer having the largest excess, that is at a depth of 1.5 m., and on the succeeding day the amount of oxygen would again increase at this depth, thus producing a diurnal variation of 1 cc. to 1.5 cc. per liter of water. But where the excess oxygen has been found in the thermocline region, no appreciable diurnal variations have been noted. That is, the difference between day and night observations did not prove to be any greater than the differences between two sets of day observations, one of which was made immediately after the other.

Several sets of day and night observations made on Elkhart and Otter lakes where this transition stratum contained a marked excess of oxygen, gave negative results. At such a depth the water was not disturbed by the wind during the day, nor by wind or convection currents at night, so that no mixture of the water took place which would have reduced the supply of oxygen. Also no appreciable amount of oxygen was lost during the night through decomposition, diffusion, and the respiration of organisms.

OXYGEN CONDITIONS IN BEASLEY, LONG, AND RAINBOW LAKES IN 1909.

Figure 48 shows the oxygen conditions in Beasley lake on March 19, 1909. It will be noted that about 2 meters of the bottom water contained no free oxygen and that there were only 1.8 cc. and 0.1 cc. per liter respectively at 9 m. and 11 m. Plate IV indicates the conditions for the following spring, summer, and autumn. This seasonal diagram shows clearly that no vernal overturn had taken place on April 22, which was only a very few days after the ice had disappeared from the lake, and later observations showed that no complete overturning took place before summer conditions set in. The first set of observations showed that the mixing process had resulted in giving the water at 12 m. and 14 m. only traces of oxygen. During the month of May, however, more of the upper water was mixed with the bottom stratum and the amount of oxygen increased slightly but it did not rise above 0.4 cc. per liter which was found on May 5. It disappeared entirely from this stratum before June was far advanced. More than 6 cc. of dissolved oxygen were found at 10 m. in the first and second observations, thus showing that the water at this depth had been mixed rather freely with the water above, but the oxygen decreased very rapidly at this depth during the latter part of May as a result of the decay which took place there, and thereafter the quantity remained small until late October.

The decrease was more gradual at 8 m. and the amount of free oxygen did not reach a minimum until late September and early October. The upper 7 m. of water, which comprised the epilimnion and the upper part of the thermocline, contained an abundance of dissolved oxygen during the time of these observations although there was a marked decrease at 7 m. in September. With this one exception, the oxygen in this upper water amounted to 90 per cent. or more of the quantity required for saturation. The curve representing the surface shows that this water contained the maximum amount of dissolved oxygen on April 22; this was followed by a gradual decrease till the first of July, after which there was an appreciable increase followed by a fairly uniform condition which lasted until late October; this was succeeded by a decrease and then a marked increase the last of October and in early November. In this diagram it will be noted that the maximum quantity of oxygen was not found at the surface as in lake Mendota. As a result of the activities of chlorophyl-bearing organisms in the 3-6 m. stratum, the amount of dissolved oxygen found in this region exceeded that at the surface during almost the entire summer. At 3 m. the amount was greater than at the surface as early as May 5. The maximum was found on June 3, but within the next two weeks, a marked decrease took place because the water at this depth was gradually mixed with the upper stratum which was kept in circulation by the wind, thus preventing any accumulation of excess oxygen here. Some idea of the amount of mixing may be gained from the change in temperature. Between June 3 and June 17, the temperature at 3 m. increased 2.1° but the water at this depth had not yet been thoroughly

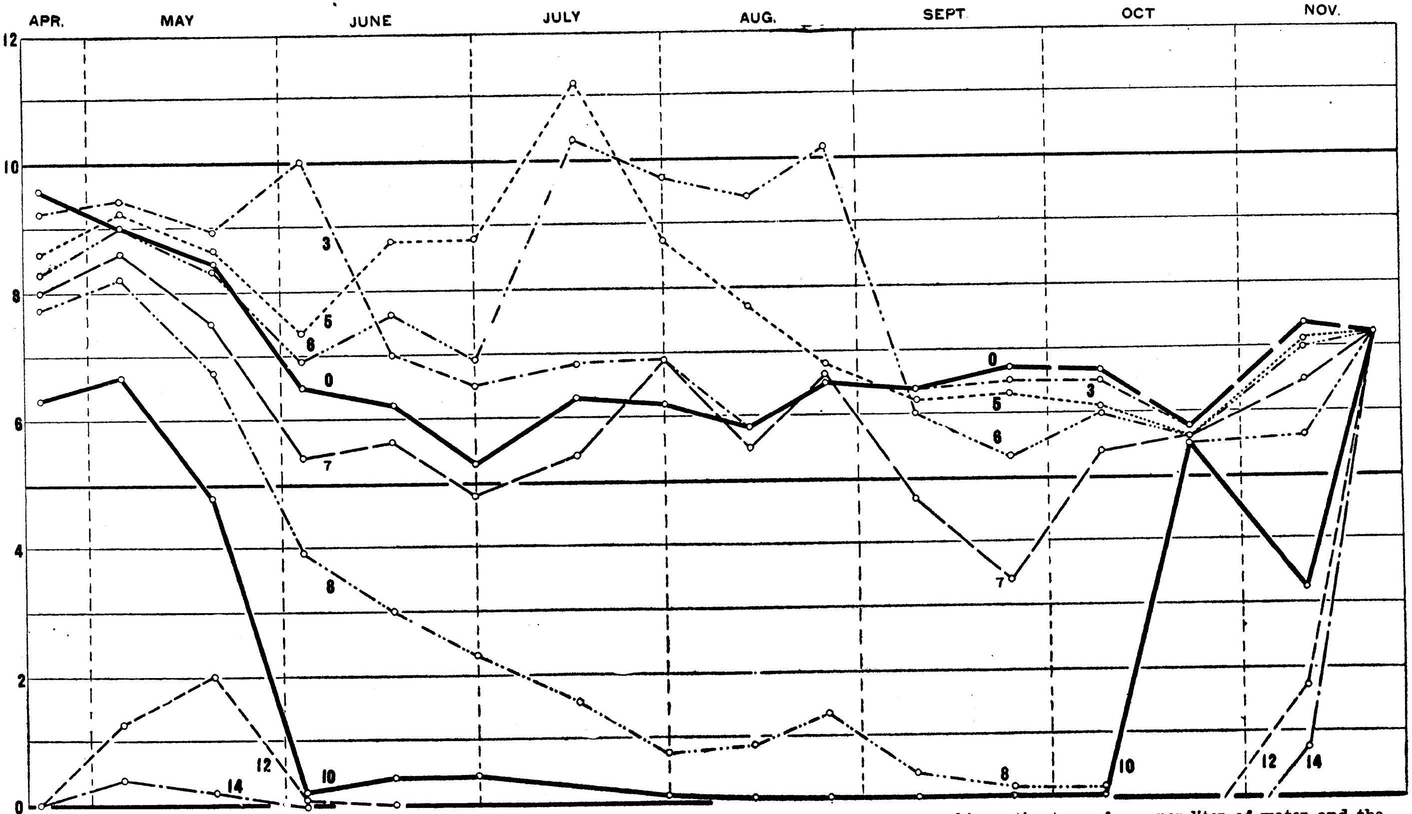

Plate IV.—Dissolved oxygen at different depths in Beasley lake in 1909. Vertical spaces represent cubic centimeters of gas per liter of water and the figures attached to the curves indicate the depth in meters.

mixed with the upper water for it was still 2.2° colder than the surface.

The decrease at 3 m. was followed by a marked increase at 5 m. which reached its maximum on July 16. This was followed by a decrease, resulting from the downward movement of the thermocline, which continued until the quantity of oxygen even fell below that at the surface in early September. The decay and respiration taking place in this region were responsible for the decrease below the average amount in this upper stratum.

The curve for 6 m. shows that coincident with the maximum at 5 m. was one nearly as great at 6 m. but the period of high oxygen at the latter depth continued until the latter part of August when it suddenly decreased because the thermocline reached this depth at this time and some of the upper water which was poorer in oxygen was mixed with the 6 m. water. At this depth also, the amount finally fell below that at the surface as a result of the respiration and decay taking place here and doubtless as a result also of mixture with more or less of the water below which contained a smaller amount of dissolved oxygen.

Oxygen conditions in the 0-6 m. stratum remained fairly uniform from September 9 to October 8, but this period was followed by a decrease because more and more of the lower water which contained little or no oxygen was added to the upper stratum as the latter cooled and because the summer algae were declining at this time and conditions favored the consumption of oxygen rather than its production. During the last week in October and the first half of November, the weather was fairly warm and calm, so that the water remained almost stationary in temperature and was not greatly disturbed by wind. As a result of these conditions, there was a marked decrease in the amount of oxygen at 10 m. which, in all probability, was due to two causes: (1) To mixture of the water in this stratum with that below which contained little or no free oxygen; (2) to the rapid oxidation of organic matter which had been accumulating in this lower water under anaerobic conditions during the summer. During this time there was an increase in the quantity of oxygen in the 0-7 m. stratum as a result of the free exposure of this water to the air and as a result of the photosynthetic activities of the autumn phytoplankton. The last set of observations represented in the diagram shows that the oxygen conditions were uniform from surface to bottom thus indicating that the autumnal overturn was completed shortly after the middle of November.

Plate V, representing the oxygen conditions in Long lake at Waupaca, shows that the vernal overturn was not completed on April 22, 1909, but on May 5 conditions were almost uniform from surface to bottom. During the next two weeks, there was an increase in the amount of oxygen in the 0–5 m. stratum and a pronounced decrease at 10 m. and below. This decrease in the lower water continued until only a trace of free oxygen was found at the bottom on July 1 and it entirely disappeared at 15 m. before the middle of August. Scarcely more than a trace was found at 10 m. from September 9 to October 8, but this condition was followed by a period of rapid and marked increase when the water at this depth was added to the upper circulating stratum as a result of the cooling of the upper water. It will be seen, also, that oxygen began to appear at 15 m. about the middle of October and steadily increased in amount till the completion of the autumnal overturn shortly after the middle of November. The water at 18 m. and 21 m. was the last to be disturbed in the overturning process and hence was the last to be aerated. So the water at these depths shows a very sudden and very marked increase in free oxygen just as the overturn was completed.

The diagram shows that there was a gradual decrease in the quantity of oxygen at 8 m. from about the middle of May till the last week in September when a minimum of 1 cc. per liter of water was found. There was a marked increase at this depth in late September and early October. There was also a decrease in the oxygen at 7 m. during the latter part of May and first half of June which was succeeded by a small, gradual increase for a month. This was followed by a second gradual decrease to a minimum of 3.7 cc. on September 24 and then an increase as autumnal conditions set in.

The surface water showed a marked decrease in dissolved oxygen in late May and early June as a result of the increase in the temperature of the water, thus lowering its capacity for dissolved oxygen. About the first of July a small but steady increase in oxygen began, the quantity rising from 6 cc. to a little more than 7 cc. per liter by October 8. A marked decrease followed in the next two weeks due chiefly to the decreased photosynthetic activities of the algae, to the decay taking place in the circulating stratum, and to the mixture of the upper water with more and more of the lower, which contained little or no free oxygen. The chlorophyl-bearing organisms produced enough oxygen at 5 m. and 6 m. to raise the amount above that at the surface during the latter part of May and this condition continued

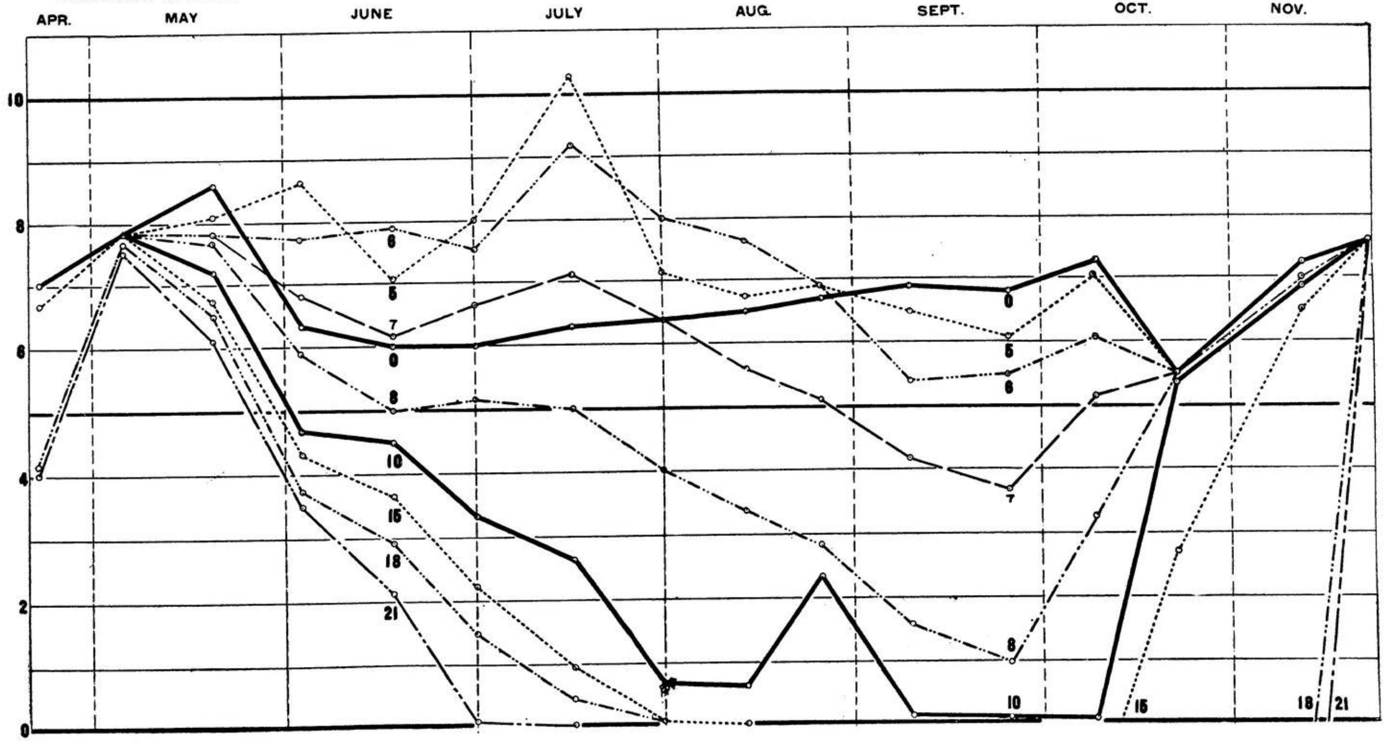

Plate V.—Dissolved oxygen at different depths in Long lake in 1909. Vertical spaces represent cubic centimeters of gas per liter of water and the figures attached to the curves indicate the depth in meters.

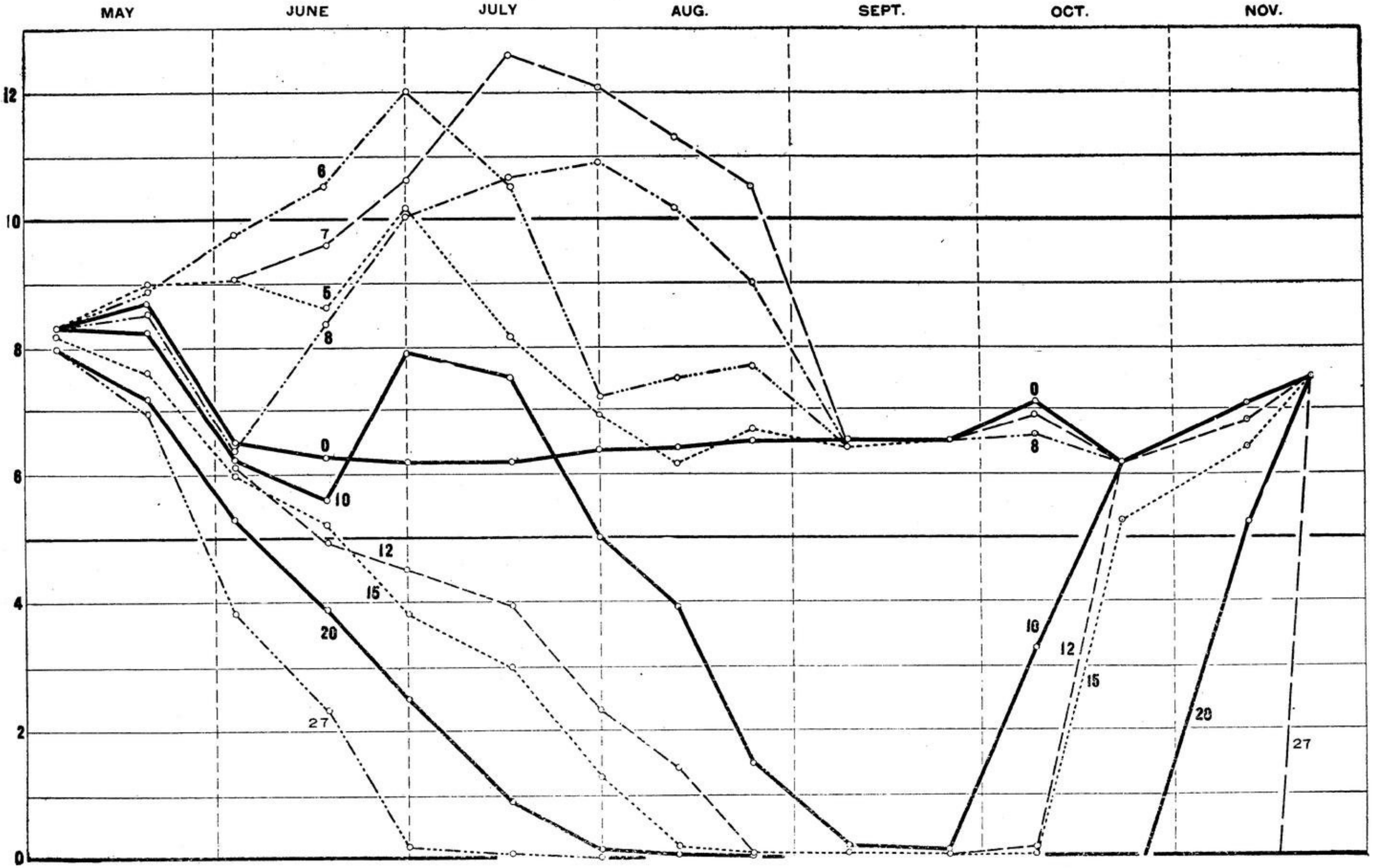

Plate VI.—Dissolved oxygen at different depths in Rainbow lake in 1909. Vertical spaces represent cubic centimeters of gas per liter of water, and the figures attached to the curves indicate the depths in meters.

until the latter part of August, the maximum amounts at these depths being found on July 16.

The diagram for Rainbow lake (Pl. VI) shows that its oxygen conditions were much like those that have already been described for Beasley and Long lakes. There was the same general decrease in the amount of oxygen in the lower water during the season, there being almost none below 10 m. for a time in September. Enough oxygen was produced by chlorophyl-bearing organisms in the 5–10 m. stratum to raise the amount above that at the surface and this condition was maintained for longer or shorter periods at the different depths. At 10 m. there was a marked increase in late June and the amount remained greater than at the surface until July 16, after which there was a gradual decrease at this depth to a minimum in September. This decrease was correlated with a marked decrease in the transparency of the water. The 5–8 m. stratum contained much more dissolved oxygen than the surface during the months of June, July, and August; in fact a maximum of a little more than twice the amount at the surface was found at 7 m. on July 16. In early August, however, the water at 5 m. was added to the upper circulating stratum and consequently the amount of oxygen at this depth was reduced to the quantity found at the surface. The 6–8 m. stratum remained undisturbed until early September when its stock of free oxygen rapidly decreased to practically the amount found at the surface because the water of this stratum also was gradually added to the circulating stratum above.

Results of Other Investigators.

Rather high supersaturations due to the action of chlorophyl-bearing organisms, have been found even in streams where one might suppose that the water was disturbed sufficiently to prevent such accumulations of oxygen. Palmer[1] found, however, in the Illinois river where the current was rather sluggish that the quantity of this gas might rise to more than 220 per cent. of saturation. Both Lord[2] and Horton[3] have noted an excess of oxygen in Ohio streams.

On the other hand, Spitta[4] found only a very few cases of supersaturation in the Spree river, the quantity of dissolved oxygen being

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[1] Streams Examination, Sanit. Dist. of Chicago, p. 88. 1902.
[2] Investigation of Rivers, Ohio St. Board of Health, 1897–98, p. 53.
[3] Thirteenth Ann. Rept. Ohio St. Bd. of Health, p. 351, 1899.
[4] Archiv für Hygiene, XXXVIII, p. 215–93. 1900.

more or less below the saturation point during almost the entire year, and in all of his samples of water from the Rhine, the oxygen was below the saturation point.

In winter, Knauthe[1] found a much larger quantity of excess oxygen in some of the ponds which he studied when they were covered with ice. In one pond he found the surprisingly large amount of 49 cc. of oxygen per liter of water, just under the ice. This was about 515 per cent. of the amount required for saturation. A phenomenal increase in oxygen was noted in this pond, the amount at the surface rising from 29.8 cc. on January 16, noon, to 42 cc. on January 17, 12:30 p. m. This period of very high oxygen lasted three days and was correlated with a very large growth of chlorophyl-bearing organisms. During the daytime when these organisms were actively producing oxygen the water became alkaline as a result of the consumption of carbon dioxid.

During the years 1901 and 1902, Voigt[2] made a study of the dissolved gases in the Grosser Plöner See. For the determination of the oxygen and nitrogen, he unfortunately employed the Tenax apparatus which so frequently gives irregular and unreliable results according to several investigators. As a consequence some of his oxygen determinations show wide variations which are wholly at variance with the results that have been obtained on Wisconsin lakes. Likewise Halbfass'[3] results for dissolved oxygen in the Pommeranian lakes show irregularities of a similar character and magnitude and it seems probable that these variations may be attributed to the faulty method employed in making the determinations and also to the fact that in some instances the determinations were not made until many hours after the samples of water were obtained.

A striking illustration of the ineffectiveness of diffusion as a factor in the distribution of oxygen in a lake, has been given by Hüfner.[4] According to his calculations, if the Bodensee, whch is 250 m. deep, should lose its supply of dissolved oxygen and should then acquire a new supply from the air by diffusion alone, it would require over a million years for the entire body of water to become saturated with this gas.

Lebedinzeff[5] has obtained some interesting results on the Caspian

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[1] Biol. Centralb. XIX, p. 783-99. 1899.
[2] Plöner Forschungsber., XII, p. 115-144, 1905.
[3] Petermanns Mitteilungen, Nr. 136, p. 97, 1901.
[4] Arch. für Anat. und Physiol. (Physiol. Abteil.) 1897, p. 112.
[5] Aus der Fischzuchtanstalt Nikolsk, No. 9, p. 113-136, 1904.

and Black seas and on a freshwater lake which he has studied. In these bodies of water, he found oxygen conditions which are very similar to those that have been found in some of the Wisconsin lakes. In the Caspian sea, which has a maximum depth of about 972 m., he found a marked decrease in the oxygen below a depth of 150 m., with only a very small amount at and below 575 m. Correlated with this was a zonal distribution of the plankton crustacea. In the upper strata crustacea were abundant and consisted chiefly of copepods; below 150 m. the copepods decreased in number gradually and the schizopods increased. A relict fauna was common up to a depth of 350 m. but it was entirely absent below this depth. Mollusca have not been found at a depth greater than 300 m.

In the Black sea, which has a maximum depth of 2500 m., Lebedinzeff found only minimal amounts of oxygen at depths of 183 to 200 m. As the quantity of oxygen diminished, living organisms decreased in numbers and no life was found below 183 m. The lower water contains more salt than the upper, hence it is heavier than the latter and as a result there is no vertical circulation to any great depth. Thus the lower strata are permanently cut off from contact with the air so that it is impossible for this lower water to obtain a supply of oxygen and this author thinks that such conditions have existed for a very long period of time. As a consequence only a little over 7 per cent. of the maximum depth of the Black sea is habitable. In both the Caspian and Black seas the lower strata contain a considerable amount of hydrogen sulphid.

In Pestowosee, which is a freshwater lake with a maximum depth of 16 m., this investigator found a minimum amount of oxygen at the bottom in late July, 0.28 per cent. of saturation. The maximum amount for the year was coincident with the lowest temperature of the water.

The following table gives some results for dissolved gases which were obtained by Delebecque[1] on lake Geneva, Switzerland and lake Nantua, France.

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[1] Les Lacs Francais, p. 240, 1898.

TABLE IX.

Lake.	Date.	Depth.	Temperature.	O_2.	N_2.	Total CO_2.
Geneva...	Aug. 14, 1894	0 m	....	6.70	....	....
		10 m	....	6.75	....	....
		20 m	....	7.97	....	....
		30 m	....	7.72	....	....
		50 m	....	7.83	....	....
		100 m	....	7.59	....	....
	July 3, 1895...	0 m	20.5	5.63	13.08	40.23
		100 m	4.8	6.70	15.98	39.39
		250 m	4.5	6.1	16.6	40.7
Nantua...	Aug 15, 1894	0 m	....	7.71	....	....
		5 m	....	8.19	....	....
		10 m	....	7.09	....	....
		20 m	....	5.87	....	....
		30 m	....	5.23	....	....
		40 m	....	1.79	....	....

It will be noted that a uniformly large amount of oxygen was found at all depths from which samples were obtained in lake Geneva, Switzerland, there being no marked decrease down to a depth of 250 m. No results are given beyond this depth, so it is impossible to say whether or not similar conditions obtained in the deepest water where the lake reaches a maximum depth of 309.4 m. Such oxygen conditions are very different from those that have been found in Wisconsin lakes in July and August, when the above observations were made. In our lakes, a more or less marked decrease in the oxygen will be found in the lower water at this season.

In lake Nantua, however, there was a distinct decrease in the dissolved oxygen at a depth of 40 m. This lake has a maximum depth of 42.9 m. which is the same as that of lake Geneva, Wisconsin, but observations made during three seasons show that the quantity of dissolved oxygen in the lower water of this Wisconsin lake has been distinctly smaller by August 15, than the amount which was found in lake Nantua on this date. (See table, p. 147.)

With respect to substances held in solution, sea water differs so widely from fresh waters that it will not be profitable to make more than two or three comparisons here. Under the same conditions of temperature and pressure a liter of sea water will hold only about 82 per cent. as much oxygen in solution as a liter of distilled water. Clowes and Biggs[1] reached the conclusion from their experiments that this decreased capacity for oxygen is due to the large amount of NaCl present in sea water. They found no difference, however, between the oxygen capacity of common river water and that of distilled water.

In some of their marine investigations, Pettersson and Ekman[2] found at times a marked decrease in the dissolved oxygen with increasing depth. The results given for July 5, 1893, show the presence of 8.17 cc. of oxygen per liter of sea water at a depth of 20 m.; at 100 m. it was 3.09 cc., and at 400 m., 1.33 cc.

In September, 1903, Lebedinzeff[3] found a marked decrease of the dissolved oxygen with increasing depth in the water of Mofjord. The amount was only 64.5 per cent. as great at 20 m. as at the surface and less than a third as much at 40 m.; it decreased to 0.24 cc. per liter at 100 m. and an average of 0.2 cc. at 200 m. No life was found in the 100-200 meter stratum.

Helland-Hansen[4] also observed a marked decrease in the amount of dissolved oxygen in the lower water of some oyster ponds situated in Norwegian fjords. The ponds were connected with the main bodies of water in the fjords only during unusually high tides. In the meantime quiescent conditions prevailed during which the dissolved oxygen in the lower water decreased, even disappearing entirely at a depth of 5 m. or 6 m. in some instances, thus threatening the destruction of the oysters.

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[1] Jour. Soc. Chem. Indus., XXIII, p. 358-9. 1904.
[2] Kgl. Sv. Vet. Akad. Handlingar, XXIX, No. 5, p. 1-125, 1897.
[3] Aus der Fischzuchtanstalt Nikolsk No. 10, p. 125. 1905.
[4] Meddelelser om Oesteravlen III, p. 1-109. 1907.

CHAPTER III.

CARBON DIOXID.

Carbon dioxid is readily soluble in water and a water which is freely exposed to the air will contain more or less free carbon dioxid under normal conditions, as this gas is one of the constituents of the atmosphere, being present in the proportion of 3 or 4 parts in 10,000. But only a small amount will be absorbed from the air because it is taken up only in proportion to its partial pressure. The free carbon dioxid of a water, however, will be affected by the presence of chlorophyl-bearing organisms when there is enough light for photosynthesis, and also, by the presence of decaying organic matter.

The normal carbonates of calcium and magnesium are only slightly soluble in pure water; a liter of such water at 16° will dissolve 0.0131 g. of $CaCO_3$ (Schlösing)[1] and at 15° about 0.627 g. of $MgCO_3$ (Treadwell and Reuter)[2]. Rainwater, however, contains some free carbon dioxid which it has absorbed from the air and it obtains still more from decaying organic matter upon its passage through the ground. This water which is charged with free carbon dioxid is an active agent in dissolving these normal carbonates when it comes in contact with them in the ground, being capable of dissolving them in proportion to the amount of free carbon dioxid which it possesses. That is, this carbonated water changes the normal carbonates of calcium and magnesium which are only slightly soluble in water, to bicarbonates which are readily dissolved and carried along with the ground water, finally reaching the lake through springs. Thus in addition to free carbon dioxid the ground water entering a lake will contain carbon dioxid which is in combination with other substances, chiefly calcium and magnesium. Surface drainage water, however, will contain a smaller amount of bicarbonates because the soil is

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[1] Compt. rend., LXXIV, p. 1552. 1872.

[2] Zeit. f. an. Chem., XVII, p. 199. 1898.

usually poor in carbonates as a result of the leaching that takes place in this stratum.

Soils from various parts of Wisconsin show a wide range in fixed carbon dioxid content, the amount varying from a minimum of 0.003 or 0.004 per cent. of the dry weight to a maximum of 6.0 per cent. In the soil and subsoil of sandy regions, such as portions of northeastern and northwestern Wisconsin, the average amounts are about 0.04 per cent. for the soil and about 0.02 per cent. for the subsoil. Some red clay soils that have been analyzed, show an average of about 0.06 per cent. with as much as 5.5 per cent. in the subsoil. In some samples of soil obtained on the shores of lake Mendota, the fixed carbon dioxid ran as low as 0.02 to 0.03 per cent.

The carbon dioxid which is found in natural water in chemical union with other substances exists in two different states. That which is united with the base in the form of normal or monocarbonate, such as $CaCO_3$, or $MgCO_3$, is known as the *fixed* or *combined* carbon dioxid; and that which is required to convert the monocarbonate into a bicarbonate is called the *half-bound* or *bicarbonate* carbon dioxid and it is indicated in the second member of the bicarbonate symbol $CaCO_3 . H_2CO_3$. The half-bound carbon dioxid is not in such a stable union as the fixed and is, therefore, intermediate between the fixed and the free. It is in such a loose combination, in fact, that the algae are able to make use of a very large part of it in their photosynthetic activities. No portion of the fixed, however, is available for the algae.

LAKE MENDOTA.

The water of lake Mendota contains from 17 to 29 parts of calcium per million, the amount varying with the season and also with the depth at certain seasons of the year, and from 20 to 26 parts of magnesium. The amount of SO_4 does not exceed 15 to 18 parts per million and the chlorin amounts to only about 3 parts, so it seems safe to assume that the calcium and the magnesium are found chiefly in the form of bicarbonates. Therefore, they may be regarded as responsible for most of the 70 to 90 cc. of half-bound and fixed carbon dioxid per liter of water which are found in this lake. In the tables of the appendix (p. 152) the results are stated in cubic centimeters of carbon dioxid per liter of water at 0° and 760 mm.

Fixed Carbon Dioxid. There are distinct and regular variations in the quantity of fixed or carbonate carbon dioxid during the various seasons of the year. With the exception of the variations in a thin stratum of water just under the ice in winter, however, the changes scarcely ever exceed 15 per cent. of the average amount contained in the water at the different seasons. Beginning with the water at the time it passes into winter conditions, we find the fixed carbon dioxid uniform from surface to bottom as a result of the autumnal circulation. The average amount at the time the lake froze over on December 16, 1905, was about 38 cc. per liter and on December 18, 1906, 34.5 cc. In the former year this amount gradually increased during the winter to an average of about 39.5 cc. throughout the main body of the lake, that is from about 1 m. to a depth of 18 m. The increase in the bottom water was more marked as it reached a maximum of 43.8 cc. on March 29, 1906. (Fig. 11.) During the winter of 1906-7 the fixed carbon dioxid increased to an average of 36 cc. in the main body of the lake while the bottom water reached a maximum of 40 cc. Thus it will be noted that the changes during these two winters were of about the same magnitude although the total quantity in the former year was somewhat greater than in the latter.

The maximum variations take place within the upper meter of water and they are caused by the inflow of drainage water, which contains only a small amount of fixed carbon dioxid. Consequently after every winter thaw which results in a considerable inflow of this water, there will be a stratum just under the ice which contains a relatively small amount of fixed carbon dioxid. On April 3, 1906, for instance, the following results were obtained: Just under the ice 3.4 cc. of fixed carbon dioxid per liter of water; at a depth of half a meter, 17.6 cc.; and at 1 m. 37.9 cc. In a few days this drainage water becomes mixed with lake water, which contains more fixed carbon dioxid and, as this mixing process goes on, a larger and larger amount of fixed carbon dioxid will be found in this stratum until finally almost or quite the normal amount may be found here if the mixing has continued for a sufficient period of time. Then this may be followed by another rain or thaw with a consequent inflow of drainage water which forms another stratum that is deficient in fixed carbon dioxid. Thus during the winter, there may be several changes in this surface stratum from almost or quite the normal amount of fixed carbon dioxid to a relatively small amount, depending upon weather conditions. In March, 1906, so much drainage water which was poor in fixed carbon dioxid flowed into the lake and became mixed with the upper stratum, that the water at a depth of 5 m. contained less than the normal amount of fixed carbon dioxid. (See figs. 8–11 and 29–31, and tables, p. 152.)

At the completion of the spring overturn the fixed carbon dioxid is again uniformly distributed from surface to bottom but there is practically no change in amount from that found in late winter. The average for all depths on March 29, 1906, a few days before the overturn, was 37.5 cc. per liter of water and just after the overturn it was found to be 37.6 cc. In 1907 the averages were respectively 35.7 cc. and 35.8 cc. Within a short time after the overturn there was a decrease at all depths amounting to about 1.4 cc. in 1906 and 0.9 cc. in 1907, after which the quantity remained fairly constant until early June. During the rest of June and in July, there was a decrease in the upper water and the minimum amount (32.6 cc.) was found at the surface during the latter part of August in 1906, and the minimum for 1907 was 31.8 cc. on July 23. A gradual increase in the amount of fixed carbon dioxid in the bottom water began early in June each year and continued during the summer, reaching a maximum not long before the fall overturn. The changes which the fixed carbon dioxid underwent during the summer of 1906, are shown in figures 12 to 21. The autumnal overturn and circulation distributed the fixed carbon dioxid uniformly again and there was very little change in its quantity until after the lake was covered with ice.

As yet it has not been possible to determine definitely just what causes the decrease in fixed carbon dioxid soon after the vernal overturn of the water. In 1906 the decrease took place within 8 days and in 1907 within 5 days after the overturn, but no factor was noted which could be held responsible for the change. In the former year, the water, down to a depth of 18 m., changed from a distinctly alkaline reaction to a neutral one during the period of decrease, and this should have tended to prevent the loss of fixed carbon dioxid. In 1907 the water changed from a distinctly acid condition at all depths to a neutral one. These facts make the phenomenon still more puzzling. This period of rapid decrease was succeeded by one in which the quantity remained fairly constant and then in early summer the fixed carbon dioxid began to gradually decrease in the upper water and increase in the lower. Gravimetric analyses show that there are changes in the quantity of calcium held in solution by the water corresponding to the changes in fixed carbon dioxid; that is, that there is a decrease of calcium in the upper water during the summer and an increase in the lower. The magnesium shows very little or no change. Various factors are responsible for the decrease of calcium in the upper water during the summer. As already stated the normal carbonate of calcium is only very slightly soluble in water. When the plants remove enough half-bound carbon dioxid from the upper water to make it strongly alkaline, the normal carbonate of calcium thus produced would tend to precipitate because of its low degree of solubility. Since also the normal carbonate is not so soluble in warm water as in cold, the increase in the temperature of the water during spring and summer would increase this tendency to precipitate.

The submerged aquatic plants which grow in shallow water also remove much calcium from the upper stratum. Much calcareous material is found both on the outside and within the tissues of *Chara* for instance, and the leaves and stems of *Potamogeton* are always covered with a tolerably thick incrustation of such material. An analysis of this crust showed that nearly 34 per cent. of its dry weight was calcium and only 0.6 per cent. magnesium. In fact this incrustation is frequently so thick on the older leaves that it must impair their photosynthetic activities very materially. In some portions of the lake these plants are abundant, so that they would undoubtedly remove an appreciable amount of calcium from the upper water in the course of the summer. Analyses of *Chara* show that 28.2 per cent. of the dry weight of this plant is composed of calcium and 1.66 per cent. of magnesium. That is, it contains about 17 times as much of the former as of the latter. Also some of the lime-secreting algae which grow upon the rocks in shallow water remove more or less calcium from the water, for these rocks are frequently found with a tolerably thick coating of lime.

The molluscan population of the lake is found chiefly in the shallower water and the calcium removed by them in the formation of their shells reduces the stock of this substance in the upper water.

A very small but perhaps an appreciable amount of calcium is removed from the upper water by plankton organisms when they die and sink into the lower strata. Analyses show that these organisms contain over sixty times as much calcium as an equal mass of water. But they also contain nearly as large an excess of magnesium and there is very little or no increase in this substance in the lower water during the summer. It would seem, therefore, that the plankton plays only an unimportant rôle in the transfer of calcium and magnesium from the upper to the lower water.

Several writers have pointed out that precipitation of the carbonates in sea water and other saline waters is promoted by aeration and agitation resulting from wind action. It may be that agitation of the water in lake Mendota by wind has a tendency to produce a precipitation of the carbonates although this water is quite fresh, but some preliminary experiments along this line gave negative results. However, more thorough tests of this nature must be made before the question can be definitely answered one way or the other. There is undoubtedly a deposition of carbonates along the shore from water dashed upon it by strong winds but this deposition would result from the evaporation of the water rather than from a precipitation produced by agitation.

The increase in the amount of calcium during the summer below the thermocline is due to several factors also. As a result of the decay of organic matter, the water of this region becomes charged with various amounts of free carbon dioxid, the amount increasing as the season advances. Any calcium which might be precipitated in the water above and sink down into this region would be readily dissolved. Also this water which is charged with free carbon dioxid would exert a solvent action on any calcium carried down by the plankton organisms which die and sink into this region. The maximum amount of calcium, however, is found in the water which is in contact with the bottom mud. About 24 per cent. of the dry weight of mud found on the bottom in deep water consists of calcium and as the water in contact with it is charged with free carbon dioxid, some of the normal calcium carbonate will be changed to bicarbonate and pass into solution. By diffusion, it will then be distributed through more or less of the lower water, but the process of diffusion goes on so slowly that a comparatively thin stratum of water will have its calcium content increased in this way. The slow currents in this bottom water which result from the action of the wind on the upper water also aid in the distribution of the water having a high calcium content. The fact that there is little or no increase of magnesium in the bottom water during the summer is very probably explained by the presence of such a comparatively small amount of this substance in the mud. Magnesium constitutes only about 1.3 per cent. of the dry weight of this mud. (See table, p. 171.)

Half-bound Carbon Dioxid. In neutral waters and those which possess free carbon dioxid, the half-bound or bicarbonate carbon dioxid is equal in amount to the fixed so that a curve representing the quantity of half-bound carbon dioxid in such waters would be exactly identical with one showing the fixed carbon dioxid. If a water gives an alkaline reaction with phenolphthalein, however, it signifies that there is an excess of normal carbonate in the water, that is, the quantity of half-bound carbon dioxid is smaller than that of the fixed. In such a water, the free carbon dioxid may be regarded as a negative quantity and the bicarbonate, or half-bound carbon dioxid would be the algebraic sum of the fixed and free.

Chlorophyl-bearing organisms are able to use a very large portion of the half-bound carbon dioxid in their photosynthetic activities, which makes this portion of the carbon dioxid a very important factor from a biological standpoint. Seyler[1] concluded from his experiments with *Ulva* that the photosynthetic process stopped before all of the half-bound carbon dioxid was used up, but one of his results shows that about four-fifths of it could be removed. A set of observations on Big Butternut lake, Wisconsin, showed that the plankton algae had removed about five-sixths of the half-bound carbon dioxid from the upper stratum of that lake. This left a rather large excess of normal carbonate in both instances, which made the water strongly alkaline. (See fig. 33, p. 185, and table, p. 166.)

Free Carbon Dioxid. The water of lake Mendota which receives a sufficient amount of light to permit photosynthesis, is generally well stocked with algae during the greater portion of the year and their demands for carbon dioxid are greater than the supply of free carbon dioxid which this water obtains from various sources such as the air, the respiration of various organisms, the decay of organic matter, and the ground water. Consequently they draw upon the supply of half-bound carbon dioxid and this results in making the upper water alkaline. The degree of alkalinity varies of course, depending upon several factors, chief among which are the abundance and activity of the algae, the season of the year, and the weather conditions. As might be expected it is greatest in summer when the phytoplankton is most active and when this activity is rëenforced in a measure by that of the submerged aquatic plants growing in shallow water.

As an illustration of the effectiveness of submerged aquatic plants

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[1] Chem. News, LXX, p. 139. 1894.

in producing a high degree of alkalinity, attention may be called to some results obtained in a portion of lake Mendota known as University bay. The head of this bay is very shallow, scarcely exceeding half a meter in depth, and it is fairly well separated from the remainder of the bay by a bar which is covered by only a few centimeters of water. An abundant growth of aquatic plants, such as *Carex, Batrachium, Potamogeton,* and filamentous algae, is found in this shallow water and they draw heavily upon the half bound carbon dioxid for their supply of this gas. Following a period of calm, clear weather in June, 1910, it was found that the water in this shallow portion of the bay had a very high degree of alkalinity, a maximum equivalent to 18.7 cc. of carbon dioxid per liter of water being found on June 28. The fixed carbon dioxid amounted to only 28.8 cc. per liter of water, which was more than 3 cc. less than found in the surface water of the lake. Owing to the shallowness of this water, the oxygen liberated by the plants was readily imparted to the air and as a result this high degree of alkalinity was accompanied by only a small excess of oxygen, the amount being but 30.6 per cent. above the saturation point.

The degree of alkalinity is measured by the amount of carbon dioxid that would be required to convert the normal carbonates into bicarbonates and thus give the water a neutral reaction with phenolphthalein. For example, a titration of surface water on July 30, 1907, showed the presence of 32.3 cc. of fixed and 27 cc. of half-bound carbon dioxid per liter. The difference between these two—5.3 cc.—shows the alkalinity; that is, it would require 5.3 cc. of carbon dioxid to convert the normal carbonates into bicarbonates and make the water neutral; in other words 5.3 cc. of half-bound carbon dioxid per liter of water had been removed by chlorophyl-bearing organisms. In the diagrams showing the results of single observations, the alkalinity or negative carbon dioxid is indicated by that portion of the carbon dioxid curve which lies to the left of the zero line and the free carbon dioxid by that portion which lies to the right.

At the time the lake becomes covered with ice, the free carbon dioxid is uniform from surface to bottom as a result of the autumnal circulation. Just after the ice covered the lake in 1905, the water was found to be slightly alkaline at all depths and in 1906, the alkalinity amounted to 1 cc. per liter of water. This uniform condition does not remain for a very long period of time, however. The alkalinity in the upper water increased by 0.3 cc. to 0.5 cc. during the winters 1905–06 and 1906–07, and with the exception of one region it remained pretty constant throughout both winters. This exception was the thin stratum of drainage water that is sometimes found just under the ice and which has already been mentioned as showing large variations in oxygen and fixed carbon dioxid. This drainage water possessed free carbon dioxid so that just after its appearance this water gave an acid reaction but by mixture with lake water and through the activities of the algae it was soon changed to an alkaline condition. In this way the water of this stratum my change from alkaline to acid and back again to alkaline a few times during the winter.

As already stated, the process of decay in the bottom water, although very much retarded because of the low temperature, is not entirely suspended and its rapidity increases somewhat as winter advances, as a result of the increase in the temperature of the water. Free carbon dioxid, of course, is one of the products of decay and enough of it is produced within a comparatively short time after the lake freezes over to change the water from a neutral or distinctly alkaline reaction to an acid one and this acidity gradually increases during the winter. Thus during the winter of 1905–06, the bottom water changed from a slightly alkaline condition at the time the lake froze over to a distinctly acid one before the ice disappeared in the spring, there being 5.6 cc. of free carbon dioxid per liter of water. (See fig. 11.) During the winter of 1906–07, it changed from an alkalinity of 1 cc. to an acidity of 5 cc. and on March 6, 1909, (fig. 31), there were 9 cc. of free carbon dioxid at the bottom.

When the spring overturn is completed the conditions are again uniform from surface to bottom, the entire body of water being near the neutral point. This homogeneous state lasts as long as the entire body is kept in circulation. As the algae increase in number and become more active in the process of photosynthesis, the alkalinity increases. Plate VII shows the condition at various depths during the summer. The spaces above the zero line represent negative carbon dioxid or the alkalinity, while those below the line show the free carbon dioxid. Starting with a neutral condition on April 20, we find a distinct increase in the alkalinity at all depths, more especally in the upper water, up to May 11. As a result of incomplete circulation after this date, the water below 18 m. soon became acid, due to the presence of the free carbon dioxid produced by decomposing organic matter and by the respiration of organisms, while the water at 15 m. also, became acid early in June. The amount of free

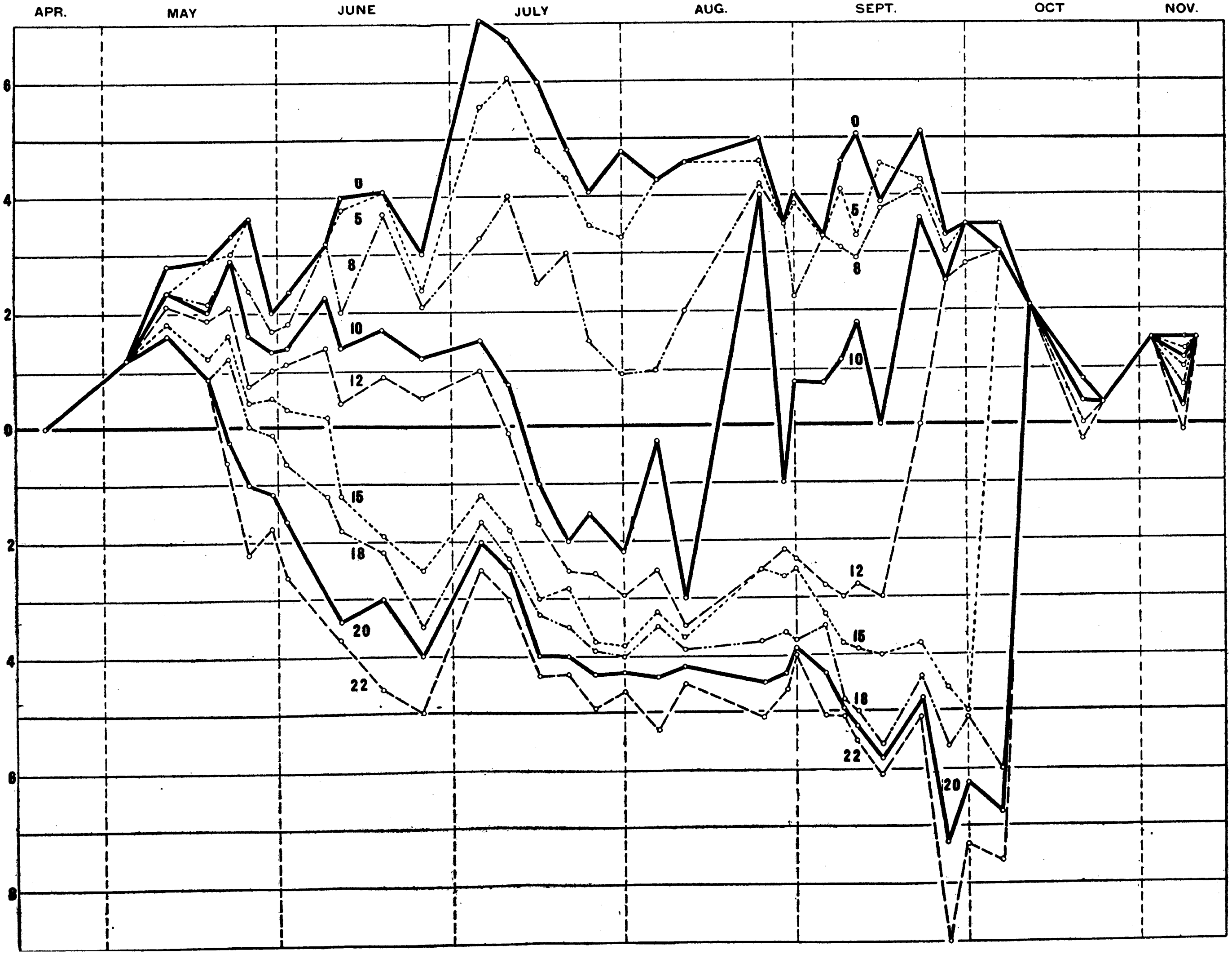

Plate VII.—Free carbon dioxid at different depths (0 m. to 22 m.) in lake Mendota in 1906. The vertical spaces represent cubic centimeters of gas per liter of water. Spaces above the zero line show negative carbon dioxid, or the alkalinity, and spaces below, the acidity in terms of carbon dioxid.

carbon dioxid at 22 m. varied somewhat during the summer, but the total result was an increase to a maximum of 9 cc. near the end of September. As long as the water at 10 m. and 12 m. was included in the upper stratum which was kept in circulation by the wind, it remained alkaline. The maximum alkalinity at these depths was reached during the latter part of May; then it declined somewhat and remained fairly constant during the month of June. At both depths however, it became acid before the middle of July because a definite thermocline was formed above them so that this water was cut off from further mixture with that above and the decay which took place there soon produced enough carbon dioxid to make the water acid. At 10 m. the water remained acid until about the middle of August when the thermocline had moved down to this depth and added this water to the circulating stratum. In its downward progress, the thermocline did not reach 12 m. till after the middle of September, consequently the water at this depth remained acid until this time. The upper 8 meters of water remained alkaline during the entire summer because it was kept in circulation by the wind and was the region in which photosynthesis was carried on; the demand for carbon dioxid in this process was greater than the supply of free; so some of the half-bound carbon dioxid was used, thus keeping the water alkaline. The alkalinity at the surface was much greater most of the time between early June and late August than at 8 m. but the difference between the surface and 5 m. was not very marked during this period.

A general decline in the alkalinity of the water of the epilimnion began toward the end of September and continued until late October. This decline was due chiefly to four factors. 1. The temperature of the water was falling at this time so that conditions for the summer algae, chiefly green and blue green forms, were gradually growing more unfavorable and the rising crop of diatoms was not so active in the process of photosynthesis. 2. As the thermocline was moving down into the deeper water rather rapidly at this time, much water which contained free carbon dioxid was mixed with the alkaline water above and the result was a tendency to reduce the alkalinity. 3. Strong winds are generally frequent at this season and the circulation of the upper stratum would be more vigorous so that the water would be frequently exposed to the air from which it could absorb free carbon dioxid. 4. The decomposition of organic matter would also furnish free carbon dioxid and much decomposable material was furnished by the lower water when it was mixed with the upper.

The overturning of the water between October 8 and 11 mixed the whole body of water thoroughly and resulted in an alkalinity from surface to bottom amounting to 2.1 cc. The effect of alternation of calm and windy periods is shown for the last half of October and the early part of November. Strong winds mixed the water thoroughly and made conditions uniform. During the calm weather, the alkalinity in the bottom water decreased rather rapidly as a result of the decomposition of organic matter there and on two occasions the bottom water was found to be acid. There was a decline in alkalinity at other depths also but decomposition was greatest at the bottom because there was a greater amount of organic material in that region.

Ammonia. In order to determine whether the alkalinity of the upper water was due in any appreciable degree to the presence of free ammonia, some samples of water taken at the surface and at a depth of 1 m. were tested by the direct nesslerization method. With phenolphthalein, these samples showed an alkalinity amounting to 5 cc. of carbon dioxid per liter, but only a trace of free ammonia was found in the nesslerization tests, the average amount being about one part per hundred million. In view of these results free ammonia may, therefore, be disregarded as a factor in causing the alkalinity. Drown[1] pointed out that free ammonia was lower in the pond waters which he studied, in summer than in winter because more of it was removed by plants in summer. Plants are capable of using free ammonia in their anabolic processes so they will readily use up more or less of the free ammonia in the water. As plants are generally more abundant and more active in summer than in winter, larger quantities of this gas will be removed from the water in summer. The upper water of lake Mendota is generally well stocked with algae in summer and they undoubtedly are responsible for keeping the free ammonia down to such a small quantity. Thresh[2] states that very few natural waters are found which do not contain some trace of ammonium salts and that, except in acid, rain, and moorland waters, it probably always exists as ammonium carbonate. In the form of a neutral bicarbonate, it would not affect the alkalinity but, if changed to a normal carbonate through the action of the phyto-

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[1] 24th Ann. Rept. St. Bd. of Health of Mass., p. 322, 1893.

[2] The Examination of Waters and Water Supplies, p. 89, Philadelphia, 1904.

plankton, it would affect the alkalinity just the same as a normal carbonate of calcium or magnesium.

Formates. A question arose as to whether the acidity in the lower water in summer might not be due in part to the presence of other substances besides free carbon dioxid. It was thought that organic acids, such as formic for instance, might be formed in the lower water, especially in those lakes where there is no free oxygen in this region so that decomposition takes place under anaerobic conditions. Accordingly two tests were made on the lower water of lake Mendota to determine whether any formic acid was present. One test was made by Dr. G. I. Kemmerer in July, 1909, on water from which the dissolved oxygen had recently disappeared, but he obtained negative results. A second test was then made by Dr. W. F. Koelker in late September, 1909, on water obtained from the bottom stratum, at which depth no free oxygen had been found for almost three months, and his results were also negative. The water used for this second test showed the presence of 6.8 cc. of free carbon dioxid per liter. From these results then it seems evident that formic acid is not responsible for any of the acidity in the lower water of such a lake as Mendota. Whether it is produced in appreciable quantities in such lakes as Garvin and Beasley, where the acidity of the bottom water is several times as great as in Mendota, has not been determined as yet. On the basis of the above results, however, all acidity has been attributed to the presence of free carbon dioxid.

CARBON DIOXID OF OTHER LAKES.

For the sake of convenience in discussing the carbon dioxid conditions, and later also, in discussing their relation to biological conditions, the lakes that have been studied may be grouped into three classes on the basis of the amount of fixed carbon dioxid present. It must be remembered, however, that the lines separating the groups are drawn rather arbitrarily, since the maximum amount of fixed carbon dioxid found in some of the lakes belonging to the first group, closely approaches the minimum amount found in some lakes belonging to the second, and the same is true of the second and third. That is, considered as a whole, these lakes form a continuous series from those having the softest water to those having the hardest.

The first group may be termed the soft water lakes, since their waters hold small amounts of calcium and magnesium in solution.

In this class have been placed those lakes whose average fixed carbon dioxid content does not exceed 5 cc. per liter of water.

Five of these lakes had less than 1 cc. of fixed carbon dioxid, the amount being 0.4 cc. in one, 0.5 cc. in two, 0.75 cc. in the fourth, and 0.9 cc. in the fifth. In 14 of the 31 lakes belonging to this group, the average amount of fixed carbon dioxid was less than 2 cc.

The second group includes those lakes which may be regarded as having a medium amount of fixed carbon dioxid, those which had the minimum amount possessed only a little more than 5 cc. per liter of water, while those at the other extreme had nearly 22 cc. Ninety-one lakes in all fall within these limits. In 58, the average amount of fixed carbon dioxid does not exceed 10 cc. per liter of water; in 22, it was between 10 and 15 cc.; and in 11, it exceeded 15 cc., four of which contained more than 20 cc. All of the lakes in northeastern and northwestern Wisconsin and Devils lake in the southeastern part of the state belong to the first and second classes. The northern lakes are situated in a glaciated region where the drift appears to contain a comparatively small amount of calcareous material. Devils lake occupies a quartzite basin which contains very little drift.

The third class may be regarded as hard water lakes. Those having the minimum amount of fixed carbon dioxid contained on an average about 32 cc. per liter while those with the maximum amount had nearly 50 cc. All of the lakes belonging to this group are situated in the southeastern quarter of Wisconsin.

Soft Water Lakes. In 26 of the 31 lakes belonging to the first group, or soft water lakes, the water gave an acid reaction with phenolphthalein at all depths, thus indicating the presence of free carbon dioxid. In the lower water of the deeper lakes there was a higher degree of acidity than at the surface, which resulted from the production of free carbon dioxid in that region during the decay of organic matter. In some cases also, there was more free carbon dioxid in the upper water than would be absorbed from the air and this larger amount was doubtless due chiefly to the decay of organic material in the upper stratum.

The five exceptions noted above were Wild Goose (fig. 35), Little Sissabagama, and Hammills lake (fig. 63), all in northwestern Wisconsin; Clear lake at Minocqua (fig. 65) and Devils lake near Baraboo (figs. 66 and 67). In the first three lakes the surface water gave an alkaline reaction with phenolphthalein. In Wild Goose lake the alkalinity amounted to 0.5 cc. of carbon dioxid per liter of water at the surface and 0.25 cc. at the bottom, but the maximum depth is only 4.5 m. In the other two lakes the water was alkaline at the surface (equivalent to 0.75 cc.) but the lower water contained considerable free carbon dioxid (8.6 cc. and 9.6 cc.). In Clear lake the water has been acid from surface to bottom two out of the four summers it has been visited (see fig. 64) but on August 11, 1909, an alkaline stratum was found, being correlated with a region of high oxygen. The alkalinity at 7 m. and 8 m. amounted to 0.75 cc. with acid water both above and below these depths. (See fig. 65.) On July 15, 1910, the water of this lake was alkaline at 6 m. and 7 m. (1.0 cc. and 1.4 cc. respectively), but it was acid both above and below these depths. (See table, p. 166.)

Likewise the water in Devils lake has been acid generally from surface to bottom but on June 15, 1907, the surface water was neutral while that at 3 m. and 6 m. was alkaline. On July 6, 1907, the water at the surface and 3 m. was again acid, but still alkaline at 6 m. and on July 27, it was acid at all depths. The alkaline stratum was correlated with a very large growth of *Staurastrum* which reached a maximum number of 176,000 individuals per liter at 3 m. on June 15. (See figs. 66–68, p. 200.)

The amount of both half-bound and fixed carbon dioxid is small in these lakes, of course, and generally both are very uniformly distributed from surface to bottom.

Medium Waters. The quantity of fixed carbon dioxid in the upper stratum of water of these lakes varied from about 6 cc. in those with the softest water to almost 22 cc. in those with the hardest. In several of these lakes which were deep enough to be distinctly stratified thermally, there was a very marked increase in the amount of fixed carbon dioxid in the lower water, more especially near the bottom. In Allequash lake the amount in the bottom water exceeded that at the surface by as much as 10.3 cc. while in others this difference varied from 5 cc. to 8 cc. In the majority of instances, however, the difference did not exceed 3 cc. (See figs. 69–71.)

Among the lakes belonging to the second group, a surface stratum varying in thickness from 2 m. or 3 m. to 8 m. or 9 m. was found to be neutral in 4 and alkaline in 38 at the time they were visited. The maximum alkalinity was found in Butternut lake (fig. 33) where it was equivalent to 10.1 cc. of carbon dioxid. This high degree of alkalinity was correlated with a large growth of algae, chiefly *Staurastrum, Anabaena,* and diatoms in the order named. In some other lakes, also, this stratum had an alkalinity of 5 cc. to 7 cc., but in the great majority it did not exceed 3 cc. An alkaline stratum was also found in Silver lake, but it did not lie at the surface. (See figs. 72 and 73.) On August 21, 1907, the upper water to a depth of 6 m. was acid but at 7 m. the alkalinity was equivalent to 1.5 cc. of carbon dioxid per liter of water while at 9 m. and below it was acid. On August 27, 1908, the alkaline stratum was found at 8 m. with neutral water at 9 m. and acid both above and below these depths. This alkaline stratum was found for a third successive season on August 9, 1909. On July 19, 1910, the water of Silver lake was alkaline from the surface to a depth of 8 m., neutral at 9 m., and acid below this depth. In 4 of the lakes of this group, the water was either alkaline or neutral from surface to bottom but the maximum depth of these lakes did not exceed 6 m. The bottom water in all except these 4, was distinctly acid and in 49 of the 91 lakes belonging to this group, the water was acid from surface to bottom, the degree of acidity in most cases increasing very perceptibly toward the bottom.

Hard Water Lakes. Lake Mendota may be taken as a fair example of the third class of lakes, or those which have tolerably hard water. Some of the lakes belonging to this group have a greater amount of fixed carbon dioxid while others have a smaller amount than Mendota so that this lake may be regarded as a good representative of the group. It may be said also that, for the most part, the history of the carbon dioxid in the lakes of this group, is substantially the same as in lake Mendota. At the time of the vernal and autumnal overturns, the carbon dioxid conditions become uniform from surface to bottom and remain so as long as the period of complete circulation lasts. In a few of these lakes, however, that is, those which are comparatively small and well protected from winds, the weather conditions may be such that the general circulation is not complete in the spring. In such instances the gas conditions do not become uniform from surface to bottom. (See table for results on Beasley lake in 1909, p. 144.)

FREE CARBON DIOXID.

Winter observations have not been made on any lake regularly other than Mendota, so that the winter story of this gas must be confined to one or two sets of observations on each of seven lakes. Taking up first the free carbon dioxid, a set of observations on Green lake made on February 15, 1906, showed that the water was alkaline from surface to bottom, the degree of alkalinity being equivalent to 1.6 cc. of carbon dioxid at the surface and 1.2 cc. at the bottom (66 m.). (See fig. 36.) On February 22, 1906, the upper 15 m. of water in Nagowicka lake (see table p. 157) gave an alkaline reaction; it was neutral at 20 m. and acid below this depth, the free carbon dioxid amounting to 4.2 cc. per liter of water at the bottom (26 m.). On March 16, 1906, the water of this lake was acid from surface to bottom and the same condition was found on March 2, 1907. On March 3, 1907, the water in both parts of North lake (see fig. 80 and table p. 158) was acid from surface to bottom. The bottom water in the east part contained 7.5 cc. of free carbon dioxid per liter and in the west part 10.1 cc. The water of Okauchee lake (fig. 91) was also found to be acid throughout its entire depth on March 4, 1907. On March 19, 1909, it was found that the water in Beasley, Long, and Rainbow lakes was acid at all depths (see tables pp. 144, 150, 161), the bottom water in Beasley having as much as 20.4 cc. of free carbon dioxid per liter.

Only a few of these lakes have been visited either immediately or very soon after the disappearance of the ice in the spring, so the history of the free carbon dioxid at this particular period is not very complete for any lake except Mendota. In those lakes whose waters experience a complete vernal overturn after the disappearance of the ice, the free carbon dioxid will be uniform from surface to bottom upon the completion of this process. But there are lakes in which the vernal overturn is not complete. Results obtained on Beasley lake on April 22, 1909, which was only two or three days after the ice disappeared, showed that no complete overturn of the water had yet taken place and subsequent observations showed that it did not take place later. Under these circumstances, the vernal carbon dioxid conditions were similar to those found in summer. That is, the upper water was alkaline while there was a bottom stratum containing considerable free carbon dioxid; but the alkaline stratum was thicker in April than in summer and the bottom water did not have such a large amount of free carbon dioxid in April as it had later in the season. The decomposition of organic matter in the lower water during the summer adds very materially to the supply of free carbon dioxid, so that by the end of summer this water may possess a large quantity of the gas. Garvin lake is a good example of this type. Its shores are well wooded and in the autumn it receives a large supply of leaves which sink and literally cover the bottom.

In addition it supports a large growth of plankton which also furnishes much decomposable material to the lower water. When this material decays a large amount of free carbon dioxid is formed in the lower water and, as it escapes very slowly by diffusion, it accumulates in this region. In this way the bottom water may become so highly charged that it will effervesce vigorously when pumped up and exposed to the air. This effervescence may be accounted for in part by the presence of considerable methane but it seems certain that it is due very largely to the large amount of free carbon dioxid present. It was found that the bottom water of Garvin lake contained as much as 49.1 cc. of this gas on October 14, 1906, (fig. 53), and 30.4 cc. per liter on August 1, 1908. The bottom water of Beasley lake contained 32.9 cc. of free carbon dioxid per liter on October 8, 1909. (See tables, pp. 145, 147.)

In the larger lakes of this class, which are more exposed to the action of the wind, so that there is a complete vernal overturn of the water, the story of the free carbon dioxid is substantially the same as in lake Mendota. At the completion of the overturn the water may be neutral or more or less alkaline from surface to bottom and during the period of the vernal circulation it becomes distinctly alkaline as a result of the action of the algae. This condition obtains as long as the circulation of the water is complete. When the bottom water ceases to take part in the general circulation, however, it soon becomes acid, thus showing the presence of free carbon dioxid. This stratum of acid water gradually increases in thickness with varying degrees of rapidity in different lakes until it finally includes all of the water below the thermocline. In a deep lake, such as Green for example, all of the water below the thermocline may not become acid before late August or early September, but in the shallower lakes, those having a depth not to exceed 30 m., all of the water below the thermocline generally becomes acid very soon after the lake becomes thermally stratified. The free carbon dioxid accumulates in this water during the summer but never reaches a maximum of more than 15 cc. per liter, the amount being much less than this in the larger, deeper lakes. The upper water of these lakes remains alkaline during the summer, the degree of alkalinity depending largely upon the abundance and activity of chlorophyl-bearing organisms.

FIXED CARBON DIOXID.

In general, the history of the fixed carbon dioxid differs but little from that in lake Mendota. There are the same uniform conditions during the vernal and autumnal periods of circulation. The former is followed by a period in which there is a decrease in the fixed carbon dioxid in the upper water during the summer and an increase in the lower, the amounts of decrease and increase varying very much in the different lakes. The summer decrease amounted to as much as 6.7 cc. in the east part of North lake and only 5 cc. in Green. The bottom increase varied from a minimum of 2.8 cc. in Green lake to a little more than 20 cc. in Garvin. The winter observations that were made on lakes of this group, showed the same conditions substantially as found in lake Mendota.

Five lakes, however, have shown some more or less pronounced peculiarities in their fixed carbon dioxid which require special consideration. These lakes are Knights, Beasley, Long, and Otter of the Waupaca chain of lakes, and North lake which belongs to the Oconomowoc-Waukesha group. The most marked variations have been found in Knights, Beasley, and Otter lakes. Some of the diagrams showing the results for fixed carbon dioxid in these lakes have well defined notches in the region of the thermocline which indicate a stratum of water with a smaller amount of fixed carbon dioxid than the water either immediately above or below it. The following diagrams show such notches in the fixed carbon dioxid: Beasley lake, May and August, 1906, (figs. 43 and 44) and August 3, 1908, (fig. 46); Knights lake, August 14 and 25, 1909, (figs. 55, 56); Otter lake, August 20, 1906, and August 13, 1909, (figs. 58, 61).

With the exception of the observations on Beasley lake in 1906, it will be seen that these strata containing a smaller amount of fixed carbon dioxid are correlated with excess oxygen, the minimum amount of the former being found at the same depth as the maximum amount of the latter. This evidence seems to point to the chlorophyl-bearing organisms which produce the excess oxygen as the cause of the decrease in the fixed carbon dioxid. In the process of photosynthesis these organisms remove half-bound carbon dioxid from the bicarbonates in this stratum and reduce them to normal carbonates.

The presence of normal carbonates in the water gives it an alkaline reaction with phenolphthalein and the degree of alkalinity depends upon the amount of normal carbonates formed and hence upon the quantity of half-bound carbon dioxid removed. The increase in alkalinity in these lake waters does not continue indefinitely, however. It rarely becomes greater than equivalent to 7 cc. to 8 cc. of carbon dioxid per liter of water. When the alkalinity reaches this stage, it appears that some of the normal carbonates are precipitated and this prevents further increase. This precipitate sinks into the lower water and leaves the high oxygen stratum with a decreased amount of fixed carbon dioxid. This decrease is represented by a notch in the fixed carbon dioxid curve. Analyses show that this notch is due almost entirely to a decrease in the calcium. $CaCO_3$ is less soluble in water than $MgCO_3$ and of course will be precipitated first. (See tables, p. 144.)

Fig. 7 (p. 106) shows results of analyses of water obtained at different depths in Beasley lake on August 3, 1908. These results are expressed in parts per million. The samples were taken at the same time and from the same depths as samples for the determination of the carbon dioxid and the dissolved oxygen. The curve representing the calcium shows a notch corresponding to the one indicated in the fixed carbon dioxid. (See fig. 46.) There was a decrease in the magnesium at this depth also, but the quantity of magnesium below the thermocline did not increase sufficiently to give a well marked notch in this curve too. Judging from these results, it appears that the loss of calcium in this stratum is chiefly responsible for the decrease in fixed carbon dioxid and that magnesium plays a minor rôle. (See tables, p. 144.)

In some instances the smaller amount of fixed carbon dioxid was correlated with neither a very large excess of oxygen nor a marked alkalinity. The most probable explanation of this seems to be that these observations were made at a time when the organisms which were responsible for these conditions, were on the decline in number and activities, so that the decay and respiration taking place in this region would soon reduce the alkalinity as well as use up some of the excess oxygen.

It is interesting to note that no decrease of fixed carbon dioxid has been found in the excess oxygen stratum before the quantity of dissolved oxygen amounted to 14 cc. or 15 cc. per liter of water. On the other hand it may be said that 14 cc. to 15 cc. have been found in strata which did not show any decrease in fixed carbon dioxid.

Turning now to the results obtained on Beasley lake in 1906 (figs. 43 and 44) we see that the stratum with a smaller amount of fixed carbon dioxid was distinctly below the region of excess oxygen and increased alkalinity. The difference in depth between the maximum amount of oxygen and the minimum amount of fixed carbon dioxid varied from 3 m. on May 18 to about 1 m. in August. Furthermore the curves show that the minimum amounts of fixed carbon dioxid were found at depths where the water was either neutral or acid, and contained less dissolved oxygen than the amount required for saturation. There are two possible explanations of this phenomenon, neither of which is very satisfactory. The paucity of fixed carbon dioxid in this stratum might have been the result of the activities of chlorophyl-bearing organisms just as indicated above for Beasley lake in 1908, and for other lakes. But this explanation would necessitate the supposition that the organisms responsible for this condition had run their course and disappeared and that, likewise, all traces of alkalinity and excess oxygen had disappeared from this stratum by May 18. Furthermore, it would be necessary to suppose that all of this had taken place in about a month's time, for the ice does not usually leave Beasley lake before the middle of April and the spring circulation disturbs the water to a greater depth than this stratum, so this condition could scarcely have been produced in the winter and remained through the spring. As soon, however, as the thermocline was well established, which was some time previous to May 18, this stratum would not be subject to further disturbance until the thermocline moved down to this depth in late summer, and this would readily account for its preservation during the summer.

On the other hand, it is possible that this stratum was the result of purely physical factors. Three sets of observations have been made on Beasley lake in the latter part of April (April 26, 1907, April 17, 1908, and April 22, 1909) and in each case the fixed carbon dioxid was found to be much smaller in quantity, except near the bottom, than the average amount a month later, or in fact at any time during the summer. This smaller amount of fixed carbon dioxid resulted, doubtless, from the dilution of the lake water with a large amount of surface drainage water during the early spring floods. The water which flows into the lake through Beasley brook, the inlet, generally contains a larger amount of fixed carbon dioxid than was found in the main portion of the lake in April. Both the inlet and outlet are situated at one end, so that the water flowing into the lake may pass on through without being mixed with any large amount of the surface water. In this way, the incoming brook water which contains a larger amount of fixed carbon dioxid would be mixed with the surface water of the lake slowly and gradually so that enough time would elapse for the formation of a more or less distinct thermocline before the mixing process would reach this depth.

The thermocline region then and a stratum below would consist of water which had a smaller amount of fixed carbon dioxid as a result of the spring floods, and there would be no further chance for the mixture of this water with that above after the formation of the thermocline except as the latter gradually moves down deeper as summer progresses. It appears that some of the bottom water, about 2 m. generally, may not be disturbed very much at the time of the spring overturn and circulation, so that it retains a considerable amount of free carbon dioxid and also possesses much more fixed carbon dioxid than the water above which has been diluted with drainage water. This would form a surface and a bottom stratum with a larger amount of fixed carbon dioxid than the middle one. The increase in the thickness of these two strata would produce a sharply defined middle stratum which was deficient in fixed carbon dioxid. But no observations were made earlier than May 18, 1906, and consequently there are no definite evidences to show how this stratum was formed in that year. (See table, p. 144.)

The results for fixed carbon dioxid in Long lake for July 7 (fig. 93), and August 22, 1906, June 24, 1907, (fig. 95), and July and August, 1907, present small irregularities in the mid-stratum of the lake which were in all probability the result of physical conditions. This is a long, narrow lake and at its upper end, a stream of water flows into it from Beasley and another from Columbian lake. Therefore it does not seem at all unlikely that this inflowing water might form a surface stratum in spring over water which had been diluted by the spring floods and thus contained a smaller amount of fixed carbon dioxid. Then the increase in the fixed carbon dioxid in the bottom water would produce the conditions noted on the above dates, that is, a more or less definitely defined middle stratum which contains a somewhat smaller amount of fixed carbon dioxid than either the water above or that below. This stratum in Long lake is too poorly defined and too deep to be attributed to biological factors.

The fifth lake which requires special mention is North lake which belongs to the Oconomowoc-Waukesha group. This body of water consists of two parts which are connected only by a shallow channel, so that the two parts are in reality two distinct lakes. The water contains more fixed carbon dioxid than any other lake that has been studied. Judging from the results obtained in May and June, 1907, it seems probable that the fixed carbon dioxid is substantially the same in amount in both parts during the spring flood and circulation periods. Then, as the season advances a difference arises. In 1906 this difference was well established as early as May 11, on which date the first set of observations was made in that year. The excess of fixed carbon dioxid in the east part varied from 1 cc. to 4 cc. during the entire season, that is from May to October. In 1907 the amount of this gas was substantially the same in both parts in May and June, slight differences being noted in the latter month; on July 10 the excess in the eastern part averaged somewhat less than 1 cc. per liter of water down to a depth of 8 m., below which the two parts were about the same; on September 4 the differences at all depths varied from 2 cc. to 4 cc., the eastern part having the larger amount. A set of observations made on July 31, 1908, showed differences of this magnitude, also. (See table p. 158.)

The increase in the fixed carbon dioxid of the eastern part is doubtless accounted for very largely by the fact that it receives a considerable amount of spring water which contains about 25 per cent. more fixed carbon dioxid than the lake water. So far as can be determined, very little ground water enters the western part so that its supply consists almost entirely of the overflow from the eastern portion.

In 1906, the west part showed an unusual distribution of the fixed carbon dioxid in three sets of observations. The curves for July 30, and September 18 (figs. 77, 78), show a slightly greater amount of this gas in the lower part of the thermocline than in the water above or in that immediately below this region. This condition was established some time between June 29 and July 30 as it was not found on the former date but was on the latter. There was a marked decrease in the fixed carbon dioxid in the upper 4 m. of water during this interval of time and the increase in the 5–8 m. stratum probably resulted from normal carbonates which were precipitated out of the upper water and and were redissolved below upon reaching water which was charged with free carbon dioxid.

On the assumption that the half-bound carbon dioxid is equal to the fixed in neutral and acid waters, it is not necessary to discuss this part of the carbon dioxid, for its history would be the same as that of the fixed carbon dioxid in such waters and in alkaline waters, its amount would be equal to the algebraic sum of the fixed and the alkalinity, the degree of the latter being represented by a negative quantity.

FREE CARBON DIOXID, WAUPACA LAKES.

The diagrams representing the seasonal results on the Waupaca lakes (Plates VIII to X) are similar to the one already described for Mendota (Plate VII). That is, the zero line indicates neutrality, the space above this line indicates the degree of alkalinity, and the space below shows the amount of free carbon dioxid. The diagram for Beasley lake on March 19, 1909, (fig. 48) shows the late winter conditions in this lake and it will be noted that the water was distinctly acid at all depths, the maximum amount of free carbon dioxid being 20.4 cc. per liter of water at the bottom. Two or three days after the disappearance of the ice, that is, on April 22, conditions were very different with respect to free carbon dioxid. The water was found to be neutral at a depth of 6 m.; above this depth it was distinctly alkaline and below distinctly acid. The maximum amount of free carbon dioxid was 7.8 cc. at the bottom, just a little more than a third as much as had been present a month earlier. The seasonal diagram for Beasley lake (Plate VIII) shows that most of the water above 10 m. became alkaline by May 5 as a result of the action of chlorophyl-bearing organisms and of the circulation of the water which had extended nearly to this depth. But the water at 8 m. soon became acid and remained so during the rest of the season. With the exception of the water at 6 m. on July 1, the entire 0–6 m. stratum remained alkaline from April 22 till about the middle of October when enough of the lower water which was strongly acid, was mixed with the upper to make the water acid at all depths. None of the upper water was ever found with a very high degree of alkalinity, however.

There was a small but gradual increase in the amount of free carbon dioxid at 10 m. as the season advanced, a more marked increase at 12 m. but the largest increase was at 14 m. where the amount reached a maximum of almost 33 cc. per liter of water on October 8. The autumnal overturn made conditions uniform from surface to bottom and the amount of free carbon dioxid in the lower water together with that which was formed by the decay of organic matter during the overturning process, was great enough to make the water acid at all depths at the completion of the overturn. The curve for 14 m. shows some rather wide variations in the amount of

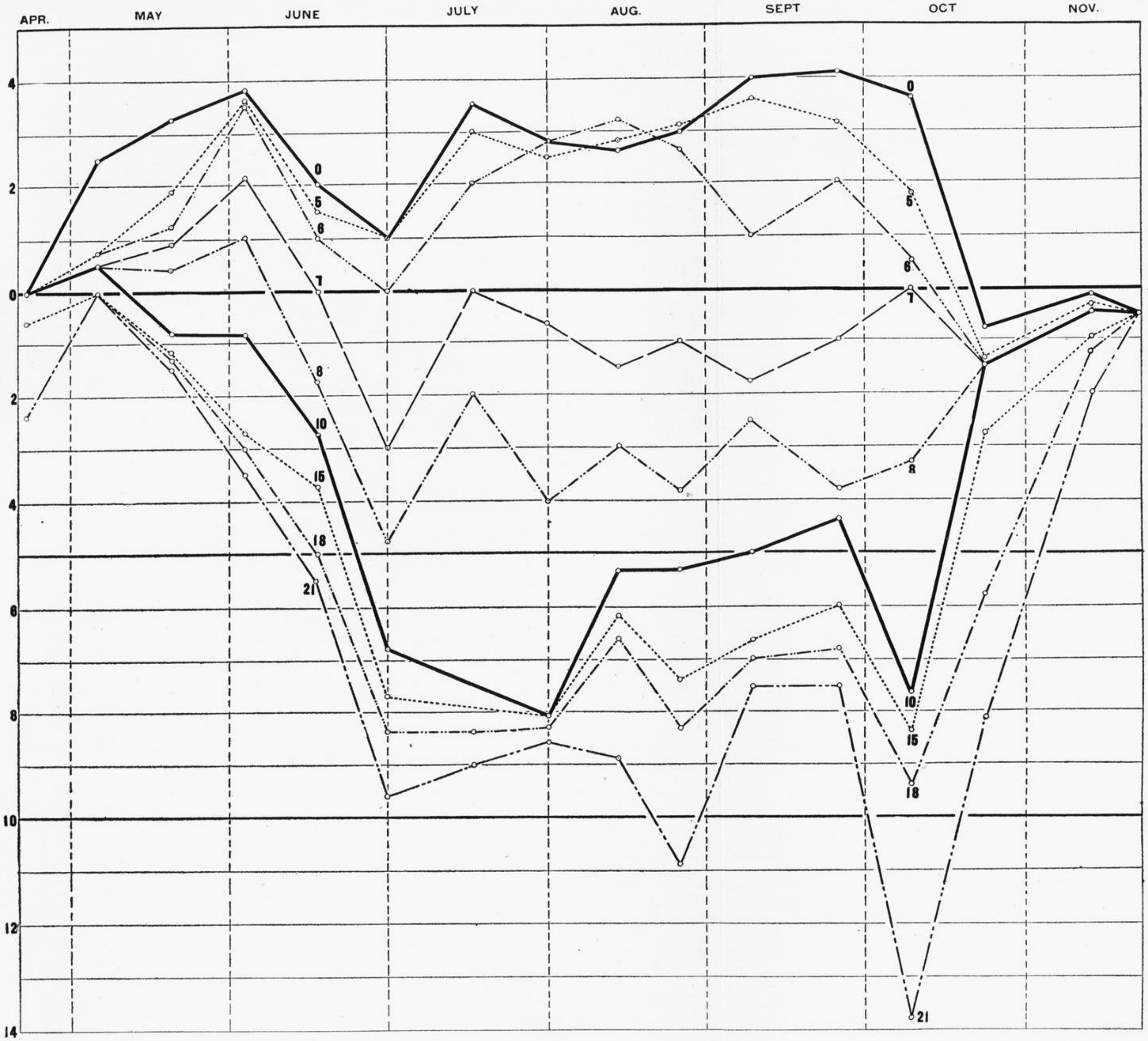

Plate IX.—Free carbon dioxid at different depths (0 m. to 21 m.) in Long lake in 1909. Vertical spaces represent cubic centimeters of gas per liter of of water. Spaces above the zero line represent the alkalinity of the water and spaces below, the acidity in terms of carbon dioxid.

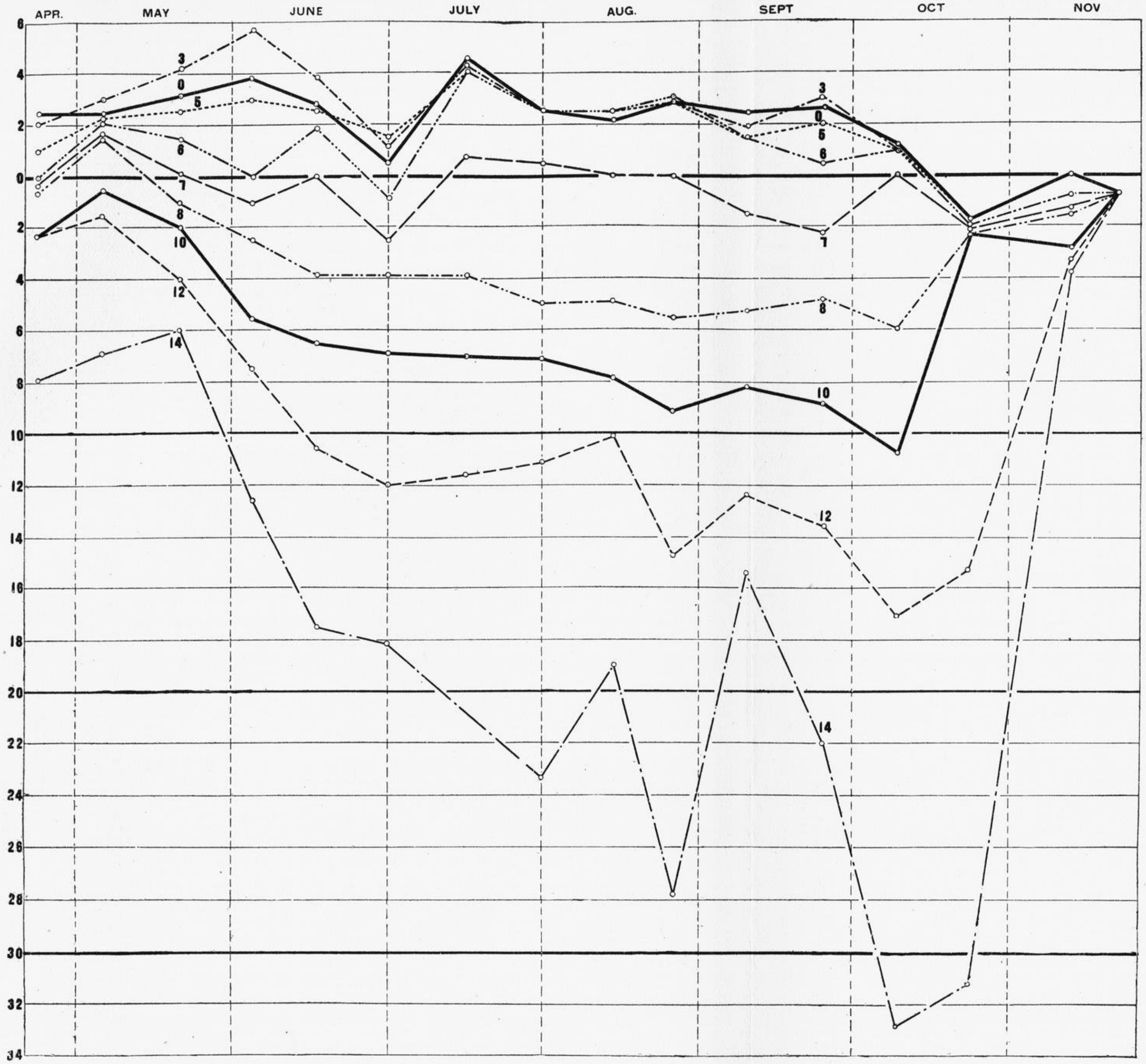

Plate VIII.—Free carbon dioxid at different depths (0 m. to 14 m.) in Beasley lake in 1906. Vertical spaces represent cubic centimeters of gas per liter of water. Spaces above the zero line represent the alkalinity of the water and spaces below, the acidity measured in terms of carbon dioxid.

free carbon dioxid at different times but it is not to be supposed that changes of such a magnitude take place in the bottom water which is practically undisturbed during the summer. These variations are to be attributed rather to differences in the distance from the bottom mud at which these bottom samples were obtained. The generation of free carbon dioxid was greatest, of course, in the bottom ooze because it contained the greatest amount of decomposable matter and the nearer to this ooze a sample was obtained, the larger would be the amount of free carbon dioxid. It was impossible to obtain a sample at exactly the same height above the ooze each time, since depths were measured from the surface, and the boat was not anchored at precisely the same place in the different visits.

The seasonal diagram (Plate IX) for free carbon dioxid in Long lake shows that the water was either neutral or alkaline at all depths on May 5. All the water from 10 m. to the bottom soon became acid and remained so during the rest of the season. That at 8 m. became acid in early June and continued so, while that at 7 m. became so about the middle of June and, with two exceptions, when it was neutral, it remained acid throughout the season. The curves for 6 m. and 7 m. show that the line of neutrality in this lake as well as in Beasley lay somewhere between these two depths during most of the summer.

There were two maxima in the alkalinity of the upper water, one on June 3 and the other on September 24, with a marked decrease on July 1. The maximum amount of free carbon dioxid at the bottom was found to be approximately 14 cc. on October 8. In Long lake, also, the water was found to be slightly acid at all depths at the completion of the autumnal overturn. (See tables, pp. 144, 150.)

The water of Rainbow lake was neutral at all depths on May 5 but within the next two weeks it had separated into an upper alkaline stratum and a lower acid stratum with 15 m. as the dividing line (see Plate X). By June 3, the water at 10 m. had become acid and it was more strongly so on June 17, but on July 1 it was neutral at this depth and distinctly alkaline on July 16. A comparison with the oxygen diagram (Plate VI) will show that this change from an acid to an alkaline reaction was correlated with a marked increase in the oxygen at 10 m. Both of these phenomena were the result of the photosynthetic activities of chlorophyl-bearing organisms in this region. At the end of the next two weeks the water at this depth was distinctly acid and it remained so until late October. The

9 m. water remained alkaline until about the middle of August when it too became acid and continued so until late October.

By May 19, the 8 m. water had become distinctly alkaline and it remained alkaline till November 12 with the exception of the set of observations made on September 9. The stratum above 8 m. was alkaline also from May 19 to November 12. There were two maximum periods of alkalinity in the upper water during the season, one about the middle of June and the other during the latter part of September. These were separated by a distinctly lower alkalinity during the month of July. It will be noted that this period of lower alkalinity in the 5–8 m. stratum was correlated with an excess of oxygen in this region and that the two maxima of alkalinity were not correlated with a maximum of oxygen. The June maximum of alkalinity was correlated with an increase in the number of green and blue green algae but these algae continued to increase in number during the latter part of June while the alkalinity was decreasing. The September maximum was not correlated with any increase in algae.

The maximum amount of free carbon dioxid was found at the bottom (27 m.) on October 8 and it amounted to just a little less than 10 cc. per liter of water. At the completion of the autumnal overturn, the water was again neutral at all depths, thus completing its summer cycle and returning to the same condition which was found on May 5. (See table, p. 162.)

Voigt's[1] results for free carbon dioxid in the Grosser Plöner See show that the upper 5 m. of water remained alkaline, with only a few exceptions, during the period covered by his observations. The water was alkaline also at 10 m. in about half of the observations made at this depth, but below this depth it gave an acid reaction, except from December to April when the water was alkaline at all depths.

Several investigators have found that sea water is alkaline, no trace of free carbon dioxid being found until very considerable depths are reached. The total amount of half-bound and combined carbon dioxid may not exceed 50 cc. per liter of sea water (Tornöe[2] 49.0 cc.; Pettersson and Ekman[3] 40.65 to 48.72 cc.) while in some of our hard water lakes, the half-bound and combined carbon dioxid may reach 80 cc. to more than 90 cc., in the upper part of the lake when the water

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[1] Plöner Forschungsber., XII, p. 115–144. 1905.

[2] Jour. f. Prakt. Chemie, XX, p. 44–75, 1879.

[3] Kgl. Sv. Vet. Akad. Handlingar, XXIX, No. 5, p. 1–125, 1897.

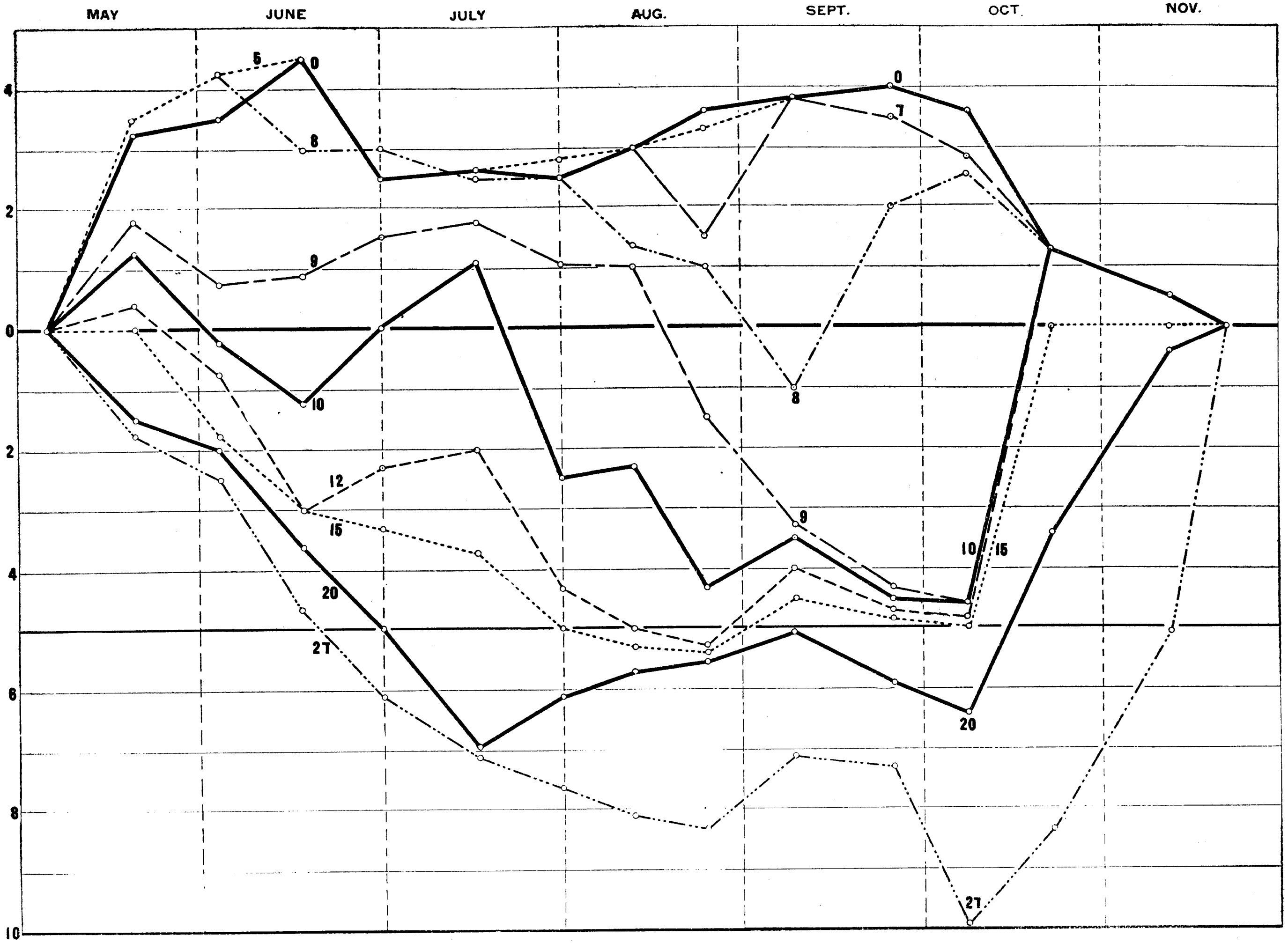

Plate X.—Free carbon dioxid at different depths (o m. to 27 m.) in Rainbow lake in 1909. Vertical spaces represent cubic centimeters of gas per liter of water. Spaces above the zero line represent the alkalinity of the water and spaces below, the acidity in terms of carbon dioxid.

is alkaline and may exceed 100 cc. in the lower water in summer when this region is acid.

CARBON DIOXID IN GROUND WATERS.

The waters of 11 springs and 29 wells, representing each of the three general lake regions considered in this report, were tested for carbon dioxid. These springs and wells are situated on the shores of lakes and their waters ought to give a fair notion of the carbon dioxid content of the ground waters in the vicinity of the lakes.

All of these waters contained free carbon dioxid, but the quantity was very variable in each of the three regions. In the ground waters of northeastern Wisconsin, the quantity ranged from a minimum of 1.3 cc. per liter to a maximum of 38.7 cc.; in northwestern Wisconsin from 2.8 cc. to 47.8 cc.; and in the southeastern part of the state from 4.2 cc. to 29.1 cc.

There was also a marked difference in the fixed carbon dioxid content of these spring and well waters. In 17 springs and wells in the northeastern part of the state, the fixed carbon dioxid varied from 2.8 cc. to 26.3 cc. per liter of water. The quantity exceeded 9.1 cc. in only two instances and, omitting them, the mean for the remainder is 6.1 cc. The quantity of this gas was smaller than that in the adjacent lake water in 4 cases, equal to it in 5, and greater in 8 instances. In the northwestern lake region, the quantity of fixed carbon dioxid ranged from 1.8 cc. to 34.7 cc. Eleven waters were tested and the mean for them is 12.6 cc. In 4 instances the ground water contained a smaller amount of fixed carbon dioxid than the adjacent lake water, in one case the two were equal and in 6 the lake water contained a smaller amount. In the ground waters of southeastern Wisconsin, the quantity of fixed carbon dioxid ranged from 44.3 cc. to 111.8 cc. per liter. The mean for 18 waters is 64.6 cc. In comparison with the waters of adjacent lakes, the amount of this gas was approximately the same in some of the ground waters as in the bottom waters of the lakes, while in others the former contained two and a half times as much. Since the surface waters of these lakes contain a smaller quantity of fixed carbon dioxid in summer than the bottom waters, a comparison of them with the ground waters would show differences somewhat greater.

In the ground waters of northeastern and northwestern Wisconsin, there was a greater range of fixed carbon dioxid content than in those of the southeastern section of the state. In the northeastern part, the maximum quantity of this gas is nearly ten times as great as the minimum; in the northwestern part, nearly twenty times as great; and in the southeastern part only two and a half times as great. The wide range of variation in the northern sections is due to local variations in the composition of the glacial drift, more especially to an irrgular distribution of calcium and magnesium. All of the waters contained free carbon dioxid, thus showing that they were not saturated with carbonates; therefore it seems safe to assume that these carbonated waters converted the normal carbonates of calcium and magnesium of the drift through which they percolated, into the bicarbonates which were found in the waters, in proportion to the amount of these carbonates in the drift. In the southeastern portion of the state, these carbonates are much more abundant and more evenly distributed in the drift and bed rock so that the variations in the fixed carbon dioxid content of the ground waters are not so great.

Lake water may be regarded as a mixture of water which is derived from two sources, viz., ground water and surface drainage water, together with the rain or snow which falls directly into the lake. The former is derived from springs and seepage and reaches the lake either directly from springs on its shores or through affluents when a lake possesses them. The surface drainage water is that which falls upon the earth and drains into the lake or its affluents quickly without percolating through much or any of the ground. This water possesses only a small amount of fixed carbon dioxid, if any, because it comes into contact with the soil only, or at most with a small portion of the sub-soil, both of which contain but small amounts of the alkaline earths. As a result this surface water contributes but a comparatively small quantity of bicarbonates at most, while rain and snow contribute none. The ground water, therefore, is practically the sole source of bicarbonates. The other water, however, plays an important rôle in determining the amount of bicarbonates in lake water because it dilutes the solution furnished by the ground water. The quantity of bicarbonates dissolved in a unit volume of water in any lake is the result of the mixture of the ground water entering the lake from various sources, and its dilution with surface water and rain. In general the greater the proportion of ground water, the greater is the relative amount of bicarbonates.

The difference in the proportion of the water derived from these two sources doubtless accounts for the annual variations in the quantity of fixed carbon dioxid in lake waters. During seasons and years in which snow and rainfall are more abundant, the proportion of water coming from these sources is greater than at times of smaller precipitation and the ground water is correspondingly diluted. This general statement applies more particularly to the hard-water lakes of southeastern Wisconsin where the ground water seems always to carry as large an amount of bicarbonates as the adjacent lake water or more. In northern Wisconsin the irregularity of the distribution of calcium and magnesium is such that the ground water often contains a smaller amount of these substances than the water of the adjacent lake. In such instances, this part of the ground water would serve to dilute the solution of bicarbonates furnished to the lake by ground water entering from other directions.

Large flowing springs are not frequent in the vicinity of the lakes owing to the depth of the covering of glacial drift, and, in most instances, the volume of water derived from the ground is small in comparison with the volume of the lake. Exceptions must be made for certain small, spring-fed lakes, such as Knights and Otter lakes, which receive a large supply of water from springs. In these lakes, however, as in all others, no springs have been found in deep water, so that practically all of the ground water is contributed to the upper water of the lake where the demand for carbon dioxid by chlorophyl-bearing organisms is greatest.

Relation Between Carbon Dioxid and Oxygen.

In the process of photosynthesis, chlorophyl-bearing organisms consume a volume of carbon dioxid equal to the volume of oxygen produced but in no case has this direct relation been observed in the lake waters, as a result of the activities of such aquatic organisms. Other processes which affect the quantity of both gases are taking place simultaneously and these tend to modify and obscure the results of the photosynthesis. When this action takes place in the upper stratum which is kept in circulation by the wind, this water will be exposed to the air from time to time and will part with some of its excess oxygen, if the amount rises above the saturation point. Also when exposed to the air, this water will have an opportunity to obtain carbon dioxid.

In the thermocline region and below, however, the water is not subject to such disturbances by the wind, and if oxygen is liberated in this water, practically none of it will be lost in this manner. But the quantity of these two gases dissolved in the lower as well as in the upper water, will be affected by the respiration of living organisms and the decay of organic matter. Thus, they will add to the complexities which make it difficult to trace the relationship between carbon dioxid consumption and oxygen production, for both processes take place in the stratum in which photosynthesis is in progress.

The largest amounts of excess oxygen have been found in small spring lakes, that is, lakes which receive a very large portion of their water supply from springs. This spring water (see p. 88) contains an abundance of available carbon dioxid which could be utilized by the chlorophyl-bearing organisms, but just how this inflowing water could furnish the required amount of carbon dioxid without the oxygen content of the supersaturated stratum being affected thereby, is not evident, for this spring water is very generally deficient in oxygen. So far as these results go, this must be left as one of the unsolved problems at present. It has not yet been possible to follow closely an excess oxygen phenomenon through all stages of its development and disappearance and such a study would doubtless throw some light on this relation between carbon dioxid and oxygen.

In observations made on lake Mendota in September, 1908, it was found that there was a general tendency for the alkalinity to increase as the quantity of oxygen increased but there were appreciable variations. Sometimes the loss of half-bound carbon dioxid was greater than the gain in oxygen and sometimes it was less. In the other lakes in which excess oxygen has been found, it may be said in general that the carbon dioxid decrease (both free and half-bound) by no means accounted for the quantity of oxygen produced.

Neither is it possible to trace any direct relation between the oxygen consumption in the lower water, due chiefly to the decay of organic matter, and the increase of free carbon dioxid there. Some of the oxygen is used up in the formation of water during the process of decay and carbon dioxid is formed in excess of the amount of dissolved oxygen consumed, for this gas is freely formed even when decay takes place under anaerobic conditions.

CHAPTER IV.

LAKES IN INDIANA.

The four lakes in Indiana (Maxinkuckee, Cook, Holem, and Tippecanoe) which have been visited, are situated in the northwestern part of that state. They are located in a glaciated region and their physical features do not differ essentially from those of lakes in southeastern Wisconsin. These Indiana lakes are some distance south of the southernmost lakes in Wisconsin that have been studied, where the climate is milder but the difference in climate is not sufficient to make any apparent differences in the general thermal and chemical conditions.

Lake Maxinkuckee has an area of about 750 ha. and a maximum depth of 26.8 m. It was visited on September 20, 1907, and the temperature and oxygen conditions were found to be essentially the same as have been observed in lake Mendota at about this season of the year. The region above the thermocline contained an abundance of dissolved oxygen; most of this water being completely saturated or slightly supersaturated with this gas. There was a marked decrease in the amount of oxygen in the thermocline and the water from 13 m. to the bottom, about half the maximum depth, contained no free oxygen. (See fig. 113, p. 221, and table, p. 169.)

An upper stratum of water about 8 m. in thickness was alkaline, showing a maximum alkalinity of 3.8 cc. at the surface. The water was neutral at 9 m. and acid below this depth, with a maximum of 5.3 cc. of free carbon dioxid at the bottom.

The water of the main part of lake Maxinkuckee contained from 15 to 30 per cent. less fixed carbon dioxid than the other three Indiana lakes and about this much less than has been found in similar lakes in southeastern Wisconsin. The amount varied from 24.5 cc. per liter of water at the surface to 31.6 cc. at the bottom, but in a portion which is known as the Kettle Hole, it varied from 26.8 cc. at the surface to 40 cc. at the bottom (11.5 m).

Cook and Holem lakes are situated only a few kilometers north of lake Maxinkuckee and they were visited on September 23, 1907. Both of these lakes are rather small and have shallow margins, for the most part, which support an abundant growth of aquatic vegetation. For this reason they possess some characteristics in common with bog lakes and the results for oxygen and free carbon dioxid give abundant proof of the effect of these physico-biological conditions on the chemical status of the water. The former has a maximum depth of 14.5 m. and the latter 8.25 m.

Both had a well marked thermocline at the time of these observations. The quantity of oxygen found in the upper water of both lakes was considerably below the saturation point, the percentage of saturation in the surface water of Holem lake being a little less than 72 and of Cook lake 81.2. This was practically the average amount for this entire stratum and such a condition seems to indicate that much decomposition of organic matter was taking place along the margins of these lakes as well as in the limnetic region, although a comparatively small amount of plankton was found. The quantity of dissolved oxygen decreased rapidly in the thermocline and the lower water in both lakes contained no free oxygen. (See figs. 112 and 114, p. 220, and table, p. 169.)

The water in both lakes was acid from surface to bottom, Holem lake being more strongly so than Cook. In the former the free carbon dioxid varied from 1.2 cc. per liter of water at the surface to 18.7 cc. at the bottom, and in the latter from 0.5 cc. to 7.5 cc. While there was a distinct increase in the amount of fixed carbon dioxid with increasing depth in Cook lake, yet the increase was much more pronounced in Holem lake. In the latter it rose from 35.5 cc. at the surface to 58.8 cc. at the bottom.

Tippecanoe lake has an area of about 365 ha. and a maximum depth of 35 m. It is a long, narrow lake and the deepest part comprises only a small portion of the entire area, as shown by the hydrographic map of Large.[1] Fairly high, wooded shores along a great portion of the deepest water, protect this part from winds so that the upper stratum which is kept in circulation by the wind in summer is comparatively thin, the thermocline extending from 6 m. to 10 m. on September 17, 1909. (See fig. 115.) On this date the water contained more or less dissolved oxygen at all depths but there were

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[1] **Proc. Ind. Acad. Sci. 1896, p. 296. (1897.)**

four fairly well marked strata. The oxygen curve shows an upper stratum which contained 3.1 cc. to 6.0 cc. of dissolved oxygen; the stratum between 8 m. and 10 m. contained only a small amount of free oxygen, there being only a trace at 9 m.; the stratum from 11 to 27.5 m. contained varying amounts, the maximum being about 40 per cent. of the amount at the surface; at the bottom there was a stratum with only traces of free oxygen. Attention has already been called to similar conditions in Wisconsin lakes but in none of them has so large an amount of free oxygen been found in the region below the thermocline, that is, between the two strata which were very poor in oxygen. (See p. 50.)

The 0–5 m. stratum was alkaline, the maximum alkalinity being at the surface 2.3 cc.; the water was neutral at 6 m. and acid below this depth, the maximum acidity being 7.5 cc. of free carbon dioxid at the bottom. The fixed carbon dioxid varied from 34.4 cc. per liter of water at the surface to 36.9 cc. at the bottom. (See table, p. 169.)

CHAPTER V.

NITROGEN, METHANE, CARBON MONOXID, AND OTHER GASES.

Nitrogen. The determinations of dissolved nitrogen were discontinued after the summer of 1906 when the boiling method was given up entirely. In fact, only about 60 determinations were made during the season of 1906, so the following discussion is based chiefly on the results obtained in 350 analyses made in 1905. Nitrogen is such an inert gas that the quantity dissolved in lake waters is not affected by the various chemical and biological processes which take place in a lake. For this reason there was no hesitation in discontinuing its determination for the purpose of making a more thorough study of the oxygen. The dissolved nitrogen varies somewhat in amount because it is more soluble in cold than in warm water; hence the maximum amount is found in winter. As the water becomes warmer in spring and summer, the quantity decreases so that, by the last of June, the upper stratum usually does not contain more than 65 to 67 per cent. as much as in winter. During the vernal period of circulation, in lakes where this circulation is complete, the water at all depths remains substantially saturated with nitrogen as long as this complete circulation lasts. During the summer, the upper water which is kept in circulation by the wind and freely exposed to the air, will also be found nearly or quite saturated with this gas. In the thermocline region, however, and below, the water may contain an excess of nitrogen.

The residual gas, that is, that which remained after the removal of oxygen and carbon dioxid from the gas obtained by boiling, has been regarded as nitrogen in most cases. In some instances, however, all of this residue can not be so regarded for more or less methane was found in the lower waters of some lakes; but in the great majority of cases, there was either no methane in this residue, or the quantity was not large enough to affect the results appreciably. Residues from 8 lakes were further analyzed for other gases, such as hydrogen, carbon monoxid, and methane and they showed substantially the same nitrogen conditions as were found in other lakes. In all of them, the upper water was found to be substantially saturated with nitrogen; in 7, the amount was 12 to 16 per cent. above saturation in the region of the thermocline and below; while in Otter lake, it was 18 to 37 per cent. above the saturation point.

This excess may have been produced in either or both of two ways. The lower water will be substantially saturated with nitrogen at the end of the vernal period of circulation. As the season advances, the temperature of this water rises more or less, hence its capacity for this gas decreases. This would tend to liberate some of the nitrogen; but the hydrostatic pressure at this depth and the lack of circulation tend to prevent its escape. Likewise, the rate of diffusion is so low that very little will be lost in this manner. As a result, the nitrogen remains in the lower water and produces supersaturation. Ground water frequently contains an excess of nitrogen and some of the excess in lake water may come from this source. It seems probable that some of the excess nitrogen found in the lower water of Otter lake is due to ground water. This lake is fed very largely by springs, but no nitrogen determinations have been made for any of them. The water of a spring about half a kilometer away on Hicks lake showed an excess of about 18 per cent. of nitrogen and the spring water entering Otter lake doubtless contained a similar excess of nitrogen.

It will be noted that a typical summer curve shows a smaller amount of dissolved nitrogen and a fairly uniform distribution of it, above the thermocline; and a larger amount in the lower, cooler strata. There is a marked rise in the amount in the thermocline region of some lakes and a more gradual rise in others; below this region, the amount gradually grows larger toward the bottom. (See figs. 9, 10, 11, 13, 15, 51, 85, 88, and 96.)

During the autumnal circulation, the nitrogen will be found quite uniformly distributed from surface to bottom and as the water cools, more and more of this gas will be absorbed from the air. As a result the lake goes into winter conditions with its water substantially saturated with nitrogen at all depths and containing practically the maximum amount for the year.

Methane. Methane is one of the products resulting from the slow decay of organic matter. It is frequently formed in the decomposition which takes place at the bottom of ponds and marshes and for this reason it is often called marsh gas. Generally a great deal of organic material decays in the lower water and at the bottom of lakes and frequently the conditions are favorable for the formation of methane. In several lakes the residue which remained after the removal of the carbon dioxid and oxygen was large enough to make it evident that this residue was composed of something besides nitrogen. Accordingly tests were made for the purpose of determining whether any hydrocarbon gases were present and, when evidence of their presence was found, analyses were made to determine the kind and quantity present.

Samples were collected from 11 lakes in all, but the hermetically sealed glass tubes containing those from three lakes all met with mishaps except one from each lake. As these three samples were not from bottom water and contained no methane, they need not be considered further. The samples of gas for the determination of the methane were obtained by the usual boiling method; the carbon dioxid and the oxygen, if any were present, were removed and a portion or all of the residue was then transferred to glass tubes of 50 to 60 cc. capacity and these glass tubes were hermetically sealed at both ends. The process was carried thus far in the field and the samples were then taken to the laboratory for further analysis. Some of the analyses were made by Dr. Victor Lenher, but most of them were made by Mr. M. E. Diemer under the direction of Dr. Lenher and the results were embodied in a thesis submitted for the degree of bachelor of arts in 1908.

Some preliminary experiments were made for the purpose of comparing the explosion and the slow combustion methods. Results obtained by these two methods checked pretty closely in most cases, the maximum difference not exceeding 0.2 cc. which was well within the limit of experimental errors. By using known dilutions it was found that the slow combustion method gave much more satisfactory results with extremely dilute methane mixtures than the explosion method and equally as good results with more concentrated mixtures even up to nearly or quite pure methane. So, the determinations were made by the former, or slow combustion method.

Mr. Diemer found it necessary to modify the burner part of the combustion apparatus described by Hempel.[1] Two glass supporting tubes were passed through the rubber stopper of the pipette. Plati-

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[1] Gas Analysis. Hempel, Translation by Dennis, p. 138. 1902.

num wires somewhat longer than the tubes passed through them. The outer ends of these tubes were fused so as to form a perfect seal around the platinum wires. As a further precaution against leakage the tubes were filled with mercury. The platinum terminals inside the burette were connected by a coil of small platinum wire which was welded to the two terminals. The external terminals of the platinum wires were connected with a storage battery and rheostat, so that the electric current could be readily and quickly controlled. Mercury was used in the combustion pipette and in the burette in which the gas was measured.

The gas was transferred to the combustion pipette and the current adjusted so that the coil was raised to a temperaure sufficient to give it a bright red color. Then a small amount of oxygen was introduced from another burette and the temperature of the spiral closely watched. Should the mixture be rich in methane or other hydrocarbon gases, the spiral begins to glow immediately and if too much oxygen be introduced (more than 10 cc.) the temperature of the spiral may rise to the fusing point if the current is not properly decreased by means of the rheostat. In order to prevent an explosion it is sometimes necessary to discontinue the current entirely. As soon as the methane is all burned, the glowing ceases and, if no glow is noted after the introduction of a fresh supply of oxygen, it may be assumed that all of the hydrocarbon gas has been burned. When the combustible gas is present in very small amounts no glowing takes place and, in such cases, the gas mixture was exposed to the heated spiral for about 10 minutes.

After combustion the gas was returned to the burette and the volume noted. The total volume (that is, the volume of the original sample plus the volume of oxygen added) minus the volume of gas after combustion, represents the contraction resulting from the formation of water. The gas in the burette is next passed into a pipette containing caustic potash, which removes the carbon dioxid, and the volume of this gas formed in the process of combustion is determined. The volume of oxygen consumed is next determined by passing the residual gas into a pipette containing a solution of alkaline pyrogallol. The amount of the contraction subtracted from the total amount of oxygen added, gives the amount of oxygen consumed.

Thus three quantitative determinations are made, viz.: The contraction resulting from the oxidation of the hydrogen in the gas to form water, the quantity of carbon dioxid formed in the oxidation of the carbon of the gas, and lastly the amount of oxygen consumed. The latter serves as a check on the results of the other two determinations. If methane alone is present, the contraction resulting from the formation of water should be twice the volume of carbon dioxid formed, and the volume of oxygen consumed in the formation of both water and carbon dioxid should equal the contraction resulting from the formation of water. All of the results fulfilled these conditions, so it was concluded that methane was the only hydrocarbon gas present in the samples.

Most of the gas samples were collected in 1906. Some were obtained from Mendota on seven different dates between March and September, 1906. The residual gas obtained from a sample of bottom water on March 29, 1906, a few days before the ice disappeared, was analyzed, but no methane was found.[1] This result was unexpected as the water contained no dissolved oxygen at that time and such a condition is favorable for the production of methane.

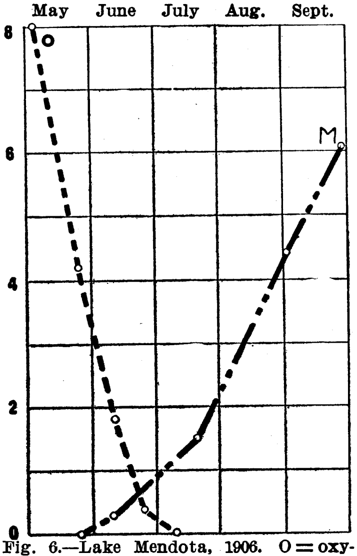

Fig. 6.—Lake Mendota, 1906. O = oxygen and M = methane in the bottom water. The vertical spaces represent cubic centimeters of gas per liter of water and the horizontal spaces represent the months from May to September, inclusive.

Figure 6 shows the oxygen and methane conditions in the bottom water of lake Mendota during the summer of 1906. Samples taken on May 4 and 25 showed a fairly large amount of oxygen in the bottom water but no methane had yet appeared there. By June 11, the oxygen had decreased to 1.8 cc. per liter of water and a small amount of methane was found, 0.26 cc. per liter. Since methane is formed when vegetable matter decays in the absence of oxygen, this small amount most probably came from the muddy ooze at the bottom where the dissolved oxygen had been exhausted. By July 9, free oxygen had entirely disappeared at the bottom and did not reappear here until the autumnal overturn. On July 17, it was found that the methane had increased to 1.2 cc. and the amount continued to increase as summer advanced until it reached a maximum of 6.1 cc. per liter of water on September 27.

On June 27, 1906, the water of Garvin lake half a meter above the bottom contained no methane but it was found in the bottom ooze (7.8 cc. per liter). Just a month later, however, the water half a meter above the bottom contained an abundance of it (10. 4 cc.) and 50.8 per cent. of the residual gas obtained from the bottom ooze was methane. By September 24, this percentage had increased to 65.

The maximum amounts of methane have been found in the bottom waters of Beasley and Garvin lakes. These lakes are small and well protected from winds so that the vernal overturn may be more or less incomplete. As a result the bottom water does not receive a very large supply of dissolved oxygen in the spring and this small stock is soon exhausted by the decay of the large amount of organic matter that is found on the bottom of these lakes. Decomposition then proceeds under anaerobic conditions, which are most favorable for the production of methane. These favorable conditions continue for a period of about 5 months and in Garvin lake so much methane and free carbon dioxid are generated during this time that, in late August and in September, many bubbles of these gases may be seen rising to the surface. On September 13, 1905, a sample of gas from the bottom water of Garvin lake contained 38.5 cc. of methane per liter and one obtained from Beasley lake on August 21, 1906, contained 28.9 cc. In its vertical distribution, the quantity of methane increases with increasing depth, the largest amount being found at the bottom where the greatest amount of decomposition takes place.

Carbon Monoxid. While gasometric analyses were being made during the summers of 1905 and 1906, some tests were made to determine whether any carbon monoxid was held in solution in the water, especially in the bottom water of lakes where anaerobic decomposition was taking place. After the removal of the oxygen and carbon dioxid, the residue was transferred to a pipette containing cuprous chlorid for the removal of any carbon monoxid that might be present. The contractions in volume obtained by this method were rather irregular and some of them seemed unusually large. This led to the conclusion that the results obtained by this method were not very reliable.

Tests were made later by another method, that is, the iodometric method as described by Kinnicut and Sanborn[1]. For these analyses, some water from Mendota at depths of 15 m., 18 m., and 22.5 m., the bottom, was obtained on September 14, 1908. For each analysis about 12 liters of water were boiled and the gas given off was collected and tested for carbon monoxid. It was found at each of the depths from which samples were obtained, but it was present in very minute quantities, the amount being 0.002 cc. per liter of water in two determinations and 0.004 cc. in the third. These results showed much smaller amounts than had been anticipated, as the cuprous chlorid method in some cases, gave results as high as 0.2 to 0.3 cc. per liter of water. Since the gas is present in such small quantities, it has very little, if any significance from a biological standpoint.

Hydrogen. Many tests have been made for hydrogen but it was not found in any of the residual gases examined. The palladium method, however, was used, and this method is not delicate enough to detect very small amounts of this gas. It seems probable that some hydrogen may be liberated in the process of anaerobic decomposition, but if such is the case, it is in such minute quantities that it cannot be detected by the palladium method. With a method for hydrogen as delicate as the iodometric one for carbon monoxid, its presence in the lower water could doubtless be demonstrated.

Hydrogen Sulphid. "An odor like that of sulphuretted hydrogen must not be taken as proof positive of the presence of that gas in a water, inasmuch as mixtures of sundry hydrocarbons will often greatly mislead the sense of smell."[2] Tests for hydrogen sulphid on several lakes where the water had such an odor gave abundant confirmation of the truth of this statement. An odor resembling that of sulphuretted hydrogen is very generally found in bottom water which possesses no dissolved oxygen, yet chemical tests did not indicate the presence of this gas in many instances, especially if anaerobic decomposition had been going on for only a comparatively short time. In late summer, however, in lakes where anaerobic decomposition has been in progress

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[1] **Jour. Amer. Chem. Soc., XXII, p. 14, 1900.**

[2] **Water Supply—Mason, W. P., p. 415, 1897.**

for some weeks in the lower water, more or less hydrogen sulphid may be found in this region. During the summer of 1908, the lower water of a number of lakes was tested for hydrogen sulphid by the iodometric method.[1] While these tests indicated the presence of this gas in the majority of the waters tested, yet it appeared only in very small amounts.

The presence of so much decomposing organic matter in the lower water raised a query as to the reliability of this method for such waters. In order to answer this question some determinations were made in duplicate, using both the iodometric and a colorimetric method. While the latter indicated the presence of hydrogen sulphid in all waters when it was so indicated by the iodometric method, yet the colorimetric gave results uniformly lower, showing only 14 to 33 per cent. as much as the iodometric. This led to the suggestion that some organic compounds of sulphur may be present which affect the iodometric determinations but not the colorimetric and thus give results somewhat higher than they should be. A single set of observations will serve to illustrate the differences in results obtained by the two methods. The amount of hydrogen sulphid is indicated in cubic centimeters per liter of water.

TABLE X.—*Mendota, September 22, 1908.*

Depth.	Iodometric.	Colorimetric.	O_2 in cc. per liter.
13 m	0.0	....	0.8
14 m	0.0	....	0.04
15 m	0.026	0.004	0.0
17 m	0.283	0.093	0.0
20 m	0.463	0.13	0.0
21.5 m	0.557	0.15	0.0

It may be said that these results furnish conclusive evidence of the formation of hydrogen sulphid in the lower water under the conditions indicated above, but they show that only very small amounts of it are formed. It was found only in water which contained very little or no dissolved oxygen.

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[1] Volumetric Analysis, Sutton, p. 336, 1907.

CHAPTER VI.

MINERAL AND SANITARY ANALYSES

In addition to the determination of dissolved gases, some mineral and sanitary analyses were made for the purpose of ascertaining the kinds and the amounts of other substances dissolved in the lake waters. It was not practicable to carry on such complete analyses extensively along with the dissolved gas determinations, so it was thought best to select a few lakes representing the various types and confine such work to them. Thus, this phase of the investigation has been of an explorative nature, and the chief aim has been to determine, if possible, whether it would be desirable to carry on such studies later on a larger scale. It may be said in passing that such analyses may aid materially in explaining some of the biological phenomena that have been observed, such for instance as the characteristic differences between the fauna and flora of different lakes as well as the differences which are found in the same lakes at different seasons of the year, or from year to year.

The water used for the mineral analyses was not filtered, since for biological reasons it was desirable to know the total amounts of the various substances, not only that which was dissolved in the water but also that contained in the micro-organisms; with the exception of the silica, however, it has been found that it makes very little difference whether the water is filtered or not. An analysis was made for the purpose of determining the effect of filtering the water and the results obtained are shown in an accompanying table. One liter was used in each case and both samples were taken from the same bottle after the water was thoroughly shaken. The difference in the silica was due to the presence of a considerable number of diatoms, which were removed, of course, from the water which was filtered. It seems fairer, however, to use unfiltered water for the analyses, because this diatom silica represents that which was previously dissolved in the water.

The results given in the following table are stated in parts per million.

TABLE XI.—*Mendota, April, 1910.*

	SiO_2.	Fe_2O_3 & Al_2O_3.	Ca.	Mg.
Filtered	2.25	1.5	28.8	20.8
Unfiltered	3.5	1.4	28.7	21.4

In the hard water lakes, one liter of water was used for the determination of the SiO_2, Fe, Ca, and Mg, but in the soft water lakes two liters or more were used for this purpose. The results of these analyses are given in a table in the appendix and the amounts are stated in parts per million. (See p. 170.)

Like the dissolved gases, these other substances which are in solution in the lake waters become uniformly distributed from surface to bottom during the autumnal period of circulation and in spring also in lakes which have a complete vernal overturn and circulation. But these periods of uniform distribution are followed by more or less marked changes in the amount of some of these substances in the different strata of the lake. This is true especially of the summer season. Chemical, physical, and biological factors are involved in the production of these changes and these will be considered in connection with the discussion of the various substances as presented below.

Silica. There appears to be a slight decrease in the amount of silica in the upper water during the summer, doubtless resulting chiefly from the activities of the diatoms. Diatoms are found most abundantly, of course, in the upper water and they remove some of the silica which is dissolved in this water in making their siliceous shells. When the diatoms die, these shells sink to the bottom, thus causing a net loss of silica in the upper water. There is a more or less marked increase in the lower water during the summer. Some of the organic compounds formed in the process of decay, have a solvent action on silica and it seems probable that the silica contained in sinking diatom shells and in those that are present in the bottom ooze, will be attacked by such substances in the lower water where decay goes on more or less vigorously, and a certain amount will be dissolved. In this way the silica content of the lower water will be augmented and as a result of the slight decrease in the upper water and the more marked increase in the lower water of some lakes, four to five times as much silica may be found in the bottom stratum as in the surface water just before the autumnal overturn. Raben[1] found a periodicity in the silica content of the waters of the Baltic sea. It was high in November and February and low in May. He attributes the May minimum to a large growth of diatoms in March or April which removed much silica from the upper water.

The curve representing the silica in Beasley lake on August 3, 1908, shows a pronounced notch correlated with high oxygen and low carbonates. (See fig. 7.) An examination of the plankton diagram (fig. 138) for this date reveals the fact that the maximum number of diatoms is correlated in depth with this notch in the silica curve. The colonies of *Fragilaria* and *Asterionella,* the predominant diatoms, number 17,500 per liter of water at 4 m.; 28,000 at 5 m.; 22,500 at 6 m.; and 9,800 at 7 m. Multiplying the number of colonies at 5 m., where the maximum number was found, by the average number in each colony of *Fragilaria* and *Asterionella,* gives a total of 2,168,000 individuals per liter of water. At first thought it might appear that the presence of this large number of diatoms in the sample of water which was analyzed, ought to show a larger amount of silica than at other depths where these organisms were not nearly so abundant. But this contradiction is only apparent. The most probable explanation of the decrease is that this large growth of diatoms had

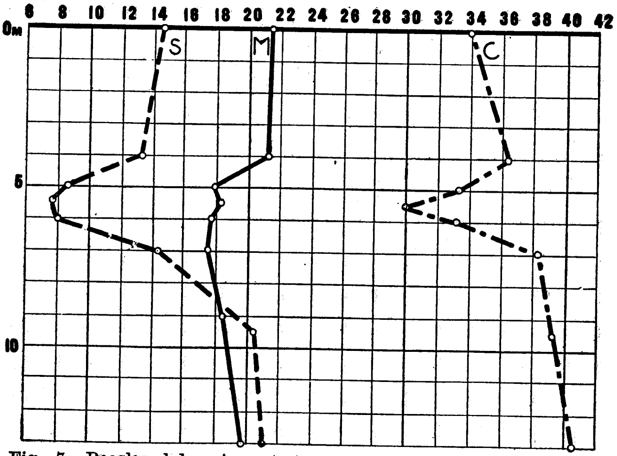

Fig. 7.—Beasley lake, August 3, 1908. S = silica, M = magnesium, and C = calcium. The vertical spaces represent depth in meters and the horizontal spaces, parts per million.

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[1] Internat. Meeresforsch. III Jahresber., p. 133. 1906.

been in progress in this 4–7 m. stratum for a considerable period of time and during this period large numbers of diatoms were dying constantly, and sinking into the lower strata, thus carrying down the silica in their siliceous shells. Such a process would in time cause an appreciable decrease of silica in the stratum which was densely populated with these organisms.

Iron and Alumina. Fe_2O_3 and Al_2O_3. In the gravimetric analyses, no attempt was made to separate the iron and alumina and they have been recorded together in the tables. These results show that there was a noticeable increase in the amount of these two substances with increasing depth in lakes whose bottom water contained no dissolved oxygen. Determinations by a colorimetric method show that this increase is due chiefly, if not wholly, to the increase of the iron. If any insoluble oxide of iron be present in the bottom ooze, it may be reduced to a lower soluble oxide in the absence of dissolved oxygen and pass into solution, thus increasing the quantity of iron held in solution by the bottom water. Bottom waters which contain a considerable amount of iron soon become cloudy when exposed to the air, as the water absorbs oxygen and the iron is changed to a higher oxide which is precipitated. At the time of the vernal and autumnal overturns, the bottom water is aerated and the ferrous iron in solution is oxidized to ferric which forms a precipitate and sinks to the bottom, only to be reduced again and pass into solution when the dissolved oxygen disappears from the bottom water. In no instance, however, has a very large amount of iron been found in the lower water as the maximum quantity of Fe_2O_3 has not exceeded 12 parts per million.

Calcium and Magnesium. It will be noted in the table that the different lakes contain very different amounts of calcium and magnesium as has been indicated in the discussion of the fixed carbon dioxid. The soft water lakes contain only a small amount of these substances in solution, while the lakes of the second class contain a medium and those of the third a relatively large amount. The amount of calcium varied from a minimum of 0.64 part per million in Bass lake at Minocqua to a maximum of 49.3 parts in the bottom water of the west part of North lake, with an average of 47 parts for the entire depth of that lake. In the same lakes the quantity of magnesium was 1.2 parts per million in the former and about 27 parts in the latter. (See table p. 170.)

In the lakes containing comparatively small amounts of calcium and magnesium, these substances were, in general, pretty uniformly distributed from surface to bottom. When a larger amount of calcium was present, as in some of the lakes of the second class and all of the hardwater ones, there was an increase in the amount of calcium with increasing depth, except during the vernal and autumnal periods of circulation. The amount of increase varied greatly. The maximum difference between the calcium content of the surface and bottom waters was found in Rainbow lake on September 10, 1907. The former contained 15.6 parts per million and the latter 28.8 or about 85 per cent. more than the surface. Generally, however, the difference between surface and bottom did not exceed 20 to 25 per cent. Magnesium showed considerable irregularity in its distribution. In some lakes there was a more or less marked increase with increasing depth; while in others a smaller amount of magnesium was found at the bottom than at the surface.

These differences in calcium and magnesium between surface and bottom are produced chiefly in two, or perhaps three ways:—(1) Through the action of the carbonated lower water on the bottom mud; (2) by the removal of these substances from the upper water by plankton organisms and by the transfer of such amounts to the lower water when these organisms die and sink; and also (3) any calcium or magnesium which might be precipitated in the upper water would sink into the lower. With respect to the first factor, it may be said that an analysis of some mud from the bottom of lake Mendota gave the following results which are stated in percentages of the weight of the dry sample: Calcium, 23.7; Magnesium, 1.3. The difference in the solubility of the normal carbonates of calcium and magnesium is undoubtedly one of the important factors responsible for the marked difference in the proportion of these two substances in the bottom mud. Magnesium is so much more soluble than calcium that it would not be deposited so readily. The presence of such a small proportion of magnesium in the bottom mud helps to explain why the carbonated bottom water contained comparatively little, if any, more magnesium than the surface water. In a few instances it actually contained less. But marked increases of calcium were noted in the bottom water in several instances.

Chemical analyses show that plankton contains appreciable quantities of these two substances which would be carried into the lower water when these organisms die and sink but the amounts are so minute that the plankton can be regarded only as an unimportant factor in the transfer of calcium and magnesium from the upper to the lower water. The lower water is charged with free carbon dioxid in summer and any precipitate of calcium or magnesium which might sink into this water from above would be readily dissolved.

The production of irregularities in the distribution of calcium and magnesium in Beasley, Knights and Otter lakes by chlorophyl-bearing organisms, has already been discussed in connection with the fixed carbon dioxid of those lakes and needs no further consideration here. Figure 7 shows the distribution of these substances in Beasley lake on August 3, 1908. (See p. 106.)

The chemical analyses also show that the ratio of calcium to magnesium varies very much in the different lakes. In some these two substances were found in almost equal amounts in the surface waters, while in others there were two to three times as much calcium as magnesium, and in still others, nearly twice as much magnesium as calcium. These differences in relative proportions are doubtless due to differences in the proportions of these two substances in the drift and rock of the drainage basins of the different lakes. It is also interesting to note that the lakes which have the smallest amount of calcium and magnesium and, therefore have the softest water, possess no inlets and with one exception (Bass lake, Minocqua) no outlets. It would seem that the scarcity of calcium and magnesium in the waters of such lakes depends chiefly upon about three factors: (1) The scarcity of these substances in the surrounding drift and rock; (2) the small amount of ground water entering the lake; (3) a small drainage basin so that the water reaches the lake quickly and therefore has little opportunity to dissolve calcareous materials on its way to the lake.

Sodium. Sodium was found in small amounts. A maximum of 4.6 parts per million was found in the bottom water of lake Mendota in one set of analyses. More than 4 parts per million were noted in only three other instances. The general average was about 2 parts.

Potassium. The amount of potassium dissolved in these waters was still less than the sodium. It reached a maximum of 4.5 parts in one lake but this was the only instance which showed more than 4 parts, the average being less than 2 parts.

Chlorin. Small quantities of chlorides are very general constituents of ordinary soils, hence they will be found in small amounts in the drainage waters which enter the lakes. The amount of chlorin found in the waters of the various lakes that have been studied varies considerably, but most that have been tested show less than 5 parts per million. A maximum of 10 parts was found in the east part of North lake on September 4, 1907. In general the chlorin was pretty evenly distributed from surface to bottom. In a few instances, however, only about half as much chlorin was found at the bottom as at the surface. This condition may have been due to an increase in the chlorides in the upper water after the bottom water had ceased to take part in the vernal circulation.

Sulphur. The various lakes, also, show wide differences in the quantity of SO_4. The waters of two lakes contained no trace of sulphates so that the SO_4 varied from none in these instances to a maximum of 23.7 parts per million in the west part of North lake. The sulphates were highest in the lakes which contained the largest amounts of calcium and magnesium.

Weith[1] has asserted that the waters of the Swiss lakes have a constant composition and Forel[2] has made a similar statement for the water of lake Geneva. On the other hand, Delebecque[3] found that the composition of the waters of the French lakes varies not only with the season but also with the depth. For instance he found a chemical stratification of the water which was parallel with the thermal stratification during the summer, but chemical conditions became uniform from surface to bottom in autumn. These variations are attributed to several factors by this author, water brought in by affluents, as well as physical, chemical, and biological factors. Delebecque observed that, when the quantity of $CaCO_3$ exceeds 0.05 to 0.06 gr. per liter (20 to 24 parts of Ca per million) the surface water in summer contains less than the bottom. This fact he attributes to two factors, the rise in the temperature of the upper water, which would tend to precipitate the $CaCO_3$, and the removal of a portion of this substance by living organisms. He found also that silica was removed from the upper water during summer by the diatoms. The results obtained on Wisconsin lakes fully confirm Delebecque's observations and they show that the water of a lake may not only present marked seasonal changes in composition but that there are also variations from year to year.

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[1] Internationale Fischerei-Ausstellung zu Berlin, 1880, p. 96, et seq. (See Delebecque—Les Lacs Francais, p. 211.)

[2] Le Léman, T. II, p. 588. 1895.

[3] Les Lacs Francais, p. 187–241. 1898.

ORGANIC MATTER.

It has already been pointed out that more or less decomposable organic matter is found in the water of the lakes and that such material is derived from the plankton, from the larger aquatic plant and animal forms, and, also, to a certain extent from the shore forms. The effect of the decomposition of this material on the oxygen dissolved in the water has also been discussed. But this decomposing matter plays another very important rôle. When this organic material breaks down, the first step in the process is the oxidation of the carbon, hydrogen, and nitrogen therein to carbon dioxid, water, and ammonia. If liberated in a region where photosynthesis takes place, this carbon dioxid contributes to the stock of this gas which may be drawn upon by chlorophyl-bearing organisms. The free ammonia may be used up directly by the algae, or it may undergo further oxidation, being converted first into nitrous acid, forming nitrites and ultimately into nitric acid forming nitrates. These nitrites and nitrates constitute a very important source of food for aquatic plants. This supply of nitrogen compounds is increased by that derived from other sources. Rainwater, for example, obtains ammonia from the air and the water which sinks into the soil comes into contact with and dissolves some of the nitrogen salts, which are then carried along with it and eventually reach the lake.

Plants require nitrogen in an available form for their anabolic processes and the free floating aquatic forms must obtain their supply of this substance from the nitrogen compounds dissolved in the water. Therefore, the scarcity or abundance of available nitrogen in the water of a lake is doubtless a very important factor in determining the scarcity or abundance of the phytoplankton in such lake, just as the available nitrogen in a soil bears a very close relation to the size of the crop which will grow thereon. This then may be one of the very important factors which are responsible for the characteristic differences in the phytoplankton content of different lakes. As yet, however, no studies of this nature have been taken up on lakes which show striking differences in phytoplankton.

Only a few analyses of this character have yet been made and the results of them are shown in an appended table. The determinations for Garvin lake show a marked increase in the free and albuminoid ammonia and nitrates with increasing depth. The same was also true of Mendota on September 25, 1905. In the latter lake, however, the albuminoid ammonia was found to be greater at the surface and bottom than in the mid-region. Four analyses of surface and bottom water were made for lake Mendota between June 30 and July 8, 1905. The results indicate larger amounts of free ammonia, nitrites, and nitrates at the bottom than at the surface. This might naturally be expected, perhaps, because most of the decomposition took place in the lower water. Nitrites were found only in the deeper water and then only in very small amounts. In three of the four analyses there was more albuminoid ammonia at the surface than at the bottom. This may be accounted for by the large amount of plankton found in the upper water at this time, because a larger amount of plankton would yield a larger amount of albuminoid ammonia.

The results given in the following tables are stated in parts per million.

TABLE XII.—*Lake Garvin, October 10, 1905.*

Depth.	Free ammonia.	Albuminoid ammonia.	Nitrites.	Nitrates.
0 m	0.14	0.25	....	0.25
5 m	0.24	0.36	....	0.75
6 m	0.27	0.50	....	0.80
7 m	1.03	0.64	....	0.90
8 m	1.76	0.68	....	1.10
9 m	3.04	0.81	....	1.25
9.75 m	9.21	1.20	....	1.40

TABLE XIII.—*Lake Mendota.*

Date.	Depth.	Free ammonia.	Albuminoid ammonia.	Nitrites.	Nitrates.
June 30, 1905	0 m	0.12	0.37	0.0	tr.
	22	0.6	0.4	tr.	0.5
July 1, 1905	0	0.15	0.41	0.0	0.06
	22	0.23	0.36	tr.	0.8
July 7, 1905	0	0.11	0.44	0.0	tr.
	22	0.45	0.22	0.1	0.7
July 8, 1905	0	0.10	0.44	0.0	tr.
	22	0.29	0.39	0.05	
September 25, 1905	0	0.175	0.365		
	14	0.410	0.300		
	15	0.630	0.275		
	18	1.135	0.275		
	22	1.355	0.447		
	Ooze.	10.675	0.720		

CHAPTER VII.

DISTRIBUTION OF THE PLANKTON AND ITS RELATION TO CHEMICAL CONDITIONS.

One may safely say that the most important element in the environment of strictly aquatic, free floating or free swimming organisms, is the water which they inhabit. This factor of their environment is not the same for all bodies of water, since the various waters possess very different chemical characteristics, as has already been indicated. In fact, this is quite true of the same body of water at different periods, for each passes through a series of chemical changes during the different seasons of the year. Given then, such variations in this important element of the environment, it may be well to consider some of the causes and results of these variations from a biological standpoint. It may be well to state here that the following discussion of this question is only a partial one, as it is confined almost entirely to the dissolved gases. Other factors are involved also, but, up to the present time, it has not been possible to collect enough data to permit a more extended consideration of them.

The relations between chemical and biological conditions in lakes present two chief phases which are closely allied and interwoven, but which it may be well to separate for purposes of discussion. The first of these phases is the effect of living organisms on the chemical condition of the water and the second is the consequent effect of the chemical status of the water on the living organisms inhabiting it. Since the first phase has been more or less fully presented in previous chapters, it is not necessary here to give any extended discussion of this question. Attention has been called to the fact that the living organisms of a lake as well as of the immediate environs, contribute decomposable matter to the water and that the decomposition of these organic substances affects the chemical conditions in a marked degree, especially with respect to some of the dissolved gases in the lower water of lakes that are thermally stratified. Some or all of the dissolved oxygen in the lower stratum is used up in the process of decay and carbon dioxid and ammonia are formed. The latter is then oxidized to nitrous and nitric acids in the presence of free oxygen, which combines with other substances to form nitrites and nitrates. Frequently, also, methane is formed and in some instances hydrogen sulphid and carbon monoxid. In the process of respiration of both animal and plant forms, dissolved oxygen is removed from the water and carbon dioxid is contributed to it. The various excretions of living organisms, also, tend to alter chemical conditions.

On the other hand, chlorophyl-bearing organisms remove free or half-bound carbon dioxid from the water in their photosynthetic activities and liberate oxygen. The atmospheric tension of the former gas is so slight and its rate of diffusion is so low that it does not pass into the water readily from the air and it diffuses upward very slowly from the lower water which may contain an abundant supply of this gas in a free state. Consequently, it frequently happens that not enough free carbon dioxid passes into the stratum in which the chlorophyl-bearing organisms are most active, to supply the needs of any considerable number of them and as a result the free carbon dioxid may be largely or entirely exhausted from a stratum of water which varies in thickness in different lakes. The consumption of carbon dioxid may proceed beyond the point of neutrality or complete exhaustion of the free gas and some of the half-bound is often removed, thus making the water more or less strongly alkaline. It has been found that in lakes which have either a hard or a moderately hard water, the upper stratum very generally becomes alkaline in early spring and continues so until the autumnal overturn. Indeed, it has been noted that more or less of the upper water in lake Mendota may remain either neutral or alkaline throughout practically the entire year. In the hard-water lakes the alkalinity may reach a point where some of the normal calcium carbonate will be precipitated, thus forming a layer in which the combined carbon dioxid will show a pronounced decrease. (See figs. 46, 55, 56, 58, 61.) Alkaline strata have also been found in lakes which have very soft water. (See figs. 65 to 67.)

At the same time that carbon dioxid is being used up, an equal volume of oxygen is being liberated. Where conditions are favorable for the accumulation of this oxygen, the water will be found supersaturated with it, the amount of supersaturation reaching 364.5 per cent. in Knights lake. As yet, however, it has not been possible to trace any direct correlations between the amount of carbon dioxid consumed and the quantity of oxygen liberated. And it may be said further, that only in a very general way has it been possible to trace any quantitative relation between chlorophyl-bearing organisms and either alkalinity or high oxygen.

Turning now to the second phase of the subject, which is the relation of chemical to biological conditions, the effect of the former on the animal forms will be considered first and on the plant forms later. Those lakes which are so shallow that the entire body of water is kept in circulation by the wind during the summer, may be disregarded. The deeper lakes, those which show a thermal stratification in summer, may be divided into three classes. To the first class belong those lakes which have an abundance of free oxygen in all of the water below the thermocline during the summer, such for example as Green lake. The second class includes those lakes in which the free oxygen entirely disappears from a portion of the cool water below the thermocline during the summer; and the third class includes those lakes in which practically all of the water below the thermocline is devoid of free oxygen in late summer.

During the vernal overturn and circulation the plankton organisms are distributed almost or quite uniformly from surface to bottom in all three classes of lakes, with the exception of those in which these processes are not complete. As soon, however, as the bottom water begins to lag behind in the process of circulation, a differentiation in the vertical distribution of these organisms sets in. The phytoplankton forms are the first to show a marked change. In the deeper lakes, of course, the light conditions in the bottom water are not favorable and soon after this water ceases to take part in the general circulation, its phytoplankton population begins to decrease. At the same time the conditions in the upper stratum are becoming more favorable as a result of the increase in the temperature of the water and the phytoplankton population of this region increases. The net result of these conditions, then, is a marked change in the distribution of these organisms, the lower stratum being scantily populated by them while the great majority occupy the upper strata. The animal forms however, which are not influenced so markedly by light conditions may still continue to be fairly uniformly distributed from surface to bottom. But as summer advances the vertical distribution of the animal forms (that is, those which do not bear chlorophyl and are not therefore, dependent in any way on light) becomes different in the three classes of lakes mentioned above.

Concerning the diagrams discussed below, it may be said that the catches were made by the pump method as already indicated and that the number of individuals was determined by the regular counting method. The circles indicate the depths at which catches were made as well as the number of organisms per liter at these depths and the curves have been made by simply connecting these points. The phytoplanktonts far outnumber the zooplanktonts, so it is not possible to plot curves for both groups of organisms on the same scale. In order to obviate this difficulty, the curves for the latter have been platted on a separate scale to the left of a zero line and the diatoms and other algae to the right. This enables one to readily make direct comparisons between the two groups of organisms at the various depths. It will be noted also that the scale for the zooplanktonts as well as that for the phytoplanktonts varies in the different diagrams, owing to the fact that the numbers vary a great deal in the different lakes.

Attention may be called to the fact that a few of the curves show that some of the organisms were rather irregularly distributed vertically, such for instance as the diatoms in figs. 137 and 141. Such results, however, should be expected, for only during the vernal and autumnal periods of circulation would there be any marked tendency toward a uniform distribution. During the summer period of thermal stratification and also during the winter when a lake is covered with ice, there seems to be ample evidence to show that the phytoplanktonts may collect in different strata as well as the zooplanktonts. At first glance, it might be supposed that some of the marked irregularities were due to errors in taking the samples or in counting the material. But a comparison of such curves with those representing other organisms in the same catch gives abundant testimony against such a supposition. If such variations had been due to faulty methods, similar variations ought to appear in all the curves, but such is not the case. On the other hand, attention may be called to the remarkable regularity of most of the curves.

Pine (New Auburn) and Trout lakes may be taken as good examples of lakes belonging to the first class. Figures 116 and 117[1] show that the plankton organisms in these two lakes were fairly uniformly distributed throughout their entire depths. In Pine lake, *Tabellaria* was the chief diatom in the upper water but the marked increase below 15 m. was due to *Asterionella* which would seem to in-

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[1] See explanation of figures, p. 223.

dicate that this form was on the decline after a period of maximum development. The remaining phytoplankton consisted chiefly of *Staurastrum* and *Aphanocapsa*. Down to a depth of 25 m. *Diaptomus* was the predominant crustacean, but *Daphne hyalina* was alone responsible for the marked increase below that depth. It will be noted also that the nauplii were more abundant in the lower water while *Diaptomus* and *Cyclops* were practically as abundant here as elsewhere, so that on the whole, the chemical condition of the bottom water may be regarded as very favorable for the crustacea.

In Trout lake the crustacea were still more uniformly distributed but nauplii were not found below 18 m. and rotifers were not so abundant in the lower water. On September 9, 1906 the bottom of this lake contained only about 0.9 cc. of dissolved oxygen per liter and 5.6 cc. of free carbon dioxid. In addition to the considerable number of crustacea found in the bottom water, several specimens of the Mackinaw trout *(Cristivomer namaycush)* were obtained from this stratum, thus showing that the chemical conditions which existed there not only did not affect the vertical distribution of the crustacea, but that they were such as to permit fish to occupy this region. Green lake also belongs to this group but figures 118 and 119 show that the region above the thermocline was much more densely populated than the region below. It will be noted, however, that, while the microcrustacea appeared in only very small numbers below the thermocline, yet they were found near the bottom in the deepest water. Likewise specimens of whitefish were obtained from the bottom water at a depth of 68 m. This would seem to indicate that the chemical condition of the bottom water can not be regarded as responsible for the paucity of the crustacean population in this region. As a further evidence of the favorable conditions here for crustacea, it may be said that *Pontoporeia hoyi* is a regular inhabitant of the bottom water.

Elkhart and Geneva lakes may be taken as examples of the second class, that is, lakes in which only a comparatively small portion of the lower water becomes devoid of free oxygen during the summer. As long as the bottom water in lakes belonging to this class, contains 0.2 cc. of dissolved oxygen per liter or more, the vertical distribution of the rotifers and microcrustacea does not differ essentially from that found in lakes belonging to the first class. As soon, however, as the free oxygen in a bottom stratum falls below 0.1 cc. these planktonts withdraw from the region having such a small amount of this gas. As this stratum which is almost or quite devoid of free oxygen increases in thickness with the advancing season, these organisms gradually move upward into water which possesses a sufficient amount of dissloved oxygen to supply their needs or else die off.

Fig. 120 shows the vertical distribution of plankton organisms in Elkhart lake on July 3, 1906. With the exception of algae (almost exclusively *Oscillatoria*), it will be noted that the organisms were fairly uniformly distributed from surface to bottom. The diatoms consisted almost exclusively of *Synedra* and were most abundant in the upper water. *Diaptomus* was the predominant crustacean in the upper 7 m. and *Cyclops* thence to the bottom. *Bosmina* has been omitted from the bottom observation because such a large number (828 per liter of water) was present that it could not be shown in the diagram. This is the only case where *Bosmina* was found in great numbers. On the other hand, fig. 121 shows that the vast majority of the organisms were found in the 10–20 m. stratum on October 2, the total number in the upper 10 m. being small and almost none below 20 m. *Synedra* was still the chief diatom and *Oscillatoria* the chief alga. The marked increase in the number of rotifers in the 10–15 m. stratum was caused chiefly by an increase in *Anuraea cochlearis. Cyclops* was the predominant crustacean.

Fig. 122 indicates the vertical distribution in lake Geneva on September 25, 1906. It will be noted that the upper 16 m. were populated most densely by algae, but there was also a relatively large number below this depth. Only a few crustacea and rotifers were found below 35 m. and none at all in the bottom 2 m. in which only a trace of oxygen was found. Nauplii were absent below a depth of 32.5 m.

The third class of lakes may be regarded as a more advanced stage of the second class. That is, in these lakes the conditions are such that practically all of the water below the thermocline loses its stock of dissolved oxygen during the summer. Figures 123 to 137 show the results of a few series of plankton catches on lake Mendota in 1906 and 1907. It is the purpose of these few diagrams to give only a general idea of the vertical distribution of the plankton organisms and not any notion of their quantitative seasonal distribution. It is hoped that a special report on seasonal distribution may be made in the future which will include all of the material that has been collected during the progress of this work. These diagrams show that the organisms were fairly uniform in distribution from surface to bottom during the vernal circulation as shown in figures 123 and 132. As the season advances, the lower water ceases to take part in the circulation and thermal stratification appears. Under such conditions, the phytoplankton population becomes confined chiefly to the upper strata where light conditions are more favorable, only senile forms and those which habitually live saprophytically being found in the deeper water. The decrease of the phytoplankton in the lower water is shown in figures 125 to 128. Attention may be called to the fact here, that these diagrams show the seasonal changes in the relative proportions of the diatoms and all the other algae. That is, they show that the diatoms exceeded in number the green and blue-green algae combined, up to early July and after early September in 1906, the latter predominating during the latter half of July and during August. Conditions were slightly different in the spring of 1907, for green and blue-green algae predominated for a short time in May; otherwise the conditions were substantially the same as in 1906.

The zooplanktonts are very evenly distributed from surface to bottom in spring. (Fig. 133.) In early summer, however, they may become more numerous in the upper water, yet they will continue to occupy the lower strata in considerable numbers until the quantity of dissolved oxygen becomes too small for them, that is less than 0.2 cc. per liter of water. When the dissolved oxygen falls below this amount in the bottom stratum, there is a marked decrease in the number of rotifers and plankton crustacea in that region. This decrease is due in part to the migration of the more active individuals to the water above which contains more oxygen, and in part to the death of senile individuals that are no longer active enough to migrate to the water above and maintain themselves there. As more and more of the lower water becomes almost or quite devoid of free oxygen, the stratum which is occupied by only a very few or none of these organisms increases in thickness. In lake Mendota, for example, the thickness of this zone increases until practically no crustacea or rotifers are found below 10 m. or 11 m. in late summer. (See figs. 127 and 128.) The disappearance from the lower water is shown in figures 125 to 128 and 134 to 137. It will be noted that the line of demarcation between the inhabited and the uninhabited strata is very sharp and distinct. The water which is at the lower limit of habitability, that is, when it contains just enough dissolved oxygen for the rotifers and microcrustacea, may contain very large numbers of them, while they are nearly or quite absent from the water half a meter below. Frequently a much larger number of these organisms is found in the water just above the uninhabited region than at any other depth. (See figs. 127 to 129.)

In September and early October, owing to the cooling of the upper water and the more vigorous action of the winds, the thermocline moves downward, thus adding more and more of the lower water to the upper circulating stratum. Plankton organisms follow in the wake of this downward movement of the thermocline so that they become fairly uniformly distributed to greater and greater depths until the completion of the autumnal overturn, when they again occupy the entire depth of the lake. The distribution just before and just after the autumnal overturn is well illustrated in the diagrams for October 6 and 11, 1906. (Figs. 130–1.)

It may be said at this point that some preliminary experiments have shown that the various gases which are found in the bottom waters of lakes, have no noticeable effects on the plankton crustacea even when present in larger amounts than have yet been found in lake waters. So it seems evident that the disappearance of the microcrustacea from the water which possesses only a very small amount of dissolved oxygen or none at all, is due to the lack of this gas rather than to the deleterious effects of other gases that may be present.

In Beasley it has been found that the vernal overturn may not be complete and chemical conditions much like those of late winter may continue in the bottom water into summer. During the vernal circulation in 1909, for instance, the dissolved oxygen did not rise above 0.4 cc. per liter in the bottom water and this amount had been reduced to nil by June. Under these conditions, of course, the plankton organisms did not become uniformly distributed from surface to bottom and the rotifers and crustacea which invaded this bottom stratum when it contained a sufficient supply of oxygen for them, withdrew from it in the early summer. A bright green *Stentor,* however, apparently *Stentor igneus* Ehrbg. continued to occupy the stratum which had very little or no free oxygen during the entire summer in 1909. About 200 individuals per liter were found at a depth of 13.5 meters on June 3 where the water contained not even a trace of oxygen. Reference will also be made on a subsequent page to the occupation of this stratum by *Corethra* larvae.

SENSITIVENESS TO LACK OF OXYGEN.

The various zooplankton forms show different degrees of sensitiveness to the lack of oxygen in lake waters. It would seem that such active organisms as the plankton crustacea would require a rather large amount of free oxygen, but it has been found that they are able to occupy water which contains only a very small amount of this gas. *Diaptomus* is much more sensitive than *Cyclops* and is rarely found in water which contains less than 0.2 cc. to 0.3 cc. of oxygen per liter, while *Cyclops* may be found in considerable numbers in water which contains only 0.1 cc. or even less. In one experiment, some specimens of *Cyclops bicuspidatus* which had just emerged from their encysted state, lived for several hours in water which contained no free oxygen whatever. Also in Rainbow lake on October 22, 1909, specimens of this *Cyclops* were found at depths where there was no dissolved oxygen. These specimens were immature and had doubtless recently come out of the cocoon. In view of the fact that this form lives several weeks during the summer in an encysted stage, in water which does not contain dissolved oxygen, it is not so surprising, perhaps, that it shows such a very low degree of sensitiveness to lack of oxygen when it is not in the encysted stage. An ostracod, also, as indicated on a subsequent page, is able to live in water which contains no dissolved oxygen.

The copepod nauplii are able to live where only a very small amount of free oxygen exists. In a very few instances they have been found in water which contained only a trace of oxygen, but generally they do not occupy water which possesses less than 0.1 cc.

The *Cladocera* are more sensitive to lack of oxygen than the *Copepoda*. *Daphne longispina* var. *hyalina* and *D. pulex* may be found in considerable numbers in water which has only 0.2 cc. to 0.25 cc. of oxygen per liter but healthy looking individuals are practically never found in water containing less than this amount. *Daphne retrocurva, Diaphanosoma, Chydorus,* and *Bosmina* are found almost entirely in water which has a fairly large amount of dissolved oxygen. Only rarely are they taken in water which possesses less than 0.5 cc. of free oxygen and they are most abundant in water which is nearly or quite saturated with this gas. These forms, however, are very generally limited to the region above the thermocline even in lakes where there is an abundance of oxygen below this depth and it seems probable, therefore, that other factors play a more important rôle than oxygen in determining their vertical distribution.

In one instance (Beasley lake, April 22, 1909) a fairly large number of rotifers was found at two depths where only a trace of oxygen was present but rarely has any considerable number been found in water containing less than 0.1 cc. of free oxygen per liter, and more often, they are very scarce when the amount falls below 0.15 cc. to 0.2 cc.

It will be noted in some of the accompanying diagrams, for example figs. 128 and 138, that some forms show a marked increase in numbers in the region just above the water which is devoid of dissolved oxygen. These aggregations are generally found in water which contains from 0.15 cc. to 0.8 cc. of dissolved oxygen per liter. Nauplii exhibit this phenomenon most frequently, but rotifers, *Cyclops, Daphna longispina,* and *D. pulex* have occasionally shown the same phenomenon.

Corethra larvae, apparently those of *Corethra punctipennis,* are able to occupy with apparent impunity, water which contains no dissolved oxygen. In fact they seem to prefer this region in the daytime as they are almost invariably found here when they inhabit such lakes. It is not known definitely whether the two pairs of air-sacs possessed by these larvae have any respiratory function or not; but in this case, one can readily see how they may serve a very important function by acting as reservoirs for oxygenated gas. But, it will be shown below that other animals which are more or less active, and which do not possess any such reservoirs, are able to live for 2 or 3 months in a medium which contains no free oxygen. Therefore it is not necessary to assume that these larvae carry a supply of oxygen with them when they move down into the water which is devoid of this gas, for it may be that they too are able to live by intra-molecular respiration for some time.

As yet no thoroughly satisfactory reason can be assigned for the migration of these larvae to this region in the daytime. They react negatively to light, as they move down from the upper water early in the morning and remain in and below the thermocline during the day. At night, however, they are frequently found at the surface. They descend to depths of 12 m. or 15 m. in the daytime in lakes which have a very low transparency, that is, in some where a Secchi's disc disappears from view at a depth of 2 m. or even less. This seems to indicate that light is not the only factor involved, for it scarcely seems probable that light alone could be responsible for such a large depth migration in lakes which have such a low transparency. It appears then that other factors are involved which are still unknown.

In lakes whose lower water contains no dissolved oxygen, these larvae are the only regular inhabitants of such water, so they would be free from enemies here. On the other hand, however, they remain in the lower water in the daytime in lakes where there is enough oxygen to enable their enemies to occupy this region also. In North Turtle lake, for example, some specimens of *Lota maculosa* were obtained from the lower water and the stomach of one contained about 200 *Corethra* larvae while stomachs of other specimens contained from 10 to 100 larvae. In view of this fact, then, one can not say that the larvae move down into this region in such lakes to avoid their enemies.

No evidence has yet been found which indicates that a chemical factor is involved. This diurnal migration has been found in some lakes in which the water above the thermocline gave an alkaline reaction while that below gave an acid reaction on account of the free carbon dioxid present. It has also been noted in other lakes in which the water contained free carbon dioxid from surface to bottom so that it gave an acid reaction at all depths and in lakes which have soft as well as in lakes which have hard water.

In Beasley lake, another animal was found which occupied the bottom water regularly during the summer of 1909, where there was little or no free oxygen. It was the bright green *Stentor igneus* Ehrb. This protozoan has not been noted in any other lake and the fact that Beasley lake is comparatively shallow (14 m.) and the water generally has a fairly high transparency, suggests that this *Stentor* may receive enough light during the daytime to enable it to manufacture a sufficient amount of oxygen for its own respiration.

Several forms have been found in the muddy ooze at the bottom although there was no free oxygen in this region. These forms have been studied chiefly in lake Mendota and the following discussion applies particularly to this lake. The protozoa were represented by the largest number of forms. Living, active representatives of sixteen genera have been noted, *Pelomyxa, Difflugia, Colpidium, Gyrocoris, Peranema, Coleps, Loxophyllum, Paramecium, Prorodon, Lacrymaria, Uronema, Monas, Metopus, Spirostomum, Loxodes,* and *Stentor.* All of the individuals representing these genera were perfctly normal so far as could be determined. They showed no evidences of unusual vacuolation, or any other signs of ill effects resulting from the anaerobic conditions under which they lived. Some of the parasitic protozoa live under practically anaerobic conditions constantly so it is not surprising, perhaps, that the above forms should adapt themselves to such conditions when necessary. These anaerobic conditions exist in lake Mendota for a period of about three months each summer and it has been found that these protozoa are as numerous and as active toward the end of this period as at the beginning. Apparently, then, these organisms are able to carry on their life processes just as well under anaerobic as under aerobic conditions.

Higher invertebrates were also found in this muddy ooze. The worms were represented by specimens of *Tubifex, Limnodrilus,* and *Anguillula;* the rotifers by *Chaetonotus* and *Philodina;* the crustacea by an ostracod belonging to the genus *Candona* and by encysted specimens of *Cyclops bicuspidatus;* insect larvae by a large red chironomid larva; and the mollusca by *Corneocyclas idahoensis.*

Some observations were made to determine how active some of these forms are under anaerobic conditions. Muddy water containing them was pumped into glass jars that could be sealed and kept airtight. This muddy water was pumped through the jars so that they could be thoroughly flushed and all of the material removed that had been exposed to the air. The jars were sealed immediately after the material was obtained and they were then taken to the laboratory and placed in a refrigerator in order to keep the temperature about the same as that of the mud in the bottom of the lake. They were kept at a temperature of 13° to 15° which was 1.5° to 2.5° above that of mud at the time the material was obtained. The jars were carefully removed from the refrigerator from time to time, and examined in order to determine how active the various animals were.

The worms were as active under anaerobic as under aerobic conditions. So far as could be determined, they were not affected in the least by the absence of free oxygen. It has been found that some parasitic forms which live under essentially anaerobic conditions, have a very high glycogen content but no determinations have yet been made to ascertain the relative proportion of glycogen in these nonparasitic forms.

Candona kept itself buried in the mud most of the time and so far as could be determined was not very active, but when placed in aerated water it soon became more active and moved around in the dish as usual under such conditions.

The encysted individuals of *Cyclops bicuspidatus* remained quiescent of course. They go into this state in lake Mendota about the first of June and remain in the cyst, lying on the bottom, until about the time of the autumnal overturn, which takes place either in late September or during the first half of October. The cocoon or cyst is oval in outline, about 0.65 mm. long and 0.5 mm. in cross diameter. It consists of two layers, an inner composed of a yellowish or brownish gelatinous substance and an outer composed of this adhesive substance and particles of mud, vegetable debris, etc. The entire *Cyclops* is covered by this cyst with the exception of the abdominal setae. The abdomen is generally bent forward ventrally, coming close to the under side of the thorax, so that the caudal setae project toward the anterior end of the animal. These individuals are well developed, perhaps three quarters grown or more, when they pupate, but they are sexually immature.

Both the encystation in early summer and the emergence from the cocoon stage in autumn do not seem to be coincident with any marked physical or chemical changes in the water to which they might be attributed. Both in 1906 and 1907, most of the pupation took place in lake Mendota when the bottom water reached a temperature of 9° to 10°. Marsh[1] reports that this *Cyclops* is found in lake Winnebago only in the months from October to June. That is, it is found in this lake as a winter form only. This lake is large and shallow so that the water at all depths becomes very warm during the summer. Kofoid[2], also, states that *C. bicuspidatus* is only a winter and early spring constituent of the plankton of the Illinois river. Such evidence as this might lead to the conclusion that encystation is merely a temperature phenomenon which is started by a rise in the temperature of the water to 9° or 10°, but there are complexities which can not be explained in so simple a manner. For example cysts have been found in lakes which had an abundance of water which was colder than 9° during the summer and which also contained a fairly large amount of dissolved oxygen.

Therefore, if pupation is simply a temperature phenomenon, it is not clear why it should take place at all in such a lake. It can not be attributed to any marked or sudden rise in the temperature of the bottom water, for most of the pupation took place in lake Mendota in 1906 while the bottom water rose from 9.6° to 10.1° or only half a degree.

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[1] The Plankton of L. Winnebago and Green Lake, p. 27. 1903.

[2] Bull. Ill. State Lab. Nat. Hist., VIII, Art. 1, p. 264. 1908.

At first it was supposed that the chemical condition of the cool lower water might be the cause of the pupation but further investigation has shown that this does not account for the phenomenon satisfactorily. In 1906, it was found that individuals went into the cocoon stage in lake Mendota when the bottom water still contained 4 cc. of dissolved oxygen per liter and 2.6 cc. of free carbon dioxid; in 1907, however, the first cocoons were found on May 28 and on this date the bottom water contained 7 cc. of oxygen and showed an alkalinity equal to 2.6 cc. of carbon dioxid. Thus it will be seen that the cocoons are formed while the lower water still possesses an abundance of dissolved oxygen and while it may be either acid or alkaline. Cocoons have been found also in lakes whose cool lower water contains more or less oxygen during the entire summer, enough in fact to support a fairly large population of other crustacea.

Marsh[1] states that *C. bicuspidatus* is found at all seasons in several Wisconsin lakes which he studied and this seems to indicate that in some of the lakes only a part of the individuals go into the cocoon stage while others remain active during the summer.

Forbes states that this *Cyclops* (*C. thomasi*) was the dominant copepod in the summer plankton of lake Michigan[2] and he also found it abundant in lake Superior[3] in summer. Scourfield[4] and Scott[5] have also reported this form as a constituent of the summer plankton of English and Scottish waters. This, of course, makes the cause of the encystation still more puzzling. In lake Mendota, this *Cyclops* has not been found in the summer catches made in 1906, 1907, and 1908.

Emergence from the cocoon in the fall begins and seems to be almost completed before oxygen reaches the bottom water in appreciable quantities and before the temperature of the bottom water changes very much. In 1906 the cocoons began to hatch before the end of September and almost all had disappeared before October 8th; and the water at 16 m. and below that depth still contained no free oxygen and had 4.9 cc. of free carbon dioxid per liter. The temperature of the bottom water also had changed only half a degree in 9 weeks, that is, on August 1, it was 12.5° and on October 8, 13°. Thus the cause of the emergence from the cocoon is equally as puzzling as the cause of its formation.

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[1] Plankton of L. Winnebago and Green Lake, p. 27. 1903.
[2] Amer. Nat., XVI, p. 641, 1882.
[3] Rept. U. S. Comm. of Fish and Fisheries, 1887, p. 707. 1891.
[4] Essex Naturalist, X, p. 264, 1898.
[5] Ann. Rept. Fishery Bd. Scotland, XVII, p. 132-204, 1899.

In emerging, the *Cyclops* breaks the cocoon and loosens it by violently extending and flexing the abdomen. The animal then backs out of the part which covers the body. No moulting accompanies the release from the cocoon, nor does any development of the animal take place in the exit. Observations were made on material that was brought to the laboratory in order to determine the length of time required for hatching. It was found that there are always great individual differences in this respect but in general the results showed that the cocoons hatch more promptly in September than in early June. During the latter month most of the cocoons will hatch in about a week while in September the time varies from 6 or 8 hours to as much as 4 or 5 days. Just how great a food supply is stored for use during the resting period has not been determined. Encysted individuals always possess rather large globules of oil but these do not seem to decrease appreciably in size during the summer. Neither have any glycogen estimations been made to ascertain how much reserve food of this character is stored up for use during pupation.

No specimens of *Chironomus* larvae were noted in the jars on which observations were made.

Corneocyclas remained quiescent with the valves tightly closed. Some of the jars were kept under observation for two weeks and no living specimens were ever found with the valves open. The mud in the bottom of the jars was also carefully examined for indications of activity, but no evidences of it were found. When removed from the jars, however, and placed in aerated water, or when the contents of the jars were poured into crystallizing dishes and exposed to the air, the specimens of *Corneocyclas* soon became very active, freely moving about in the mud. These results seem to indicate that this mollusk remains quiescent or dormant during the period when the muddy ooze at the bottom contains no dissolved oxygen. If this be true, this quiescent period lasts for three months or more each summer in lake Mendota.

Several interesting problems with respect to the life of *Corneocyclas* are still untouched. It would be interesting to know how widely it is distributed over the bottom of the lake and whether it extends into the shallower water where the bottom ooze contains enough oxygen to enable the animal to continue its usual activities during the summer. Neither has the time at which it reproduces been determined as yet. No attempt has been made either to ascertain whether the tissues undergo any appreciable change during the quiescent period, and whether a special supply of fat and glycogen are stored previous to the latent life period to serve as food during that time.

The medium in which all of these forms were found in lake Mendota in summer is not only devoid of dissolved oxygen but may contain from 7 cc. to 15 cc. of free carbon dioxid per liter as well as 6 cc. to 8 cc. of methane and traces of carbon monoxid and hydrogen sulphid. So far as could be determined, however, these substances produced no deleterious effects on the organisms.

From these results, then, it is evident that, if we wish to understand the physiology of some of these lake inhabiting organisms, we must study them in their natural environment and not merely in the laboratory where they are subjected to a purely artificial environment. It is only necessary to give two or three instances to show that the results obtained under the former conditions may differ materially from those obtained under the latter. Some observers have found that a number of forms of protozoa show marked changes when they are placed in water containing no dissolved oxygen. Most of the protozoa become strongly vacuolated, in many the cell membrane bursts and the protoplasmic contents flow out; and in those which do not fare so badly, characteristic changes in the protoplasm have been noted. Under natural conditions, it has already been stated that representatives of no fewer than 16 genera of protozoa have been found living under anaerobic conditions without exhibiting any evidences whatever of ill effects resulting therefrom. And they withstood such conditions for a period varying from about three months in some lakes to as much as five months in others. It has been observed, also, in laboratory experiments, that anaerobic conditions have a bad effect on the process of reproduction, yet it does not appear that such conditions affect this process under natural anaerobic conditions. While no stages in this process have been noted in the material examined, yet the protozoa were as abundant and in as good condition at the end of the anaerobic period as at the beginning, and this could scarcely have been true if the reproductive process had been seriously interfered with.

Loeb[1] has found that the heliotropic reactions of some of the fresh-water crustaceans can be readily controlled by specific chemical substances, especially carbon dioxid. He states that both *Cyclops* and *Daphne* can be made positively heliotropic by carbon dioxid and suggests that the consumption of this gas at the surface of lakes by the

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[1] Univ. Calif. Pub., Physiol. II, p. 1–3, 1904.

algae "may contribute toward making these animals negatively heliotropic and thus forcing them to migrate downward." This suggestion is open to at least two very serious objections. The first is that the downward migration of the crustacea takes place very early in the morning, or before there is a sufficient amount of light to enable the algae to carry on the process of photosynthesis and, therefore, before there has been any change in the carbon dioxid content of the upper water which is deserted by them. In the second place, this downward migration takes place in lakes whose waters are distinctly acid from surface to bottom due to the presence of free carbon dioxid and where the amount of carbon dioxid at the surface is the same as at the depths to which the crustacea migrate.

On the other hand, these diurnal depth migrations have been noted in lakes during the vernal circulation when the water was uniformly and distinctly alkaline from surface to bottom. In summer this phenomenon has been observed in lakes whose upper water was alkaline and whose lower was acid. In addition it may be said that no diurnal changes of the water from an alkaline to an acid reaction have been found in Wisconsin lakes. Such changes take place slowly and hence extend over a considerable period of time. When the upper stratum of a hard water lake becomes alkaline in the spring, for instance, it has always remained so until autumnal conditions set in, so far as these observations go. The degree of alkalinity may vary during this long period of time, but these variations are not diurnal.

It appears then that the various protozoa and microcrustacea of the different lakes have become delicately adjusted to their natural environments, including chiefly perhaps, such factors as light and the thermal and chemical conditions of the water. Hence, subjecting these organisms to artificial laboratory conditions upsets this adjustment and produces results which may be partially or wholly at variance with those which are found under natural conditions. If we wish to understand the life and activities of such organisms, then, we must study them as fully as possible in their natural environments.

With respect to high oxygen, it may be said that water which is supersaturated with this gas seems to have no effect whatever on the vertical distribution of the various zooplankton forms. They are neither attracted nor repelled by such a stratum of water. The diagram for Knights lake on August 25, 1909, (fig. 140) shows how little the high oxygen affects the distribution of these organisms.

Some tests were made on fishes in order to ascertain how the lower water which contained no free oxygen, would affect them. Perch (*Perca flavescens*) and crappies (*Pomoxis*) were used for this purpose as they are very hardy. Aquaria and specimens of these two fishes were taken out in a boat on lake Mendota and some of the lower water free from dissolved oxygen was pumped into an aquarium, the discharge end of the hose extending to the bottom of the aquarium so as to expose the water to the air as little as possible. The aquarium was well flushed and then a fish was quickly introduced. In nearly all cases the specimens turned ventral side up in 20 to 30 seconds after they were placed in this water and specimens which remained in the water died in a few minutes. If they were removed, however, after 2 or 3 minutes and placed in aerated water, they quickly revived. These results only confirmed what had been taken for granted before performing the experiments, that is that the lower water is uninhabitable for fishes when it contains no dissolved oxygen.

No further experiments have yet been made to ascertain the resistance of fishes to lack of oxygen. König[1] found that he could keep fish (kind not specified) in water which contained 2.95 cc. and 1.38 cc. of dissolved oxygen per liter without any apparent ill effects. Thörner[2] found that a fish epidemic was caused by the absence of free oxygen. Hoppe-Seyler and Duncan[3] state that the trout which were kept from one and a half to two and a quarter hours in water having only from 0.98 to 1.71 cc. of oxygen per liter showed marked signs of dyspnoea. Paton[4] in experiments on young rainbow trout, found that a fall in the amount of dissolved oxygen below one-third of the normal amount, *i. e.,* below 2 cc. per liter of water, is prejudicial and generally fatal. Some individuals, however, were able to sustain life for long periods in water which contained only minimal traces of dissolved oxygen.

Knauthe[5] found that carp kept for an hour and twenty minutes in water which contained 1.33 cc. of oxygen per liter, did not show any signs of dyspnoea, while others became dyspnoeic in water containing from 2 cc. to 3.1 cc. of this gas.

Only two instances have been noted which give some notion of the resistance of any species of fish to the lack of dissolved oxygen. The Mackinaw trout (*Cristivomer namaycush*) has a peculiar geographical

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[1] Die Verunreinigung der Gewässer, II, p. 37, 1879.
[2] Forschungsber. über Lebensmittel, IV, p. 172, 1897.
[3] Zeitschr. für physiolog. Chemie, XVII, p. 165, 1893.
[4] Proc. Roy. Soc. Edinburgh, XXIV, p. 145, 1904.
[5] Biol. Centralbl., XVIII, p. 788. 1898.

distribution in the lakes of northern Wisconsin and some observations were made for the purpose of ascertaining, if possible, the cause of this peculiarity. In the course of this work, Trout lake, in which the Mackinaw is fairly abundant, was visited in early September, 1906. This lake consists of two parts connected by a comparatively narrow but deep channel, and both parts have a maximum depth of about 30 m. Some gill nets were set on the bottom in the deepest water of the south part, that is, in water 28.5 m. to 30 m. deep, and in 24 hours 6 trout were obtained. At the time the nets were raised, some samples of the bottom water at this point were taken and these showed that the water at 29 m. contained 0.9 cc. of dissolved oxygen per liter and at 27 m. there were 2.1 cc.

The position of the trout in the nets indicated that they were within one meter, or perhaps less, of the bottom and therefore in water which did not contain more than about 1 cc. of dissolved oxygen per liter and very probably less. Also, on September 12, 1909, six specimens of a whitefish were obtained at a depth of 67 m. in Green lake where the water contained but very little more than 1 cc. of oxygen per liter. It is impossible to say just how long individuals of these two species of fish could remain with impunity, in water with such a relatively small amount of oxygen, but the facts seem to warrant the conclusion that they do not hesitate in the least to enter water which contains as little as 1 cc. of dissolved oxygen per liter, or perhaps even a little less than this amount.

The inability of fishes to occupy water which contains no free oxygen means that their vertical distribution is very much restricted in some lakes in summer. In the smaller lakes which are well protected from winds and which contain much decaying organic matter, the dissolved oxygen may entirely disappear below a depth of 5 m. or 6 m. in late summer. In such lakes, then, the fishes would be restricted to a warm, upper stratum only 5 m. or 6 m. thick. Even in so large a lake as Mendota which has an area of about 39 sq. km., there is practically no dissolved oxygen below a depth of 10 m. or 12 m. in August and early September. As this lake has a maximum depth of only about 25 m., this means that about half the maximum depth of the lake is uninhabitable for fishes at this time. Scarcely more than a third of the maximum depth of some lakes is habitable for fishes in late summer.

Thus it will be seen that the oxygen condition of the lower water may be a very important factor in determining the geographical distribution of a species of fish. Such a fish as the Mackinaw trout, for instance, which requires cool water during the summer would not find conditions favorable for it in a lake where all of the dissolved oxygen disappeared from the cool lower water during the summer. Consequently it would be limited to the lakes which have cold water with enough free oxygen to supply its needs. This fact is of very practical importance in the introduction of this species of trout or of species of whitefish into new waters. A determination of the quantity of dissolved oxygen in the cool, lower water of a lake in the month of August will show whether the introduction of these fishes is likely to prove successful or not.

Plankton organisms, either directly or indirectly, constitute a very important element of the food of most fishes at some stage of their development; in fact it has been asserted that the production of fish is closely correlated with the amount of plankton produced by a lake, or stream. But some of the foregoing results show that this statement must be modified somewhat for lakes. It has been pointed out that plankton is a very important factor in determining the oxygen condition of the lower water since it furnishes a large amount of decomposable matter. Beyond a certain limit, then, an increase in the amount of plankton would tend toward a decrease in the production of fish in lakes, more especially those species which live in the cool lower water in the summer, rather than an increase, because it would make conditions unfavorable for them in the lower strata. The decomposable matter derived from a very large growth of plankton would use up the dissolved oxygen in the lower water, thus making conditions unfavorable for fishes which prefer cool water and also causing a very considerable restriction in the vertical distribution of even those which are able to live in the warm upper water. So far as oxygen conditions in the lower water are concerned, then, a lake that is poor in plankton would be best adapted to fish life in that region, but the question of food now enters as a factor of equally great importance. Therefore the quantity of plankton that is best adapted to fish life in a lake is that which will give the maximum amount of food and still not furnish enough decomposable material to the lower water to exhaust all of its dissolved oxygen and render this region uninhabitable for fishes.

In experiments on *Fundulus heteroclitus* Packard[1] found that the

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[1] Amer. Jour. Physiol., XV, p. 30-42. 1905-06.

power of resistance to lack of oxygen was increased by sodium bicarbonate and that decreasing the alkalinity by injecting acetic acid into the blood decreased the resisting power. From these results, it may be inferred that the resistance to lack of dissolved oxygen depends in a measure, at least, upon the chemical composition of the blood. Thus, if a fish possessed the power to alter the composition of its blood somewhat, it would be able to adapt itself to water which contains only a comparatively small amount of dissolved oxygen. The ability to increase their resisting power would doubtless be useful to fishes in many of the Wisconsin lakes and it is possible that they may possess some power of adaptation to such unfavorable conditions.

In this connection, also, it may be said that Packard[1] has found that the presence of a depolarizer, such as carbohydrates, increases the power of fishes to resist low oxygen. This may help to explain why the various forms which occupy water that contains no free oxygen, are enabled to do so. There are substances in this water which would act as depolarizers and would thereby facilitate intra-molecular respiration.

Knauthe[2] calls attention to the fact that Gasch, Marsson, and Hofer have found undoubted evidences of a close relation between an insufficient amount of dissolved oxygen and fish diseases of both a parasitic and bacterial nature. So far very little attention has been given to this problem in the studies on Wisconsin lakes but a few observations have been made which seem to show that some fish epidemics have been closely correlated with unfavorable oxygen conditions. It has been noted, for instance, that *Leucichthys sisco* which is found in Okauchee lake and which seems to occupy the cooler water below the thermocline during most of the summer, dies off sometimes in very large numbers in late August and early September when the cooler water just below the thermocline does not contain a very large amount of dissolved oxygen. The most serious epidemic that has been noted within the last few years occurred in late August and early September, 1909, when the cooler water of this region contained the smallest amount of dissolved oxygen that has been found here in four years. In 1905, the maximum amount below the thermocline was 0.74 cc. per liter of water; in 1906, 0.95 cc., in 1907, 1.7 cc.; in 1909, 0.44 cc. In 1909, the epidemic was very serious, the shore in places being covered with large numbers of dead fish.

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[1] Amer. Jour. Physiol., XVIII, p. 164, 1907.

[2] Das Süsswasser, p. 148. 1907.

Hofer (loc. cit.) has, also, found that a scarcity of oxygen will produce epidemics among the larger crustacea.

With respect to the biological relation of dissolved nitrogen, it may be said that Marsh and Gorham[1] reached the conclusion that this gas is the chief, if not the sole, cause of the gas disease in fishes. These investigators found that an excess of about 2 cc. of nitrogen per liter of water was sufficient to produce symptoms of the disease and that an excess of 6 cc. killed most adult fishes in a few hours. Not enough data bearing on this point have yet been obtained in these investigations to enable one to say whether similar conditions in natural environment will produce similar results or not. But attention may be called to a set of observations on Otter lake which has more or less bearing on this question. On August 20, 1906, the water of this lake contained an excess of nitrogen at all depths. The amount of excess varied from a minimum of 0.4 cc. at the surface to a maximum of 5 cc. at 5 m. There was an excess of 3.6 cc. at a depth of 3.5 m. This lake has a fairly large fish population and the water contains enough dissolved oxygen at all depths to supply their needs. The vertical distribution of the fishes could not be determined at the time of making the gas analyses, so it is impossible to say definitely whether they occupied water which contained an excess of 2 cc. or more of nitrogen per liter or not. But it seems very probable that they did because they would have been limited to the upper 2 m. if they had not occupied water which contained an excess of 2 cc. of nitrogen per liter or more. No unusual fish mortality was noted at the time of these observations and therefore, if they were inhabiting water that contained an excess of 2 cc. or more of nitrogen it produced no serious results.

Knudsen[2] reached the conclusion from his experiments that the quantity of free carbon dioxid found in water depends chiefly upon the nature of the plankton. Copepods decreased the oxygen perceptibly and increased the carbon dioxid in three hours. Diatoms kept in the dark, absorbed a little oxygen and gave up an appreciable amount of carbon dioxid but those exposed to light used up almost a quarter of the total quantity of free carbon dioxid and gave off oxygen.

In the Wisconsin lakes, however, decomposition of organic matter seems to be the most important factor concerned in the consumption

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[1] Rept. U. S. Comm'r of Fisheries for 1904, p. 356. (1905.)

[2] Comptes Rendus, CXXIII, p. 1091–3, 1896.

of dissolved oxygen and in the production of free carbon dioxid. While both fish and living plankton organisms may play more or less prominent rôles in this process, yet they are by no means as important a factor as decomposition.

With respect to the effect of the chemical conditions of the water on the phytoplankton, the carbon dioxid will be considered first. The phytoplankton and the chlorophyl-bearing zooplankton as well, require the presence of a certain quantity of carbon dioxid in an available form for the manufacture of carbohydrate food material photosynthetically. The amount of this gas which will be required depends upon the scarcity or abundance of these organisms. But the amount of available carbon dioxid is a fairly uniform and fixed amount for any one lake, the quantity differing, however, in different lakes. Such being the case then, what is the effect of these fixed conditions on the chlorophyllaceous microorganisms? So far as the hard water lakes are concerned, there is enough available carbon dioxid to support large growths of these organisms, because there is a fairly large supply of half-bound carbon dioxid which may be drawn upon after the free carbon dioxid is exhausted.

But the soft water lakes, especially those with very soft water, present a very different set of conditions. Attention has already been called to the fact that the upper water, which these organisms inhabit chiefly, appears to obtain carbon dioxid from the air at a slow rate and it receives very little by diffusion upward from the lower water. From these sources then no large supply of free carbon dioxid is rapidly obtainable by the upper water, and since only a small quantity of half-bound carbon dioxid will be present in a very soft water, the total available carbon dioxid will be limited in amount. Thus such a lake may not possess enough available carbon dioxid to support a large growth of organisms which depend upon a supply of this gas for the manufacture of their most important food element. Generally, then, one may expect to find only a comparatively small number of chlorophyl-bearing organisms, more especially algae, in such a lake; in other words, such a body of water will very generally be poor in phytoplankton.

The smallest quantity of available carbon dioxid found in any Wisconsin lake was 0.5 cc. per liter of water, which is still somewhat larger than the amount usually found in a liter of air (0.3 to 0.4 cc.). But the ease with which land plants come into contact with large quantities of air, results in their exposure to a much larger supply of carbon dioxid in the course of a day, than a submerged aquatic plant in such a lake. In order to make good this deficiency resulting from poorer circulation, and produce an exposure to an equal volume of carbon dioxid in a given time, lake water must contain a much larger proportion of this gas in an available form than the air.

Whipple and Parker[1] state that, "in Massachusetts water-supplies, heavy growths of organisms were somewhat more likely to occur in hard water than in soft waters." They attribute this phenomenon, in part at least, to a scarcity of available carbon dioxid in the soft water. In general, the soft water lakes of Wisconsin on which observations have been made, that is those in which the fixed carbon dioxid does not exceed 4 cc. to 5 cc. per liter of water, do not support so large a phytoplankton population as the hard water lakes. There are some exceptions, however, to this general statement. Some fairly large growths of such organisms have been found in Devils lake both in 1907 and 1909 and this lake has a soft water, averaging somewhat less than 4 cc. of fixed carbon dioxid per liter.

On the other hand, it seems certain that other factors also, may be concerned in the production of the paucity since all hard water lakes do not support continuous large growths of phytoplankton. The deep lakes especially are usually poor in phytoplankton. They may possess fairly large growths of algae at times, but these growths do not continue for any considerable period of time as in the shallower lakes. No hard water lake has yet been found, however, which contained so little phytoplankton as many of the soft water lakes.

The data at hand do not indicate definitely just what factors are responsible for the paucity of phytoplankton in the deeper lakes, such as Geneva and Green. It seems evident, however, that the thermal stratification of the water as well as the size and the shape of the lake basin, are factors which play a more or less prominent rôle in producing this phenomenon. In thermal stratification, the lake is separated into an upper, warm stratum and a lower, cool one and there is no intermixture of the water of these two strata as long as stratification continues. The phytoplankton which is active in the process of photosynthesis is confined chiefly to the upper stratum or the epilimnion and any factor which tends to make conditions unfavorable in this region for these organisms, tends to prevent a large growth of them. After

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[1] Trans. Amer. Micro. Soc., XXIII, p. 140, 1902.

thermal stratification is once established, practically all of the products, such as carbon dioxid and nitrogenous compounds, that are formed in the lower water during the process of decay, remain in this region, and are, therefore, unavailable as food for the algae as long as this stratification continues. In other words the lower water serves as a safe deposit region for this material until the autumnal overturn. The deeper lakes have much steeper sides so that a much larger proportion of the decomposition takes place in the lower water. Hence a proportionately larger amount of food material becomes unavailable for the algae in the epilimnion of the deeper lakes. In lake Geneva and Green lake the water is thermally stratified for a period of about five months each year and in that period of time considerable amounts of food material are transferred from the upper water to the lower because organisms which populate the former are constantly dying and sinking into the lower strata where they decay. Thus, food conditions become more and more unfavorable for the algae of the epilimnion during the period of thermal stratification which includes practically all of the most favorable growing season of the year.

In the shallower lakes, especially those with wide, shallow margins, a larger proportion of the decay takes place in the water above the thermocline and the resulting decomposition products are again available as food for the algae of this water. Thus, during the period of thermal stratification in the shallower lakes, much of this material may be used again and again by the phytoplankton. Large shallow-water, aquatic plants are more numerous in the shallower lakes and the decomposition of these contributes additional food material to the upper water. Thus in proportion to the volume of water, the shallower lake presents more favorable food conditions for the phytoplankton during the period of thermal stratification than the deeper lake because a greater proportion of the decomposition takes place in the epilimnion where the resulting products are available as food for the algae.

The size of a lake is not as important a factor as the shape of the basin, that is the depth, in determining the quantity of phytoplankton, but it seems to have some influence at least. In a large lake, the wind is more effective in keeping the upper water in circulation, so that the epilimnion is thicker, hence the volume of water which may be occupied by the phytoplankton is proportionately greater.

From the qualitative standpoint, the phytoplankton of soft water lakes is characterized by the presence of relatively large numbers of desmids. These forms are frequently found in the plankton of hard water lakes also, but not in such relatively large proportions nor in such variety of species. *Staurastrum* is almost the only desmid that is found in the plankton from hard water lakes, but usually several genera will be represented in catches from soft water lakes. The more common forms are *Micrasterias, Cosmarium, Xanthidium, Staurastrum, Sphaerozosma, Hyalotheca*, and *Desmidiu.m* *Staurastrum*, however, is usually the most abundant and a very large growth of this was found in Devils lake in 1907. It reached a maximum number of 176,000 per liter. Neither this nor any other desmid has ever been found in such numbers in any other lake.

Similar phytoplankton conditions have been noted by W. and G. S. West[1] in the soft water lakes of Scotland. These authors state that the phytoplankton of the Scottish lakes "is unique in the abundance of its Desmids. No known plankton can compare with it in richness and diversity of Desmid flora." They also say that the commonest and most abundant forms are the *Staurastrums*. G. S. West[2] makes the statement that "Desmids thrive best in soft water, and they are most numerous in peaty water which has a trace of acidity." The observations on Wisconsin lakes fully confirm two of these points, that is, that desmids thrive best in soft water which gives an acid reaction owing to the presence of free carbon dioxid, but whether the water is peaty or not does not appear to make any difference. In fact the largest numbers have been found in Devils lake where the water has no trace of peaty material.

The presence of nitrites or nitrates is of vital importance to the phytoplankton, also, but so far only a very few quantitative determinations of these compounds have been made. So it is impossible to say at present what rôle they may play in determining the scarcity or abundance of these organisms. Likewise it is probable that other substances which are in solution in lake waters, may affect these microorganisms more or less markedly but no investigations along this line have yet been made.

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[1] Jour. Linn. Soc. Botany, XXXV, p. 519-56, 1903.

[2] The British Freshwater Algae, p. 147, 1904.

Unsolved Problems.

A general investigation in a new field, such as that reported in this paper, is sure to suggest numerous problems which it does not answer. This study is no exception to the rule and one of its interesting features has been the number of unsettled questions which have arisen during its progress, some of which are of great importance in limnology. The data which we have accumulated in the course of a general study are insufficient to answer them. We must be satisfied with mentioning them and are quite content if our study offers a fairly secure general basis of fact for these more special investigations. Since these phenomena of lakes are not peculiar to Wisconsin and are so important as to be well worth the attention of other students, it seems advisable to summarize some of these questions, although most if not all of them have been mentioned in the course of the report. These problems are, in general, of two types: (1) Those which concern the establishment of details of quantity and time in the processes of gaseous exchange in the lakes; (2) Those which concern the physiological origin and significance of these processes. Many questions, of course, involve both lines of study, as will appear in the following statement.

Among problems relating to oxygen may be named: (1) The diurnal variation of the oxygen supply in the zone of photosynthesis. Our studies failed to disclose a daily pulse in the oxygen, but theoretically the supply of this gas must decline at night and be renewed by day. Perhaps more detailed study and more delicate methods may show that there are measurable variations; and if present they should give a clue to the rate of the processes of respiration and decomposition in the open water. (2) The causes of the frequently observed rapid decline of oxygen in the thermocline region. These sometimes lead to its extinction there while still present in considerable amount in the water below. This is one of a whole group of questions relating to decomposition and other factors concerned in the consumption of dissolved oxygen. (3) The sunlight in the zone of photosynthesis offers numerous problems both quantitative and qualitative; the relation between transparency and color of water and the depth to which photosnythesis may extend; the relation of light conditions to the rate of liberation of oxygen by chlorophyl-bearing organisms, and especially the rate of liberation and accumulation of this gas in the excess oxygen stratum; the factors, whether due to light or other causes, which fix a lower limit of depth for the manufacture of excess oxygen; the position of aggregations of algae in the water with reference to the place of the stratum of maximum oxygen. (5) The question needs further study, whether the oxygen liberated by plants growing on the bottom may produce a supersaturation in a stratum of water extending across the limnetic region. (6) The striking decline of oxygen in autumn needs careful study, both as to the amount of the decline and the frequency of its occurrence, as well as in regard to its causes. (7) The rate at which oxygen may be absorbed from the air and the rapidity with which it may be circulated to the deeper water should be determined in detail.

There is an equally large number of unsettled questions relating to carbon dioxid. Several of the problems suggested above might be attacked from the side of the carbon dioxid as well as from that of oxygen and probably would be studied from both sides. There should be, for instance, a daily variation in the carbon dioxid of the zone of photosynthesis, in a reverse direction to that of the oxygen. Among other questions may be named: (1) The quantity of carbon dioxid absorbed by the lake from the air, compared with that received from other sources; the effect of the quantity of dissolved carbonates on this absorption. (2) The relation of the quantity of algae and that of carbon dioxid available for them; or, in other words, the optimum supply of carbon dioxid for the algae and the part played by the bicarbonates in furnishing it. (3) The decrease of fixed carbon dioxid immediately following the thawing of the lake is a phenomenon whose causes are still unknown. Nor is it known how wide-spread the fact is, since it has been studied only in the hard water lakes of the southeastern district. (4) The sources of the supply of carbon dioxid needed to furnish the oxygen liberated in the excess oxygen stratum are still largely unknown. There does not seem to be at hand a supply sufficient to furnish so much oxygen as is found. Nor is the rate of supply yet correlated with that of liberation of oxygen. (5) The water below the thermocline contains so much free carbon dioxid that it is difficult to see how carbonates precipitated from the epilimnion can reach the bottom undissolved. May these carbonates originate in those deposited in or on bottom plants near the shore and brought out into the limnetic region by fall storms? This leads on to the much discussed question of the formation of marl in lakes, on which perhaps the last word has not yet been said. (6) If carbonates are precipitated from the epilimnion, as seems to be the case, why is there not more frequently an accumulation of them just below the thermocline, where free carbon dioxid is first found? The reduction of these substances in the epilimnion is a regular phenomenon in all hard water lakes, but there is rarely observed an amount below the thermocline, in excess of that in water somewhat lower down. (7) The relative rôles of the bicarbonates of calcium and magnesium in supplying carbon dioxid for photosynthesis need study as well as the vertical distribution of these substances in the lake.

Still another most important set of problems associated with those of the gases concerns the organic substances dissolved in the water; the relation of these substances to the reduction of oxygen in various strata of the lake and at particular times, such as the fall overturn. These questions, almost wholly untouched as yet, are an important part of the great complex of problems offered by the annual cycle of life and death in the lake, of which the problems of dissolved gases and of the lake's respiration are also a part.

APPENDIX

EXPLANATION OF TABLES SHOWING DISSOLVED GASES.

In these tables, D = depth in meters; T = temperature in degrees centigrade; C = free carbon dioxid, the minus sign indicates that the water was alkaline, and the plus sign that it was acid to phenolphthalein; N = neutral; Cb = fixed carbon dioxid; O = oxygen; and N = nitrogen. The results for the gases are given in cubic centimeters per liter of water, at a temperature of 0° C. and a barometric pressure of 760 mm. The district in which the lake is located is indicated by N. E., N. W., and S. E.

In some instances the lower water, especially at the bottom, is assigned an amount of gas in the nitrogen column in excess of the quantity of nitrogen which could be derived from the air. In a few of these cases the excess may be nitrogen derived from the ground water, but more frequently it is due to the presence of some methane, which was not separately determined.

I. TYPICAL SERIES OF OBSERVATIONS.

BEASLEY LAKE (S. E.)

Date.	D	T	C	Cb	O	N	Date.	T	C	Cb	O	N	Date.	T	C	Cb	O	N
Aug. 16, '05	0	23.2	— 3.9	33.7	6.0	11.5	Apr. 18, '06	24.2	— 3.0	37.4	5.9	......	May 18, '06	19.9	— 4.1	37.0	6.6	......
	3	21.5	......	......	6.2	12.0	(See p. 191.)	23.6	— 2.7	37.4	5.6	......	(See p. 191.)	13.2	— 5.7	35.6	9.7	......
	4	......	......	......	......	......		22.7	— 2.2	37.4	6.5	......		9.7	— 4.7	33.3	9.5	......
	5	18.4	— 6.2	34.9	8.7	13.3		18.5	— 3.0	32.6	7.8	......		8.6	......	......	......	......
	6	12.8	— 6.7	36.2	11.1	15.8		12.7	n	31.1	3.7	......		6.6	+ 2.2	26.9	3.6	......
	7	......	......	......	......	......		9.1	+ 2.8	32.1	0.77	......,		5.3	......	......	......	......
	9	6.6	+ 5.23	42.7	0.08	18.5		5.5	+ 6.6	40.0	Tr.	......		4.3	+ 5.4	42.0	0.16	......
	11	......	+ 6.74	44.9	0.0	26.3		5.0	+10.5	46.3	0.0	......		4.0	......	......	......	......
	14	5.1	+14.8	49.5	0.0	42.6		4.6	+22.5	52.6	0.0	......		4.0	+ 7.7	45.7	0.08	......
July 7, '06	0	21.8	— 2.0	38.4	6.1	......	Apr. 26, '07	7.2	— 5.0	34.9	9.9	......	May 24, '07	14.0	— 4.8	37.5	7.9	......
	3	20.6	— 2.7	38.4	6.1	......		6.9	— 6.1	34.9	9.8	......		12.7	— 4.0	37.5	8.9	......
	4	17.5	— 2.7	......	6.6	......		6.5	— 4.6	34.9	9.1	......		12.1	— 3.5	37.6	8.9	......
	5	12.6	— 2.0	32.1	6.3	......		6.25	— 4.0	34.9	8.9	......		9.5	— 3.3	36.5	10.3	......
	6	8.7	+ 0.9	29.3	3.9	......		6.1	— 1.3	34.7	8.3	......		6.8	— 0.8	35.2	7.7	......
	7	5.5	+ 3.8	29.8	0.33	......		5.0	+ 0.8	33.1	7.6	......		6.1	+ 1.5	35.2	6.4	......
	9	4.8	+ 7.8	42.9	0.0	......		4.7	+ 1.3	33.1	7.6	......		5.3	+ 4.0	35.2	3.5	......
	11	......	......	......	......	......		4.7	+ 1.3	33.5	7.3	......		5.0	+ 6.8	36.4	0.2	......
	14	4.3	+14.7	47.9	0.0	......		4.6	+ 4.8	35.2	1.2	......		4.8	+ 8.8	37.5	0.1	......
June 23, '07	0	22.7	— 2.5	36.6	5.7	......	Sept. 9, '07	17.9	— 1.0	37.2	5.0	......	Aug. 3, '08	25.7	— 2.5	36.9	6.1	......
	3	18.7	— 3.7	37.6	7.2	......		17.5	— 0.2	37.4	5.3	......	(See p. 192.)	24.7	— 2.5	37.7	6.2	......
(See p. 192.)	4	15.1	— 4.3	37.6	8.4	......		17.3	n	37.4	5.3	......		23.8	— 2.5	36.9	6.7	......
	5	12.4	— 4.0	37.6	7.6	......		17.1	+ 2.0	37.4	4.3	......		19.1	— 6.6	32.4	15.3	......
	6	9.1	— 1.3	36.4	6.3	......		14.6	+ 4.0	37.4	2.1	......		13.8	— 4.6	33.4	12.3	......
	7	7.1	+ 0.75	35.6	4.9	......		9.6	+ 7.6	36.7	0.1	......		9.7	+ 5.0	36.4	0.5	......
	9	5.7	+ 4.3	35.6	0.3	......		6.5	+ 8.3	37.9	0.1	......		6.7	+ 8.5	37.6	0.07	......
	11	5.2	+ 6.6	37.6	0.1	......		5.7	+11.2	38.9	0.0	......		5.7	+10.6	41.7	0.0	......
	14	5.0	+11.8	42.0	0.0	......		5.4	+15.9	43.8	0.0	......		5.4	+14.7	42.8	0.0	......
Aug. 31, '08	0	23.2	— 1.2	37.4	5.7	......	Mar. 19, '09	1.4	+ 3.9	42.0	7.0	......	Apr. 22, '09	6.75	— 2.5	35.4	9.6	......
	3	21.0	......	......	7.1	......		2.4	+ 6.0	41.5	6.2	......		6.0	— 2.0	35.4	9.0	......
(See p. 193.)	4	20.3	— 1.2	......	7.1	......	(See p. 193.)	......	......	......	......	......	(See p 48.)	5.5	— 2.0	35.4	9.0	......
	5	19.8	— 1.0	37.4	5.3	......		2.5	+ 6.0	......	6.2	......		......	......	......	......	......
	6	18.1	+ 1.8	36.4	4.8	......		......	......	......	......	......		5.5	n	......	8.3	......
	7	14.3	+ 4.6	35.9	1.8	......		2.7	+ 6.9	41.5	6.2	......		5.2	......	......	8.0	......
	9	7.2	+10.1	38.0	Tr.	......		3.1	+10.5	43.5	1.8	......		4.7	+ 1.5	35.4	6.3	......
	11	6.0	+13.6	39.7	0.0	......		3.8	+14.1	44.7	0.12	......		4.6	+ 2.4	36.0	Tr.	......
	14	5.6	+25.3	45.5	0.0	......		4.5	+20.4	46.2	0.0	......		4.5	+ 7.8	44.3	Tr.	......

May 5, '09	0	9.0	— 2.5	37.7	9.0	......
(See p. 55.)	3	7.0	— 3.0	......	9.5	......
	4	6.7	— 2.5	......	9.5	......
	5	......	......	......	......	......
	6	5.9	— 2.3	......	9.0	......
	7	......	......	......	8.6	......
	9	5.4	— 1.0	37.7	7.5	......
	11	5.1	+ 1.0	38.0	......	......
	14	4.5	+ 6.8	40.7	0.4	......
May 19, '09	0	15.9	— 3.25	37.75	8.4	......
	3	12.7	— 4.3	......	8.9	......
	4	11.0	— 4.0	......	8.9	......
	5	7.0	......	......	......	......
	6	6.1	— 1.5	......	8.3	......
	7	5.9	— 0.5	......	8.0	......
	9	5.6	+ 1.5	37.75	5.7	......
	11	5.4	+ 3.0	38.0	3.4	......
	14	5.1	+ 6.0	39.75	0.17	......
June 3, '09	0	21.8	— 3.6	39.0	6.5	......
	3	16.2	— 5.6	39.25	10.0	......
	4	12.8	— 5.1	39.0	10.6	......
	5	7.9	— 3.0	37.95	7.3	......
	6	6.4	n	37.95	6.9	......
	7	6.1	+ 1.2	37.95	5.3	......
	9	5.6	+ 4.0	39.00	1.9	......
	11	5.4	+ 6.65	40.4	0.16	......
	14	5.1	+12.6	46.0	0.0	......
June 17, '09	0	20.5	— 2.75	39.0	6.19	......
	3	18.3	— 3.75	38.75	6.22	......
	4	15.4	— 4.0	38.75	7.76	......
	5	10.1	— 2.5	38.0	8.79	......
	6	7.5	— 1.75	37.75	7.63	......
	7	6.3	n	37.75	5.62	......
	9	5.8	+ 5.1	39.0	0.42	......
	11	5.5	+ 8.5	40.5	0.20	......
	14	5.25	+17.5	45.25	0.0	......
July 1, '09	0	27.7	— 0.5	38.7	5.3	......
(See p. 55.)	3	23.7	— 1.2	39.7	6.5	......
	4	18.1	— 2.0	39.7	8.0	......
	5	13.7	— 1.5	39.2	8.8	......
	6	9.0	+ 0.75	39.2	6.9	......
	7	7.0	+ 2.5	......	4.8	......
	9	6.0	+ 6.8	39.5	1.2	......
	11	5.3	+ 8.9	41.5	0.06	......
	14	5.2	+18.2	46.6	0.0	......
July 16, '09	0	22.4	— 4.6	37.2	6.3	......
	3	23.5	......	......	......	......
	4	21.4	— 4.1	......	7.2	......
	5	15.4	— 4.1	......	11.2	......
	6	9.9	— 4.1	37.2	10.3	......
	7	7.3	......	......	......	......
	9	6.3	......	......	......	......
	11	5.7	+ 6.3	39.7	0.13	......
	14	5.3	......	......	......	......
July 31, '09	0	24.4	— 2.5	37.9	6.2	......
	3	22.7	— 2.5	38.3	6.9	......
	4	21.7	— 2.5	38.5	6.4	......
	5	18.0	— 2.6	38.8	8.7	......
	6	11.7	— 2.6	38.8	9.7	......
	7	8.8	— 0.5	40.0	6.9	......
	9	6.5	+ 6.0	40.6	0.39	......
	11	5.8	+ 9.1	42.7	Tr.	......
	14	5.3	+23.3	49.1	0.0	......
Aug. 13, '09	0	22.8	— 2.2	37.9	5.8	......
	3	22.4	— 2.5	38.5	5.8	......
	4	22.0	— 2.6	38.5	5.8	......
	5	20.0	......	......	7.7	......
	6	13.5	— 2.5	38.7	9.4	......
	7	9.5	n	38.7	5.5	......
	9	6.6	+ 5.9	40.5	0.1	......
	11	5.9	+ 9.1	42.9	Tr.	......
	14	5.6	+19.0	48.0	0.0	......
Aug. 25, '09	0	23.7	— 2.8	38.7	6.5	......
	3	22.3	— 2.8	......	6.6	......
	4	22.1	— 2.8	38.7	6.6	......
	5	21.8	— 2.95	38.9	6.8	......
	6	13.8	— 3.1	39.0	10.2	......
	7	10.2	n	39.7	6.7	......
	9	7.0	+ 8.1	41.2	0.1	......
	11	7.8	+10.3	42.3	Tr.	......
	14	5.3	+27.8	50.9	0.0	......
Sept. 9, '09	0	18.4	— 2.5	38.2	6.4	......
	3	18.4	......	......	6.4	......
	4	......	......	......	......	......
	5	18.4	— 1.5	38.2	6.2	......
	6	17.1	— 1.5	......	6.0	......
	7	12.2	+ 1.5	38.2	4.7	......
	9	7.4	+ 6.8	41.7	0.08	......
	11	6.2	+11.1	46.8	Tr.	......
	14	5.4	+15.4	51.9	0.0	......
Sept. 24, '09	0	18.2	— 2.6	39.0	6.7	......
(See p. 56.)	3	17.8	— 3.0	......	6.5	......
	4	17.7	— 2.5	......	6.6	......
	5	17.5	— 2.0	......	6.3	......
	6	16.6	— 0.5	......	5.3	......
	7	12.4	+ 2.3	39.0	3.4	......
	9	7.7	+ 7.5	41.5	0.12	......
	11	6.3	+10.5	42.8	Tr.	......
	14	5.6	+22.0	49.6	0.0	......
Oct. 8, '09	0	14.7	— 1.2	39.2	6.7	......
(See p. 56.)	3	14.3	— 1.0	......	6.5	......
	4	......	......	......	......	......
	5	......	......	......	......	......
	6	14.1	— 1.0	39.2	6.0	......
	7	13.8	n	39.7	5.4	......
	9	7.7	+ 7.9	41.0	0.11	......
	11	6.3	+13.9	44.0	Tr.	......
	14	5.6	+32.9	50.6	0.0	......
Oct. 22, '09	0	7.6	+ 1.77	40.8	5.7	......
	3	......	......	......	......	......
	4	......	......	......	......	......
	5	......	......	......	......	......
	6	7.5	+ 2.0	40.8	5.6	......
	7	......	......	......	5.6	......
	9	......	+ 2.3	41.0	5.5	......
	11	7.3	+ 6.3	42.4	2.3	......
	14	5.7	+31.2	52.0	0.0	......
Nov. 12, '09	0	7.6	n	41.0	7.38	......
	3	......	......	......	7.36	......
	4	......	......	......	......	......
	5	......	......	......	......	......
	6	7.2	+ 0.75	41.0	6.98	......
	7	......	......	......	6.89	......
	9	6.6	+ 2.0	41.3	4.4	......
	11	6.4	+ 2.9	41.8	1.84	......
	14	6.2	+ 3.8	42.3	0.78	......
Nov. 21, '09	0	5.0	+ 0.75	41.24	7.23	......
(See p. 56.)	3	......	......	......	......	......
	4	......	......	......	7.02	......
	5	......	......	......	......	......
	6	......	......	......	......	......
	7	......	......	......	......	......
	9	......	+ 0.75	......	7.02	......
	11	......	......	......	7.15	......
	14	5.0	+ 0.75	41.24	7.22	......

BEASLEY LAKE (S. E.)—Continued.

Date	D	T	C	Cb	O	N	Date	T	C	Cb	O	N	Date	T	C	Cb	O	N
Jan. 2, '10	0	0.1	+ 1.5	41.0	7.91	......	Mar. 23, '10	2.75	+ 2.5	30.4	6.8	......	Apr. 4, '10	12.4	— 2.5	38.7	8.65	......
	3	......	......	......	......	......		4.75	+ 4.0	37.7	6.8	......		10,5	— 2.8	37.0	10.1	......
	4	......	......	......	......	......		4.5	+ 4.0	38.0	6.7	......		5.7	— 1.4	37.7	9.4	......
	5	1.7	+ 1.75	......	7.5	......		4.25	+ 4.0	38.0	6.7	......		4.6	n	38.5	8.85	......
	6	......	......	......	......	......		......	......	......	......	......		4.1	+ 1.5	40.5	7.93	......
	7	......	......	......	......	......		3.6	+ 4.3	40.0	6.3	......		......	+ 2.79	40.7	5.73	......
	9	......	......	......	......	......		3.7	+ 8.0	41.25	1.4	......		4.1	+ 5.3	41.7	2.14	......
	11	2.0	+ 4.3	41.4	3.2	......		4.2	+ 8.7	42.0	0.24	......		4.2	+ 7.34	42.8	0.09	......
	14	......	+ 5.76	42.5	1.2	......		4.7	+12.5	44.0	0.18	......		4.6	+11.1	44.8	0.09	......

DEVILS LAKE (S. E.)

Date	D	T	C	Cb	O	N	Date	T	C	Cb	O	N	Date	T	C	Cb	O	N
May 29, '07	0	11.4	+ 0.25	3.5	7.3	......	June 15, '07	17.3	n	2.8	6.6	......	July 6, '07	22.5	+ 0.12	2.5	5.7	......
	3	11.0	+ 0.4	......	......	......		15.5	— 0.5	3.0	6.9	......		22.5	+ 0.25	2.8	5.7	......
(See p. 77.)	6	10.8	......	......	7.3	......	(See p. 200.)	14.75	— 0.2	3.0	6.8	......	(See p. 200.)	19.2	— 0.3	......	6.8	......
	9	10.7	......	......	7.2	......		12.3	+ 0.12	3.0	6.8	......		13.3	+ 0.75	2.8	6.5	......
	12	10.3	+ 0.4	3.5	7.0	......		10.7	+ 1.2	3.0	4.8	......		11.4	+ 4.0	3.0	2.66	......
July 27, '07	0	24.0	+ 0.12	3.1	5.5	......	June 12, '09	18.2	+ 0.75	3.25	6.40	......	Sept. 7, '09	20.4	+ 0.5	3.3	5.7	......
	3	23.9	+ 0.12	3.2	5.5	......		17.2	+ 0.87	3.25	6.45	......		......	......	......	5.9	......
(See p. 77.)	6	22.2	+ 0.5	3.2	5.35	......		15.3	+ 1.1	......	6.34	......	(See p. 201.)	......	......	......	......	......
	9	13.9	+ 2.0	3.8	4.4	......		10.5	+ 2.5	3.5	5.85	......		20.3	+ 1.25	3.7	6.2	......
	12	11.7	+ 4.3	4.3	1.8	......		9.3	+ 6.5	3.75	1.75	......		10.9	+ 7.5	6.8	0.1	......

ELKHART LAKE (S. E.)

Date	D	T	C	Cb	O	N	Date	T	C	Cb	O	N	Date	T	C	Cb	O	N
May 13, '06	0	10.7	— 3.2	44.1	7.7	......	July 3, '06	21.2	— 4.1	41.5	5.8	......	Aug. 9, '06	23.3	— 4.5	41.2	5.7	12.6
	5	10.4	......	......	......	......		21.0	— 4.3	41.7	5.8	......		23.2	— 4.5	41.2	5.8	......
(See p. 50.)	8	9.7	......	......	......	......		13.8	— 3.1	43.8	7.1	......	(See p. 213.)	16.0	— 3.5	44.0	8.0	15.9
	10	8.5	— 3.3	44.3	7.6	......		10.6	— 1.2	44.5	6.5	......		11.3	— 2.5	45.0	6.6	......
	12	8.0	......	......	......	......		8.5	n	44.5	5.9	......		9.0	— 1.0	45.3	5.4	16.2
	15	7.1	— 2.4	44.3	7.4	......		7.1	+ 1.0	......	4.2	......		7.0	+ 2.3	45.8	2.1	......
	20	6.0	— 0.7	45.4	6.4	......		6.0	+ 1.9	......	3.3	......		6.3	+ 3.3	46.0	1.8	17.8
	24	4.8	......	......	......	......		5.4	+ 2.5	......	3.0	......		5.9	+ 3.8	46.0	0.9	......
	28	4.5	n	45.1	5.6	......		5.2	+ 3.5	44.5	2.3	......		5.3	+ 5.4	46.6	0.1	......
	32	4.4	+ 0.4	45.1	5.2	......		5.2	+ 5.3	45.3	0.9	......		5.3	+ 5.9	47.8	0.2	......
Oct. 2, '06	0	18.4	— 5.6	39.2	6.1	......	Sept. 2, '08	21.3	— 4.1	38.5	6.3	......	Aug. 23, '09	24.3	— 3.5	40.7	6.3	......
	5	17.8	— 4.6	39.5	6.1	......		21.4	......	......	5.7	......		23.4	— 4.3	42.0	6.4	......
	8	17.7	— 4.4	39.5	6.0	......		21.3	— 4.2	39.2	6.1	......		15.4	— 4.0	43.0	11.5	......

	10	14.2	— 1.5	43.8	6.1	......		11.7	— 2.0	42.0	9.4	....		12.4	— 3.0	44.0	9.5	....
	12	9.2	+ 2.5	45.0	2.5	......		9.8	+ 2.5	42.5	5.5	....		9.8	n	45.0	6.7	....
	15	7.2	+ 4.0	45.8	0.12	......		8.2	+ 5.1	42.5	2.0	....		8.7	+ 3.3	45.8	3.1	....
	20	6.2	+ 5.3	45.8	0.09	......		7.6	+ 7.7	42.7	1.0	....		7.7	+ 4.5	45.8	1.7	....
	24	5.7	+ 5.3	45.8	0.09	......		7.4	+ 7.9	43.2	1.0	....		7.5	....	....	0.95	....
	28	5.5	+ 5.3	46.6	0.08	......		7.3	+ 8.1	44.1	0.13	....		7.45	+ 5.4	46.0	0.15	....
	32	5.4	+ 7.0	46.6	0.0	......		7.0	+ 8.1	44.3	0.08	....		7.4	+ 6.6	46.5	0.06	....

GARVIN LAKE (S. E.)

May 9, '06 (See p. 194.)	0	10.5	— 2.9	40.1	7.0	......	June 26, '06 (See p. 194.)	21.1	— 4.1	36.7	6.2	12.3	July 27, '06 (See p. 48.)	24.2	— 4.8	35.7	5.9	11.9
	3	10.2	....	....	......	......		19.8	— 3.8	36.9	6.5	....		24.0	— 4.8	35.8	5.9	....
	5	10.1	....	....	......	......		13.7	— 2.8	40.0	6.9	15.5		17,4	— 2.8	40.5	6.0	....
	6	9.9	— 2.1	39.9	5.45	......		10.3	+ 4.55	41.5	0.12	....		12.1	+ 1.8	41.7	0.7	....
	7	6.7	+ 3.8	40.6	2.59	......		8.3	+ 5.6	42.5	0.0	....		8.8	+ 7.6	43.5	Tr.	....
	9	6.0	+ 4.55	41.3	0.29	.. ...		6.8	+18.0	48.3	0.0	19.0		6.9	+15.9	50.6	0.0	....
Sept. 22, '06	0	22.2	— 4.3	36.7	6.2	......	Oct. 14, '06 (See p. 48.)	12.5	— 0.5	36.2	5.1	....	June 8, '07	15.2	— 3.8	37.2	6.75	....
	3	22.0	— 5.1	36.7	5.9	......		12.2	— 0.3	36.2	4.5	....		15.0	— 5.1	37.2	6.80	....
	5	21.1	— 2.7	37.4	3.8	......		12.0	n	36.3	4.4	....		12.75	— 3.6	38.0	6.6	....
	6	17.8	+ 3.5	44.0	0.16	......		11.9	+ 0.25	36.4	4.3	....		11.0	— 1.3	38.0	5.5	....
	7	12.2	+ 5.6	44.8	0.35	......		11.8	+ 0.75	37.0	2.8	....		8.7	+ 1.9	38.0	4.6	....
	9	7.8	+30.9	57.2	0.0	......		7.8	+49.1	58.1	1.0	....		5.9	+15.7	39.7	0.0	....
Sept. 5, '07	0	20.9	— 5.6	34.0	5.7	......	July 21, '09	23.7	— 5.0	35.9	6.4	.. ....	Sept. 2, '09	21.7	— 4.1	34.7	6.8	....
	3	20.7	— 5.6	34.0	5.7	......		23.7	— 4.5	35.9	6.5	....		21.6	— 4.1	34.7	6.6	......
	5	19.9	— 4.0	34.7	5,1	......		14.5	— 4.1	38.0	13.6	....		19.2	— 3.6	36.7	7.3	....
	6	14.5	+ 3.8	40.0	0.1	......		10.4	— 2.0	40.7	8.8	....		13.7	+ 3.8	41.0	2.0	......
	7	10.6	+ 4.8	41.0	Tr.	......		7.4	+ 6.3	42.5	0.35	....		9.8	+ 5.3	42.3	0.0	....
	9	7.4	+27.3	50.8	0.0	......		6.2	+44.0	63.2	0.0	....		6.8	+45.5	63.2	0.0	....

GENEVA LAKE (S. E.)

May 29, '06 (See p. 46.)	0	13.0	— 2.8	37.8	7.0	......	July 12, '06 (See p. 62.)	23.0	— 4.5	39.2	6.2	....	Aug. 23, '06	26.0	....	....	6.3	....
	5	12.9	....	....	......	.. ...		22.3	— 3.6	39.5	6.3	....		25.0	— 5.6	35.7	6.3	....
	8	12.7	....	....	......	......		21.0	— 3.3	39.5	6.5	....		24.4	— 4.5	35.9	6.2	....
	10	11.8	— 3.1	38.1	7.1	......		17.3	— 2.8	39.8	6.2	....		24.0	— 2.0	36.7	5.4	....
	12	11.6	....	....	......	......		15.7	— 1.5	39.8	5.8	....		18.6	— 1.5	38.2	5.4	....
	15	11.1	— 2.7	38.4	7.3	......		13.3	— 1.5	40.0	5.8	....		13.3	+ 0.4	38.7	4.4	....
	20	9.3	— 2.7	38.9	7.3	......		10.7	— 0.8	40.0	5.6	....		11.3	+ 0.4	38.7	3.8	....
	30	7.6	— 2.3	38.9	7.5	......		8.6	+ 0.5	40.1	5.3	....		8.6	+ 2.8	39.2	1.9	....
	35	7.3	— 2.1	38.9	7.3	......		8.1	+ 1.1	46.8	4.5	....		8.4	+ 3.0	39.2	0.8	....
	40	......	— 1.7	....	6.6	......		....	+ 2.0	46.8	4.0	....		8.2	+ 4.2	39.2	0.1	....
	42	7.2	— 1.2	38.9	6.5	......		8.0	....	....	....	....		8.1	+ 4.6	39.5	0.0	....

GENEVA LAKE (S. E.) Continued.

Date	D	T	C	Cb	O	N	Date	T	C	Cb	O	N	Date	T	C	Cb	O	N
Sept. 25, '06	0	21.2	— 5.6	38.2	6.1	......	Nov. 1, '06	11.2	— 1.5	36.4	5.7	......	June 11, '09	16.5	— 3.63	38.7	6.8	......
	5	21.1	— 6.6	38.2	6.1	......		......	......	......	......	......		14.8	— 3.4	38.7	7.0	......
(See p. 190.)	8	21.0	— 6.6	37.9	6.1	......	(See p. 190.)	......	......	......	......	......		13.5	......	......	......	......
	10	20.8	— 6.6	37.2	5.9	......		11.1	— 1.5	36.4	5,7	......		12.4	— 2.9	......	7.3	......
	12	20.8	— 6.6	37.2	5.9	......		......	......	......	......	......		10.7	......	......	......	......
	15	13.6	+ 1.0	40.0	2.4	......		......	......	......	......	......		10.0	— 1.94	......	7.0	......
	20	11.2	+ 1.0	41.2	1.5	......		11.1	— 1.5	36.5	5.7	......		9.2	— 1.69	38.7	7.0	......
	30	8.8	+ 3.0	41.2	0.53	......		9.2	+ 3.8	39.2	0.3	......		7.3	— 0.49	39.3	6.9	......
	35	8.4	+ 3.0	41.2	0.11	......		8.7	+ 4.3	......	0.1	......		6.8	— 0.48	39.4	6.8	......
	40	8.1	+ 4.4	41.2	0.07	......		8.4	+ 4.3	40.5	0.06	......		......	n	......	6.18	......
	42	8.0	+ 4.7	41.2	Tr.	......		8.3	+ 4.8	40.5	0.05	......		6.6	+ 0.48	39.4	5.94	......
July 13, '09	0	22.2	— 3.5	40.2	4.9	......	Sept. 4, '09	21.0	— 3.5	37.4	5.6	......	Nov. 5, '09	9.6	— 0.5	39.9	6.3	......
	5	21.5	......	......	4.3	......		......	......	......	5.7	......		......	......	......	......	......
	8	20.8	— 3.5	......	......	......		......	......	......	......	......	(See p. 190.)	......	......	......	......	......
	10	18.8	— 3.0	40.2	5.7	......		21.0	— 3.0	37.4	5.6	......		......	......	......	6.1	......
	12	12.2	......	......	......	......		15.8	+ 2.3	40.1	2.7	......		......	......	......	......	......
	15	10.7	— 1.3	40.5	......	......		11.5	+ 3.0	......	3.3	......		......	......	......	......	......
	20	9.4	n	40.7	4.6	......		10.0	+ 4.0	40.4	2.6	......		9.5	— 0.45	40.25	6.3	......
	30	7.5	+ 0.62	40.7	4.2	......		8.1	+ 4.8	42.3	1.4	......		9.5	— 0.45	40.25	5.8	......
	35	7.0	......	......	3.4	......		7.5	+ 7.8	42.3	0.84	......		9.3	+ 1.5	40.5	3.8	......
	40	......	+ 1.7	40.9	2.7	......		7.3	+ 5.0	42.5	0.11	......		9.0	+ 3.8	41.5	1.0	......
	42	7.0	+ 1.8	41.0	2.4	......		7.2	+ 5.0	42.5	0.11	......		8.5	+ 4.56	42.0	0.16	......

GREEN LAKE (S. E.)

Aug. 20, '05	0	23.0	— 6.7	31.6	5.6	11.6	Feb. 15, '06	0.3	— 1.6	39.3	10.6	19.5	May 15, '06..	8.0	— 2.5	39.3	8.24	......
	10	20.7	— 3.1	33.6	3.9	12.8		0.9	— 1.6	39.3	9.1	18.7		6.1	— 2.5	......	8.1	......
	12	17.3	— 2.7	34.6	4.0	13.1	(See p. 186.)	......	......	......	......	......	(See p. 186.)	......	......	......	......	......
	15	12.6	— 2.7	36.3	4.8	14.4		......	......	......	......	......		......	......	......	......	......
	20	8.6	— 2.4	36.7	5.5	15.7		0.9	— 1.6	39.3	9.2	18.9		5.6	......	......	8.0	......
	30	7.4	— 3.0	36.3	6.4	16.1		1.1	— 1.6	39.3	9.2	18.5		5.6	......	......	8.0	......
	40	6.2	— 2.3	36.3	6.6	16.8		1.5	— 1.6	39.3	8.7	18.1		5.1	......	......	......	......
	50	6.0	— 1.8	37.0	6.3	16.7		1.7	— 1.5	39.3	8.5	18.5		4.8	— 2.5	......	7.9	......
	60	5.8	— 2.0	37.6	4.4	16.6		1.9	— 1.6	39.0	8.4	18.1		4.75	— 1.9	......	7.7	......
	65	......	+ 0.89	39.8	1.4	16.6		2.3	......	......	......	......		......	......	......	......	......
	70	5.7	+ 1.33	40.2	0.66	16.4		2.3	— 1.2	39.4	8.1	18.3		4.75	— 1.9	39.3	7.6	......
July 5, '06	0	19.8	— 3.0	37.7	6.4	......	Aug. 14, '06	24.5	— 4.1	36.7	6.0	12.4	Oct. 4, '06	17.9	— 4.6	34.7	6.0	......
	10	19.0	— 3.5	37.8	6.4	......		20.1	— 2.5	37.9	5.2	13.6		17.7	— 3.8	34.7	5.8	......
(See p. 187)	12	13.6	— 3.3	38.2	6.5	......	(See p. 188.)	16.5	— 0.8	39.5	5.0	14.5	(See p. 189.)	17.7	— 3.8	34.8	5.9	......

	15	10.1	− 1.6	38.5	6.5	......		12.3	....	....	4.9	16.1		12.3	+ .75	38.0	3.6	....
	20	7.3	− 1.6	....	6.4	......		8.2	− 0.7	39.7	5.5	....		8.1	+ 1.3	38.5	4.5	....
	30	6.6	− 1.3	....	7.0	......		6.8	....	....	6.3	....		6.7	....	38.5	5.4	....
	40	6.3	− 0.8	....	7.0	......		6.8	....	....	6.3	....		6.2	+ 1.3	38.5	5.5	....
	50	6.0	− 0.8	38.5	6.7	......		6.1	....	....	5.8	....		5.9	+ 1.1	38.5	5.6	....
	60	5.75	+ 1.0	39.0	6 0	......		5.8	+ 1.0	40.7	3.5	....		....	+ 1.9	39.2	2.9	....
	65	5.6	+ 1.0	39.0	5.1	......		....	+ 2.5	41.5	1.1	....		....	+ 3.5	40.3	0.81	....
	70	5.3	+ 1.8	38.6	4.5	......		5.7	+ 5.1	42.0	0.88	....		5.7	+ 3.5	40.3	0.8	....
Sept. 14, '07 (See p. 50.)	0	18.8	− 4.1	34.4	6.1	......	Sept. 3, '08	20.4	− 3.6	34.2	5.9	....	Aug. 20, '09	25.6	− 4.1	36.9	6.5	....
	10	17.5	− 3.9	35.2	5.9	......		20.2	− 3.6	34.2	5.9	....		21.5	− 2.5	37.9	5.9	....
	12	14.1	− 0.8	36.2	5.9	......		18.0	− 0.5	35.7	5.2	....		15.6	....	....	6.8	....
	15	9.7	+ 0.5	36.9	5.9	......		11.3	+ 1.2	36.9	5.3	....		11.8	− 0.5	39.2	6.9	....
	20	7.7	....	37.1	5.7	......		7.7	+ 2.3	36.9	5.5	....		8.0	....	....	6.8	....
	30	6.6	+ 0.76	37.4	6.1	......		6.8	+ 2.3	36.9	5.8	....		7.1	....	....	6.7	....
	40	5.8	+ 0.9	38.4	6.0	......		5.9	+ 2.3	36.9	6.2	....		6.9	+ 1.0	39.2	6.6	....
	50	5.6	+ 1.5	38.7	5.6	......		5.8	+ 2.8	36.9	5.4	....		6.7	+ 1.25	39.2	6.4	....
	60	5.4	+ 2.0	39.0	3.8	......		5.7	+ 5.0	37.7	2.1	....		6.5	+ 2.8	39.7	4.8	....
	65	......	....	....	......	......		....	....	....	....	....		....	....	....	....	....
	70	5.2	+ 3.4	40.5	1.1	......		5.5	+ 5.6	39.2	1.0	....		6.5	+5.0	40.5	1.2	....

KAWAGUESAGA LAKE, MINOCQUA (N. E.)

Sept. 6, '06	0	19.3	− 0.5	9.6	5.3	......	Aug. 5, '07	19.3	+ 0.4	9.2	5.7	....	Aug. 24, '08 (See p. 217.)	20.7	+ .75	9.1	5.5	....
	5	19.5	+ 0.12	9.6	5.1	......		19.1	+ 0.7	9.2	5.7	....		....	....	....	5.2	....
	7	19.2	+ 0.5	9.9	4.8	......		18.5	+ 1.2	9.2	5.2	....		18.7	+ 1.25	9.2	5.0	....
	9	18.6	+ 1.5	....	3.6	......		11.1	+ 5.8	9.7	1.5	....		18.6	+ 2.5	9.2	4.7	....
	10	16.2	+ 4.0	10.4	0.1	......		9.7	+ 6.1	9.8	1.6	....		16.8	+ 4.0	10.6	1.1	....
	12	12.5	+ 5.6	13.4	0.0	......		9.1	+ 7.0	10.2	0.9	....		12.5	....	....	0.0	....
	16	11.3	+ 7.1	13.7	0.0	......		8.1	+ 8.1	11.6	0.0	....		10.4	+11.4	15.2	0.0	....

KNIGHT'S LAKE (S. E.)

Aug. 14, '09 (See p. 196.)	0	22.3	− 1.1	38.5	6.1	......	Aug. 25, '09 (See p. 197.)	23.0	− 1.7	41.2	6.4	....	Sept. 9, '69 (See p. 52.)	18.0	− 2.8	40.0	7.1	....
	2	21.0	....	....	......	......		22.3	....	....	6.4	....		17.4	....	....	7.1	....
	3	20.4	− 0.8	40.0	6.8	......		21.1	− 2.0	41.2	7.4	....		17.0	− 3.6	40.0	8.3	....
	4	16.1	− 5.6	37.2	19.2	......		17.2	− 7.6	35.9	21.8	....		16.3	− 4.0	40.2	9.1	....
	5	12.6	− 7 1	35.9	23.6	......		13.0	− 7.1	40.5	21.3	....		12.7	n	42.5	9.1	....
	6	9.8	+ 4.3	44.8	4.9	......		10.9	+ 8.0	46.3	0.84	....		10.1	+ 9.6	45.8	Tr.	....
	7	9.0	+ 6.5	45.8	2.6	......		8.8	+ 9.1	48.3	0.07	....		8.6	+10.1	47.6	Tr.	....
	9	8.2	+ 9.5	48.4	0.12	......		8.5	+10.5	50.0	0.06	....		8.1	+10.4	48.0	0.0	....
	11	8.1	+13.9	51.9	0.0	......		8.0	+11.9	52.1	Tr.	....		8.0	+14.2	50.6	0.0	....

LONG LAKE (S. E.)

Date.	D	T	C	Cb	O	N	Date.	T	C	Cb	O	N	Date.	T	C	Cb	O	N
Apr. 24, '07	0	6.6	— 1.0	36.9	9.1	......	May 24, '07	12.1	— 3.8	37.5	8.2	......	June 24, '07	22.5	— 3.8	37.4	5.9	......
(See p. 84.)	3	6.6	— 1.0	37.2	9.0	......	(See p. 212.)	11.0	— 3.1	37.7	8.2	......	(See p. 212.)	19.0	— 1.4	38.5	5.4	......
	5	6.6	— 1.0	......	9.0	......		10.2	— 2.6	38.0	7.8	......		14.5	— 2.8	40.2	7.5	......
	7	6.5	— 1.0	......	8.9	......		9.3	— 1.6	......	7.2	......		10.8	— 2.0	38.7	6.4	......
	10	5.25	— 0.5	37.2	8.3	......		7.3	+ 0.9	38.0	6.5	......		7.6	+ 2.5	39.0	2.7	......
	12	5.0	n	37.4	8.3	......		......	+ 0.9	37.5	6.2	......		7.1	+ 2.9	39.2	2.2	......
	15	4.9	+ 0.5	37.4	8.2	......		6.5	+ 0.9	36.9	6.1	......		7.0	+ 2.9	39.5	2.0	......
	18	4.8	+ 0.5	37.4	8.0	......		6.3	+ 1.6	......	5.7	......		6.8	+ 2.9	39.5	1.7	......
	22	4.75	+ 1.1	37.4	7.9	......		6.0	+ 3.0	36.9	4.2	......		6.5	+ 5.3	40.2	0.16	......
Aug. 31, '08	0	23.3	— 2.5	37.5	6.4	......	Mar. 19, '09	0.4	+ 3.0	37.2	6.9	......	Apr. 22, '09	5.2	n	36.9	7.0	......
	3	21.6	— 2.5	......	6.8	......	(See p. 79.)	2.9	+ 3.9	43.2	7.1	......	(See p. 87.)	......	......	......	......	......
	5	18.5	— 1.5	39.5	5.8	......		3.3	+ 4.2	43.5	6.9	......		5.2	n	36.9	7.0	......
	7	14.9	+ 5.8	40.0	0.3	......		......	......	......	......	......		......	......	......	......	......
	10	8.9	+ 7.5	40.0	0.1	......		3.4	+ 4.5	43.7	5.4	......		5.0	n	37.4	7.0	......
	12	8.4	+ 8.1	......	0.1	......		......	......	......	......	......		......	......	......	......	......
	15	8.2	......	......	Tr.	......		3.8	+ 5.1	44.0	0.6	......		4.8	+ 0.6	38.2	6.7	......
	18	8.1	+10.1	40.0	0.0	......		4.0	+ 6.0	45.5	0.06	......		4.5	+ 2.4	40.0	4.2	......
	22	7.8	+13.4	41.7	0.0	......		4.6	+ 6.0	48.2	0.0	......		4.2	+ 2.4	40.5	4.1	......
May 5, '09	0	6.9	— 2.5	38.2	7.8	......	May 19, '09	14.3	— 3.25	37.75	8.6	......	June 3, '09	21.0	— 3.8	38.4	6.3	......
(See p. 84.)	3	......	......	......	......	......		12.0	— 3.45	37.75	8.1	......		15.8	......	......	6.6	......
	5	6.5	— 0.75	......	7.8	......		11.1	— 2.7	......	8.1	......		12.8	— 3.8	......	8.6	......
	7	5.8	......	......	......	......		8.7	......	......	......	......		9.5	— 2.3	......	7.2	......
	10	5.5	— 0.5	38.2	7.83	......		6.8	+ 0.62	38.0	7.4	......		7.0	+ 0.8	38 4	4.9	......
	12	......	......	......	......	......		6.0	+ 1.25	38.0	6.75	......		6.3	+ 2.5	38.7	4.2	......
	15	......	......	......	......	......		5.9	......	......	6.75	......		6.2	......	......	4.3	......
	18	5.3	n	38.5	7.7	......		5.8	......	......	6.5	......		......	+ 3.0	39.0	3.7	......
	22	5.2	n	38.7	7.5	......		5.8	+ 1.5	38.0	6.1	......		5.9	+ 3.5	39.5	3.5	......
June 17, '09	0	18.8	— 2.0	40.0	5.99	......	July 1, '09	25.4	— 1.0	39.0	6.0	......	July 16, '09	23.4	— 3.5	35.9	6.3	......
	3	18.1	......	......	6.25	......		20.7	— 1.0	41.0	6.4	......		21.5	— 4.1	38.5	7.4	......
	5	13.8	— 1.5	40.25	7.10	......		15.8	— 1.0	40.7	8.0	......		17.0	— 3.0	38.7	10.3	......
	7	9.2	n	......	6.18	......		9.8	+ 3.0	39.7	6.7	......		10.3	n	40.2	7.1	......
	10	6.8	+ 2.75	......	4.54	......		6.0	......	......	......	......		6.6	+ 5.8	40.0	2.6	......
	12	6.3	+ 3.25	......	3.74	......		5.8	+ 7.1	39.5	2.4	......		6.4	......	......	......	......
	15	......	+ 3.75	......	3.66	......		5.6	......	......	2.2	......		6.1	+ 6.1	39.7	0.95	......
	18	......	+ 5.0	......	2.88	......		5.4	......	......	1.5	......		5.9	+ 8.5	39.9	0.36	......
	22	6.0	+ 5.5	40.25	2.15	......		5.3	+ 9.6	41.2	Tr.	......		5.9	+ 7.3	40.0	0.32	......

July 31, '09	0	24.0	— 2.8	39.0	6.4	......	Aug. 13, '09	21.7	— 2.6	39.5	6.5	....	Aug. 25, '09	23.7	— 3.0	40.7	6.7	....
	3	20.8	— 1.3	41.0	6.4	......		20.7	— 2.5	40.2	6.6	....		22.0	....	....	7.1	....
	5	18.8	— 2.0	41.0	7.1	......		18.8	....	....	6.7	....		20.2	— 3.1	42.3	6.9	....
	7	10.9	....	....	6.4	......		12.0	+ 1.5	40.9	5.6	....		17.0	— 2.6	42.3	5.1	....
	10	7.0	+ 8.1	40.0	0.6	......		7.2	+ 5.3	....	0.6	....		7.3	+ 5.3	41.7	2.3	....
	12	6.5	....	....	0.09	......		6.7	+ 5.8	40.5	0.15	....		6.7	+ 6.6	41.7	0.08"	....
	15	6.4	+ 8.1	40.0	0.06	......		6.5	....	....	0.1	....		6.4	....	....	Tr.	....
	18	6.2	....	40.2	0.06	......		....	+ 6.6	40.7	0.05	......		....	+ 8.3	42.0	Tr.	....
	22	6.1	+ 8.6	41.7	0.06	......		6.4	+ 8.9	42.0	0.0	....		6.1	+10.9	44.0	0.0	....
Sept. 9, '09	0	18.3	— 4.0	39.2	6.9	......	Sept. 24, '09	18.5	— 4.1	39.5	6.8	....	Oct. 8, '09	15.0	— 3.6	39.8	7.3	....
	3	18.2	— 4.1	40.0	6.9	......		17.5	....	....	6.8	....		....	— 3.6	....	7.2	....
	5	17.1	— 3.6	40.0	6.5	......		16.5	— 3.1	40.5	6.1	....		14.7	— 1.8	....	7.1	....
	7	14.5	+ 1.8	40.2	4.2	......		14.9	+ 1.0	40.7	3.7	....		13.0	n	....	5.2	....
	10	7.8	+ 5.0	41.2	0.08	......		7.7	....	....	0.12	....		8.7	+ 7.6	....	0.09	....
	12	6.8	....	....	0.07	....		7.0	+ 5.0	41.2	0.06	....		7.2	....	....	Tr.	....
	15	6.7	....	....	0.07	......		6.8	....	....	0.06	....		6.8	+ 8.4	40.8	Tr.	....
	18	......	....	....	0.08	......		6.6	+ 6.8	41.5	0.0	....		6 7	+ 9.4	41.5	0.0	....
	22	6.5	+ 7.5	42.8	0.0	......		6.5	+ 7.5	42.0	0.0	....		6.6	+13.7	41.8	0.0	....
Oct. 22, '09	0	7.8	+ 0.75	40.8	5.4	......	Nov. 12, '09	7.7	+ 0.12	41.0	7.32	....	Nov. 21, '09	5.6	+ 0.5	41.24	7.66	....
	3	......	+ 1.27	....	5.2	......		....	....	....	6.9	....		....	....	....	....	....
	5	......	+ 1.3	40.8	5.5	......		....	....	....	7.0	....	(See p. 87.)	....	....	....	....	....
	7	......	+ 1.5	....	5.5	......		....	....	....	7.0	....		....	....	....	....	....
	10	7.8	+ 1.5	....	5.3	......		....	....	....	6.9	....		....	+ 0.5	41.24	7.66	....
	12	7.8	+ 1.5	41.1	5.2	......		7.4	+ 0.4	....	6.6	....		....	....	....	....	....
	15	7.4	+ 2.8	41.1	2.7	......		7.3	+ 0.9	41.0	6.5	....		....	....	....	....	....
	18	6.8	+ 5.8	....	0.0	......		7.25	+ 1.25	....	6.3	....		....	....	....	7.56	....
	22	6.6	+ 8.1	42.1	0.0	......		6.7	+ 2.0	41.0	4.7	....		5.6	+ 0.5	41.24	7.66	....

MARL LAKE (S. E.)

Aug. 24, '06	0	24.4	— 2.5	35.9	6.3	......	June 26, '07	22.0	— 3.0	37.2	6.3	....	Aug. 14, '09	23.0	— 2.5	37.9	6.5	....
	3	24.4	— 2.3	36.2	6.3	......		19.0	— 3.0	37.6	7.9	....		23.0	— 2.5	37.9	6.5	....
	4	22.2	— 1.6	39.0	14.5	......		15.0	— 2.7	37.6	10.2	....	(See p. 199.)	22.4	— 1.3	39.2	10.4	....
	5	16.1	— 1.0	41.7	12.1	......		11.9	— 2.8	38.2	10.8	......		17.5	— 1.3	40.0	12.5	....
	6	12.8	— 0.3	43.3	10.0	......		10.1	— 2.3	40.5	10.1	....		14.4	— 1.3	41.0	12.3	....
	7	10.8	n	45.3	7.4	......		9.1	— 0.1	....	7.8	....		12.2	— 1.0	41.0	11.4	....
	10	9.0	+ 1.5	46.6	3.6	......		8.7	+ 1.0	41.0	6.8	....		....	+ 1.0	44.5	6.6	....
	12	8.6	+ 3.5	46.8	1.5	......		8.5	+ 2.3	41.1	5.4	....		9.2	+ 5.6	44.5	2.4	....
	17	8.2	+ 5.6	47.8	0.2	......		7.5	+ 4.6	42.0	1.9	... ...		8.4	+ 7.6	46.3	0.17	....

LAKE MENDOTA. (S. E.)

Date.	D	T	C	Cb	O	N	Date.	T	C	Cb	O	N	Date.	T	C	Cb	O	N
Jan. 26, '06	0	0.5	n	38.2	9.0	19.0	Feb. 12, '06	0.5	......	......	9.9	21.0	Feb. 25, '06	0.5	— 1.0	34.8	9.4	18.5
	5	0.5	n	38.2	9.0	19.1		1.2	— 0.9	38.8	9.1	19.0		1.3	— 1.3	39.3	9.4	19.3
(See p. 174.)	8	......	......	......	......	......	(See p. 29.)	......	......	......	......	......	(See p. 174.)	......	......	......	......	......
	10	0.6	n	......	......	......		1.2	— 0.8	39.0	9.1	18.9		1.4	— 1.3	39.3	9.6	19.4
	12	......	......	......	......	......		......	......	......	......	......		......	......	......	......	......
	15	0.7	n	38.5	8.9	19.4		1.2	— 1.1	39.3	9.4	19.3		1.4	— 1.3	39.3	9.4	19.2
	18	......	......	......	......	......		......	......	......	......	......		1.8	n	39.4	7.7	19.0
	20	......	......	38.5	8.5	19.4		1.6	n	39.6	6.6	19.0		2.0	+ 1.4	40.5	5.0	18.9
	22	1.1	n	38.5	7.7	19.3		2.3	+ 0.8	42.3	2.1	19.3		2.5	+ 3.4	42.1	1.5	19.1
Mar. 8, '06	0	0.1	+ 1.6	13.3	6.0	18.5	Mar. 29, '06	2.0	— 3.6	11.7	12.5	20.1	Apr. 8, '06	2.3	— 2.4	37.8	7.8	19.6
	5	1.5	— 0.6	39.2	9.6	19.8		1.8	— 1.0	36.3	8.3	19.8		......	......	......	......	......
(See p. 175.)	8	......	......	......	......	......	(See p. 175.)	......	......	......	......	......	(See p. 176.)	......	......	......	......	......
	10	1.5	— 1.6	39.2	9.3	19.6		1.8	— 0.7	38.9	8.3	19.8		2.3	— 2.7	37.6	7.8	19.5
	12	......	......	......	......	......		......	......	......	......	......		......	......	......	......	......
	15	1.5	— 1.3	39.2	9.1	19.1		2.1	+ 1.2	40.2	6.7	19.7		2.3	— 1.9	37.6	8.0	19.5
	18	1.6	— 0.8	39.6	7.5	19.3		2.3	+ 3.2	40.4	3.3	19.5		......	......	......	......	......
	20	2.0	+ 3.6	40.4	4.2	19.4		2.4	+ 4.4	41.6	0.7	19.8		2.3	+ 1.2	37.6	7.8	19.6
	22	2.5	+ 4.2	43.2	0.75	19.5		2.7	+ 5.6	43.8	0.0	20.1		2.3	......	......	8.0	19.5
Apr. 20, '06	0	5.1	n	36.1	8.0	18.6	May 11, '06	12.5	— 2.8	36.0	......	......	May 22, '06	15.6	— 3.3	36.2	7.9	......
	5	5.0	n	36.1	......	......		11.6	— 2.4	36.0	......	......		15.0	— 3.0	36.2	7.9	......
(See p. 176.)	8	......	......	......	......	......	(See p. 33.)	......	......	......	......	......	(See p. 176.)	......	......	......	......	......
	10	4.9	n	36.2	8.0	18.4		11.3	— 2.4	36.4	......	......		14.5	— 2.9	36.2	7.0	......
	12	......	......	......	......	......		......	......	......	......	......		12.8	— 2.1	36.2	6.9	......
	15	4.9	n	36.2	8.0	18.4		11.1	— 1.8	36.4	......	......		12.4	— 1.6	36.2	6.7	......
	18	......	......	......	......	......		......	......	......	......	......		11.7	— 1.2	36.2	6.3	......
	20	4.6	n	36.2	7.7	18.7		10.7	— 1.6	36.4	......	......		11.1	+ 0.3	36.6	5.4	......
	22	4.5	n	36.2	7.5	19.0		10.7	— 1.6	36.4	......	......		11.1	+ 0.6	37.2	5.2	......
May 25, '06	0	17.0	— 3.6	36.4	7.2	14.6	June 11, '06	19.1	— 4.0	36.0	6.3	13.1	June 18, '06	21.9	— 2.3	36.5	6.5	13.2
	5	13.7	— 3.6	36.4	8.0	......		18.7	— 3.8	36.2	6.4	13.2		18.0	......	......	6.4	13.9
	8	......	......	......	......	......	(See p. 177.)	16.7	— 2.0	36.2	6.0	......	(See p. 177.)	17.5	— 3.7	36.5	6.2	......
	10	......	......	......	......	......		16.0	— 1.4	36.4	5.5	14.1		16.7	— 1.7	36.5	5.4	14.0
	12	11.5	— 0.6	36.4	5.8	15.9		14.0	— 0.4	36.4	4.9	......		14.0	+ 0.88	36.5	4.1	......
	15	......	......	......	......	......		12.9	+ 1.2	36.8	4.1	......		12.9	+ 1.9	36.6	3.0	......
	18	10.5	n	36.4	5.8	16.1		11.8	+ 1.8	37.0	2.6	15.1		12.1	+ 2.3	37.3	2.5	15.0
	20	10.2	+ 1.0	36.6	5.2	16.0		11.5	+ 3.4	37.4	2.1	15.2		11.7	+ 3.0	37.7	1.3	15.3
	22	9.7	+ 2.2	36.8	4.2	16.5		11.5	+ 3.7	37.4	1.8	15.2		11.4	+ 4.6	38.1	0.37	15.3

July 5, '06	0	19.8	— 7.1	36.2	6.2	......	July 10, '06 (See p. 178.)	24.2	— 6.6	35.9	7.0	......	July 17, '06	23.3	— 4.5	34.4	6.3	12.5
	5	19.3	— 5.6	36.2	6.1	......		20.1	— 6.1	36.2	6.9	......		23.0	— 4.8	34.4	6.3	......
	8	16.1	— 3.3	36.2	4.8	......		17.7	— 2.0	36.4	4.0	......		22.1	— 2.9	35.3	5.0	12.5
	10	14.1	......	......	......	......		15.2	— 0.5	36.7	3.1	......		17.4	+ 0.4	37.0	2.4	13.6
	12	13.2	— 1.0	36.4	2.4	......		14.0	n	36.7	2.2	......		14.9	+ 1.8	37.3	0.6	......
	15	12.5	+ 0.7	36.6	1.6	......		13.1	+ 1.8	36.9	0.84	......		13.0	+ 4.8	37.7	Tr.	......
	18	11.7	......	......	......	......		11.5	+ 2.3	36.9	0.1	......		12.5	......	......	......	......
	20	11.5	+ 2.0	36.9	0.43	......		11.2	+ 2.4	37.3	Tr.	......		12.2	......	......	......	......
	22	11.1	+ 2.5	37.2	0.12	......		10.7	+ 3.0	38.0	0.0	......		12.1	+ 4.6	39.0	Tr.	13.5
July 20, '06 (See p. 178.)	0	22.9	— 4.8	34.9	6.2	......	July 24, '06 (See p. 36.)	24.1	— 4.1	33.4	6.1	......	July 30, '06	25.5	— 4.8	33.4	5.9	......
	5	22.5	— 4.3	35.0	6.2	......		23.2	— 3.7	34.3	5.8	......		24.6	— 3.3	33.4	5.2	......
	8	21.6	— 3.0	35.4	4.9	......		19.6	— 1.0	36.7	2.7	......		23.7	+ 1.1	36.4	2.5	......
	10	17.7	+ 2.0	36.9	1.7	......		16.6	+ 1.5	37.4	1.3	......		16.6	+ 2.2	38.7	0.6	......
	12	15.6	+ 2.5	37.2	1.1	......		15.0	+ 2.1	37.4	0.9	......		15.0	+ 2.9	38.3	0.16	......
	15	15.0	+ 2.8	37.5	0.2	......		13.7	+ 3.0	37.9	0.5	......		13.8	+ 3.8	38.5	0.1	......
	18	13.6	+ 3.5	37.5	0.07	......		13.1	+ 3.5	38.5	0.1	......		13.1	+ 4.0	38.7	0.1	......
	20	12.9	+ 4.0	38.2	Tr.	......		12.4	+ 3.6	38.7	0.08	......		12.9	+ 4.3	38.5	0.1	......
	22	12.4	+ 4.3	38.5	Tr.	......		12.3	+ 4.9	39.5	0.0	......		12.4	+ 4.6	38.5	0.0	......
Aug. 6, '06 (See p. 36.)	0	24.5	— 4.3	33.4	5.8	......	Aug. 24,'06	25.0	— 5.0	32.6	5.6	......	Aug. 30, '06	22.5	— 4.1	33.4	5.2	......
	5	24.3	— 4.3	33.4	5.4	......		24.6	— 4.6	32.9	5.2	......		22.5	— 4.4	33.4	4.7	......
	8	21.2	— 1.0	35.0	2.3	......		21.0	— 4.2	33.9	3.0	......		22.5	— 2.2	33.5	4.6	......
	10	17.4	+ 0.25	37.7	0.3	......		19.0	— 4.0	35.9	0.1	......		20.8	— 0.8	34.2	3.7	......
	12	15.8	+ 2.3	38.4	0.2	......		15.5	+ 2.53	37.7	Tr.	......		16.5	+ 2.3	37.9	0.09	......
	15	14.5	+ 2.6	39.0	Tr.	......		13.5	+ 2.5	37.9	Tr.	......		14.6	+ 2.5	38.3	0.07	......
	18	13.0	+ 3.5	39.5	Tr.	......		11.9	+ 3.6	38.5	0.0	......		13.7	+ 3.7	38.7	0.0	......
	20	12.5	+ 4.4	39.8	0.0	......		......	......	......	......	......		......	......	......	......	......
	22	12.5	+ 5.3	40.5	0.0	......		11.5	+ 5.1	39.2	0.0	......		12.8	+ 4.0	39.7	0.0	......
Sept. 7, '06	0	......	— 3.8	34.7	7.4	......	Sept. 14,'06 (See p. 179.)	......	— 3.8	33.4	6.2	......	Sept. 27. '06	19.8	— 3.3	33.4	6.2	13.1
	5	......	— 4.1	34.7	5.6	......		......	— 4.6	34.3	5.9	......		19.7	—3 .3	33.9	5.9	......
	8	......	— 2.6	34.5	5.3	......		......	— 4.1	34.4	5.4	......		19.7	— 3.0	34.1	5.8	......
	10	......	— 2.6	34.7	4.5	......		......	n	35.2	2.5	......		19.6	— 2.5	34.4	5.7	......
	12	......	+ 3.0	39.7	0.07	......		......	+ 3.0	38.7	0.12	......		19.5	— 2.6	34.2	5.6	12.7
	15	......	+ 3.8	40.0	Tr.	......		......	+ 4.0	39.5	Tr.	......		14.0	+ 4.6	38.7	0.0	16.6
	18	......	+ 4.8	42.0	0.0	......		......	+ 5.6	40.0	0.0	......		13.2	+ 5.6	39.7	0.0	......
	20	......	......	......	......	......		......	......	......	......	......		......	......	......	......	......
	22	......	+ 5.1	42.8	0.0	......		......	+ 6.1	40.7	0.0	......		12.8	+ 9.1	41.2	0.0	19.9
Sept. 30, '06	0	18.5	— 3.5	33.4	5.9	......	Oct. 6, '06	17.4	— 3.5	33.4	5.1	......	Oct. 8, '06 (See p. 180.)	16.7	— 2.5	33.6	5.1	......
	5	18.4	— 3.51	33.9	5.7	......		17.4	— 3.0	33.9	5.1	......		16.7	— 2.4	33.5	5.1	......
	8	18.3	— 3.55	34.1	5.3	......		17.3	— 3.0	34.0	5.1	......		16.7	— 2.4	38.5	5.0	......
	10	18.2	— 3.6	34.2	5.4	......		17.3	— 3.1	34.1	5.1	......		16.7	— 2.3	33.4	4.9	......
	12	18.2	— 2.8	34.9	4.7	......		17.3	— 3.1	34.2	5.1	......		16.7	— 2.3	33.4	4.8	......
	15	14.0	+ 5.0	39.2	0.0	......		17.2	— 3.1	34.2	5.1	......		15.2	+ 3.2	36.3	0.14	......
	18	13.3	+ 5.0	39.7	0.0	......		13.1	+ 6.1	40.0	0.0	......		13.5	+ 4.9	38.5	0.0	......
	20	......	......	......	......	......		12.8	+ 7.0	40.7	0.0	......		13.3	+ 4.9	38.6	0.0	......
	22	12.7	+ 7.3	41.0	0.0	......		12.8	+ 7.6	40.7	0.0	......		13.9	+ 4.9	38.8	0.0	......

LAKE MENDOTA—Continued.

Date.	D	T	C	Cb	O	N	Date.	T	C	Cb	O	N	Date.	T	C	Cb	O	N
Oct. 11, '06	0	14.4	— 2.1	34.2	4.9	......	Oct. 20, '06	14.2	— 0.8	34.4	6.0	......	Oct. 23, '06	13.4	— 0.3	33.4	5.9	......
(See p. 180.)	5	14.4	— 2.1	34.2	4.5	......	(See p. 39.)	......	......	......	......	......	(See p, 40.)	......	......	......	......	......
	8	14.4	— 2.1	34.2	4.5	......		......	......	......	......	......		......	......	......	......	......
	10	14.4	— 2.1	34.2	4.5	......		......	......	......	......	......		......	......	......	......	......
	12	14.4	— 2.1	34.2	4.4	......		13.8	n	......	5.3	......		......	......	......	5.5	......
	15	14.3	— 2.1	34.2	4.5	......		......	......	......	......	......		......	— 0.3	33.5	5.6	......
	18	14.2	— 2.1	34.2	4.8	......		......	n	......	4.8	......		......	......	......	5.6	......
	20	14.0	— 2.1	34.2	5.0	......		......	......	......	......	......		......	......	33.6	5.6	......
	22	13.8	— 2.1	34.2	5.5	......		13.6	+ 0.25	34.4	4.6	......		13.4	— 0.3	33.9	5.7	......
Nov. 2, '06	0	10.3	— 1.5	34.5	7.1	......	Nov. 8, '06	10.1	— 1.5	34.2	7.1	......	Nov. 10, '06	9.5	— 1.6	34.7	7.0	......
(See p. 41.)	5	......	......	......	......	......	(See p. 181.)	10.0	— 1.3	......	7.1	......	(See p. 41.)	......	......	......	......	......
	8	......	......	......	......	......		......	......	......	......	......		......	......	......	......	......
	10	......	......	......	6.7	......		......	......	......	7.0	......		......	......	......	......	......
	12	......	......	......	......	......		......	......	......	6.9	......		......	......	......	......	......
	15	......	......	......	......	......		......	— 1.0	34.4	6.8	......		......	— 1.5	34.9	6.9	......
	18	......	......	......	6.7	......		......	......	......	6.4	......		......	......	......	......	......
	20	......	......	......	6.6	......		......	......	......	6.0	......		......	......	......	......	......
	22	10.0	— 1.5	34.5	6.5	......		9.8	+ 0.12	34.8	5.5	......		9.5	— 1.5	34.9	6.9	......
Nov. 24, '06	0	5.5	— 1.0	34.4	7.6	......	Jan. 5, '07	0.9	— 1.3	34.4	9.0	......	....	......	......	......	......	......
(See p. 41,)	5	......	......	......	......	......	(See p. 29.)	......	......	......	......	......	....	......	......	......	......	......
	8	......	......	......	......	......		......	— 1.3	......	......	......	....	......	......	......	......	......
	10	......	......	......	......	......		1.0	......	34.4	9.0	......	....	......	......	......	......	......
	12	......	......	......	......	......		......	......	......	......	......	....	......	......	......	......	......
	15	......	......	......	......	......		......	......	......	......	......	....	......	......	......	......	......
	18	......	......	......	7.6	......		......	......	......	......	......	....	......	......	......	......	......
	20	......	......	......	......	......		......	......	......	......	......	....	......	......	......	......	......
	22	5.2	— 1.0	34.4	7.6	......		1.7	+ 0.4	34.7	8.8	......	....	......	......	......	......	......
Feb. 1, '07	0	0.4	— 2.0	36.0	9.6	......	Feb. 13, '07	0.5	— 2.0	35.9	10.0	......	Mar. 9, '07	0.8	— 1.5	30.6	8.7	......
	5	......	......	......	......	......	(See p. 29.)	......	......	......	......	......		2.3	— 1.1	35.8	8.55	......
	8	......	......	......	......	......		......	......	......	......	......		......	......	......	......	......
	10	1.2	......	......	......	......		1.6	n	35.4	8.3	......		2.3	— 1.0	35.9	8.6	......
	12	......	......	......	......	......		......	......	......	......	......		......	......	......	......	......
	15	1.4	— 2.4	36.4	7.6	......		1.8	+ 0.5	35.4	7.1	......		2.4	— 1.0	36.4	8.3	......
	18	1.9	+ 1.2	36.6	6.3	......		2.3	+ 2.5	36.7	5.0	......		2.6	+ 2.02	36.7	4.65	......
	20	2.2	......	......	5.0	......		......	......	......	......	......		3.00	......	......	......	......
	22	2.5	+ 3.8	36.7	4.5	......		3.2	+ 4.3	37.7	2.4	......		3.75	+ 5.0	40.0	0.58	......

Mar. 19, '07	0	2.1	+ 0.25	21.5	7.65	......	Mar. 25, '07 (See p. 181.)	2.9	+ 0.7	35.0	7.7	......	Mar. 30, '07 (See p. 42.)	3.9	— 0.8	34.4	8.5	......
	5	2.4	— 1.0	35.9	8.6	......		2.9	+ 0.6	35.7	7.7	......		......	n	34.9	8.6	......
	8	......	......	......	......	......		......	......	......	......	......		......	......	......	......	......
	10	2.4	— 0.7	35.9	8.6	......		2.9	+ 0.6	35.9	7.7	......		......	n	35.2	8.5	......
	12	......	......	......	......	......		......	......	......	......	......		......	......	......	......	......
	15	2.4	— 0.6	36.0	8.6	......		2.9	+ 0.5	36.1	7.7	......		......	+ 0.25	35.9	8.3	......
	18	2.4	+ 3.8	37.8	3.25	......		2.9	+ 1.2	36.1	6.5	......		......	......	......	......	......
	20	2.9	+ 4.0	38.5	2.2	......		2.9	+ 2.0	36.7	5.9	......		......	+ 0.25	35.9	8.1	......
	22	3.5	+ 5.0	38.6	0.55	......		3.5	+ 2.8	37.4	4.75	......		3.9	+ 0.5	36.0	8.1	......
April 10, '07 (See p. 42.)	0	4.1	n	35.1	8.6	......	April 14, '07	4.2	n	34.9	8.8	......	May 1, '07	5.9	— 2.5	35.0	8.0	......
	5	4.1	n	34.9	8.6	......		4.1	......	34.9	......	......		5.5	— 2.5	......	8.1	......
	8	......	......	......	......	......		......	......	......	......	......		......	......	......	8.0	......
	10	4.0	......	......	8.5	......		4.0	......	35.0	......	......		5.3	......	......	8.0	......
	12	......	......	......	......	......		......	......	......	......	......		......	......	......	......	......
	15	......	......	......	8.5	......		3.9	......	......	......	......		......	— 2.5	......	......	......
	18	......	......	......	8.6	......		......	......	......	......	......		......	......	......	8.0	......
	20	......	......	......	8.6	......		......	......	......	......	......		......	......	......	......	......
	22	4.0	n	34.9	8.6	......		3.8	n	35.2	8.7	......		5.3	— 2.5	35.0	7.9	......
May 16, '07	0	8.6	— 1.8	34.9	7.9	......	May 28, '07	10.3	— 2.5	35.0	7.4	......	June 11, '07	13.8	— 3.1	34.4	7.0	......
	5	......	— 1.8	......	7.9	......		10.2	— 2.3	35.0	7.4	......		13.5	— 2.6	34.4	6.7	......
	8	......	......	......	......	......		......	......	......	......	......		......	......	......	......	......
	10	8.4	— 1.8	34.9	7.9	......		10.0	......	......	7.3	......		12.8	— 1.8	34.4	6.6	......
	12	......	......	......	7.8	......		......	......	......	......	......		......	......	......	......	......
	15	8.3	......	......	7.7	......		9.7	— 2.3	35.0	7.3	......		12.7	— 1.5	34.6	6.4	......
	18	......	......	......	......	......		......	......	......	......	......		......	......	......	......	......
	20	......	......	......	......	......		......	......	......	7.1	......		11.75	— 1.3	34.6	5.8	......
	22	8.1	— 1.9	35.0	7.7	......		9.6	— 2.3	35.2	7.0	......		11.5	— 1.0	34.6	5.6	......
June 18, '07 (See p. 42.)	0	21.1	— 3.0	34.9	6.8	......	June 23, '07	19.1	— 3.3	......	6.5	......	July 2, '07 (See p. 182.)	22.2	— 2.8	34.4	7.0	......
	5	14.8	— 3.2	......	6.9	......		14.8	— 1.5	......	6.5	......		21.5	— 3.1	34.4	7.0	......
	8	13.3	— 2.7	......	6.3	......		13.5	— 1.3	......	5.6	......		15.1	— 0.6	34.5	5.2	......
	10	13.0	— 2.3	......	5.9	......		13.1	— 1.1	......	5.3	......		13.4	......	......	......	......
	12	12.7	— 1.8	......	5.4	......		12.5	n	......	4.7	......		13.1	+ 0.75	34.9	4.2	......
	15	12.3	— 1.3	34.9	5.0	......		12.3	— 0.4	......	4.3	......		12.75	+ 1.2	34.9	4.0	......
	18	12.1	— 0.55	35.0	4.4	......		12.1	+ 2.3	......	2.7	......		12.6	+ 2.0	34.9	3.5	......
	20	11.8	+ 0.75	35.2	3.8	......		12.0	+ 2.5	......	2.5	......		12.3	+ 3.3	35.4	1.2	......
	21	11.7	+ 1.2	35.4	3.4	......		11.8	+ 2.5	......	2.3	......		11 9	+ 3.3	35.7	0.8	......
July 16, '07	0	22.6	— 5.6	32.9	6.6	......	July 23, '07	25.1	— 5.5	31.8	5.8	......	July 30, '07 (See p. 182.)	24.65	— 5.3	32.3	6.0	......
	5	22.4	— 5.1	32.9	6.3	......		24.2	— 4.5	31.8	5.6	......		......	— 5.0	......	5.6	......
	8	20.5	— 3.5	32.9	5.2	......		21.9	— 3.3	32.1	4.5	......		19.2	— 3.1	33.4	1.52	......
	10	14.3	— 0.8	32.9	2.8	......		14.7	+ 1.8	32.9	2.3	......		15.3	+ 2.5	......	0.8	......
	12	13.4	+ 1.5	32.9	2.8	......		13.4	+ 2.3	......	1.9	......		13.6	+ 4.3	......	0.4	......
	15	12.8	+ 2.0	33.1	2.4	......		12.8	+ 2.3	32.9	1.2	......		12.8	+ 4.3	33.4	0.2	......
	18	......	+ 3.3	33.4	1.2	......		......	+ 3.0	33.3	Tr.	......		12.4	+ 4.3	34.6	Tr.	......
	20	......	+ 3.3	33.4	0.15	......		......	+ 3.5	34.4	0.0	......		......	......	......	......	......
	22	12.3	3.8	34.2	0.06	......		12.1	+ 4.0	34.9	0.0	......		11.9	+ 5.0	36.2	0.0	......

LAKE MENDOTA—Continued.

Date.	D	T	C	Cb	O	N	Date.	T	C	Cb	O	N	Date.	T	C	Cb	O	N
Sept. 6, '07	0	21.2	— 3.0	33.1	5.8	......	Sept. 18, '07	20.0	— 5.0	33.1	6.0	......	Sept. 7, '08	21.3	— 3.3	32.9	6.25	......
(See p. 183.)	5	20.8	— 3.5	33.1	5.8	......		19.8	— 4.3	......	5.8	......		21.1	— 3.3	......	5.7	......
	8	20.5	— 2.5	......	5.8	......		19.5	— 3.7	33.3	5.5	......		......	......	......	......	......
	10	20.5	— 0.8	33.4	4.5	......		19.0	— 2.6	33.4	4.5	......		21.0	— 3.3	32.9	5.0	......
	12	16.7	+ 4.55	34.6	Tr.	......		18.5	— 1.5	33.6	3.5	......		18.9	+ 2.5	34.2	1.1	......
	15	12.9	+ 6.32	35.9	0.0	......		14.0	+ 3.5	35.7	0.0	......		14.5	+ 6.1	37.2	0.0	......
	18	12.5	+ 7.4	......	0.0	......		12.8	+ 4.3	35.9	0.0	......		12.9	+ 8.2	38.5	0.0	......
	20	......	+ 9.45	36.5	0.0	......		12.5	+ 5.8	36.4	0.0	......		12.3	+ 9.6	39.5	0.0	......
	22	12.0	+14.4	38.2	0.0	......		12.3	+ 7.0	37.9	0.0	......		12.0	+10.1	39.7	0.0	......
Sept. 21, '08	0	24.5	— 6.3	33.4	7.8	......	Oct. 13, '08	14.1	— 1.0	35.4	5.5	......	Oct. 17, '08	14.3	— 1.8	36.2	6.7	......
(See p. 43.)	5	20.9	— 5.1	33.4	7.1	......		......	— 1.0	......	5.3	......		......	......	......	6.7	......
	8	20.6	— 4.2	33.6	6.2	......		......	......	......	......	......		......	......	......	......	......
	10	20.3	— 3.3	33.9	5.4	......		......	......	......	5.3	......		......	— 1.0	36.2	......	......
	12	19.7	— 1.3	34.7	3.6	......		......	......	......	......	......		......	......	......	......	......
	15	14.0	+ 5.8	38.0	0.0	......		......	— 0.7	35.4	5.0	......		......	......	......	6.4	......
	18	12.6	+ 9.6	38.9	0.0	......		14.0	+ 1.0	36.3	4.2	......		......	......	......	......	......
	20	12.2	+10.0	39.7	0.0	......		13.6	+ 3.4	37.4	2.6	......		......	— 0.5	......	6.0	......
	22	11.8	+10.6	40.5	0.0	......		13.4	+ 4.6	38.0	1.8	......		14.2	— 0.2	36.4	5.9	......
Jan. 26, '09	0	0.3	n	12.3	8.5	......	Feb. 6, '09	0.3	— 2.5	35.4	9.6	......	Mar. 6, '09	0.4	— 0.5	33.4	8.8	......
(See p. 183.)	5	1.7	— 1.0	36.4	9.4	......	(See p. 184.)	1.8	— 2.0	36.4	9.25	......	(See p. 184.)	2.1	— 2.1	36.7	9.0	......
	8	......	......	......	......	......		......	......	......	......	......		......	......	......	......	......
	10	1.7	— 1.0	36.4	9.5	......		1.8	......	......	9.3	......		......	— 1.9	36.7	9.1	......
	12	......	......	......	......	......		......	......	......	......	......		......	......	......	......	......
	15	2.0	n	38.0	8.4	......		2.0	— 1.0	36.6	8.1	......		2.2	n	37.2	7.2	......
	18	2.3	+ 2.4	39.2	5.2	......		2.3	+ 1.2	38.2	7.5	......		2.7	+ 0.5	38.2	6.0	......
	20	2.5	+ 4.6	40.5	1.6	......		2.[illegible]	+ 2.5	40.0	4.0	......		3.0	+ 4.3	40.5	0.39	......
	22	3.2	+ 6.3	41.5	1.5	......		3.4	+ 5.8	43.0	0.7	......		4.2	+ 8.9	45.0	0.0	......
June 23, '09	0	21.7	— 2.25	35.75	6.6	......	July 8, '09	21.9	— 3.6	32.9	6.4	......	Aug. 30, '09	22.9	— 3.7	33.7	6.2	......
(See p. 36.)	5	20.4	— 2.25	35.75	6.95	......		21.3	— 3.0	32.9	6.1	......	(See p. 36.)	22.7	......	......	6.4	......
	8	14.8	n	36.0	5.01	......		16.7	— 2.0	34.4	4.8	......		22.3	— 3.1	33.7	5.4	......
	10	12.4	+ 5.5	......	3.67	......		13.7	+ 2.5	3[illegible].9	2.5	......		17.2	+ 3.3	36.2	0.05	......
	12	......	......	......	......	......		11.7	+ 4.0	37.2	1.8	......		14.9	+ 3.5	37.2	Tr.	......
	15	10.2	+ 6.25	36.25	2.43	......		10.9	......	......	......	......		12.4	+ 3.8	37.4	0.0	......

	18	10.0	......	......	1.13	......		10.1	+ 4.4	37.2	0.87	......		10.9	+ 6.3	38.5	0.0	......
	20	9.8	+ 7.5	36.6	0.86	......		9.9	......	......	......	......		......	......	......	......	......
	22	9.7	+10.0	37.0	0.50	......		9.7	+ 5.1	37.7	0.91	......		10.1	+ 7.1	39.2	0.0	......

MOUSE LAKE (S. E.)

May 11, '06	0	12.8	......	......	......	......	June 7, '06	22.4	— 4.1	39.7	6.2	......	Aug. 1, '06	23.4	— 4.3	36.4	5.9	12.1
	3	12.6	......	......	......	......		21.9	— 3.8	......	6.5	......		23.4	— 4.0	36.4	6.0	......
(See p. 49.)	6	11.8	......	......	......	......		15.4	— 2.5	39.8	6.5	......		22.4	— 4.0	36.4	5.8	......
	8	10.3	— 1.7	40.7	6.8	......		11.2	— 0.8	40.1	5.9	......		14.2	— 1.8	41.0	5.6	15.1
	10	7.1	......	......	......	......		8.1	......	......	......	......		10.0	+ 2.3	42.5	3.9	16.8
	12	5.3	+ 1.8	43.3	3.4	......		6.0	+ 2.3	40.4	2.9	......		7.0	+ 4.3	44.8	0.47	......
	15	4.7	......	......	......	......		5.2	+ 4.6	43.7	0.3	......		5.7	+ 5.3	47.3	0.09	......
	18	4.6	+ 3.8	46.1	0.09	......		5.0	+ 5.7	46.3	Tr.	......		5.4	+ 9.6	49.6	Tr.	22.5
Sept. 19, '06	0	26.2	— 4.0	36.9	5.7	......	May 11, '07	8.5	— 2.0	37.6	7.7	......	June 6, '07	17.3	— 1.7	37.6	6.4	......
	3	22.5	— 4.0	36.9	5.8	......		......	......	......	7.8	......		14.5	— 1.7	37.6	6.7	......
	6	21.6	— 4.0	36.9	5.7	......	(See p. 49.)	8.2	— 2.0	......	7.8	......		12.75	— 1.7	37.6	6.6	......
	8	17.0	+ 0.75	42.5	5.1	......		7.5	......	......	7.6	......		11.4	— 1.2	37.6	6.1	......
	10	10.6	+ 4.3	43.0	1.1	......		6.9	— 0.7	......	7.5	......		10.0	+ 1.0	38.2	5.6	......
	12	8.2	+ 4.6	44.8	0.34	......		......	......	......	......	......		8.7	+ 1.8	38.4	5.0	......
	15	6.6	+ 5.9	47.4	Tr.	......		6.5	— 0.7	37.6	7.3	......		7.6	+ 2.4	......	4.4	......
	18	5.8	+ 9.9	50.8	0.0	......		6.0	+ 2.38	37.7	6.6	......		7.0	+ 3.3	39.5	3.0	......

NAGOWICKA LAKE (S. E.)

Feb. 22, '06	0	0.8	n	46.2	8.7	18.6	Mar. 17, '06	0.8	+ 3.0	16.0	10.5	18.7	July 1, '06	22.2	— 5.5	44.5	6.3	......
	5	1.3	— 1.0	46.2	9.0	19.4		1.8	+ 3.0	46.7	8.5	19.3		20.8	— 4.0	44.5	6.0	......
(See p. 79.)	8	......	......	......	......	......	(See p. 79.)	......	......	......	......	......		16.3	— 2.0	46.0	4.4	......
	10	1.3	......	......	11.1	19.5		1.8	+ 3.0	46.6	8.2	19.4		13.0	— 0.2	46.0	3.8	......
	12	......	......	......	......	......		......	......	......	......	......		11.0	+ 1.3	46.0	3.8	......
	15	1.3	— 0.7	46.2	9.0	19.2		1.8	+ 3.4	46.6	8.0	19.4		9.4	+ 1.7	46.0	3.8	......
	20	1.3	n	47.5	8.2	19.4		1.8	......	......	7.4	19.5		8.3	+ 3.0	46.0	3.0	......
	23	......	+ 0.88	47.7	7.5	19.5		1.8	+ 4.2	51.2	6.5	19.5		......	+ 3.5	46.3	2.3	......
	27	1.6	+ 4.2	52.6	7.2	19.5		2.0	+ 5.3	56.1	4.7	20.2		7.8	+ 4.8	46.8	1.0	......
Aug. 2, '06	0	23.0	— 4.6	42.3	5.7	12.5	Sept. 20, '06	22.3	— 3.8	41.2	6.4	......	Mar. 2, '07	0.75	+ 1.0	43.7	7.6	......
	5	22.6	— 4.3	42.8	5.6	......		20.8	— 2.2	41.2	5.8	......		2.0	+ 1.2	44.3	7.75	......
	8	17.0	+ .75	47.3	1.4	......		20.1	— 1.3	41.8	4.1	......		......	......	......	......	......
	10	13.6	+ 2.8	47.8	1.0	......		16.2	+ 4.6	47.0	0.07	......		......	+ 1.5	44.3	7.8	......
	12	11.5	+ 2.8	47.1	1.55	15.8		11.1	+ 5.6	48.1	Tr.	......		......	......	......	......	......
	15	9.3	+ 3.3	47.1	2.2	......		9.6	+ 5.3	48.1	Tr.	......		......	+ 1.8	44.8	7.6	......
	20	8.4	+ 4.3	48.6	0.7	......		8.6	+ 6.3	48.1	Tr.	......		2.0	+ 2.5	45.0	7.4	......
	23	8.2	+ 4.9	49.1	0.3	......		8.5	+ 6.9	48.6	Tr.	......		......	+ 3.2	46.5	6.6	......
	27	7.9	+ 5.8	49.3	0.0	......		8.2	+ 7.3	50.3	Tr.	......		2.5	+ 6.6	49.1	1.9	......

NORTH LAKE (EAST.) (S. E.)

Date.	D	T	C	Cb	O	N	Date.	T	C	Cb	O	N	Date.	T	C	Cb	O	N
May 11, '06	0	10.7	— 2.4	50.6	7.4	......	June 7, '06	21.6	— 6.0	50.6	6.3	......	June 29, '06	22.7	— 5.6	48.6	6.3	......
(See p. 84.)	4	9.9	......	......	......	......		17.0	— 4.5	......	6.1	......		19.1	— 5.6	49.6	6.6	......
	5	9.5	......	......	......	......		14.2	— 3.7	......	5.7	......		17.5	— 3.6	49.6	5.5	......
	6	9.2	......	......	......	......		14.1	— 2.7	......	5.4	......		14.25	— 1.0	49.6	3.8	......
	8	8.9	......	......	......	......		11.7	......	......	......	......		11.25	+ 2.0	......	3.0	......
	10	8.6	......	......	......	......		9.5	+ 0.2	......	5.0	......		9.6	+ 2.3	......	3.2	......
	12	8.3	n	......	6.3	......		8.5	......	......	......	......		8.25	+ 3.0	......	3.0	......
	15	7.0	+ 1.4	......	5.9	......		7.8	+ 1.8	......	4.2	......		7.8	+ 3.5	......	2.2	......
	18	......	......	......	......	......		......	+ 2.0	50.6	3.6	......		7.7	+ 5.6	49.6	2.0	......
	21	6.4	+ 2.0	50.6	5.5	......		7.5	+ 3.0	50.8	3.2	......		7.7	+ 6.8	49.8	1.9	......
July 30, '06	0	23.8	— 4.0	46.0	6.0	11.8	Sept. 18, '06	22.0	— 2.8	48.6	5.6	......	Oct. 13, '06	12.2	+ 0.9	47.8	5.5	......
	4	23.0	— 4.0	46.8	5.6	......		21.1	— 1.5	48.8	5.1	......		12.1	+ 0.9	......	5.4	......
	5	21.1	— 2.5	47.8	4.1	......		20.8	— 1.2	48.8	4.8	......		......	......	......	......	......
	6	15.9	+ 3.9	52.4	0.17	......		20.5	— 1.0	49.3	4.2	......		......	......	......	......	......
	8	11.8	+ 4.3	52.4	0.67	......		14.2	+ 5.8	52.9	0.08	......		12.0	+ 0.9	......	5.2	......
	10	9.8	+ 4.3	52.4	1.0	......		12.2	+ 6.6	52.9	Tr.	......		12.0	+ 1.9	47.8	5.1	......
	12	8.5	+ 5.0	52.6	0.4	......		9.8	+ 7.6	53.1	Tr.	......		9.0	+ 8.7	49.9	0.14	......
	15	7.9	+ 5.8	53.1	Tr.	......		9.5	+ 8.1	53.9	Tr.	......		8.2	+ 8.7	50.6	Tr.	......
	18	7.8	+ 6.1	53.1	0.0	......		9.5	+ 8.1	54.1	0.0	......		8.0	+ 9.0	50.6	Tr.	......
	21	7.7	+ 6.3	53.1	0.0	16.9		9.0	+ 8.1	54.1	0.0	......		7.9	+10.1	50.6	0.0	......
Mar. 3, '07	0	1.7	+ 0.5	21.5	10.5	......	May 10, '07	7.2	— 3.5	45.8	9.2	......	June 7, '07	13.8	— 4.5	45.0	7.6	......
	4	......	......	......	......	......		7.4	— 3.7	46.0	9.1	......		13.3	— 4.2	......	7.7	......
	5	1.9	+ 2.5	49.1	7.0	......		......	— 4.0	......	8.9	......		12.9	— 3.8	......	7.2	......
	6	......	......	......	......	......		7.3	— 4.3	46.0	8.8	......		12.4	— 3.5	......	6.8	......
	8	......	......	......	......	......		......	......	......	......	......		11.3	— 2.5	......	6.6	......
	10	......	+ 3.7	49.1	7.0	......		7.1	......	......	8.8	......		10.2	— 1.5	45.0	6.4	......
	12	......	......	......	......	......		6.8	— 4.0	......	8.6	......		9.4	— 1.5	46.0	6.25	......
	15	......	+ 3.7	49.4	6.15	......		6.2	— 4.0	......	8.5	......		9.25	+ 1.0	46.8	5.9	......
	18	2.0	+ 6.6	50.3	4.9	......		......	— 2.2	......	8.15	......		8.0	+ 1.25	46.8	5.6	......
	21	2.8	+ 7.5	51.7	1.6	......		6.0	— 1.8	46.0	8.15	......		7.9	+ 2.2	47.4	5.2	......
Sept. 4, '07	0	20.5	— 4.4	47.4	6.0	......	July 20, '09	23.2	— 3.0	46.0	6.1	......	Sept. 1, '09	21.0	— 3.0	46.0	6.6	......
	4	20.5	— 4.1	48.1	6.0	......		19.8	......	......	7.0	......		20.9	— 3.0	......	5.2	......
	5	19.4	+ 3.0	48.6	2.5	......		17.2	— 3.0	46.0	1.3	......		20.8	— 3.0	46.0	5.2	......
	6	16.7	+ 4.3	......	0.15	......		13.0	+ 3.06	46.3	2.0	......		18.7	+ 5.3	46.3	1.2	......
	8	11.5	+ 5.1	......	Tr.	......		9.8	+10.1	......	3.1	......		11.4	+10.0	......	Tr.	......
	10	10.3	+ 5.1	......	Tr.	......		8.8	......	......	2.9	......		9.4	......	......	0.38	......
	12	9.4	......	48.6	Tr.	......		7.8	+10.1	46.3	3.1	......		8.5	+10.0	46.3	0.39	......
	15	8.9	+ 5.6	49.3	Tr.	......		7.4	......	......	2.0	......		8.0	......	......	0.44	......

	18	8.7	+ 5.9	49.6	0.0	......		7.3	+10.1		1.5	......		7.8	+10.0	46.6	0.44	......
	21	8.5	+ 7.3	51.9	0.0	......		7.2	+10.6		0.55	......		7.7	+10.5	47.6	0.0	......

NORTH LAKE (West) (S. E.)

May 11, '06	0	11.0	— 2.5	48.2	7.8	......	June 7, '06	22.5	— 5.8	48.1	6.2	......	June 29, '06	23.5	— 5.6	46.8	5.9	......
	4	......	......	......	......	......		15.6	— 4.7	......	5.9	......		19.1	— 5.6	......	6.3	......
(See p. 202.)	5	9.7	......	......	......	......	(See p. 203.)	14.8	— 4.0	......	5.7	......	(See p. 203.)	17.9	— 4.3	......	5.7	......
	6	......	......	......	......	......		14.1	— 3.5	......	5.5	......		16.0	— 2.3	......	3.7	......
	8	9.3	......	......	......	......		12.5	— 2.6	......	5.1	......		11.5	n	......	3.0	......
	10	8.7	— 1.3	48.0	6.4	......		8.2	+ 1.4	......	4.5	......		9.0	+ 2.3	......	2.7	......
	12	7.4	......	......	......	......		7.4	......	......	......	......		7.2	+ 3.8	......	2.3	......
	15	5.9	+ 1.6	......	4.8	......		6.4	+ 2.6	......	3.7	......		6.1	+ 4.8	......	2.1	......
	18	5.0	......	......	......	......		5.4	+ 3.0	......	2.6	......		5.7	+ 6.1	46.8	1.4	......
	21	4.7	+ 2.0	48.0	3.05	......		5.1	+ 4.5	48.1	1.4	......		5.0	+ 7.1	47.8	0.0	......
July 30, '06	0	23.5	— 4.1	43.3	5.8	......	Sept. 18, '06	22.5	— 2.8	44.0	5.5	......	Oct. 13, '06	12.2	+ 0.25	42.5	5.4	......
	4	23.0	— 4.0	44.0	5.6	......		20.5	— 1.8	44.3	4.9	......		12.1	+ 0.38	43.6	5.3	......
(See p. 204.)	5	21.2	— 2.5	47.8	5.0	......	(See p. 204.)	20.2	— 1.5	44.3	4.8	......	(See p. 205.)	12.1	+ 0.38	43.6	5.3	......
	6	17.7	— 1.0	50.3	3.4	......		19.8	— 0.4	44.8	4.0	......		......	......	......	......	......
	8	10.8	+ 3.5	49.8	0.77	......		12.5	+ 5.1	50.1	Tr.	......		12.0	+ 0.63	43.6	5.3	......
	10	9.1	+ 3.8	48.3	1.1	......		10.3	+ 6.4	50.1	0.0	......		11.8	+ 0.63	43.9	5.0	......
	12	7.5	+ 5.8	48.3	0.8	......		9.3	+ 7.8	48.6	0.0	......		8.0	+ 7.1	46.3	Tr.	......
	15	6.4	+ 6.6	48.1	0.68	......		8.0	+ 7.6	50.1	0.0	......		6.7	+ 8.7	46.3	Tr.	......
	18	6.0	+ 6.8	48.8	Tr.	......		7.8	+ 8.1	......	0.0	......		6.0	+10.1	46.9	0.0	......
	21	5.4	+ 7.8	49.8	0.0	......		7.3	+10.4	51.4	0.0	......		5.6	+11.4	48.8	0.0	......
	0	0.9	+ 1.8	46.5	7.7	......	May 10, '07	7.0	— 6.0	46.0	9.5	......	June 7, '07	14.2	— 5.2	45.2	7.2	......
Mar. 3, '07	4	......	......	......	......	......		......	......	......	......	......		13.7	— 4.7	45.7	7.0	......
	5	2.0	+ 2.3	47.5	7.5	......	(See p. 84.)	......	— 4.8	......	9.5	......	(See p. 206.)	......	......	......	......	......
(See p. 205.)	6	......	......	......	......	......		......	......	......	......	......		13.3	— 4.0	46.0	6.8	......
	8	......	......	......	......	......		......	......	......	......	......		11.6	......	......	......	......
	10	......	+ 2.4	47.8	7.45	......		7.0	— 4.5	......	9.4	......		9.8	— 1.0	46.0	6.2	......
	12	......	......	......	......	......		......	......	......	......	......		8.2	n	46.5	6.0	......
	15	......	+ 2.4	48.6	7.4	......		5.8	— 3.8	46.0	8.8	......		6.8	+ 0.75	46.9	6.4	......
	18	2.3	+ 4.2	48.8	5.2	......		......	......	......	......	......		6.3	+ 2.0	47.0	5.6	......
	21	3.3	+10.1	51.4	0.0	......		5.4	— 2.5	46.0	8.4	......		4.9	+ 4.8	47.8	1.7	......
Sept. 4, '07	0	20.9	— 5.6	44.3	5.7	......	July 20, '09	23.7	— 3.5	42.0	5.7	......	Sept. 1, '09	22.4	— 3.5	42.0	5.9	......
	4	20.7	— 4.8	......	5.6	......		23.1	......	......	5.9	......		21.3	......	......	4.6	......
(See p. 206.)	5	20.5	— 3.1	44.8	4.3	......		17.8	— 3.5	42.0	6.3	......	(See p. 207.)	21.3	— 3.5	42.0	3.4	......
	6	18.8	+ 2.5	44.8	Tr.	......		15.1	+ 3.5	44.3	2.4	......		18.4	+ 3.5	44.3	1.3	......
	8	11.9	+ 3.8	45.5	Tr.	......		11.7	+ 6.1	46.0	1.8	......		12.4	+ 6.1	46.0	0.45	......
	10	9.5	......	45.8	Tr.	......		8.7	......	......	3.1	......		8.8	......	......	0.73	......
	12	8.4	+ 4.0	......	0.0	......		7.1	+ 7.1	46.0	3.8	......		7.5	+ 7.1	46.0	1.2	......
	15	7.3	+ 4.6	......	0.0	......		6.3	......	......	3.8	......		6.9	......	......	1.3	......
	18	6.7	......	45.8	0.0	......		6.0	+ 7.6	46.5	2.7	......		......	+ 7.5	46.5	0.44	......
	21	6.15	+ 7.6	50.1	0.0	......		5.7	+ 8.9	49.6	0.7	......		6.0	+ 8.8	49.6	0.0	......

OKAUCHEE LAKE (S. E.)

Date	D	T	C	Cb	O	N	Date	T	C	Cb	O	N	Date	T	C	Cb	O	N
Aug. 4, '05	0	22.4	— 4.9	36.6	5.7	11.9	Oct. 15, '05	14.7	— 1.6	40.4	5.4	13.6	June 26, '06	21.0	— 4.1	41.0	6.0	......
	5	22.3	......	......	5.4	......		14.7	......	......	......	......		18.6	— 2.7	41.2	6.8	......
	8	16.6	+ 1.11	41.2	4.5	12.7	(See p. 207.)	14.7	— 1.3	41.1	5.4	13.5	(See p. 208.)	15.8	n	41.2	4.3	......
	10	12.6	+ 1.11	40.8	2.1	14.4		14.7	— 1.1	41.8	5.4	13.4		11.9	+ 1.3	42.5	4.1	......
	12	10.8	+ 1.22	41.2	......	......		13.7	+ 1.14	43.1	3.5	13.6		10.1	+ 2.3	42.5	4.2	......
	15	9.6	......	......	2.4	15.7		9.6	+ 3.16	43.5	Tr.	15.2		9.0	+ 2.5	42.5	4.6	......
	18	7.8	......	......	......	......		8.0	+ 3.54	43.9	Tr.	15.5		7.8	+ 2.5	42.5	4.0	......
	22	7.0	+ 2.67	41.2	2.6	16.1		7.2	+ 5.44	44.1	Tr.	16.7		7.1	+ 2.5	42.5	4.1	......
	27	6.4	+ 2.67	41.2	0.0	17.3		6.5	+ 5.94	46.1	Tr.	17.5		6.4	+ 2.5	42.5	3.0	......
July 26, '06	0	24.2	— 4.8	36.9	5.7	11.9	Sept. 21, '06	22.0	— 4.6	36.7	5.8	......	Oct. 14, '06	12.5	— 1.7	37.0	5.9	......
	5	23.6	— 4.8	37.2	5.7	......		22.0	— 4.1	36.7	5.6	......		12.3	— 1.8	37.3	5.9	......
(See p. 209.)	8	17.0	— 0.6	42.3	2.2	12.7	(See p. 210.)	19.9	— 0.5	38.2	2.5	......	(See p. 209.)	12.1	— 1.5	37.3	5.5	......
	10	11.7	+ 1.3	43.0	2.3	15.4		14.2	+ 4.8	44.0	Tr.	......		12.0	— 1.5	37.4	5.4	......
	12	10.3	+ 1.8	43.3	2.8	......		11.0	+ 4.8	44.5	0.25	......		11.9	— 1.5	37.4	5.3	......
	15	9.2	+ 1.8	43.3	2.9	......		9.6	+ 4.8	44.5	1.1	......		11.7	n	37.7	4.8	......
	18	8.0	+ 1.8	43.3	3.2	......		8.4	+ 4.6	44.5	0.95	......		8.2	+ 6.3	42.4	0.18	......
	22	7.25	+ 3.0	43.3	2.1	......		7.5	+ 6.6	44.5	Tr.	......		7.3	+ 7.2	43.4	0.0	......
	27	6.75	+ 5.6	45.4	0.0	......		6.7	+ 8.3	47.0	0.0	......		6.9	+ 7.8	44.6	0.0	......
Mar. 4, '07	0	0.75	+ 1.3	39.2	7.8	......	Sept. 5, '07	20.8	— 5.6	35.7	5.7	......	Sept. 2, '09	21.2	— 4.0	35.9	6.1	......
	5	2.5	+ 1.3	39.7	7.6	......		20.7	......	......	......	......		20.7	— 4.5	35.9	6.2	......
(See p. 210.)	8	......	......	......	......	......		20.4	— 5.0	36.0	5.4	......	(See p. 133.)	17.0	— 4.6	36.2	5.7	......
	10	......	+ 1.4	40.2	7.7	......		13.3	+ 2.0	37.9	1.9	......		12.2	......	......	0.30	......
	12	......	......	......	......	......		11.7	+ 3.4	40.5	......	......		10.2	+ 5.0	43.0	0.13	......
	15	2.5	+ 1.5	40.6	7.7	......		10.2	+ 3.6	......	1.9	......		8.9	......	......	0.44	......
	18	......	......	......	......	......		8.5	+ 3.5	40.5	1.7	......		7.8	+ 5.3	43.0	0.15	......
	22	2.5	+ 1.5	42.0	7.7	......		7.9	+ 5.0	......	0.6	......		6.8	......	......	0.11	......
	27	2.75	+ 4.5	44.1	3.4	......		7.1	+ 5.0	43.3	0.0	......		6.1	+ 6.6	45.0	0.0	......

OTTER LAKE (S. E.)

July 8, '06	0	25.0	— 3.0	36.4	8.3	......	Aug. 20, '06	26.7	— 3.8	36.7	6.0	11.9	Aug. 3, '08	27.0	— 3.6	34.7	6.1	......
	2	22.3	— 1.8	36.5	8.6	......		25.5	— 3.6	36.7	5.9	......		25.5	......	......	5.9	......
(See p. 197.)	3	20.4	— 1.3	38.7	11.2	......	(See p. 197.)	23.6	— 3.3	36.9	9.5	......		22.8	— 3.6	34.7	10.2	......
	4	14.6	+ 1.0	38.7	13.1	......		18.8	— 2.5	36.7	13.3	17.7		16.5	— 3.5	33.1	14.3	......
	5	11.3	+ 3.3	40.2	6.9	......		13.4	+ 0.75	39.7	7.2	19.2		12.2	+ 2.3	35.9	6.25	......
	6	9.8	+ 4.3	39.2	5.2	......		10.7	+ 2.8	39.0	4.5	......		10.1	+ 2.5	35.7	4.6	......
	8	8.7	......	......	5.3	......		9.0	+ 2.5	36.4	4.4	......		9.0	......	......	3.1	......
	10	8.6	+ 4.3	36.5	4.8	......		8.8	+ 3.0	37.2	3.1	......		8.7	+ 4.0	34.4	3.3	......

Aug. 29, '08	0	22.8	— 2.0	33.4	6.8	......	June 18, '09	20.5	— 2.5	40.0	6.9	....	July 2, '09	26.4	— 2.1	38.0	5.8	....
	2	21.2	....	....	......	......		20.2	— 2.0	....	6.6	....		25.1	....	....	7.7	....
	3	20.7	— 2.0	33.4	7.5	......		17.0	+ 0.75	40.0	7.9	....	(See p. 198.)	19.8	— 2.5	38.2	13.1	....
	4	18.4	— 1.3	32.9	10.7	......		12.5	+ 1.75	40.1	9.25	....		13.7	— 1.8	38.7	12.2	....
	5	13.8	+ 1.8	35.9	6.8	......		9.6	+ 2.25	40.2	6.88	....		10.4	+ 2.0	39.0	6.8	....
	6	10.8	+ 3.3	35.9	4.8	......		9.0	+ 3.5	40.0	4.02	....		8.5	+ 2.5	39.0	4.9	....
	8	......	....	....	......	......		8.9	+ 4.0	39.0	3.6	....		8.3	+ 3.5	37.2	4.4	....
	10	8.8	+ 6.6	34.4	3.2	......		8.75	+ 4.5	39.0	3.4	....		8.0	+ 3.5	37.2	4.4	....
July 17, '09	0	24.4	— 4.6	35.2	7.1	......	Aug. 2, '09	23.3	— 3.1	35.7	6.8	....	Aug. 13, '09	22.4	— 3.5	35.9	6.9	....
	2	24.4	— 3.0	35.4	7.0	......		23.3	— 3.5	35.9	6.8	....		....	....	....	....	....
(See p. 198.)	3	21.9	— 4.5	35.4	15.2	......		22.0	— 3 5	36.9	8.8	....	(See p. 198.)	22.1	— 3.5	35.9	7.5	....
	4	15.6	— 2.5	36.4	15.3	......		17.0	— 3.5	38.5	17.3	....		18.5	— 3.5	34.4	18.1	....
	5	11.4	+ 1.0	39.2	8.6	......		12.6	+ 0.75	38.5	8.7	....		13.5	n	39.0	4.4	....
	6	9.9	+ 3.5	38.2	5.4	......		10.0	+ 3.5	38.5	4.6	....		10.4	+ 4.4	36.7	4.1	....
	8	8.9	+ 2.8	36.4	5.6	......		8.9	+ 4.0	....	4.3	....		9.4	+ 4.8	36.2	3.7	....
	10	8.9	+ 4.8	35.9	4.6	......		8.8	+ 4.5	36.7	4.1	....		9.4	+ 5.0	36.2	3.2	....
Aug. 26, '09	0	25.7	....	....	7.6	......	Sept. 10, '09	19.0	— 3.5	34.4	7.3	....	Oct. 23, '09	7.8	— 1.3	39.0	7.0	....
	2	23.1	....	....	7.1	......		....	....	....	....	....		....	....	....	....	....
(See p. 52.)	3	22.8	....	....	7.5	......		19 0	— 3.3	35.4	7.1	....		....	....	....	7.0	....
	4	19.3	....	....	18.9	......		18.6	— 2.5	36.4	7.1	....		....	....	....	....	....
	5	13.0	....	....	10.4	......		15.1	+ 1.5	38.7	7.6	....		....	....	....	....	....
	6	10.4	....	....	4.3	......		11.2	+ 3.0	38.2	3.6	....		....	— 1.3	39.0	6.9	....
	8	8.2	....	....	3.6	......		9.0	+ 4.0	37.1	3.3	....		....	....	....	7.1	....
	10	7.7	....	....	3.5	......		7 9	+ 5.0	36.2	3.1	....		7.8	— 1.3	39.0	7.0	....

RAINBOW LAKE (S. E.)

Apr. 25, '07	0	5.25	— 0.8	34.2	8.2	......	May 23, '07	12.2	— 2.0	32.6	7.9	....	June 29, '07	22.6	— 2.8	31.9	5.8	....
	3	......	— 0.8	33.9	8.3	......		12.0	— 2.0	32.6	7.8	....		22.5	— 2.8	32.0	7.0	....
	5	......	....	....	....	......		11.8	....	....	....	....		17.3	— 2.5	32.1	7.6	....
	6	......	— 0.8	33.9	8.3	......		11.0	— 2.1	32.9	8.1	....		15.0	— 2.3	32.1	8.1	....
	7	......	....	....	....	......		9.9	....	....	....	....		13.0	....	....	8.2	....
	8	......	....	....	....	......		....	....	....	....	....		11.7	— 1.5	32.2	7.5	....
	10	5.1	— 0.8	....	8.3	......		9.0	— 0.8	33.1	8.1	....		10.0	+ 0.5	32.6	5.7	....
	12	......	....	....	8.3	......		7.7	+ 0.4	33.6	7.6	....		8.9	+ 1.1	....	4.6	....
	15	5.1	— 0.8	....	8.4	......		6.2	+ 1.2	33.8	7.2	....		6.5	+ 3.9	32.9	4.5	....
	20	......	— 0.8	....	8.4	......		5.75	+ 1 9	33.8	6.4	....		5.9	+ 4.7	32.9	2.2	....
	24	......	— 0.8	....	8.3	......		....	+ 2.15	34.0	6.2	....		5.7	+ 5.6	34.9	1.1	....
	27	......	— 0.8	33.9	8.2	......		5.6	+ 2.15	34.1	5.8	....		5.6	+ 6.6	35.1	0.12	....

RAINBOW LAKE (S. E.)—Continued.

Date.	D	T	C	Cb	O	N	Date.	T	C	Cb	O	N	Date.	T	C	Cb	O	N
Sept. 10, '07	0	18.8	— 4.0	27.9	6.1	......	Aug. 29, '08	22.5	— 2.5	28.1	6.2	......	Mar. 19, '09	0.2	+ 0.6	37.8	8.0	......
	3	18.7	......	......	6.1	......		......	......	......	......	......		......	......	......	......	......
(See p. 218,)	5	......	......	......	......	..		20.8	......	......	6.2	......	(See p. 79.)	2.7	......	......	......	......
	6	18.7	— 3.5	27.9	5.9	......		20.7	— 2.5	28.1	6.1	......		......	......	......	......	......
	7	18.3	— 3.0	......	5.7	......		19.7	— 0.5	28.8	5.4	......		......	......	......	......	......
	8	15.7	+ 1.5	28.0	3.9	......		14.9	+ 2.5	33.5	2.8	......		......	......	......	......	......
	10	10.5	+ 2.8	28.1	0.15	......		11.0	+ 5.0	35.9	0.13	......		2.9	+ 2.7	37.8	6.2	......
	12	9.1	+ 4.0	29.8	0.5	......		10.0	+ 5.0	35.9	0.13	......		......	......	......	......	......
	15	7.0	+ 5.0	30.8	0.25	......		8.4	+ 6.1	......	Tr.	......		......	......	......	......	......
	20	6.3	+ 5.0	32.9	0.0	......		7.5	+ 7.4	......	Tr.	......		3.5	+ 3.6	38.8	0.5	......
	24	6.1	+ 6.8	37.4	0.0	......		7.3	+ 8.1	36.4	0.0	......		3.7	+ 4.3	40.8	Tr.	......
	27	5.9	+ 7.5	40.5	0.0	......		7.2	+10.4	37.4	0.0	......		3.9	+ 4.5	41 0	0.0	......
May 5, '09	0	8.0	n	35.4	8.3	......	June 3, '09	21.0	— 3.5	34.9	6.45	......	June 17, '09	20.2	— 4.5	33.25	6.3	......
	3	......	......	......	......	......		17.8	— 4.25	34.9	7.54	......		20.2	— 4.5	......	6.2	......
(See p. 87.)	5	5.5	n	35.4	8.2	......		......	......	......	......	......		18.0	— 4.5	33.7	8.6	......
	6	......	......	......	......	......		11.2	— 4.25	34.9	9.8	......		12.5	— 4.5	33.7	10.5	......
	7	......	......	......	......	......		......	......	......	......	......		11.3	— 4.5	......	9.6	......
	8	......	......	......	......	......		9.5	......	......	......	......		9.8	— 3.0	34.0	8.4	......
	10	4.8	......	......	8.3	......		8.5	+ 0.25	35.4	6.24	......		8.3	+ 1.25	35.5	5.6	......
	12	......	......	......	......	......		7.0	......	......	......	......		7.2	+ 3.0	35.5	4.9	......
	15	......	n	35.4	8.2	......		5.8	+ 1.8	35.4	5.96	......		6.0	+ 3.0	35.5	5.2	......
	20	......	......	......	8.0	......		5.6	+ 2.0	......	5.3	......		5.6	......	......	3.9	......
	24	4.6	n	35.4	8.0	......		5.4	+ 2.5	35.4	4.75	......		5.5	+ 4.0	36.0	3.1	......
	27	4.5	n	35.4	8.0	......		5.3	+ 2.5	35.9	3.83	......		5.4	+ 4.7	36.2	2.3	......
July 1, '09	0	27.5	— 2.5	33.1	6.2	......	July 16 '09	24.4	— 2.6	30.4	6.2	......	July 31, '09	25.3	— 2.5	32.4	6.4	......
	3	26.4	......	......	6.3	......		......	......	31.4	5.8	......		23.8	......	......	7.2	......
	5	18.4	— 2.5	......	10.2	......		24.4	— 2.6	31.4	8.1	......		22.7	— 2.8	32.4	6.9	......
	6	14.1	— 2.8	33.4	11.0	......		17.9	— 2.6	31.4	10.5	......		20.6	......	......	7.2	......
	7	12.2	— 3.0	34.4	10.6	......		13.4	— 2.6	31.4	12.6	......		15.0	— 2.5	32.4	12.1	......
	8	10.4	— 3.0	34.4	9.0	......		11.4	— 2.5	32.6	10.7	......		12.0	— 2.5	33.9	10.9	......
	10	8.2	n	35.7	7.9	......		8.9	— 1.1	34.7	7.5	......		8.7	+ 2.5	36.7	5.0	......
	12	7.1	+ 2.3	......	4.5	......		7.6	+ 2.0	35.4	3.9	......		7.3	+ 4.3	36.9	2.3	......
	15	5.5	+ 3.3	35.9	3.8	......		6.4	......	......	......	......		6.0	......	......	1.3	......
	20	5.0	+ 5.1	36.7	2.4	......		5.6	+ 7.0	37.0	0.8	......		5.6	......	......	0.12	......
	24	4.9	+ 5.6	37.1	0.8	......		......	......	......	......	......		5.6	+ 6.8	38.2	0.13	......
	27	4.8	+ 6.1	37.7	0.15	......		5.6	+ 7.1	38.7	0.12	......		5.6	+ 7.6	39 2	0.0	......
Aug. 12, '09	0	23.6	— 3.0	31.1	6.4	......	Aug. 24, '09	25.5	— 3.6	30.9	6.5	......	Sept. 9, '09	19.4	— 3.8	30.6	6.5	......
	3	......	......	......	......	......		25.3	......	......	6.5	......		......	......	......	......	......
	5	23.4	— 3.0	31.1	6.2	......		22.9	— 3.3	31.1	6.7	......	(See p, 219.)	19.1	......	......	6.4	......
	6	20.4	— 2.5	32.4	7.5	......		20.5	— 2.0	32.9	7.7	......		......	......	......	......	......
	7	16.9	— 2.9	32.9	11.3	......		16.6	— 1.5	33.4	10.5	......		18.3	— 3.8	30.6	6.2	......
	8	13.2	— 1.3	34.4	10.2	......		14.5	— 1.0	34.4	9.0	......		14.3	+ 1.0	33.9	6.4	......
	10	9.3	+ 2.3	37.4	3.9	......		9.7	+ 3.8	37.9	1.5	......		9.3	+ 3.5	37.9	0.14	......

	12	7.9	+ 5.0	37.4	1.4	......		8.3	+ 5.3	38.2	0.11	......		8.1	+ 4.3	......	0.13	......
	15	6.2	....	....	0.15	......		6.8	....	....	Tr.	......		6.6	....	......	Tr.	......
	20	5.8	+ 5.7	38.7	0.10	......		5.5	+ 5.4	38.7	Tr.	......		5.7	+ 5.0	38.2	Tr.	......
	24	5.6	+ 7.1	39.7	0.0	......		....	+ 6.6	40.7	0.0	......		5.5	+ 6.0	......	0.0	......
	27	5.4	+ 8.1	40.7	0.0	......		5.3	+ 8.4	42.0	0.0	......		5.3	+ 7.1	40.5	0.0	......
Oct. 22, '09	0	8.6	— 1.3	32.8	6.0	......	Nov. 2, '09	7.7	— 0.5	34.1	7.1	......	Nov. 21, '09	5.75	n	34.4	7.62	......
(See p. 87.)	3	......	....	....	......	......		....	....	....	......	......	(See p. 88.)	....	....	....	......	......
	5	......	— 1.3	33.0	......	......		....	....	....	7.0	......		....	....	....	7.5	......
	6	......	....	....	......	......		....	....	....	......	......		....	....	....	......	......
	7	......	....	....	......	......		....	....	....	......	......		....	....	....	......	......
	8	......	....	....	......	......		....	....	....	......	......		....	....	....	......	......
	10	......	....	....	......	......		....	....	....	7.06	......		....	....	....	7.5	......
	12	8.6	— 1.3	33.0	6.2	......		....	....	....	......	......		....	....	....	......	......
	15	8.25	n	33.5	5.3	......		7.5	n	34.1	6.4	......		....	....	....	7.5	......
	20	5.6	+ 3.4	38.8	0.0	......		7.3	+ 0.4	34.6	5.27	......		....	....	....	7.5	......
	24	......	....	....	0.0	......		5.9	+ 5.0	42.0	Tr.	......		....	....	....	7.5	......
	27	5.4	+ 8.35	43.0	0.0	......		5.5	+ 0.08	43.5	0.0	......		5.75	n	34.4	7.43	......

SILVER LAKE (N. E.)

Aug. 21, '07	0	19.7	+ 0.9	7.3	6.1	......	Aug. 27, '08	18.8	+ 0.25	6.6	6.1	......	Aug. 9, '09	23.3	+ 0.5	7.3	5.8	......
(See p. 78.)	3	......	....	....	......	......	(See p. 202.)	....	....	....	6.2	......	(See p. 202.)	22.8	n	....	5.8	......
	5	19.4	+ 1.0	....	6.1	......		....	....	....	......	......		21.0	— 0.5	7.3	6.5	......
	6	19.2	+ 0.3	7.3	6.1	......		18.8	+ 0.25	....	6.2	......		16.2	— 1.5	7.3	9.1	......
	7	15.6	— 1.5	7.3	10.4	......		18.7	+ 0.25	....	6.2	......		10.1	— 1.4	7.5	10.3	......
	8	10.9	....	....	9.9	......		13.3	— 0.8	....	9.2	......		7.7	— 0.7	7.5	9.8	......
	9	7.9	+ 0.3	7.3	8.8	......		10.3	n	6.6	8.5	......		6.8	+ 0.38	7.5	9.1	......
	10	7.1	+ 1.1	7.3	7.9	......		8.7	+ 3.0	....	7.3	......		6.0	+ 0.5	....	8.6	......
	12	6.6	+ 4.0	7.3	5.0	......		7.0	+ 5.4	6.8	2.8	......		5.0	+ 5.6	....	2.4	......
	14	5.4	+ 8.9	7.3	0.3	......		6.6	+ 8.3	7.1	0.4	......		....	+ 8.6	8.1	0.1	......
	16	5.2	12.4	10.4	0.0	......		6.2	+ 8.9	7.3	0.15	......		4.8	+10.6	9.9	0.0	......

TROUT LAKE (N. E.)

Sept. 7, '06	0	19.5	— 0.7	10.1	5.6	......	Aug. 26, '08	18.4	+ 0.75	8.6	6.2	......	Aug. 9, '09)	23.0	— 0.8	9.9	6.1	......
(See p. 214.)	5	19.4	— 0.5	10.1	5.6	......		....	....	....	6.2	......		22.5	— 0.54	......	6.2	......
	8	19.2	— 0.5	10.1	5.5	......		....	+ 0.75	8.6	5.9	......		16.9	+ 0.30	......	6.6	......
	9	19.1	— 0.5	10.1	5.6	......		....	....	....	......	......		12.2	+ 0.75	......	7.7	......
	10	14.2	+ 1.6	10.1	5.5	......		18.3	+ 0.5	8.8	6.15	......		9.0	+ 1.25	......	8.1	......
	12	10.0	+ 2.0	9.9	4.8	......		13.4	+ 3.0	8.8	4.8	......		7.2	+ 2.0	......	7.1	......
	15	9.0	+ 2.5	10.1	4.1	......		9.2	+ 3.5	....	4.1	......		6.3	....	......	6.8	......
	20	8.6	+ 2.5	10.1	3.2	......		7.7	+ 4.0	8.8	3.7	......		5.8	....	......	5.8	......
	25	8.4	+ 4.3	10.1	2.1	......		7.2	+ 5.6	....	3.1	......		5.6	+ 3.5	......	5.0	......
	29	8.0	+ 5.6	10.1	0.87	......		6.8	+ 6.6	8.8	1.9	......		5.2	+ 5.6	9.9	3.2	......

CATHERINE LAKE (N. E.)

Date	D	T	C	Cb	O	N
Aug. 24, '07.......	0	18.8	+ 0.75	2.3	4.8	....
	8	17.4	+ 0.75	2.3	4.7	....

FISH TRAP LAKE (N. E.)

Aug. 16, '07.......	0	20.3	+ 1.5	8.6	5.4	....
	5	20.0	+ 1.8	8.6	5.0	....
	6	13.3	+ 7.8	8.9	Tr.	....
	9	8.3	+12.6	12.1	Tr.	....

ARBOR VITAE LAKE (N. E.)

Aug. 10, '07......	0	20.7	n	11.1	6.5	....
	4	....	+ 0.75	11.4	6.0	....
	5	19.9	+ 1.5	11.1	5.2	... .
	6	19.8	+ 1.5	11.1	4.9	....
	8	17.5	+ 7.6	13.4	0.25	....

BASS LAKE (N. E.).

Sept. 6, '06.......	0	21.0	+ 0.5	1.5	5.2	....
(See p. 220.).....	7	21.0	+ 1.13	1.5	4.7	....

ALLEQUASH LAKE (N. E.).

Aug. 20, '07.......	0	19.4	+ 1.5	8.85	5.3	....
	3	19.2	....	....	5.3	....
(See p. 201.).....	5	19.2	+ 1.8	8.85	4.0	....
	6	12.4	+ 9.4	10.6	0.6	....
	7	9.7	+18.2	19.2	0.0	....

CLEAR CROOKED LAKE (N. E.).

Aug. 15, '07.......	0	20.7	+ 0.76	2.8	5.6	....
	10	19.6	+ 0.76	2.8	5.6	....

STAR LAKE (N. E.).

Aug. 12, '07.......	0	20.4	+ 0.76	7.1	5.5	....
	5	20.1	+ 1.3	... .	5.6	....
	6	19.4	+ 4.0	... ...	3.6	....
	8	15.6	+ 4.5	7.1	2.2	....

TENDERFOOT LAKE (N. E.).

Aug. 15, '07......	0	20.2	+ 0.76	7.6	5.5	....
	3	19.9	+ 0.76	8.0	5.4	....
	4	18.1	+ 3.5	8.3	3.0	....
	5	15.4	+ 6.1	8.3	0.35	....
	8	8.1	+ 7.8	10.4	0.0	....

NORTH TWIN LAKE (N. E.)

Date.	D	T	C	Cb	O	N
Aug. 19, '07........	0	18.9	+ 0.76	9.4	5.8	....
	5	18.9	....	....	5.8	....
	8	18.7	+ 0.76	9.4	5.7	....
	9	15.7	+ 3.2	9.6	3.4	....
	10	11.7	+ 5.8	10.4	0.4	....
	13	10.4	+ 6.6	11.1	Tr.	....

TOMAHAWK LAKE (N. E.)

Aug. 10, '07........	0	20.4	+ 0.25	7.8	6.0	....
(See p. 217.).....	6	20.0	+ 0.25	7.8	6.2	....
	8	17.9	+ 0.75	8.0	5.85	....
	10	10.4	+ 2.5	8.1	5.5	....
	12	9.3	+ 3.3	8.1	4.9	....
	15	8.8	....	....	3.3	....
	18	8.5	+ 6.6	8.3	2.4	....

CRAWLING STONE (N. E.)

Aug. 6, '07........	0	19.6	+ 0.6	6.1	6.5	....
	5	19.3	+ 0.6	6.2	5.9	....
	8	18.9	+ 1.0	5.9	5.9	....
	10	11.2	+ 2.15	6.2	5.4	....
	15	9.1	+ 3.16	6.2	5.0	....
	20	7.4	....	....	4.4	....
	24	6.9	+ 6.1	6.45	2.3	....

LAKE LAURA (N. E.)

Aug. 13, '07.......	0	20.1	+ 0.76	4.3	5.8	....
	5	19.9	....	....	5.8	....
	7	18.9	+ 0.76	....	6.0	....
	8	14.4	+ 0.76	....	6.8	....
	9	11.4	+ 2.0	....	5.9	....
	10	10.0	+ 3.8	4.3	3.9	....
	12	8.9	+ 8.4	4.6	Tr.	....

FENCE LAKE (N E.)

Aug. 7, '07........	0	18.6	+ 1.0	7.1	5.9	....
	5	18.6	+ 1.0	6.8	5.9	....
	10	14.6	+ 1.4	6.8	6.8	....
	15	9.0	+ 2.3	....	6.0	....
	20	8.5	+ 3.3	....	5.7	....
	24	8.2	+ 3.3	6.8	5.6	....
	27	8.1	+ 3.5	7.1	4.9	....

BIRD LAKE (Minocqua) (N. E,)

Aug. 25, '08........	0	20.4	+ 0.75	0.6	5.8	....
	5	19.5	....	....	5.7	....
	7	19.4	+ 0.75	0.6	5.7	....
	8	18.5	+ 2.3	....	4.5	....
	9	13.3	+ 7.3	0.75	0.5	....
	10	11.7	+ 7.8	0.75	0.4	....
	12	10.4	+15.2	2.8	0.0	....

TIDE, OR LOST CANOE LAKE (N. E.)

Date.	D	T	C	Cb	O	N
Aug. 14, '07	0	20.5	+ 0.5	5.0	5.9	....
	5	20.3	+ 0.5	5.0	6.1	....
	6	13.9	+ 0.5	5.0	8.2	....
	7	10.3	+ 0.5	5.3	7.7	....
	8	8.7	+ 3.5	5.3	5.0	....
	9	8.2	+ 8.4	5.8	Tr.	....
	13	6.9	+14.6	8.9	Tr.	....

LITTLE TROUT LAKE (N. E.)

Date.	D	T	C	Cb	O	N
Aug. 8, '07	0	19.8	+ 0.25	3.7	5.8	....
	5	19.5	....	....	5.8	....
	10	14.5	+ 0.75	3.7	5.4	....
	15	8.1	+ 2.3	3.5	5.3	....
	20	7.4	+ 2.9	....	4.9	....
	25	6.9	+ 3.3	3.5	4.5	....
	28	6.8	+ 3.3	3.5	4.4	....

BIG CARR LAKE (N. E.)

Date.	D	T	C	Cb	O	N
Aug. 10, '09	0	23.4	+ 0.38	0.9	5.9	....
	5	22.0	+ 0.38	....	6.0	....
	7	11.8	....	....	....	....
	8	9.1	+ 0.38	0.9	8.8	....
	9	7.3	+ 1.75	....	7.4	....
	10	6.5	+ 3.0	1.0	5.9	....
	12	5.7	+ 4.8	....	4.3	....
	17	5.5	+ 5.3	1.0	3.1	....

WHITE SAND LAKE (N. E.)

Date.	D	T	C	Cb	O	N
Aug. 14, '07	0	19.9	+ 1.3	7.1	5.8	....
	5	19.4	+ 1.3	7.2	5.8	....
	8	12.9	+ 2.0	7.3	6.6	....
	10	8.8	+ 3.3	....	5.8	....
	12	7.4	+ 4.6	....	4.1	....
	15	6.7	+ 4.9	....	3.1	....
	18	6.4	+ 6.6	7.3	2.0	....
	20	6.3	+ 7.1	8.1	Tr.	....

CLEAR LAKE (N. E.)

Date.	D	T	C	Cb	O	N
Aug. 11, '09	0	22.2	+ 3.8	2.02	6.1	....
(See p. 200.)	6	2.0	+ 3.8	....	6.1	....
	7	17.6	— 0.75	....	8.6	....
	8	11.4	— 0.75	....	10.3	....
	9	8.5	+ 0.63	....	8.7	....
	10	7.5	+ 2.3	2.02	6.9	....
	15	6.5	+ 3.5	2.02	5.4	....
	22	6.2	+ 5.0	2.02	4.1	....

BIG BUTTERNUT LAKE (N. W.)

Date.	D	T	C	Cb	O	N
Aug. 8, '08	0	24.8	—10.1	12.6	10.2	....
(See p. 185.)	1	....	....	....	....	....
	2	23.2	....	....	....	....
	3	....	....	....	....	....
	4	23.0	— 4.0	12.9	5.0	....
	6	20.7	+ 6.3	19.0	0.0	....

BIG BUTTERNUT LAKE (N. W.)

Date.	D	T	C	Cb	O	N
Aug. 3, '09	0	24.7	— 8.1	14.4	6.9	....
	1	24.5	— 8.6	....	6.9	....
(See p. 185.)	2	24.3	— 6.3	....	5.5	....
	3	23.5	— 4.0	14.4	3.8	....
	4	22.5	+ 0.5	14.7	0.85	....
	6	21.5	+ 1.25	14.7	0.11	....

BALSAM LAKE (N. W.)

Aug. 7, '08	0	23.8	— 5.0	14.4	8.2	....
	2	....	....	....	8.1	....
	3	23.2	— 4.6	14.7	7.7	....
	4	20.5	+ 3.7	15.7	1.6	....
	5	18.2	+ 4.8	15.9	0.1	....
	8	11.1	+ 7.8	....	Tr.	....
	13	9.7	+ 9.6	21.0	Tr.	....

BEAVER DAM LAKE (N. W.)

Aug. 14, '08	0	22.3	— 1.0	8.6	5.9	....
	5	22.3	— 0.5	8.6	5.8	....
(See p. 215.)	6	22.2	n	8.6	5.0	....
	7	21.3	+ 3.0	9.1	2.0	....
	8	18.6	+ 4.3	9.1	1.7	....
	10	16.5	+ 5.0	9.6	1.1	....
	12	14.5	+ 5.0	9.9	2.0	....
	15	10.8	+ 5.0	9.9	2.1	....
	20	9.8	+ 6.1	....	1.6	....
	25	8.3	+ 6.6	....	Tr.	....
	28	7.3	+ 7.3	9.9	Tr.	....

BARDON LAKE (N. W.)

Aug. 20, '08	0	20.4	+ 0.5	2.5	6.2	....
	8	20.4	+ 0.5	2.5	6.3	....
(See p. 216.)	10	20.4	+ 1.0	....	5.8	....
	11	18.8	+ 3.8	2.8	3.25	....
	15	11.4	+ 5.1	....	2.25	....
	20	9.0	+ 6.6	2.8	0.8	....
	25	8.3	+ 7.5	....	Tr.	....
	30	8.0	+ 8.3	3.0	0.0	....

ATKINS (Grandview) (N. W.)

Aug. 22, '08	0	18.9	+ 0.5	1.0	5.9	....
	5	18.9	+ 0.5	1.0	5.7	....
	6	17.5	+ 3.0	1.0	3.6	....
	7	12.8	+ 4.6	1.25	2.1	....
	8	10.2	+ 5.8	1.25	1.7	....
	10	8.3	+ 6.8	1 25	0.7	....
	15	7.7	+ 7.8	1.5	Tr.	....
	18	7.6	+ 8.0	1.7	Tr.	....

ISLAND LAKE (N. W.)

Date	D	T	C	Cb	O	N
Sept, 2, 07.........	0	20.9	— 1.3	14.2	6.3	....
	3	....	— 0.7	14.4	6.1	....
	5	20.1	+ 1.9	....	4.3	....
	7	18.9	+ 3.8	14.7	2.3	....
	8	16.3	+ 5.4	16.1	Tr.	....
	10	11.6	+ 9.1	16.2	Tr.	....
	14	10.8	+ 9.1	18.1	0.0	....

LOWER BASS LAKE (N. W.)

Aug. 21, '08........	0	21.0	+ 1.0	1.0	6.0	....
	5	20.5	....	....	5.9	....
	8	13.4	+ 3.0	....	5.0	....
	10	9.7	+ 5.8	....	2.4	....
	15	6.3	+ 7.5	1.0	1.0	....
	20	6.3	....	....	Tr.	....
	24	6.3	+ 9.6	1.25	Tr.	....

NICHOLS LAKE (N. W.)

Aug. 5, '08........	0	25.5	— 2.5	12.9	4.2	....
(See p. 217.).....	3	25.4	— 2.0	....	4.6	....
	4	22.4	+ 3.3	12.9	Tr.	....
	5	21.2	+ 3.7	12.9	Tr.	....
	8	16.8	+ 4.0	12.9	Tr.	....
	10	11.2	+ 5.8	13.5	Tr.	....
	15	....	+ 6.3	14.4	Tr.	....
	20	8.0	+ 6.3	15.9	0.0	....

HAMMILLS LAKE (N. W.)

Aug. 17, '08........	0	21.3	— 0.76	1.26	6.7	....
(See p. 199.).....	5	21.2	— 0.76	1.21	6.8	....
	6	20.0	+ 0.75	1.5	6.2	....
	7	14.5	+ 5.3	2.0	1.9	....
	8	12.3	+ 7.5	2.25	0.2	....
	10	9.5	+ 7.5	2.25	0.1	....
	12	8.3	+ 9.4	2.5	0.0	....
	15	7.9	+ 9.6	3.4	0.0	....

OWEN LAKE (N. W.)

Aug. 20, '08........	0	20.2	—0 .5	11.6	5.8	....
(See p. 215.).....	7	20.2	— 0.5	....	5.9	....
	9	20.2	— 0.5	11.6	5.9	....
	10	19.4	n	11.9	5.7	....
	11	16.4	+ 1.8	12.1	5.1	....
	12	13.0	+ 2.5	12.1	4.2	....
	15	10.0	+ 6.6	12.1	0.9	....
	18	....	+ 7.3	12.1	Tr.	....
	20	9.2	+ 8.1	12.1	Tr.	....
	23	....	+ 9.9	12.9	Tr.	....
	27	8.8	+10.4	13.9	Tr.	....

MINNEUSING LAKE (N. W.).

Aug. 22, '08.......	0	18.8	+ 1.0	8.6	6.0	....
	5	18.5	+ 1.0	9.1	5.3	....
	7	16.8	+ 2.5	10.6	0.9	....

PINE LAKE (New Auburn) (N. W.)

Date.	D	T	C	Cb	O	N
Aug. 31, '07........	0	20.4	+ 0.4	1.26	5.8	....
	8	18.8	+ 1.0	1.26	5.6	....
(See p. 216.).....	10	10.9	+ 2.5	....	5.4	....
	12	9.9	+ 3.2	....	4.9	....
	15	8.9	+ 4.0	1.5	4.2	....
	20	6.9	+ 4.8	1.5	3.2	....
	25	6.7	....	....	2.7	....
	30	6.5	+ 5.7	1.6	2.2	....

WHITEFISH LAKE (N. W.)

Aug. 11, '08........	0	23.0	— 0.5	7.6	5.9	....
	5	22.6	— 0.5	....	5.8	....
	8	16.8	+ 1.8	....	4.4	....
	10	13.5	+ 3.5	....	3.3	....
	15	9.6	+ 5.0	....	2.8	....
	18	9.1	+ 5.0	7.6	2.8	....
	21	8.5	+ 5.3	7.8	2.6	....

HOLEM LAKE, Ind.

Sept. 23, '07........	0	20.65	+ 1.2	35.3	4.7	....
	5	20.6	+ 2.0	35.6	4.7	....
(See p. 220.)....	6	18.6	+ 6.0	40.6	Tr.	....
	7	14.4	+10.0	41.0	0.0	....
	8	11.7	+18.7	58.8	0.0	....

LAKE MAXINKUCKEE, Ind.

Aug. 20, '07........	0	22.3	— 3.8	24.5	6.3	....
	5	22.2	— 3.6	24.5	6.1	....
(See p. 221.).....	7	21.6	— 3.0	24.5	5.5	....
	8	19.7	— 1.1	24.8	4.0	....
	9	....	n	25.8	2.7	....
	10	19.0	+ 0.4	25.8	2.2	....
	11	....	+ 1.4	25.9	1.3	....
	12	18.0	+ 2.5	26.8	0.4	....
	15	15.1	+ 3.2	31.3	0.0	....
	20	14.4	+ 3.9	31.4	0.0	....
	25	13.9	+ 5.3	31.6	0.0	....

TIPPECANOE LAKE, Ind.

Sept. 17, '09.......	0	21.6	— 2.3	34.4	6.0	....
	5	20.7	— 1.5	34.4	5.1	....
(See p. 222.).....	6	19.8	n	....	3.9	....
	7	18.8	+ 1.25	....	3.9	....
	8	16.2	+ 5.0	35.9	0.20	....
	10	11.0	+ 6.3	35.9	0.11	....
	12	9.6	+ 6.6	36.2	0.53	....
	15	8.6	....	....	1.4	....
	20	7.8	+ 6.6	36.2	2.3	....
	25	....	....	....	0.95	....
	30	....	+ 7.1	36.2	Tr.	....
	35	7.2	+ 7.5	36.9	Tr.	....

II. MINERAL ANALYSES.

Results stated in parts per million.

Lake.	Date.	Depth in meters.	SiO_2	$Fe_2O_3+Al_2O_3$	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl
Bass (Minocqua)	September, 1907	0	5.0	5.0	0.6	1.2	0.3	0.6	0.0	4.9	1.4	2.5
Beasley	August 25, 1906	0	9.0	0.5	34.3	22.9	....	....	7.0	93	5.5	5.0
		14	26.0	1.1	47.0	23.4	....	....	0.0	111	3.4	3.4
	September 9, 1907	0	13.3	1.7	46.6	27.8	2.4	2.0	2.0	104	10.3	2.8
		8	21.6	0.8	43.5	27.8	2.2	2.1	0.0	118	9.4	2.5
		14	33.0	4.0	47.1	28.0	2.6	1.9	....	121	11.8	2.0
	August 3, 1908	0	14.4	0.5	33.9	21.5	....	....	....	....	....	....
		5	9.5	0.7	33.3	17.9	....	....	....	....	....	....
		5.5	7.8	0.7	30.0	18.3	....	....	....	....	....	....
		6	8.0	1.2	33.2	17.9	....	....	....	....	....	....
		7	14.3	1.2	38.3	17.6	....	....	....	....	....	....
		9.5	20.3	1.7	39.2	18.6	....	....	0.0	111	....	....
		14	21.0	4.6	40.6	19.8	....	....	0.0	119	....	....
Clear	September, 1907	0	1.1	0.7	0.7	0.3	....	....	0.0	11	5.3	4.5
Devils	November, 1908	0	2.2	0.7	3.2	1.1	....	....	0.0	8.4	8.1	8.2
Elkhart	September 12, 1907	0	6.9	0.8	16.2	19.5	3.8	2.4	8.0	107	10.7	6.0
		10	8.5	1.1	19.1	24.8	3.9	1.9	4.0	121	12.7	5.0
		21	9.4	1.8	24.1	26.8	4.3	2.2	0.0	129	10.6	5.2
		33	19.8	2.6	24.9	26.0	4.5	2.4	0.0	136	12.4	6.5
Garvin	September 5, 1907	0	6.1	1.5	16.9	9.0	3.6	0.8	11.0	88	12.8	6.0
		6	7.6	1.8	23.0	23.0	....	....	0.0	117	11.4	5.0
		9	16.9	9.1	28.4	25.1	2.0	1.4	....	153	11.5	5.6
Geneva	September 26, 1907	0	7.8	0.7	18.3	25.8	4.6	2.5	11.0	94	12.5	5.0
		15	....	0.7	20.0	27.0	4.4	2.5	0.0	111	13.0	5.0
		30	....	1.1	21.8	27.3	4.1	2.2	0.0	113	....	5.0
		41	11.1	2.0	22.8	27.5	4.2	2.8	0.0	114	14.1	3.5
Green	September 14, 1907	0	8.4	1.6	16.4	25.9	3.0	3.1	8.0	87	16.0	6.0
		15	8.4	2.0	23.8	26.0	3.5	2.8	0.0	109	15.8	5.5
		40	10.3	2.1	24.0	....	3.4	2.9	0.0	110	16.3	6.2
		65	10.4	2.2	21.7	25.3	3.6	3.1	0.0	112	18.6	5.5
Kawaguesaga	August 26, 1907	0	14.2	1.6	6.9	2.2	2.6	1.7	0.0	29	7.9	2.7
		15	18.9	10.8	7.6	3.4	....	....	0.0	45	....	....
Knights	August 27, 1909	3	14.6	1.7	39.1	24.1	....	....	....	....	3.7	2 3
		4	14.3	1.1	32.5	22.7	....	....	....	....	4.0	2.5
		4.5	13.6	0.7	29.3	22.7	....	....	....	....	4.1	2.3
		5	18.6	1.4	38.8	23.8	....	....	....	....	3.4	1.9
Long (Waupaca)	September 9, 1907	0	14.9	1.0	30.4	17.1	2.9	3.3	2.0	111	8.6	2.5
		22	21.5	3.9	33.3	18.3	3.0	3.0	0.0	120	12.2	2.5
Mendota	September 14, 1906	0	1.3	0.4	22.4	24.2	....	....	....	....	....	....
		13	3.7	1.2	27.1	26.6	....	....	....	....	....	....
		22	4.7	2.0	29.1	25.8	....	....	....	....	....	....
	January 15, 1907	0	0.8	1.4	27.4	21.3	....	....	....	....	....	....
	May 3, 1907	0	1.2	0.8	28.5	25.5	....	....	5.0	89	12.2	3.0

	September 18, 1907	0	9.2	1.6	17.4	21.8	2.7	2.6	10.0	74	15.2	3.0
		14	8:5	1.6	17.6	20.0	....	....	0.0	108	15.4	....
		17	9.0	1.8	17.6	20.2	....	....	0.0	116	15.7	3.0
		22	21.2	2.8	22.2	21.5	4.6	1.8	0.0	132	15.1	3.0
	March 7, 1908	17	6.5	1.2	22.6	23.7	....	....	0.0	112	17.8	3.0
	April 10, 1910	0	3.5	1.4	28.8	21.1	....	....	....	....	....	....
	July 4, 1910	0	4.0	1.5	19.0	22.2	....	....	....	....	3.6	....
North—East part	September 4, 1907	0	13.6	1.2	34.1	24.2	....	....	8.0	126	16.0	10.0
		22	14.3	2.6	41.6	24.8	....	....	0.0	139	18.7	5.0
North—West part	Aug. 10, 1906	0	2.5	0.5	31.3	30.0	....	....	8.0	99	12.5	3.0
		6.5	2.6	....	46.2	32.0	....	....	....	....	....	....
		8	9.1	0.8	49.1	27.5	....	....	0.0	131	14.4	2.5
		15	9.7	1.1	49.2	26.4	....	....	....	127	12.1	4.0
		22	11.5	....	49.3	27.4	....	....	....	128	10.2	2.5
	May 10, 1907	0	3.0	0.6	47.3	28.0	....	....	12.0	114	13.4	4.0
	September 4, 1907	0	11.4	0.7	32.9	25.1	2.4	1.2	11.0	115	18.4	9.0
		22	20.7	2.7	43.7	25.9	2.0	1.2	0.0	151	13.9	4.5
	September 1, 1909	0	10.2	1.8	34.9	28.3	3.4	1.7	....	....	13.4	5.7
		22	22.0	2.2	49.6	32.7	6.2	3.0	....	....	9.2	2.7
Okauchee	September 5, 1907	27	17.6	1.5	34.3	25.9	3.2	1.4	0.0	66	13.9	4.0
Owen	August 20, 1908	0	8.8	0.8	12.0	4.0	....	....	1.0	33	0.0	1.5
		11	8.9	....	15.6	3.3	....	....	0.0	34	0.0	2.0
		26	12.0	4.5	14.5	3.6	....	....	0.0	34	0.0	2.3
Pike	Aug. 25, 1908	0	10.9	1.2	14.9	3.9	....	....	0.0	34	0.0	0.5
		8	8.5	1.1	15.1	3.9	....	....	0.0	34	0.0	0.5
		10	12.5	2.5	14.8	4.4	....	....	0.0	34	0.0	0.5
		14	15.0	11.2	16.3	4.2	....	....	0.0	38	0.0	0.5
Rainbow	September 10, 1907	0	12.0	1.4	15.6	14.6	2.2	3.3	8.0	90	8.6	4.5
		27	26.9	3.0	28.8	17.4	2.5	3.4	0.0	120	9.1	4.0
Trout (South Part)	August, 19, 1907	0	13.0	1.1	6.7	2.5	0.8	0.3	0.0	28	6.4	3.0
Two Sister	August 27, 1907	19	22.9	8.5	4.5	2.2	4.5	4.5	0.0	23	8.2	5.6

The following table shows the results of an analysis of mud obtained from lake Mendota. They are stated in percentages of the dry weight.

Loss of H_2O at 105°	Loss on ignition.	SiO_2	$Fe_2O_3+Al_2O_3$	CaO	MgO	Na_2O	K_2O	SO_3	Total.
1.29	41.99	15.85	2.51	33.21	2.16	0.95	0.34	1.37	99.67

The crust from *Potamogeton* leaves gave the following results, stated in percentages of dry weight: Fe_2O_3 and Al_2O_3 0.46; CaO 47.0; MgO 0.94.

Analyses of *Chara* gave the following results, stated in percentages of dry weight: SiO_2 0.93; $Fe_2O_3+Al_2O_3$ 0.67; CaO 39.28; MgO 2.75; ash 51.73.

EXPLANATION OF FIGURES SHOWING DISSOLVED GASES.

The curves in the accompanying figures showing the results of the gas determinations are designated as follows: C = carbon dioxid, that portion of the curve to the left of the zero line indicates negative carbon dioxid or alkalinity and that to the right is free carbon dioxid; Cb = fixed or carbonate carbon dioxid; O = oxygen; N = nitrogen; and T = temperature. The vertical spaces represent the depth in meters; the horizontal spaces show the cubic centimeters at 0° and 760 mm. per liter of water in the curves representing the gases and the degrees centigrade in the temperature curve. In designating the fixed carbon dioxid in the hard water lakes, the numeration in the horizontal scale has been interrupted in order to avoid making the diagrams too large. In such cases the figures for fixed carbon dioxid have been placed on a line slightly higher than that to the left in order to show the interruption. These raised figures pertain only to the fixed carbon dioxid. In the curves, the depths at which observations were made are indicated by small circles. The lines making up the curves have been drawn directly from one point of observation to the next without any attempt to round off the curves. With the first diagram for each lake there are given the following facts regarding the lake: The district in which it is located (northeastern, northwestern, or southeastern); the length in km. = L; the direction of the long axis (N—S, etc.); the greatest breadth, measured about at right angles to L, = B; the maximum depth is given approximately by the diagram.

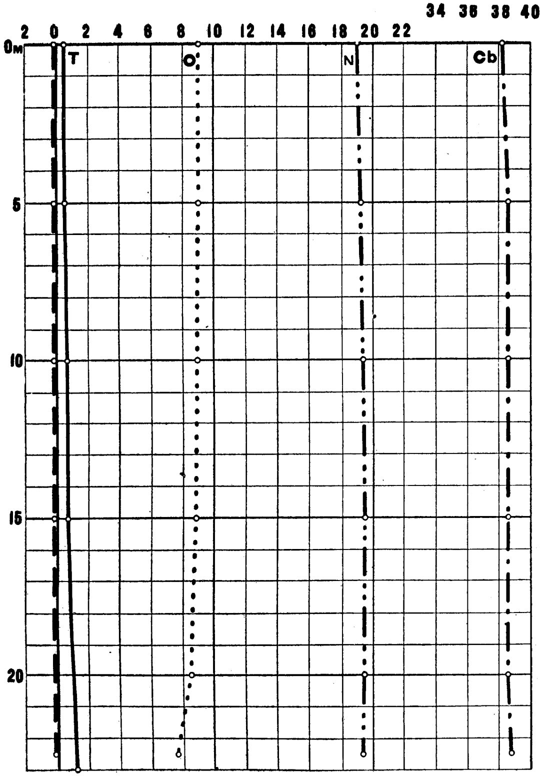

Fig. 8.—Lake Mendota, southeastern Wisconsin. (L. 9.5 km., E-W; B. 7.4 km.). January 26, 1906. An early winter stage. See p. 29.

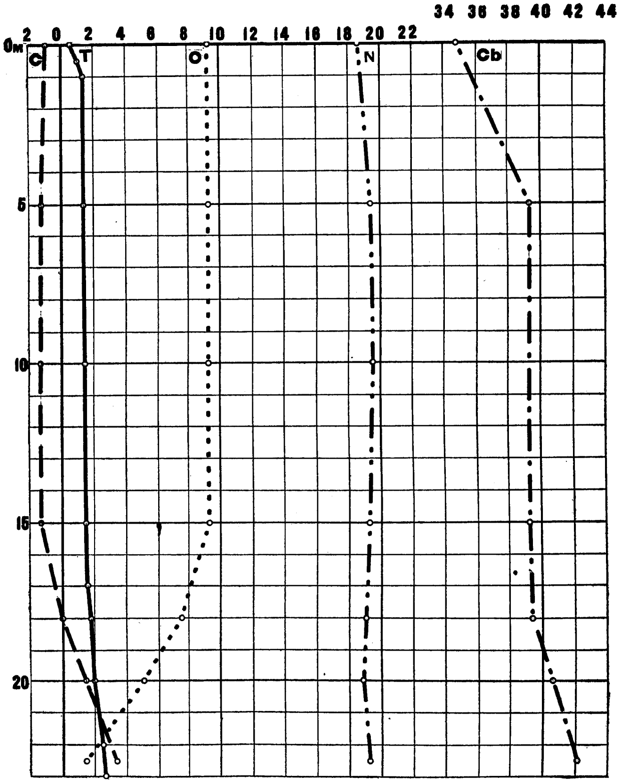

Fig. 9.—Lake Mendota, February 25, 1906. Compare with fig. 8. Note decrease in fixed carbon dioxid in upper water, and in lower water, increase of free and fixed carbon dioxid and decrease of oxygen.

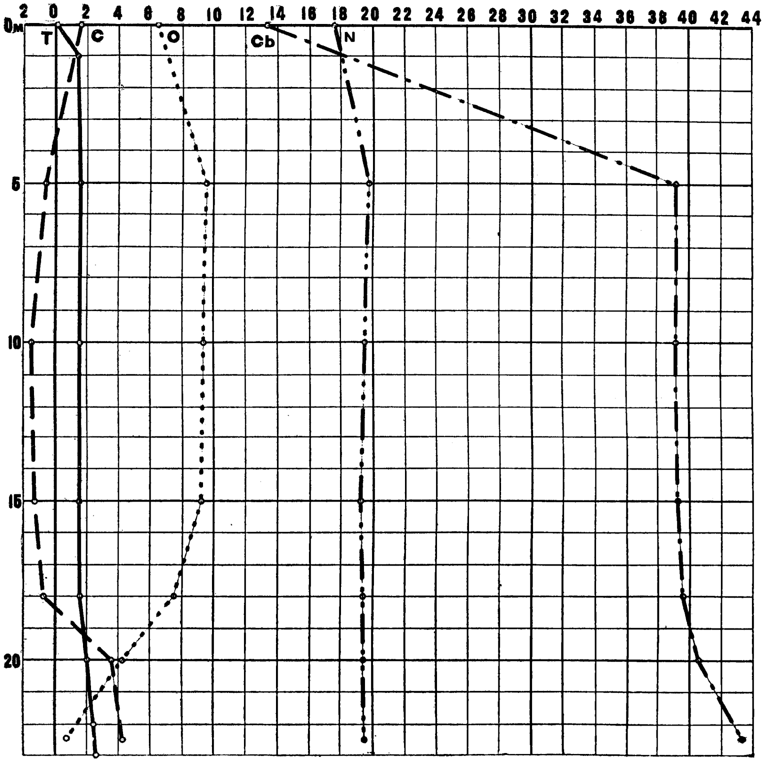

Fig. 10.—Lake Mendota, March 8, 1906. Note the decrease in fixed carbon dioxid and oxygen at the surface and the change in reaction of the water from alkaline to acid.

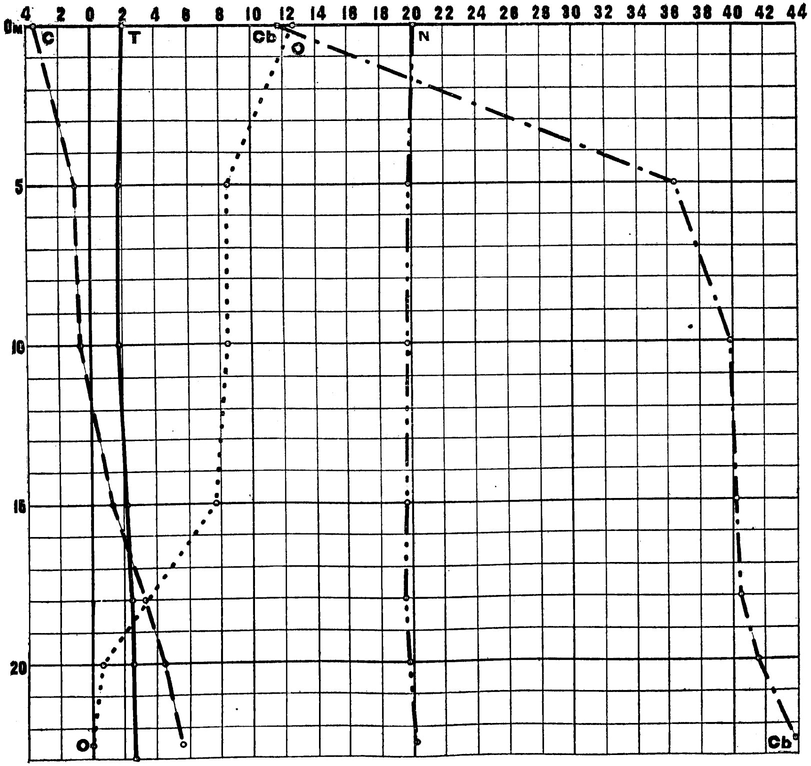

Fig. 11.—Lake Mendota, March 29, 1906. The surface water was supersaturated with oxygen and was distinctly alkaline as a result of the action of algae. Compare with figs. 9 and 10. See p. 29. No observations were made between 0 m. and 5 m. See fig. 29 for a more accurate diagram.

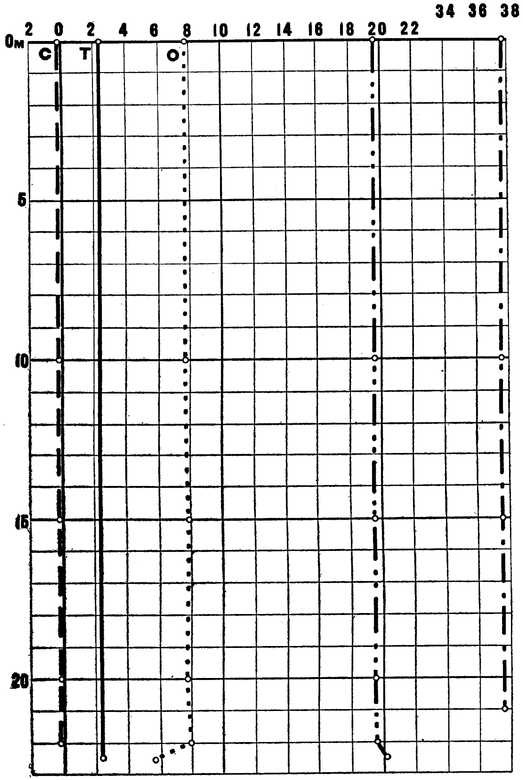

Fig. 12.—Lake Mendota, April 8, 1906. Note that the vernal overturn was almost but not quite complete. Ice disappeared from lake on April 7. The lines indicating nitrogen and fixed carbon dioxid are not lettered. See p. 33.

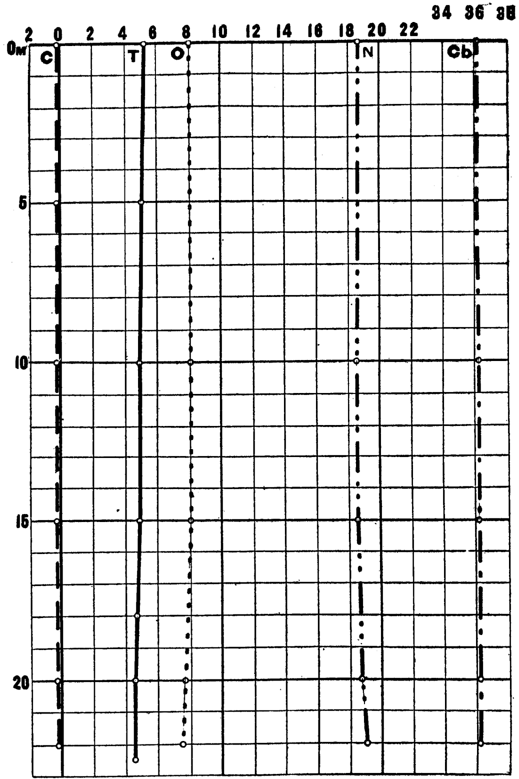

Fig. 13.—Lake Mendota, April 20, 1906. Note the uniform conditions produced by complete vernal circulation.

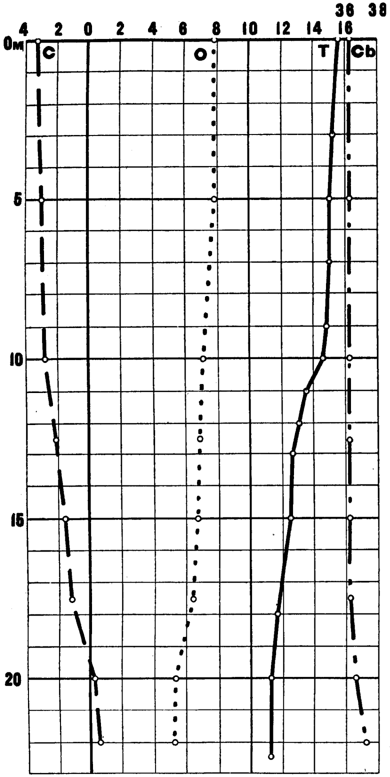

Fig. 14.—Lake Mendota, May 22, 1906. An early stage in the development of summer conditions. See p. 36.

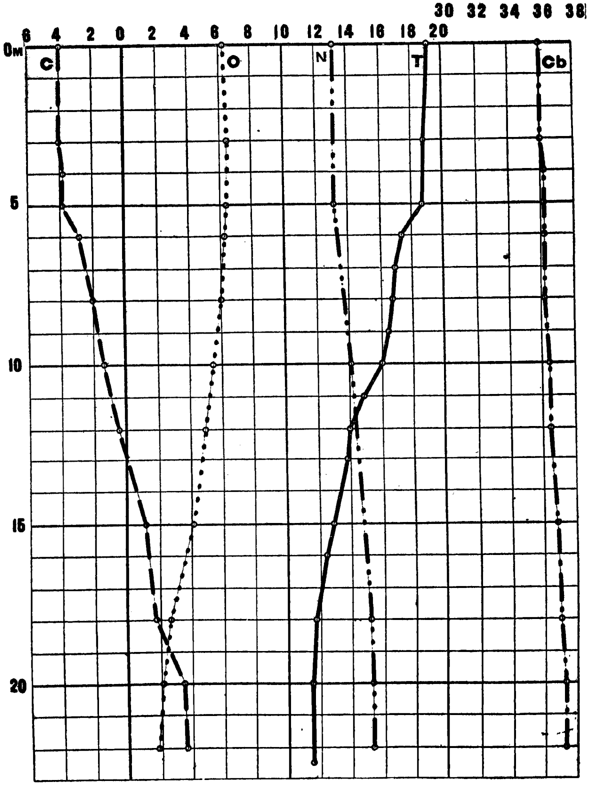

Fig. 15.—Lake Mendota, June 11, 1906. Compare with fig. 25. Note the increase in temperature and decrease of oxygen in the upper water and the decrease of oxygen and increase of free carbon dioxid in the lower water. The restriction of the circulation is indicated by the temperature and free carbon dioxid curves.

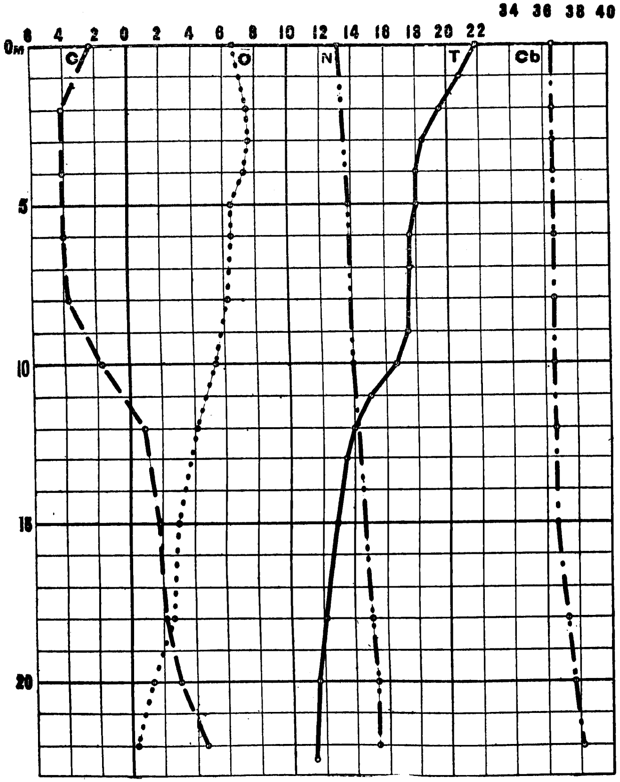

Fig. 16.—Lake Mendota, June 18, 1906. Compare with figs. 15 and 17. Observe the gradual development of summer conditions.

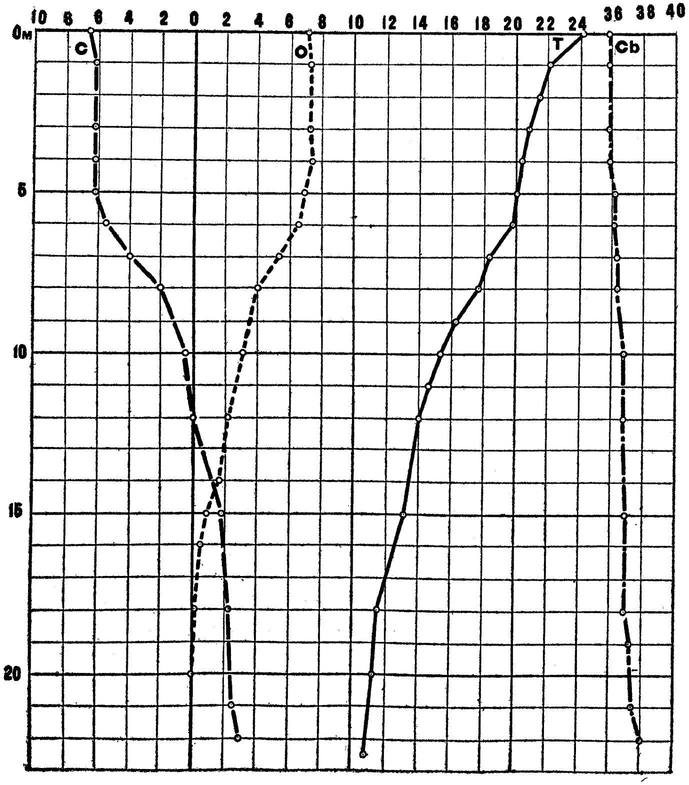

Fig. 17.—Lake Mendota, July 10, 1906. See fig. 16. The alkalinity increased in the upper water and the oxygen decreased in the lower.

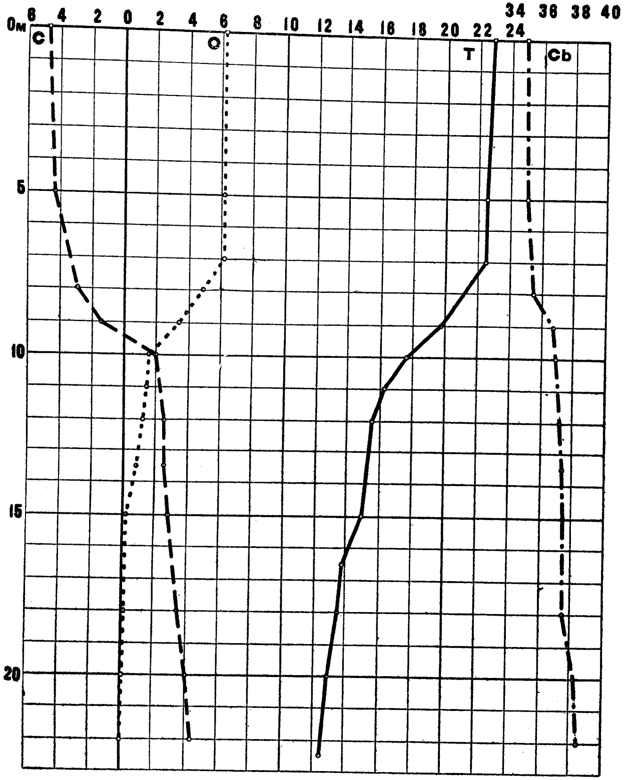

Fig. 18.—Lake Mendota, July 20, 1906. See fig. 17. The thermocline has become distinct and there is a marked decrease of oxygen in this region as well as an increase in free carbon dioxid. Note the decrease of the fixed carbon dioxid in the epiliumion.

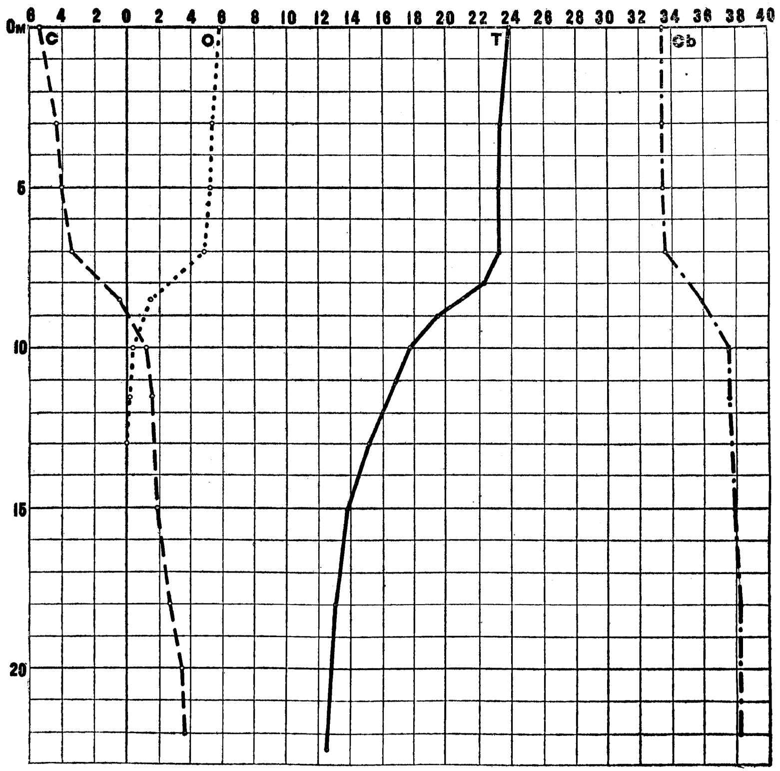

Fig. 19.—Lake Mendota, August 1, 1906. Note the very small amount of dissolved oxygen below the thermocline. Compare the free and fixed carbon dioxid curves with those in fig. 18.

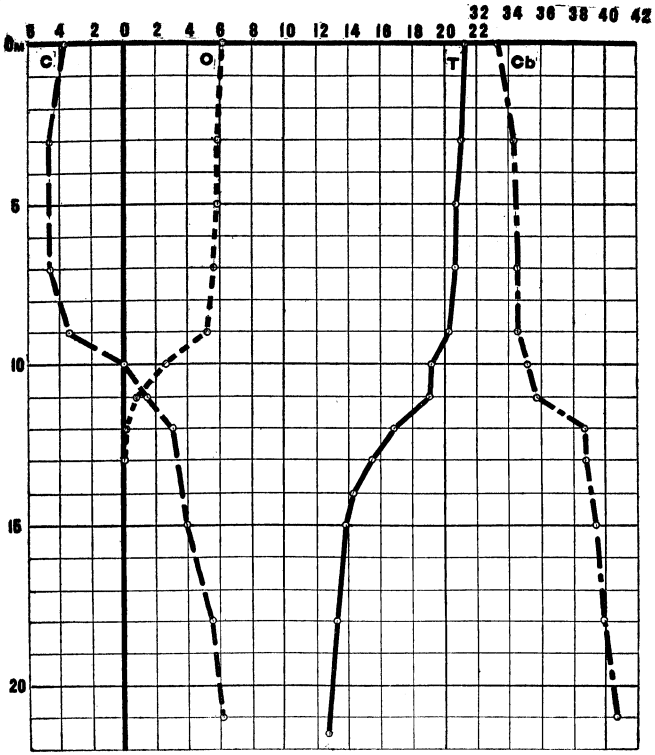

Fig. 20.—Lake Mendota, Sept. 14, 1906. Note the downward progress of the thermocline and the accompanying changes in gas conditions. Compare with figs. 18 and 19.

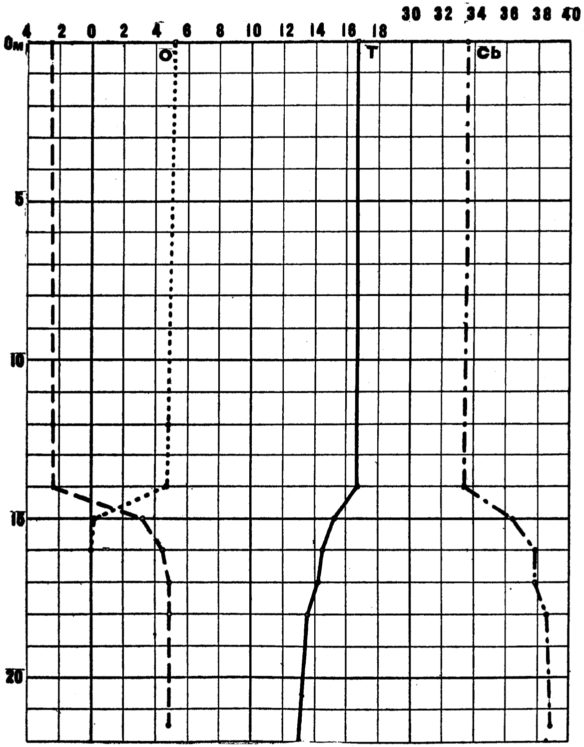

Fig. 21.—Lake Mendota, October 8, 1906. This diagram shows conditions just before the autumnal overturn. See figs. 20 and 22.

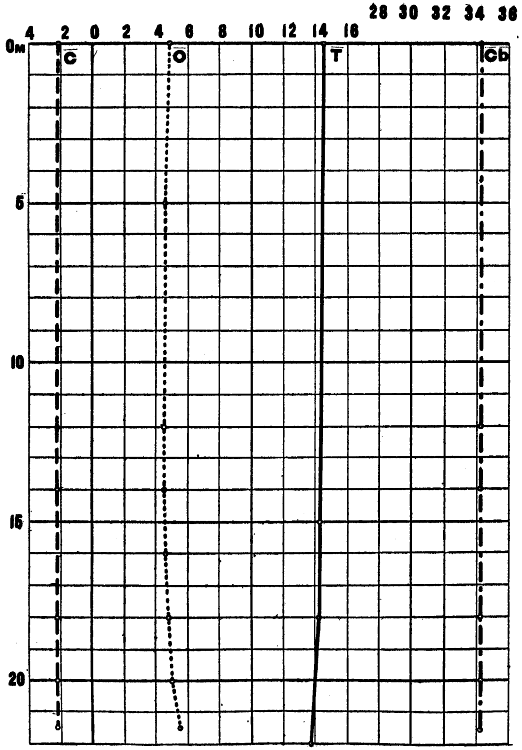

Fig. 22.—Lake Mendota, October 11, 1906. Conditions just after the autumnal overturn. Note the small amount of oxygen. See fig. 21 and text p. 39.

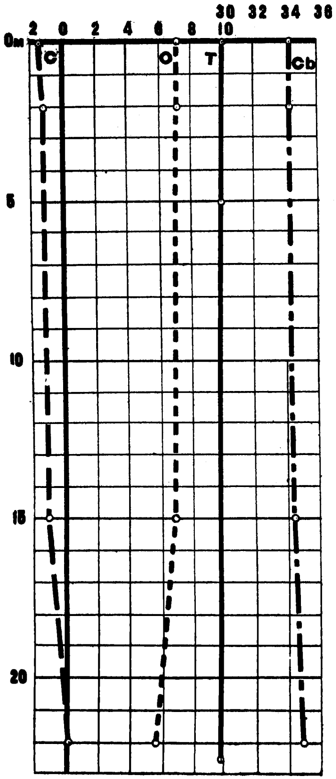

Fig. 23.—Lake Mendota, November 8, 1906. Conditions during autumnal circulation. Compare with fig. 22 and note increase in dissolved oxygen.

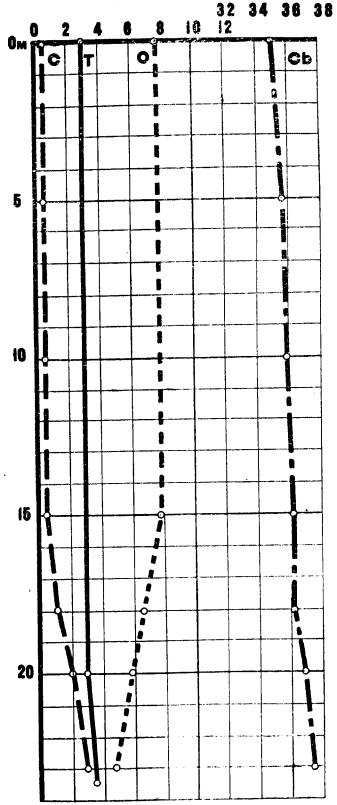

Fig. 24.—Lake Mendota, March 25, 1907. Compare with fig. 12. Note that the vernal overturn had not yet been completed.

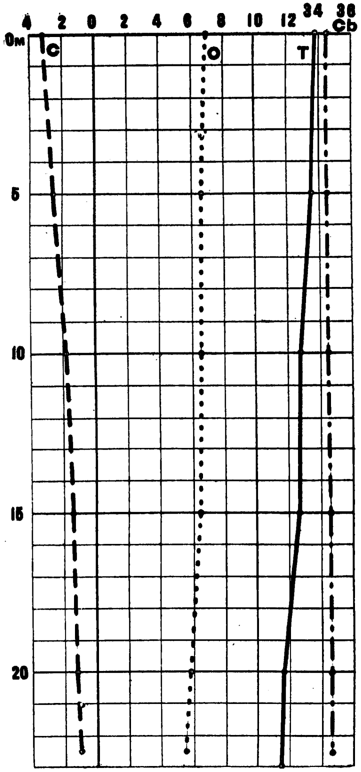

Fig. 25.—Lake Mendota, June 11, 1907. Compare with fig. 15 and note that summer conditions were much less developed than in 1906.

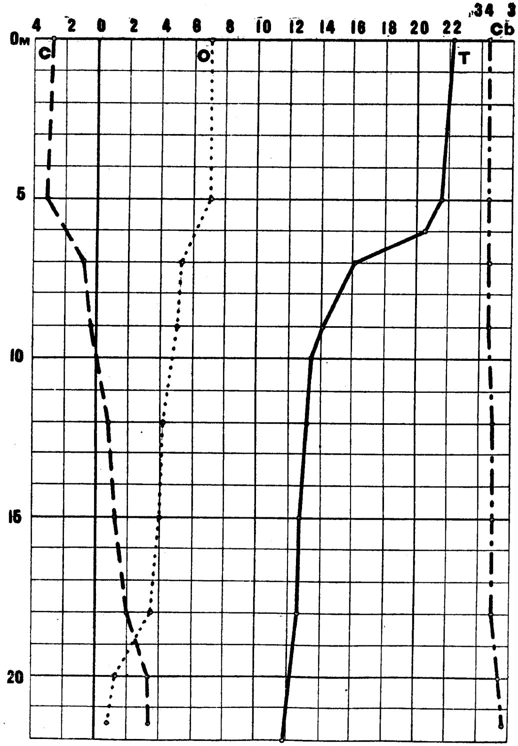

Fig. 26.—Lake Mendota, July 2, 1907. Compare with fig. 17 and note the more sharply defined thermocline in 1907 and the larger quantity of oxygen in the lower water. The alkalinity of the upper water was greater in 1906 and the fixed carbon dioxid was greater at all depths.

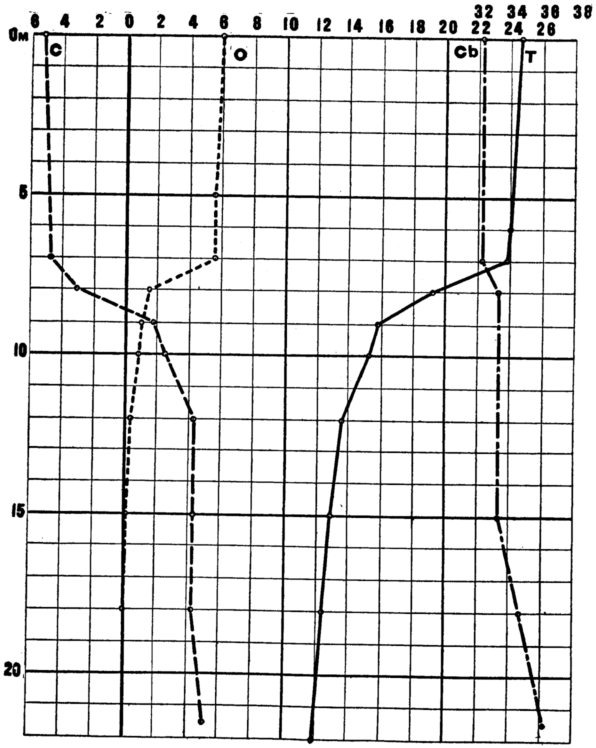

Fig. 27.—Lake Mendota, July 30, 1907. Compare with fig. 26. Note the marked decrease in oxygen and increase in free carbon dioxid in the lower water. Also, see figs. 18 and 19. See p. 42.

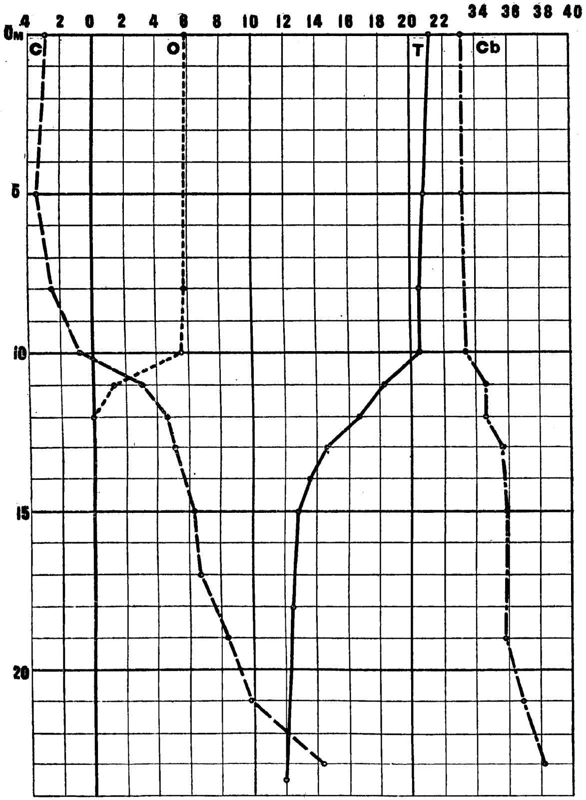

Fig. 28.—Lake Mendota, September 6, 1907. Compare with fig. 20 and note how closely the two diagrams resemble each other. The alkalinity in the upper water was higher in 1906 and there was a larger amount of free carbon dioxid in the bottom water in 1907.

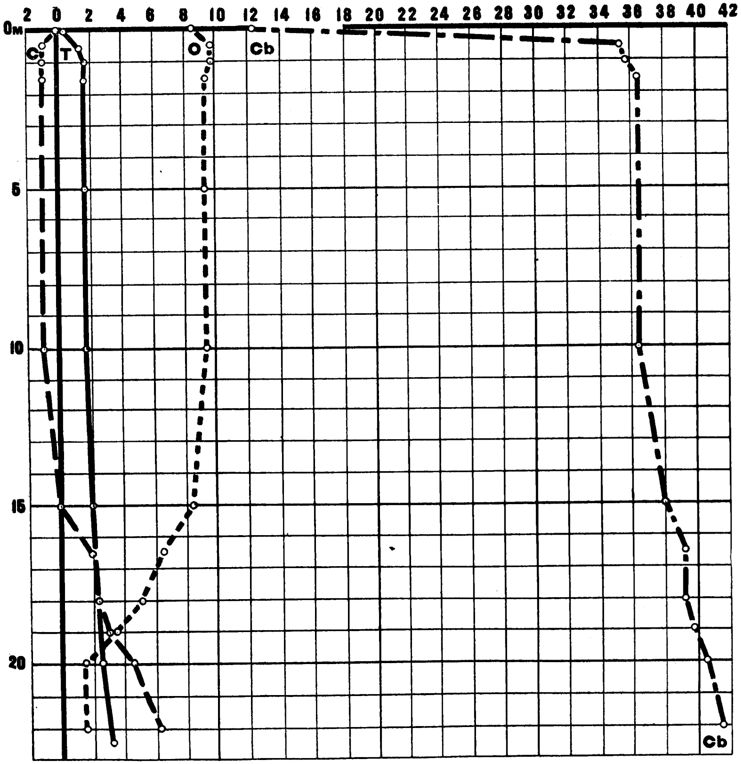

Fig. 29.—Lake Mendota, January 26, 1909. Compare with fig. 8 and note the very marked contrast in the conditions. See p. 29 and figs. 10 and 11-

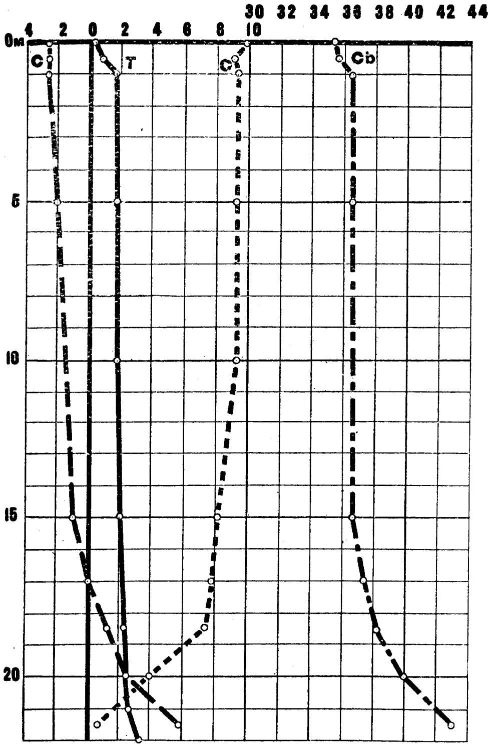

Fig. 30.—Lake Mendota, February 6, 1909. Note how closely this resembles fig. 9. Also compare with fig. 29 and note the marked difference in the quantity of fixed carbon dioxid at the surface.

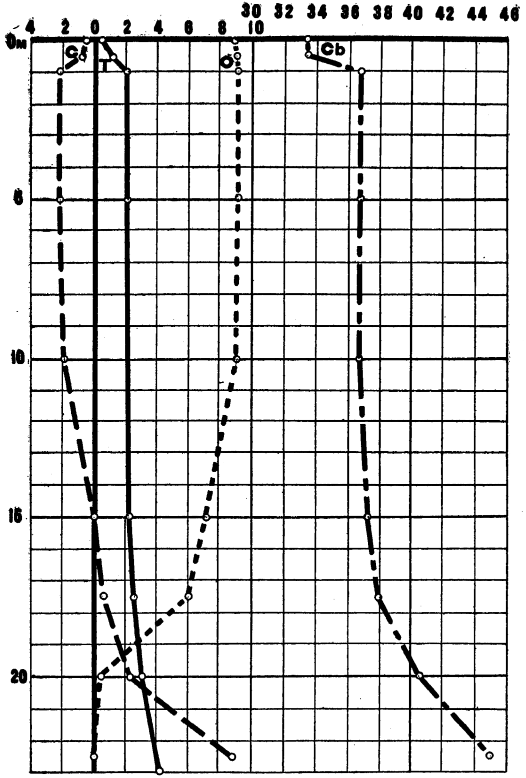

Fig. 31.—Lake Mendota, March 6, 1909. Compare with fig. 30 and note the decrease of oxygen and increase of free carbon dioxid in the bottom of the water. Also, see fig. 10 and note the smaller quantity of oxygen and fixed carbon in the surface water in 1906. The surface water was alkaline in 1907 but distinctly acid in 1906.

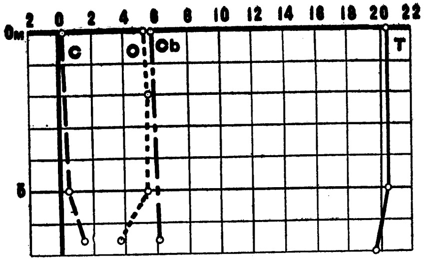

Fig. 32.—White Eagle lake, northeastern Wisconsin. (L. 1.9 km., E-W.; B. 1.8 km.). August 18, 1907. Observe the comparatively slight decrease of dissolved oxygen in the bottom water of a shallow lake. The water was acid from surface to bottom and contained a comparatively small amount of fixed carbon dioxid.

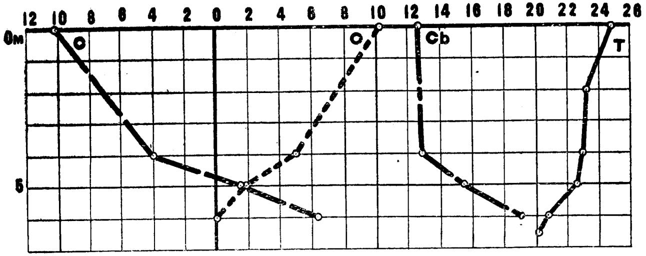

Fig. 33.—Big Butternut lake, northwestern Wisconsin. (L. 2.0 km., E-W.; B. 1.0 km.). August 8, 1908. Note the high alkalinity correlated with excess oxygen (176.5 per cent. of saturation) at the surface. Doubtless the oxygen and free carbon dioxid curves should come down straight or nearly so for a meter or two, as in fig. 34, but no observations were made at these depths. There was a marked decrease of oxygen and an increase of free and fixed carbon dioxid in the lower water. See p. 46.

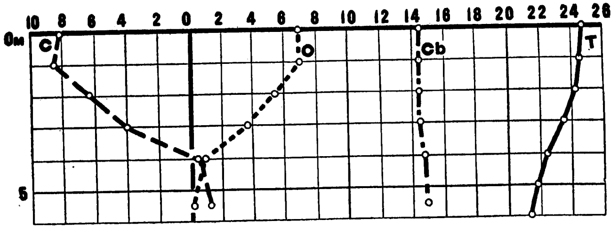

Fig. 34.—Big Butternut lake, August 3, 1909. See fig. 33 and note that a high alkalinity is here correlated with only a small amount of excess oxygen (21 per cent.).

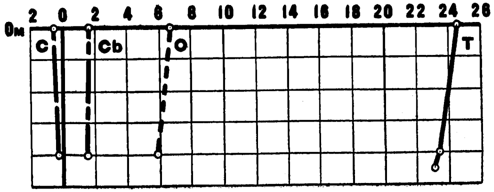

Fig. 35.—Wild Goose lake, northwestern Wisconsin. (L. 1.5 km., NW-SE; B. 1.0 km.). August 7, 1908. Note that the water was alkaline, a rather unusual condition where so little fixed carbon dioxid is present.

Diagrams on this page illustrate conditions in lakes which are too shallow for a permanent thermocline, but which are also too deep for a constant circulation. See also figs. 69–71 and 110.

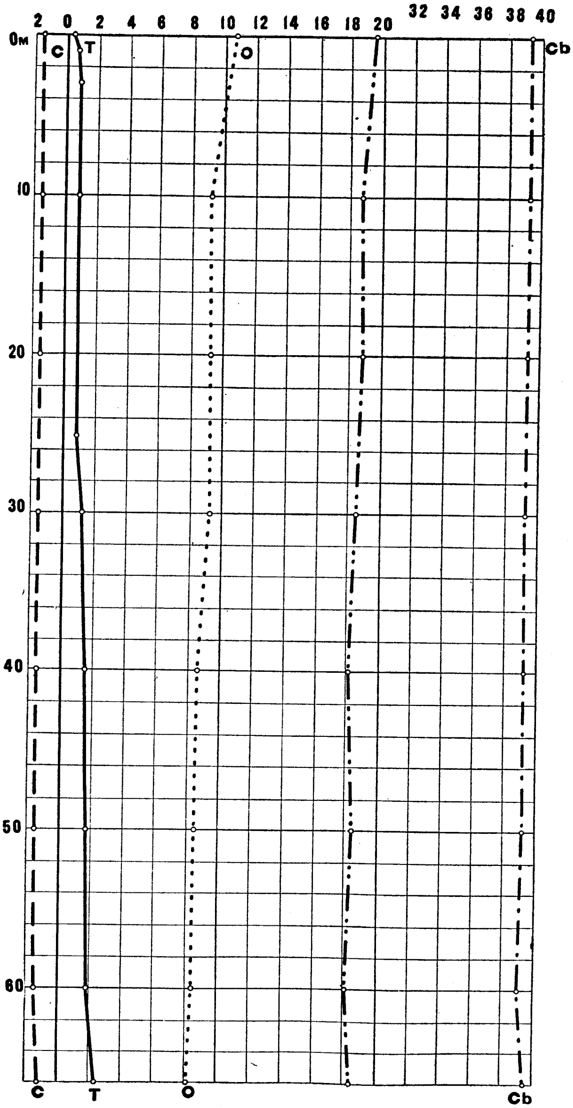

Fig. 36.—Green lake, southeastern Wisconsin. (L. 12.2 km., NE-SW; B. 3.2 km.). February 15, 1906. Note the low temperature of the water throughout this deep lake and the uniform oxygen, nitrogen, and carbon dioxid conditions. The nitrogen curve is not lettered. See p. 78.

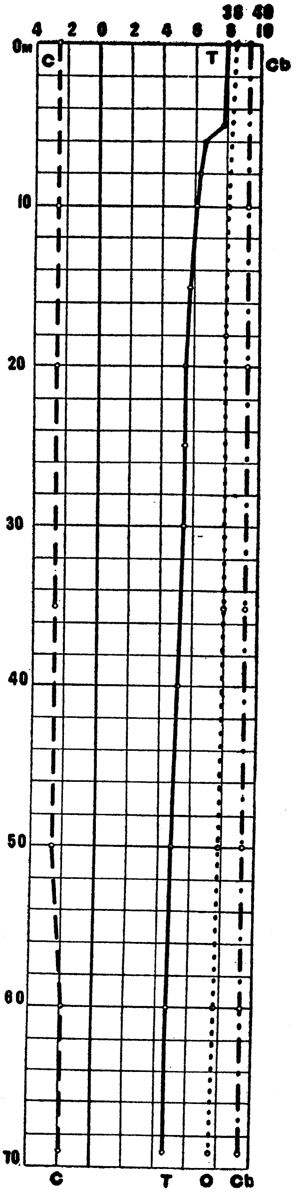

Fig. 37.—Green lake, May 15, 1906. Shows uniform conditions in late spring. The thermocline at 5 m. is only temporary and has no effect on gas conditions.

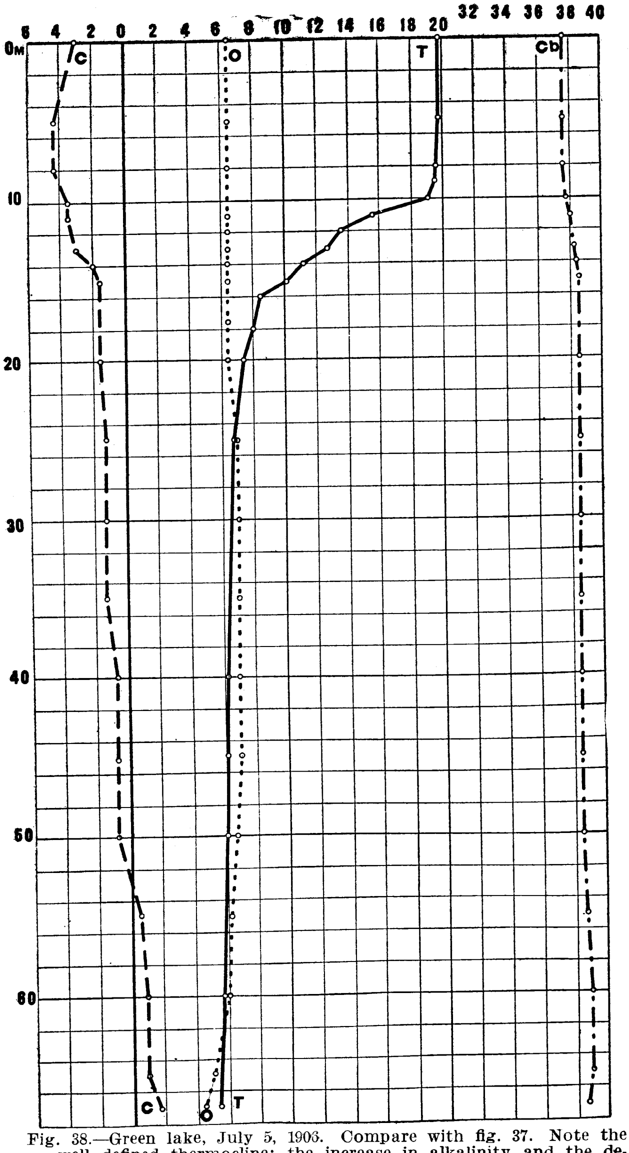

Fig. 38.—Green lake, July 5, 1906. Compare with fig. 37. Note the well defined thermocline; the increase in alkalinity and the decrease in fixed carbon dioxid in the upper water; in the bottom water, the decrease of dissolved oxygen and the change from an alkaline condition to an acid.

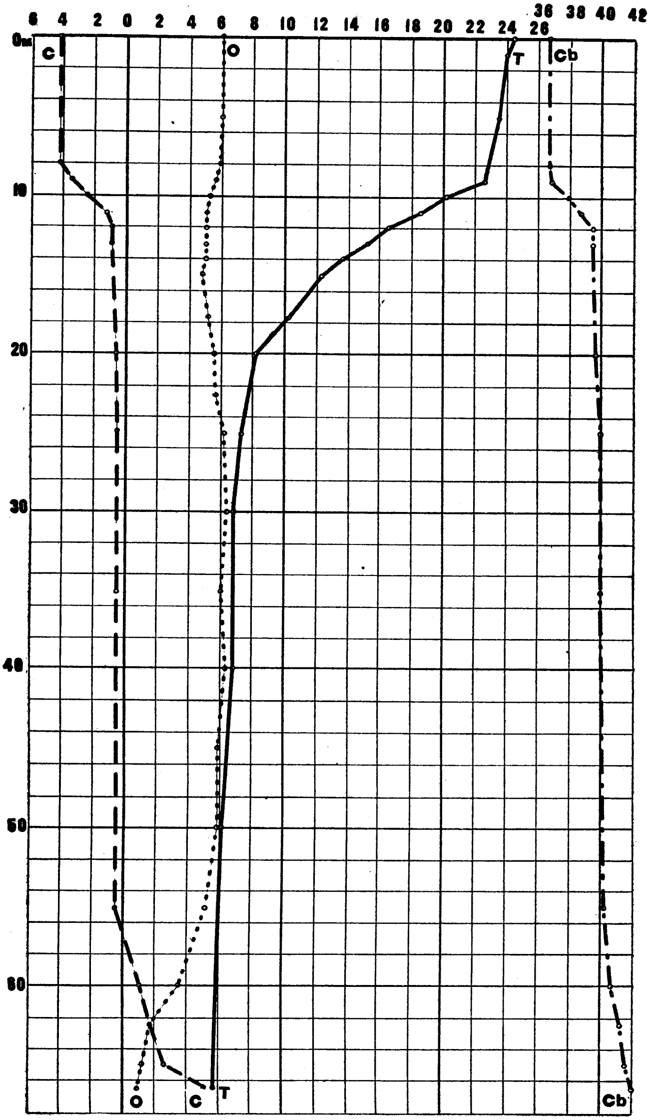

Fig. 39.—Green lake, August 14, 1906. Typical summer conditions for this lake. See fig. 38 and observe the rise in the quantity of fixed carbon dioxid in the thermocline due to a decrease above the thermocline and an increase below, and, at the bottom, the decrease of oxygen and the increase of free carbon dioxid. Also note the form of the oxygen curve in the lower water.

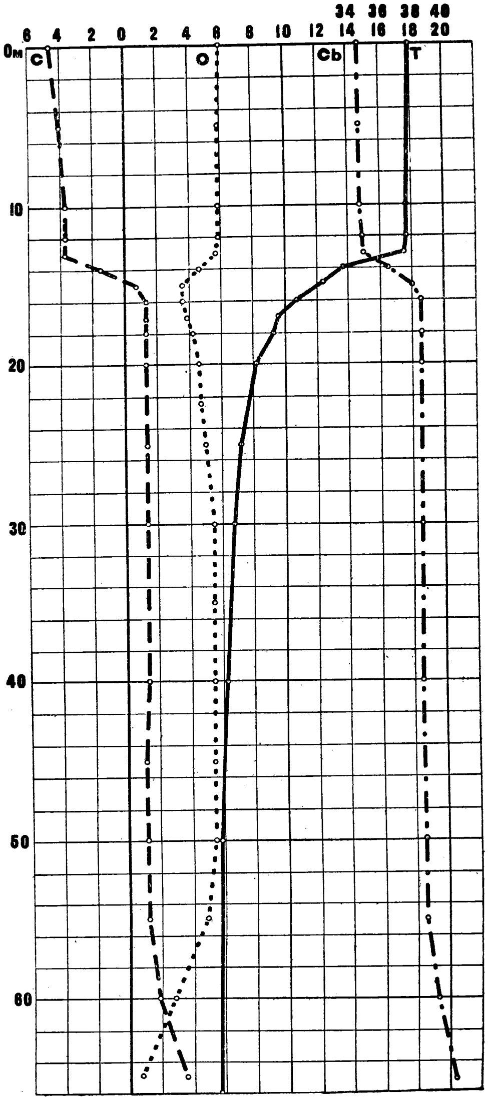

Fig. 40.—Green lake, October 4, 1906. Compare with fig. 39 and note the downward progress of the thermocline and the distinct notch in the oxygen curve in the mid-thermocline region. For similar notches in oxygen curves see figs. 77, 84. 88, 100, and 115. See text p. 50.

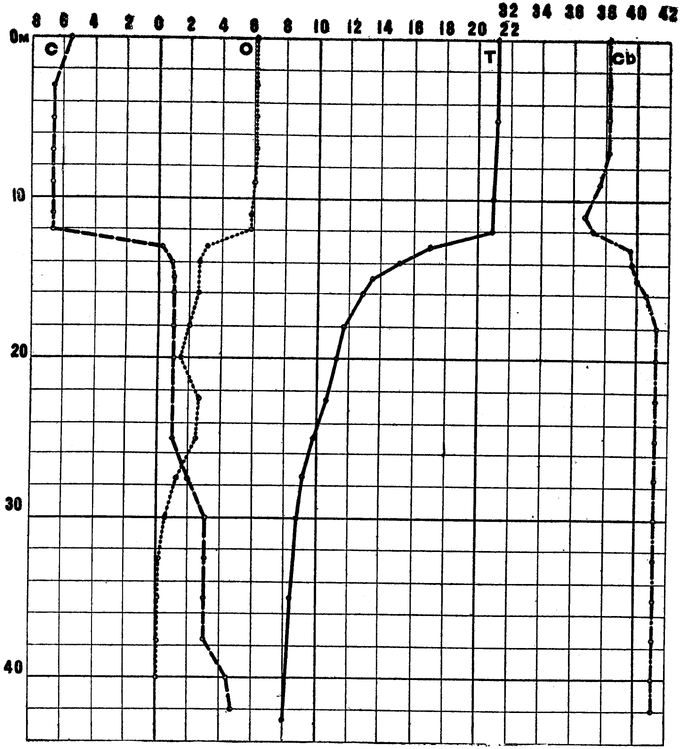

Fig. 41.—Lake Geneva, southeastern Wisconsin (L. 12.3 km., E-W.; B. 2.6 km.) September 25, 1906. Observe the notch in the fixed carbon dioxid curve in the region of the thermocline and the rise in the quantity of dissolved oxygen in the mid-stratum of the lower water. See p. 81.

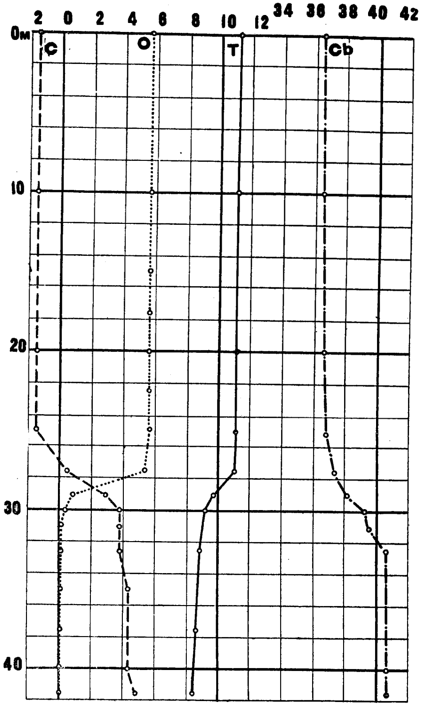

Fig. 42.—Lake Geneva, November 1, 1906. See fig. 41 and note that the thermocline was about 15 m. deeper than on September 25. There was a marked decrease in the alkalinity of the upper water.

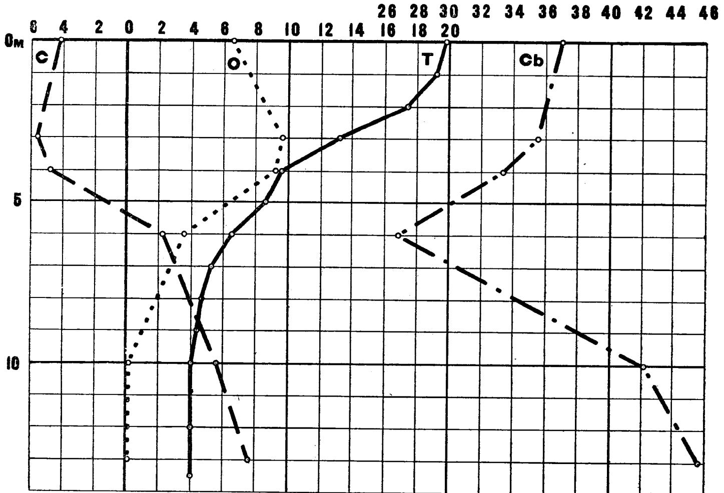

Fig. 43.—Beasley lake, southeastern Wisconsin. (L. 0.4 km., N-S; B. 0.16 km.) May 18, 1906. Note the correlation between the high oxygen and high alkalinity; also a pronounced notch in the fixed carbon dioxid curve.

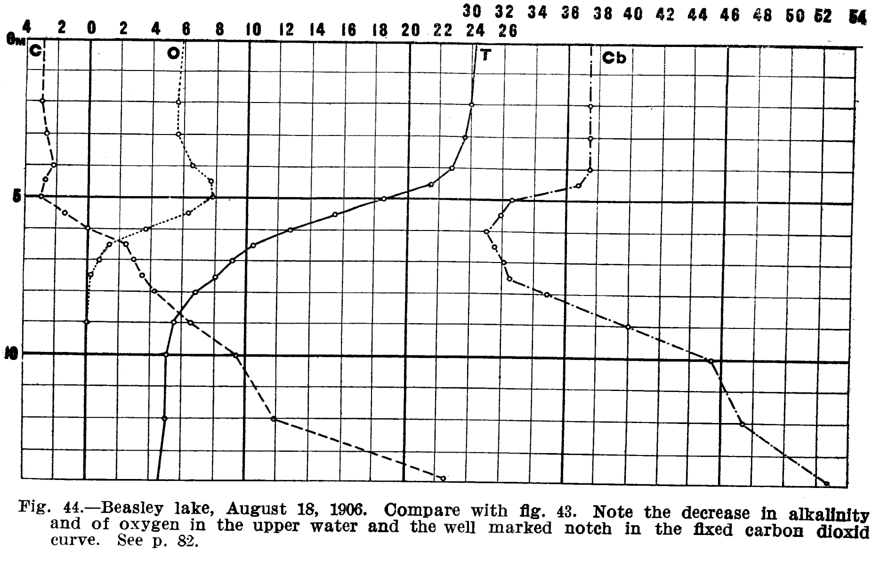

Fig. 44.—Beasley lake, August 18, 1906. Compare with fig. 43. Note the decrease in alkalinity and of oxygen in the upper water and the well marked notch in the fixed carbon dioxid curve. See p. 82.

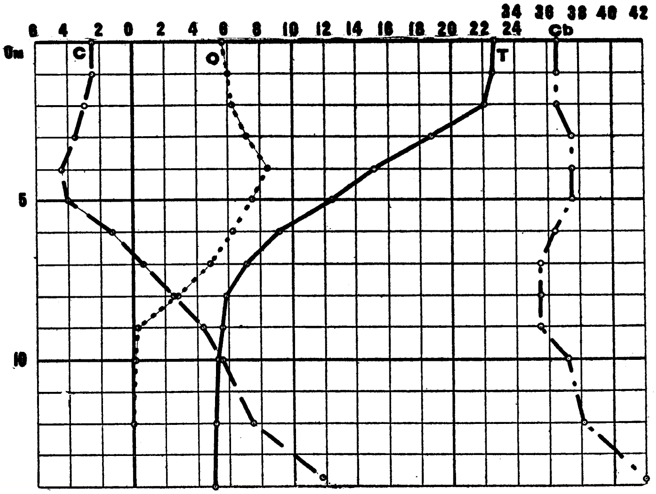

Fig. 45.—Beasley lake, June 23, 1907. Compare with fig. 44. Note the difference in the fixed carbon dioxid.

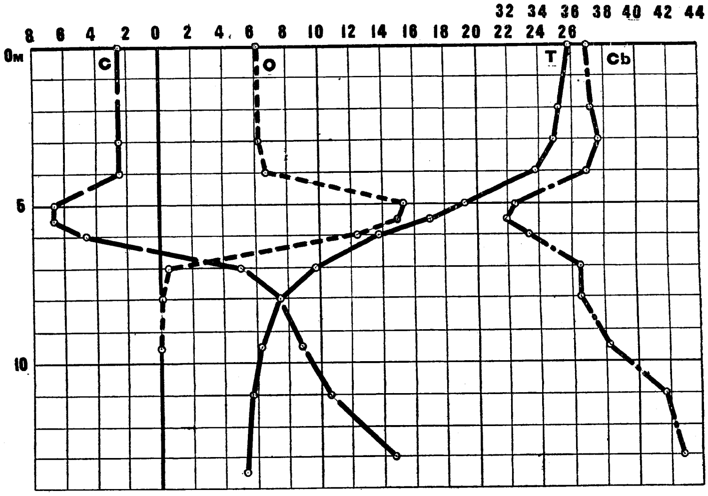

Fig. 46.—Beasley lake, August 3, 1908. Note the correlation in depth between high alkalinity, high oxygen, and the notch in the fixed carbon dioxid curve. Compare with figs. 43 and 44. See p. 82.

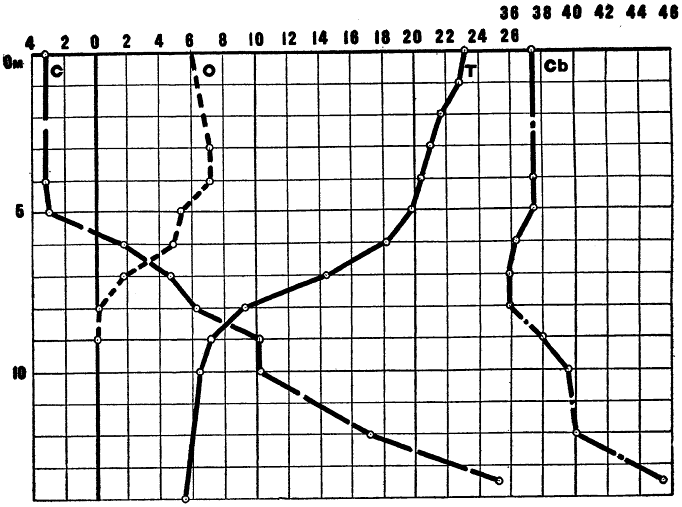

Fig. 47.—Beasley lake, August 31, 1908. Shows only a trace of excess oxygen and the notch in the fixed carbon dioxid curve. Note the large quantity of free carbon dioxid at the bottom. See fig. 46 and note the change in the gas curves resulting largely from a downward movement of the thermocline.

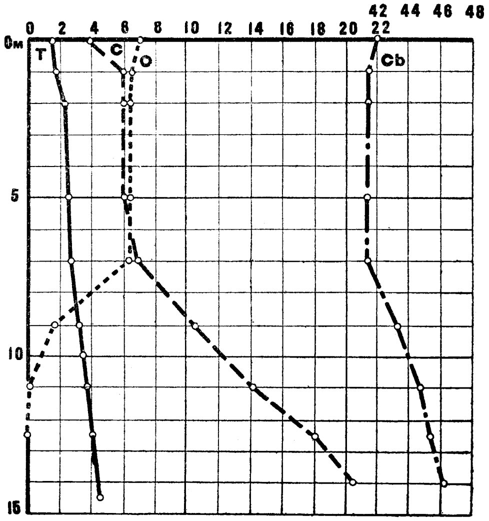

Fig. 48.—Beasley lake, March 19, 1909. Shows late winter conditions. There was no oxygen in the bottom water and the water was acid at all depths, the quantity of free carbon dioxid being fairly large at the bottom. See p. 55.

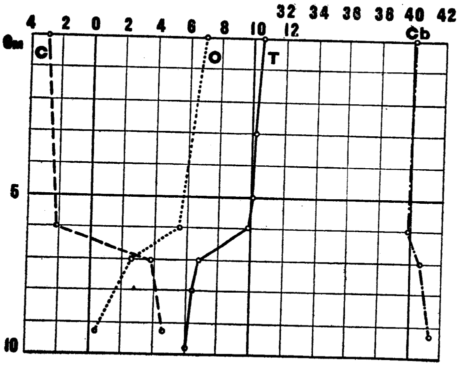

Fig. 49.—Garvin lake, southeastern Wisconsin. (L. 0.5 km., N-S; B. 0.3 km.) May 9, 1906. Shows a well defined stage of summer conditions at this early date. See p. 48.

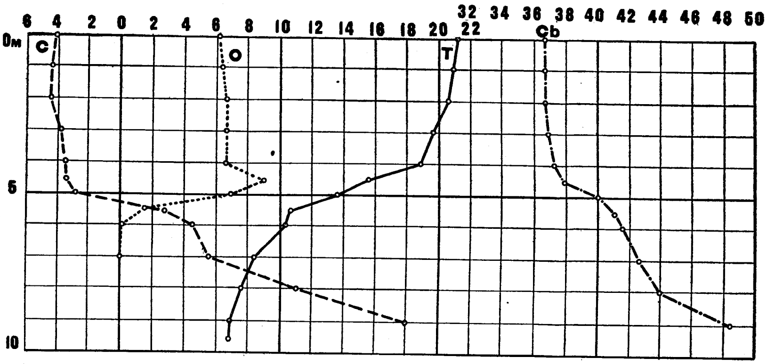

Fig. 50.—Garvin lake, June 26, 1906. Compare with fig. 49. Note the increase in alkalinity in the upper water; in the lower, the decrease of oxygen and the increase of free and fixed carbon dioxid.

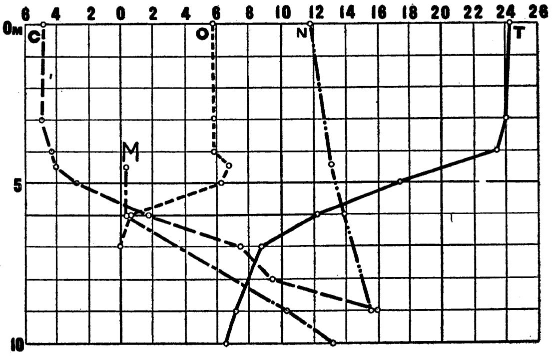

Fig. 51.—Garvin lake, July 27, 1906. Note that a rather large amount of methane (curve marked "M") was found in the lower water.

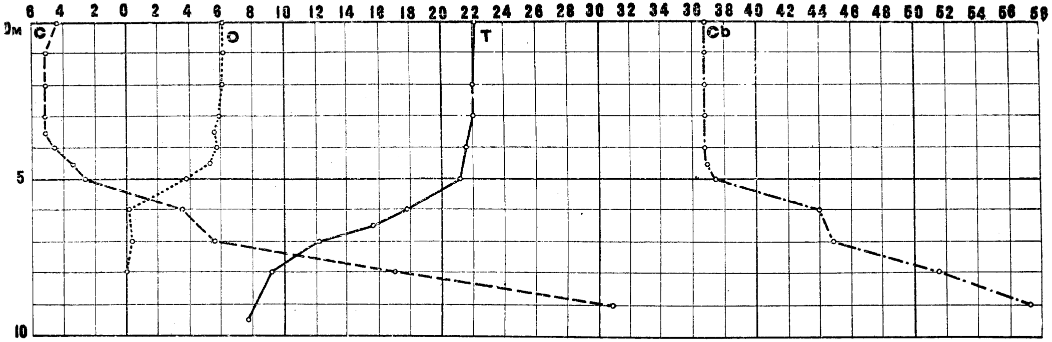

Fig. 52.—Garvin lake, September 22, 1906. Note the large amount of free and fixed carbon dioxid in the bottom water. Compare with figs. 51 and 53.

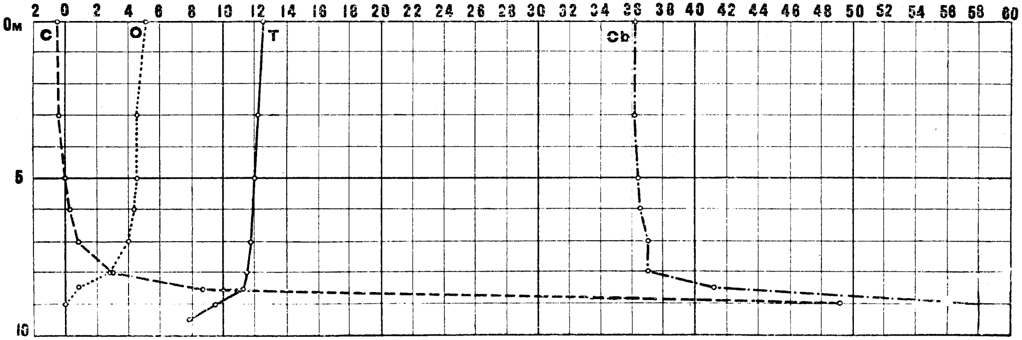

Fig. 53.—Garvin lake, October 14, 1906. Shows conditions just before the autumnal overturn. See fig. 52 and text p. 80.

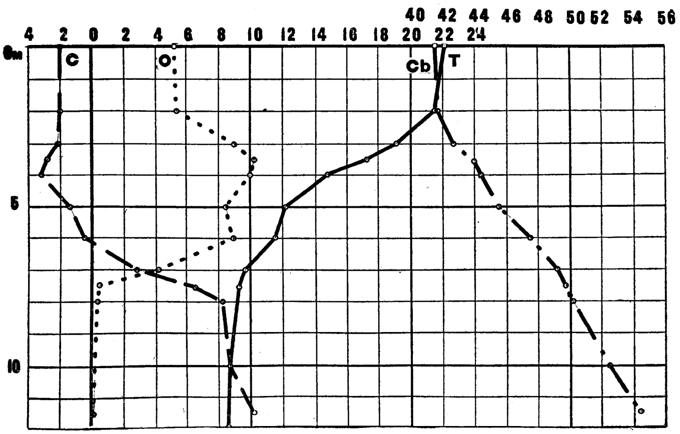

Fig. 54.—Knights lake, southeastern Wisconsin. (L. 0.5 km., E-W.; B. 0.2 km.) August 24, 1906. Note the correlation in depth between the excess oxygen and the increased alkalinity. The lake receives a large amount of ground water which greatly influences the temperature of the lower water.

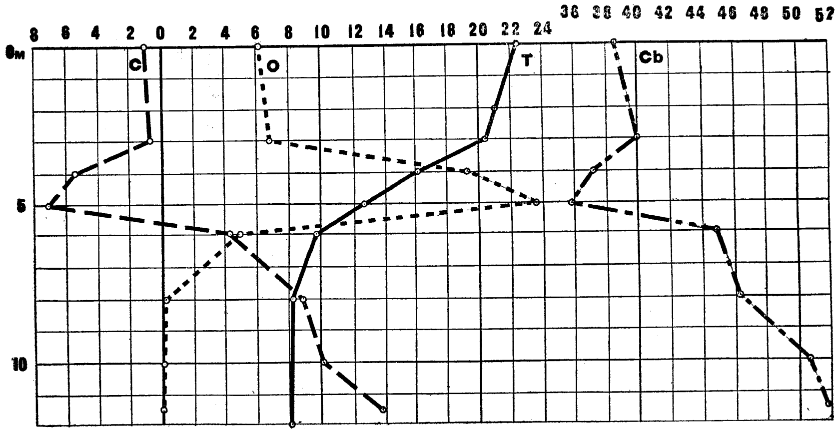

Fig. 55.—Knights lake, August 14, 1909. Note the correlation in depth between excess oxygen, high alkalinity and decrease in fixed carbon dioxid. Compare with fig 46. See p. 81.

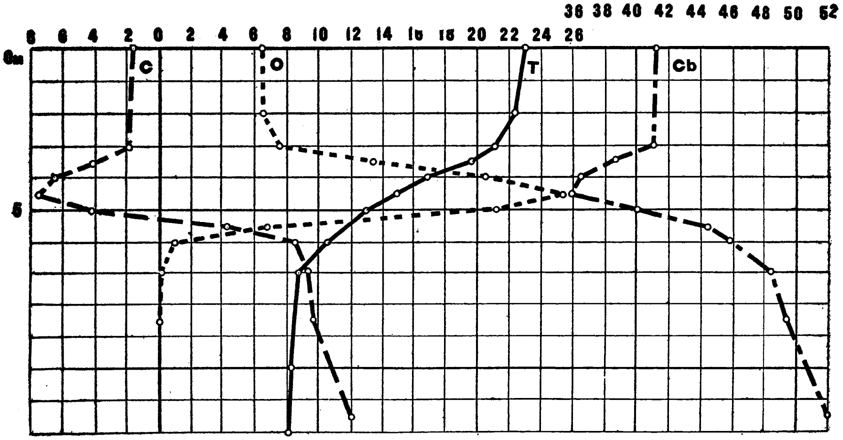

Fig. 56.—Knights lake, August 25, 1909. Compare with figs. 46 and 55. Note the correlation in depth of high alkalinity, excess oxygen, and decrease of fixed carbon dioxid.

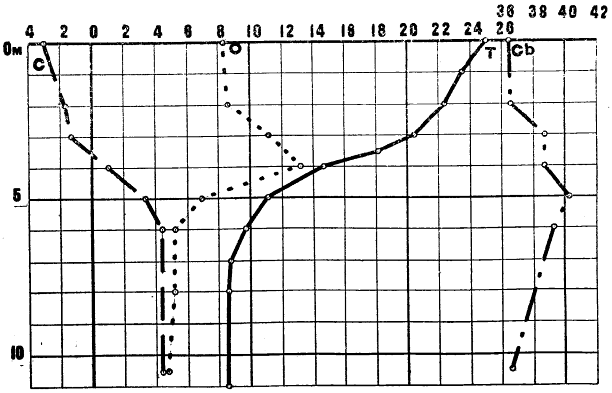

Fig. 57.—Otter lake, southeastern Wisconsin. (L. 0.6 NE-SW.; B. .01, km.) July 8, 1906. Note the excess ovygen in the upper part of the thermocline; also the peculiar distribution of the fixed carbon dioxid. The lake receives a large amount of ground water which influences the temperature of the lower stratum.

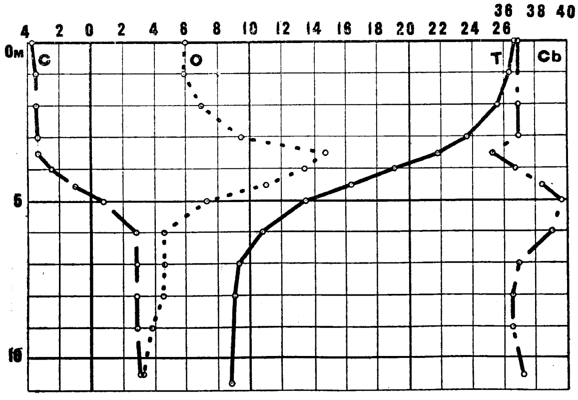

Fig. 58.—Otter lake, August 20, 1906. Note the correlation in depth between the excess oxygen and the decrease in the fixed carbon dioxid. See fig. 57 and text p. 81.

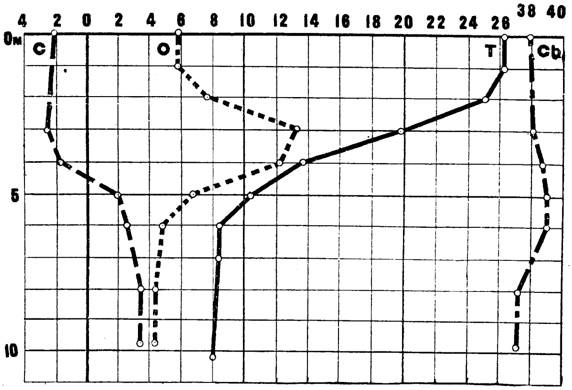

Fig. 59.—Otter lake, July 2, 1909. Compare with fig. 57.

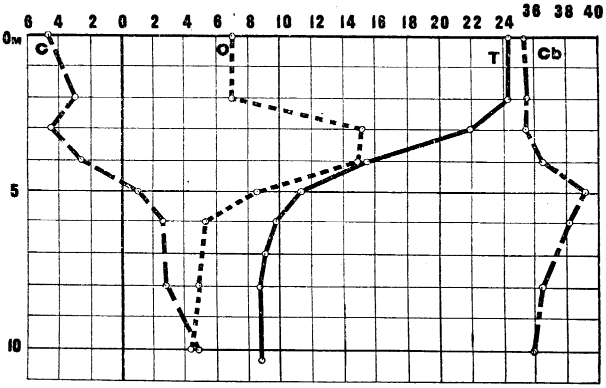

Fig. 60.—Otter lake, July 17, 1909. Compare with fig. 59 and note the increase in the alkalinity of the upper water. Observe also the decrease of fixed carbon dioxid in the epilimnion and its increase at 5 m. See p. 81

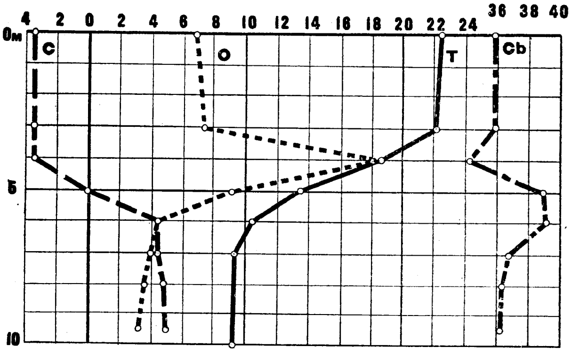

Fig. 61.—Otter lake, August 13, 1909. See figs. 59 and 60, and observe the development of the notch in the fixed carbon dioxid curve which is correlated in depth with the excess oxygen. See p. 91.

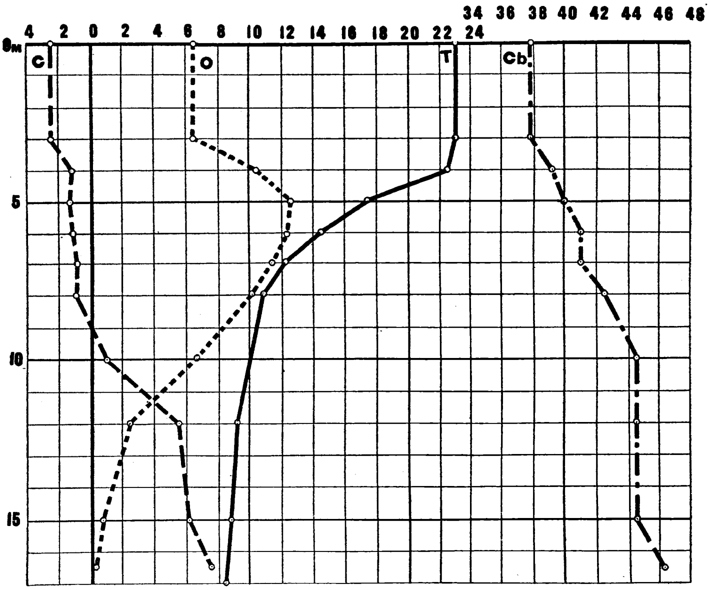

Fig. 62.—Marl lake, southeastern Wisconsin. (L. 0.48 km., NW-SE; B. 0.3 km.) August 14, 1909. Note that excess oxygen is here correlated with a decrease in the alkalinity of the water. See figs. 64 and 107.

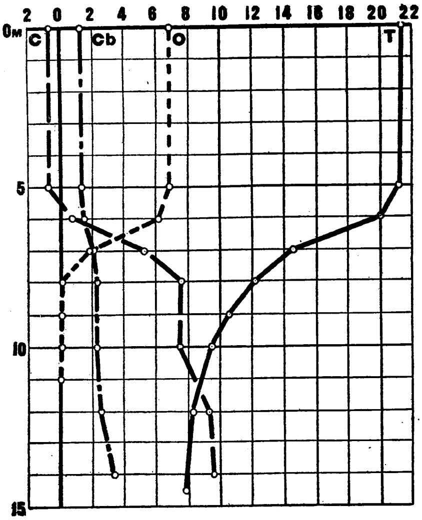

Fig. 63.—Hammills lake, northwestern Wisconsin. (L. 1.6 km., NE-SW; B. 0.9 km.) August 17, 1908. Note the small amount of oxygen below the thermocline.

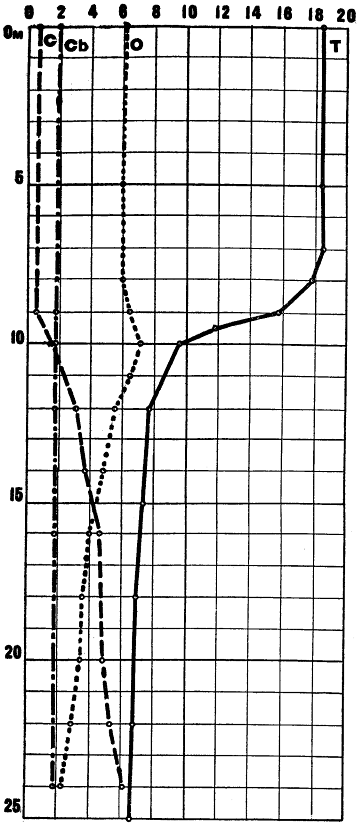

Fig. 64.—Clear lake (Minocqua), northeastern Wisconsin. (L. 3.0, NE-SW; B. 1.5 km.) August 26, 1907. Shows an increase in free carbon dioxid correlated with a slight rise in the oxygen.

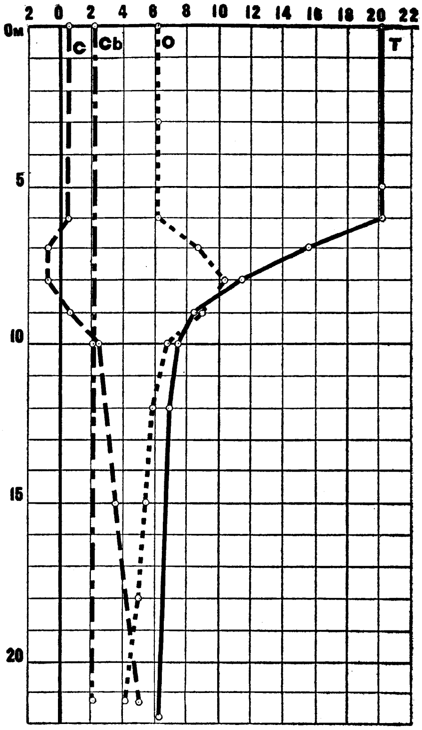

Fig. 65.—Clear lake (Minocqua), August 11 1909. Note that the excess oxygen stratum was alkaline. See figs. 64, 72, and 73 and text p. 76.

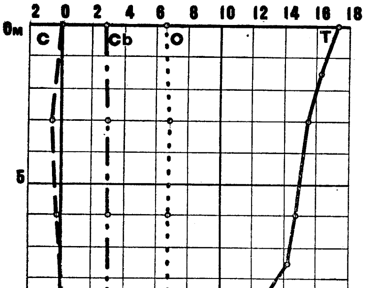

Fig. 66.—Devils lake, southeastern Wisconsin. (L. 2.0 km., N-S; B. 0.9 km.). June 15, 1907. Note that the water was alkaline at 3 m. and 6 m. See p. 77.

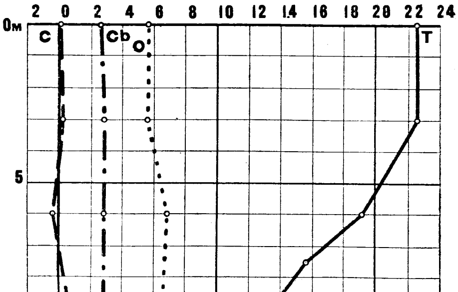

Fig. 67.—Devils lake, July 6, 1907. See fig. 66. Note the decrease of dissolved oxygen at the bottom and that the water at 6 m. was still alkaline.

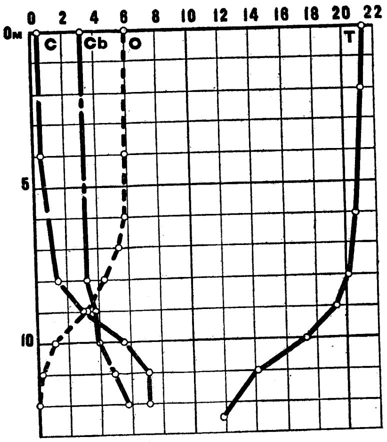

Fig. 68.—Devils lake, September 19, 1908. Late summer conditions.

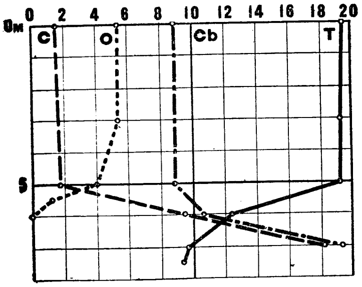

Fig. 69.—Allequash lake, northeastern Wisconsin. (L. 2.4 km., NE-SW; B. 1.4 km.) August 20, 1907. Observe the marked increase of free and fixed carbon dioxid in the bottom water. See p. 77.

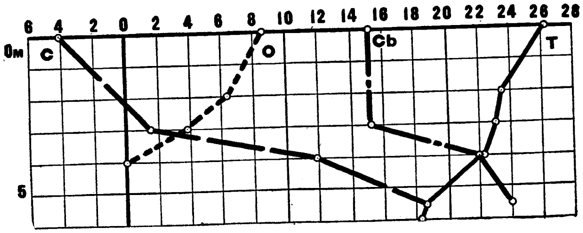

Fig. 70.—Little Trade lake, northwestern Wisconsin. (L. 1.6 km., NE-SW; B. 1.2 km.) August 10, 1908. Note the marked increase of free and fixed carbon dioxid in the lower water. See figs. 69 71, and p. 185.

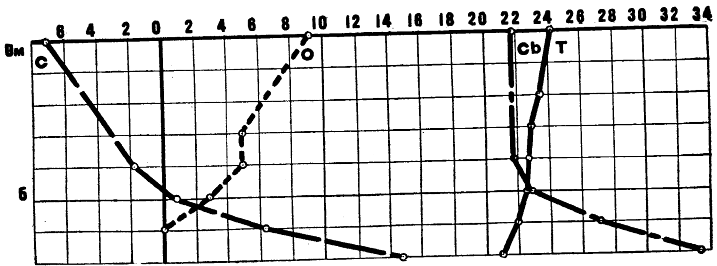

Fig. 71.—Upper Turtle lake, northwestern Wisconsin. (L. 3.6 km., NW-SE; B. 0.7 km.) August 12, 1908. Note the high alkalinity and excess oxygen (156 per cent. of saturation) at the surface and the increase of free and fixed carbon dioxid in the lower water.

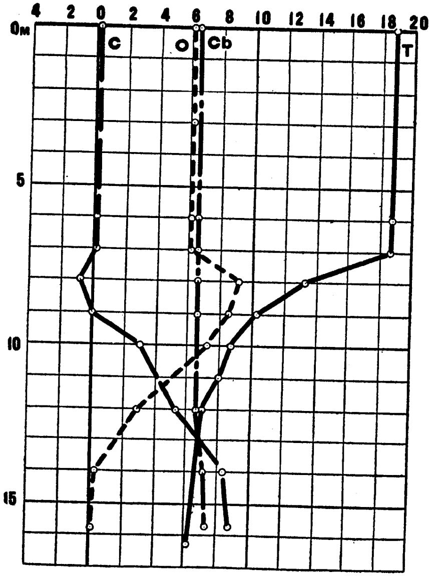

Fig. 72.—Silver lake (Minocqua), northeastern Wisconsin. (L. 1.6 km., N-S; B. 0.4 km.) August 27, 1908. Note the alkaline stratum in the thermocline correlated with excess oxygen. See p. 78 and fig. 65.

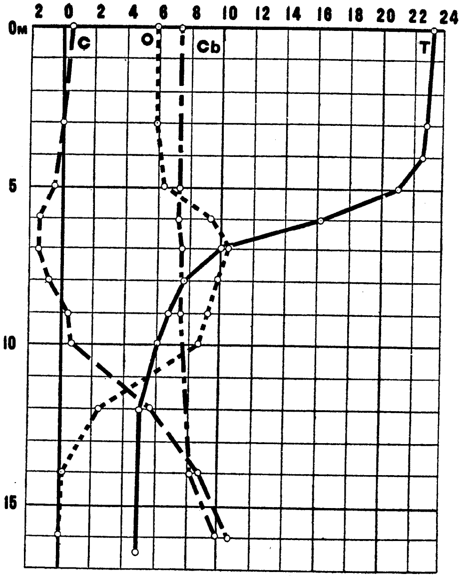

Fig. 73.—Silver lake (Minocqua), August 9, 1909. Compare with fig. 72 and note that the high oxygen-alkaline stratum is thicker.

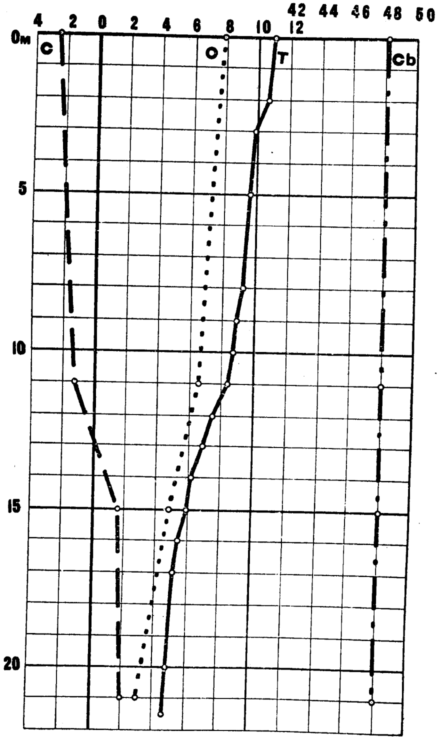

Fig. 74.—North lake (west part), southeastern Wisconsin. (L. 1.0 km., N-S; B. 0.67 km.) May 11, 1906. An early stage in the development of summer conditions.

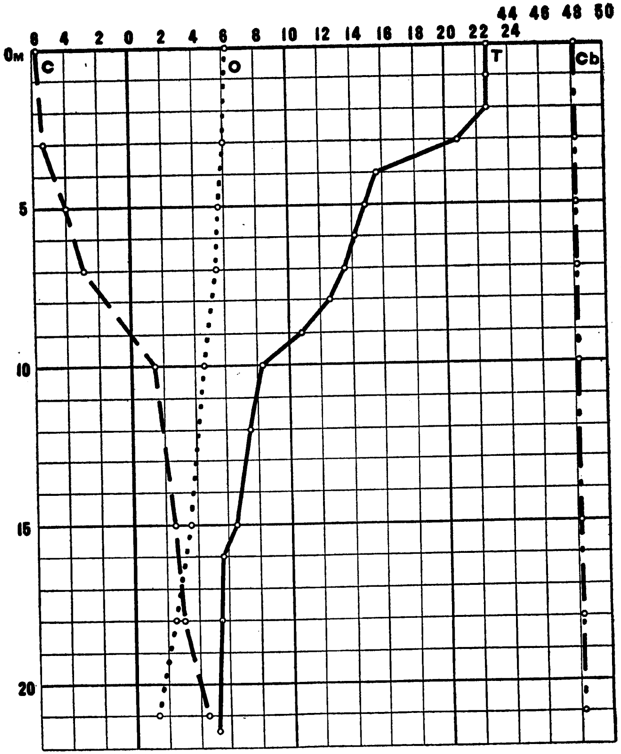

Fig. 75.—North lake (west part), June 7, 1906. Compare with fig. 74 and observe the increase in the alkalinity of the upper water and the decrease of oxygen from surface to bottom.

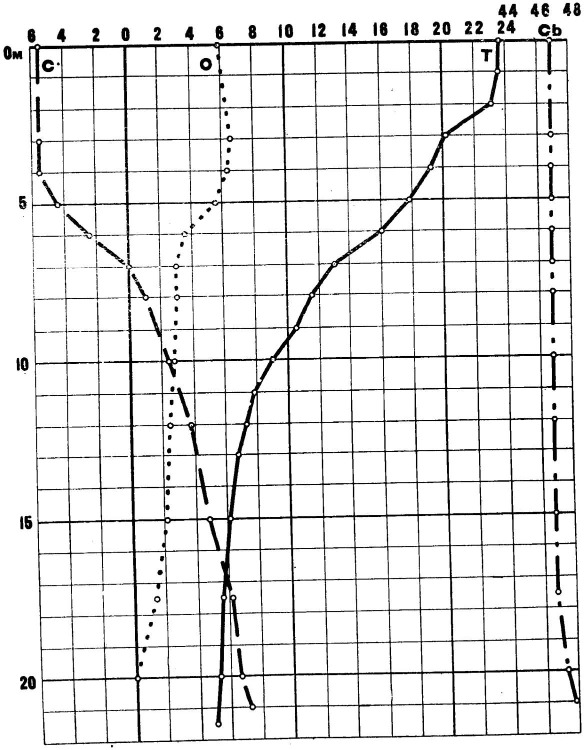

Fig. 76.—North lake (west part), June 29, 1906. See fig. 75. Note the decrease of oxygen and increase of free carbon dioxid in the lower water.

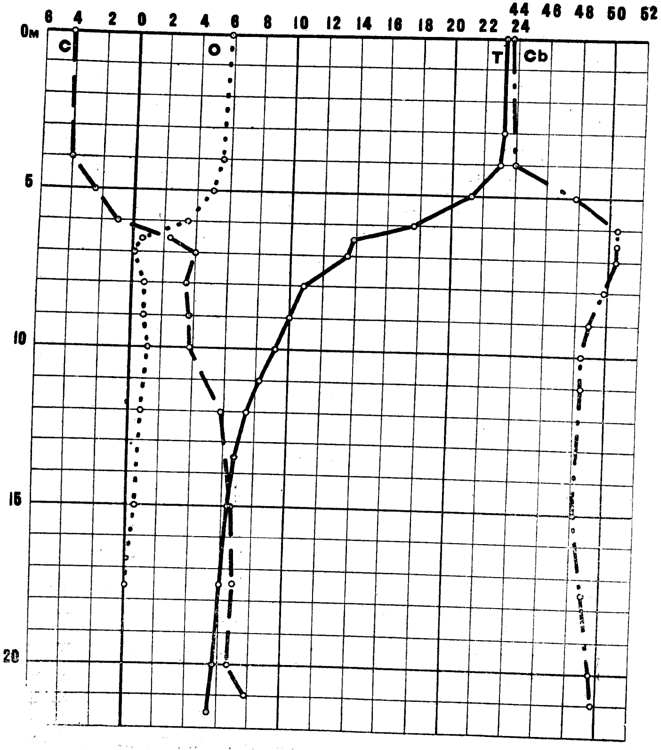

Fig. 77.—North lake (west part), July 30, 1906. See fig. 76. Observe the notch in the oxygen curve at 7 m. the decrease of fixed carbon dioxid in the upper and its increase in the lower water, with the maximum quantity in the thermocline. See p. 50 for oxygen and p. 84 for fixed carbon dioxid.

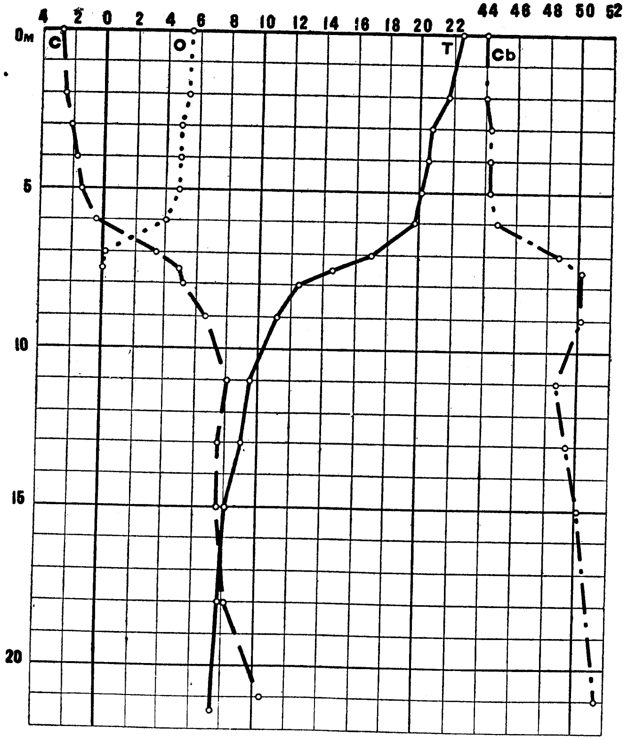

Fig. 78.—North lake (west part), September 18, 1906. All of the dissolved oxygen has disappeared from the lower water; the fixed carbon dioxid curve still shows a rise in the thermocline with a decrease immediately below. See fig. 77.

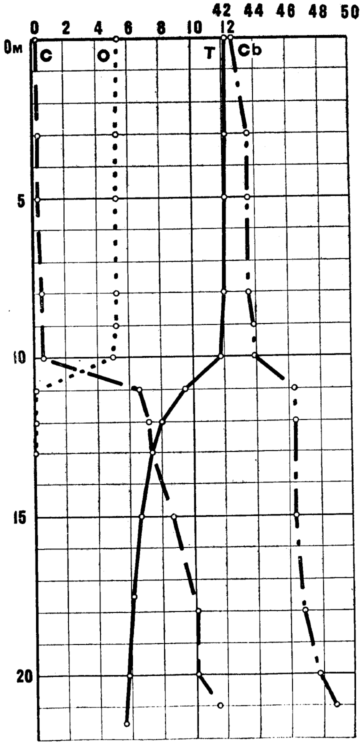

Fig. 79.—North lake (west part), October 13, 1906. Autumnal conditions a short time before the overturn. See fig. 78 and note the downward movement of the thermocline.

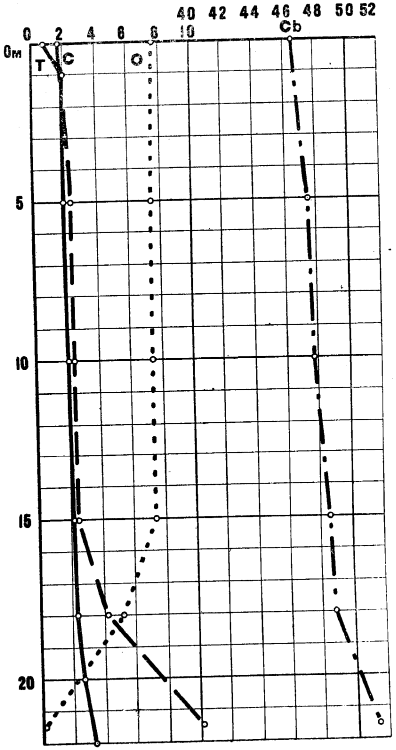

Fig. 80.—North lake (west part), March 3, 1907. Winter conditions. Note the close resemblance between this diagram and fig. 24.

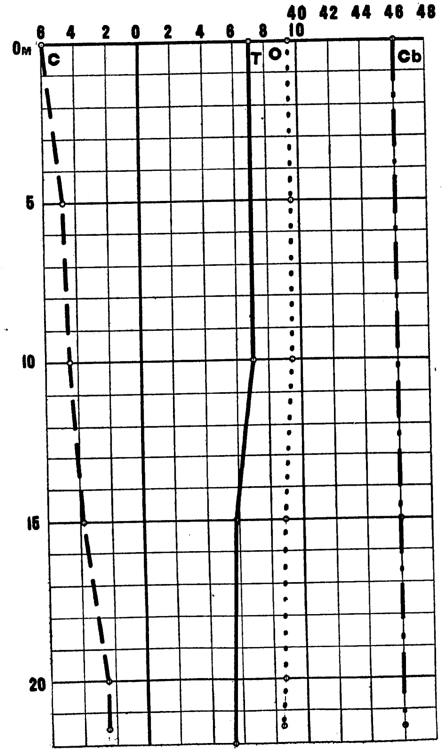

Fig. 81.—North lake (west part), May 10, 1907. See fig. 74. Observe the greater alkalinity and larger amount of oxygen than in 1906, but not so large a quantity of fixed carbon dioxid.

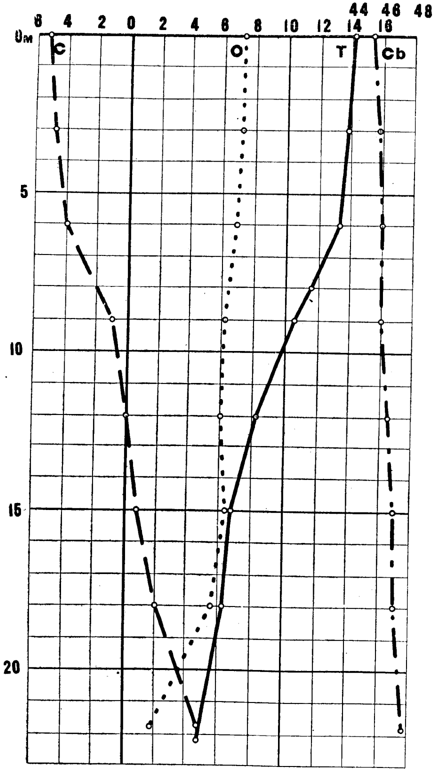

Fig. 82.—North lake (west part), June 7, 1907. Compare with fig. 75. The upper water was much warmer in 1906; the oxygen and free carbon dioxid were much the same; the quantity of fixed carbon dioxid was smaller in 1907.

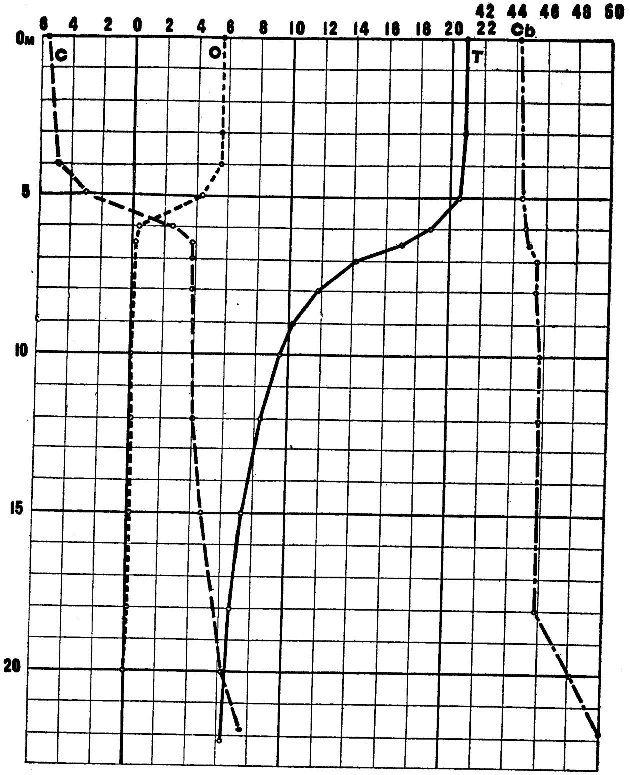

Fig. 83.—North lake (west part), September 4, 1907. Compare with fig. 78 and note the difference in the oxygen and fixed carbon dioxid curves.

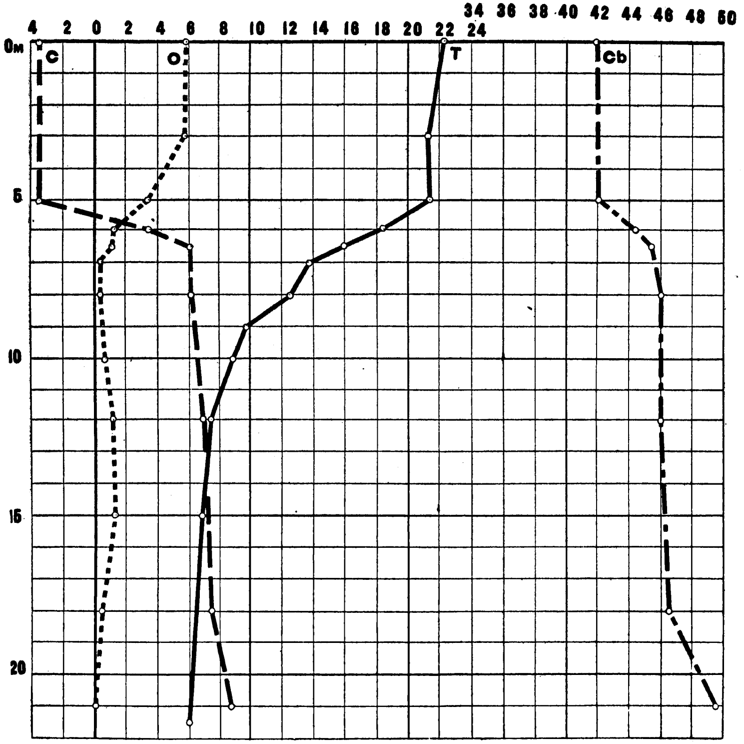

Fig. 84.—North lake (west part), September 1, 1909. Note the decrease of oxygen in the thermocline and its increase below. See p. 50. Compare with figs. 77 and 83.

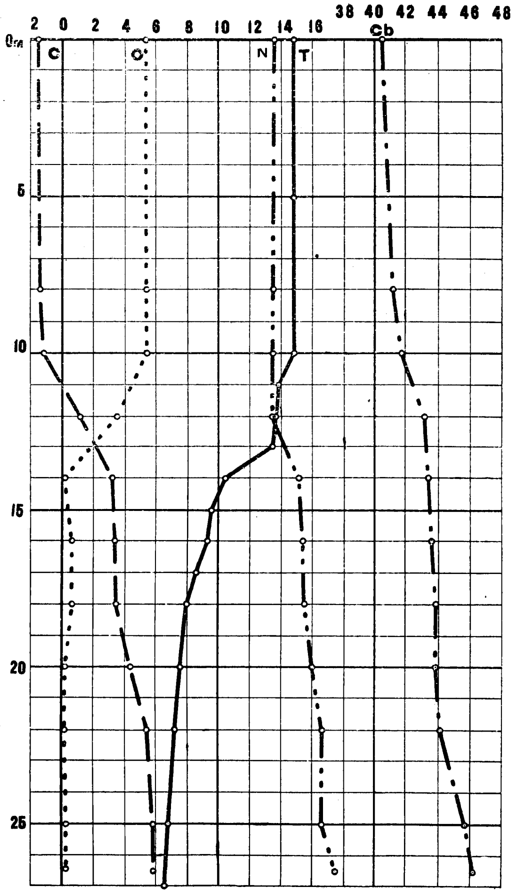

Fig. 85.—Okauchee lake, southeastern Wisconsin, (L. 3.8 km., NW-SE; B. 2.9 km.). October 15, 1905. Mid-autumn conditions.

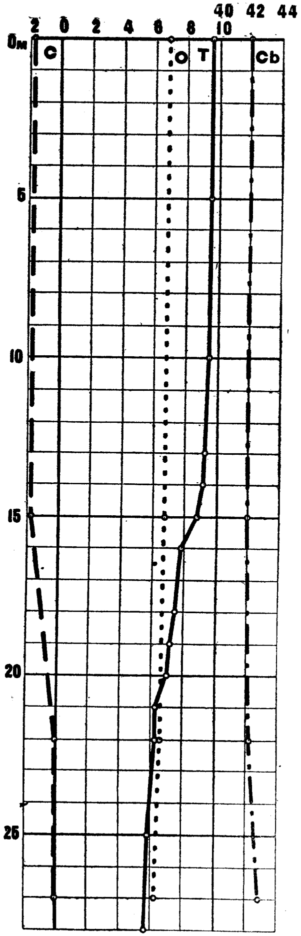

Fig. 86.—Okauchee lake, May 8, 1906. Shows conditions almost uniform from surface to bottom.

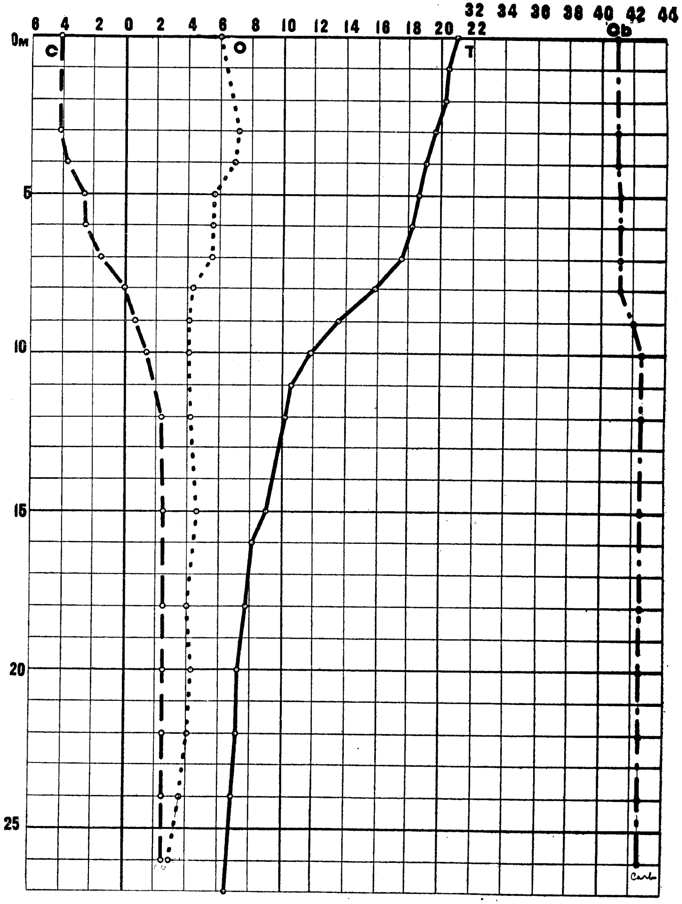

Fig. 87.—Okauchee lake, June 26, 1906. Compare with fig. 86. Note the rise in the temperature of the upper water, the increase in alkalinity, and the appreciable decrease of fixed carbon dioxid; in the lower water, the decrease of oxygen and the increase of free carbon dioxid.

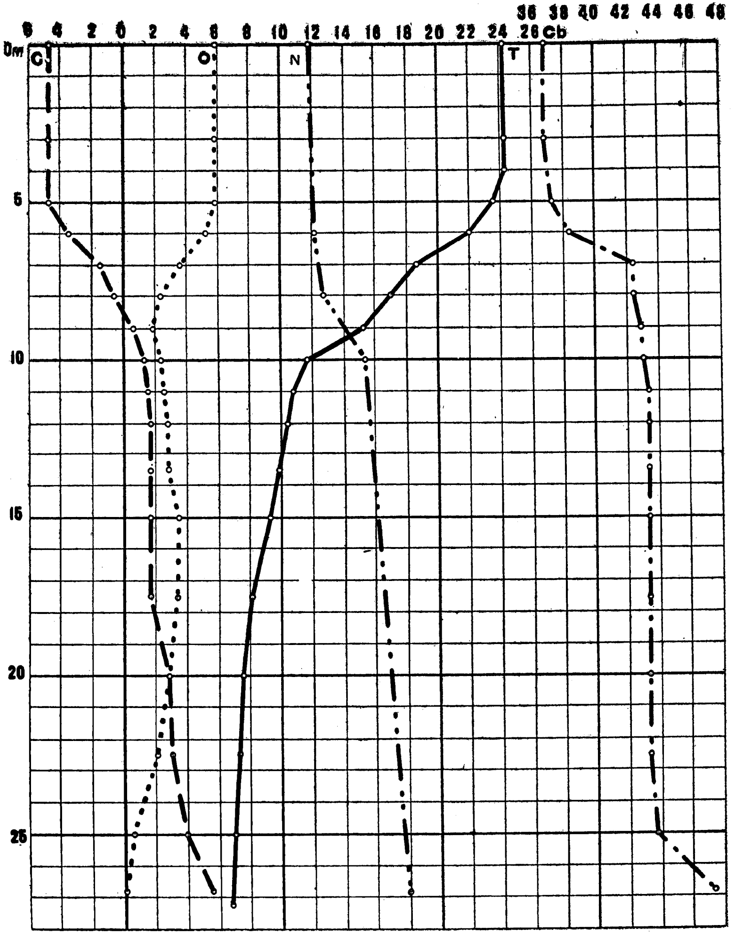

Fig. 88.—Okauchee lake, July 26, 1906. See fig. 87. Note the marked decrease of **fixed carbon dioxid** in the upper water and its increase at the bottom; also the rise of the nitrogen in the thermocline and the notch in the oxygen curve at 9 m. Compare the oxygen curve with those in figs. 40, 77, 84, 90, 100, and 115. See text p. 50.

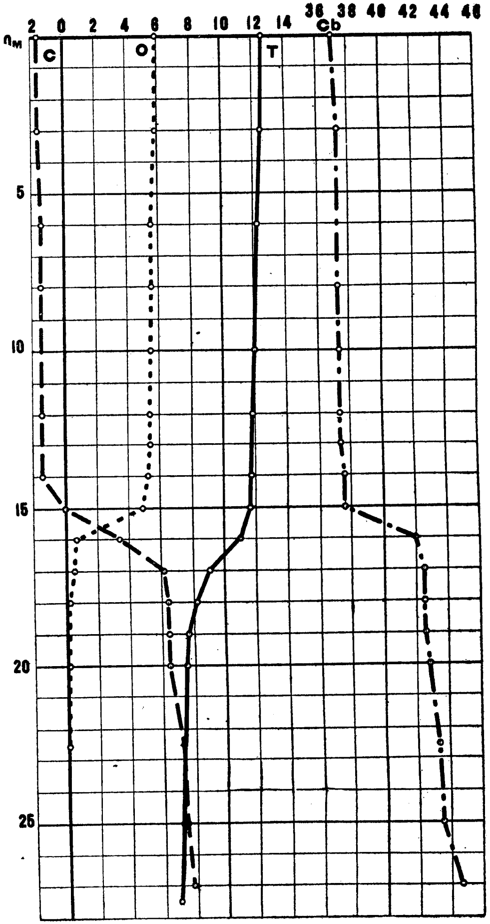

Fig. 89.—Okauchee lake, October 14, 1906. Compare with fig. 90 and note the downward progress of the thermocline. See also fig. 85 and observe the larger quantity of fixed carbon dioxid in the upper water in 1905.

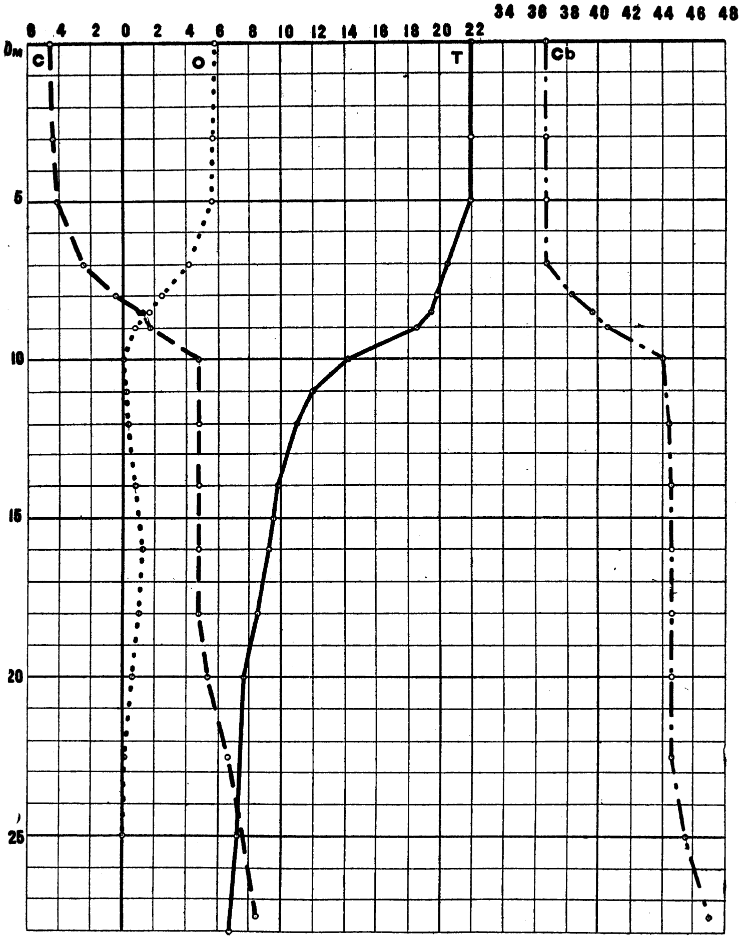

Fig. 90.—Okauchee lake, September 21, 1906. Compare with figs 87 and 88. Note the decrease of oxygen in the thermocline, producing a more distinct notch, and the increase of the free carbon dioxid in the lower water. See p. 50.

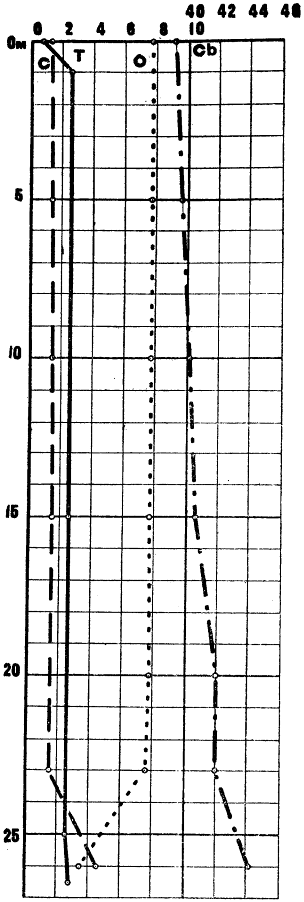

Fig. 91.—Okauchee lake, March 4, 1907. Winter conditions. Note the similarity between this diagram and fig. 80.

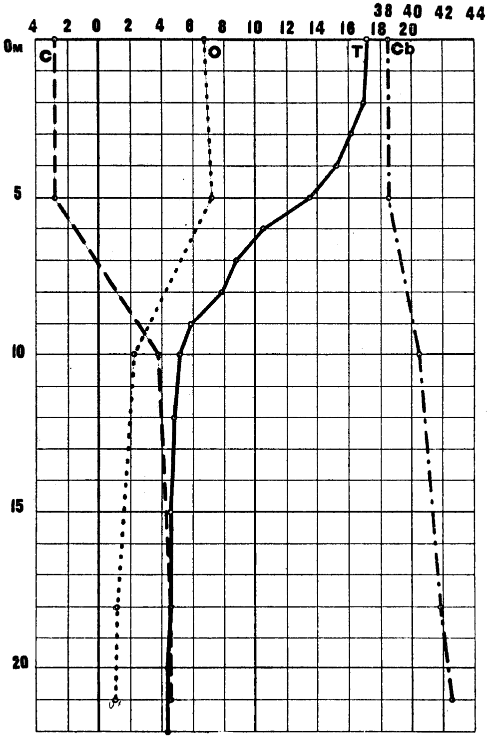

Fig. 92.—Long lake (Waupaca), southeastern Wisconsin, (L. 1.5 km., N-S; B. 0.57 km.). May 18, 1906. Early summer conditions.

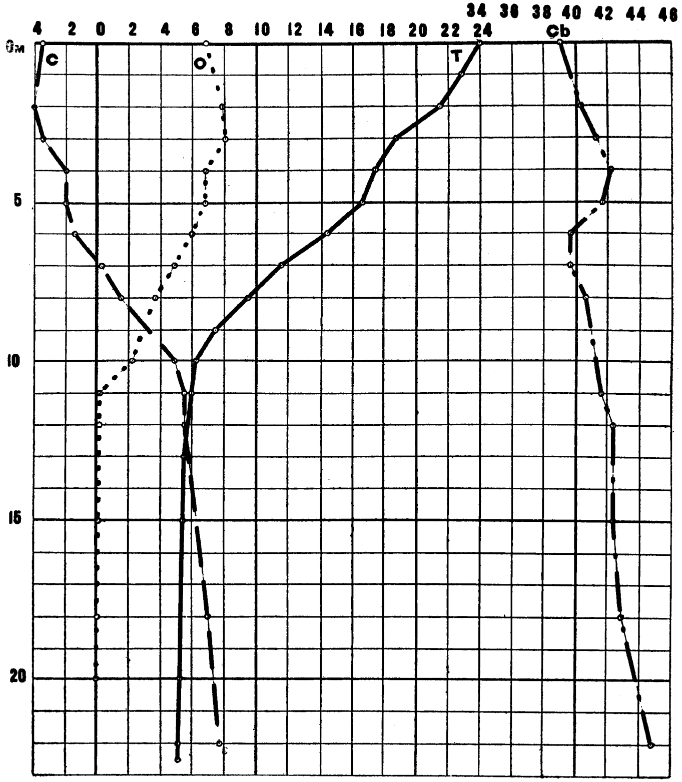

Fig. 93.—Long lake (Waupaca), July 7, 1906. Compare with fig. 92. Observe the decrease of oxygen and increase of free carbon dioxid in the lower water; also note the rise in the fixed carbon dioxid curve at 4 m. and the peculiar temperature curve which is characteristic of this lake. See p. 84.

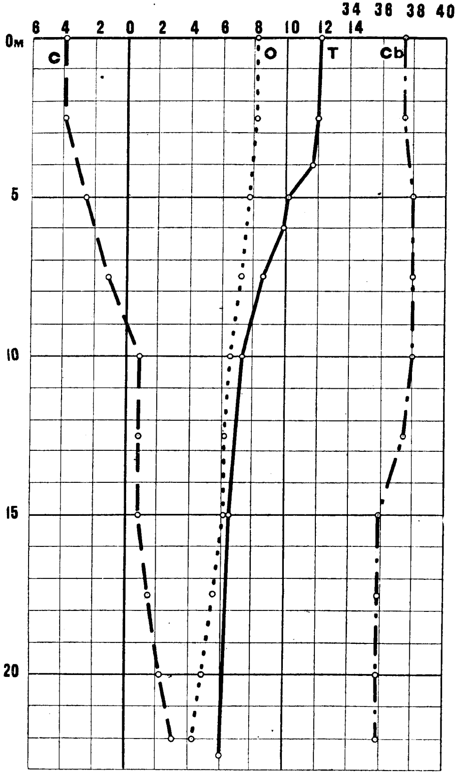

Fig. 94.—Long lake (Waupaca), May 24, 1907. Compare with fig. 92. Note that summer conditions were not nearly as far advanced as in 1906 because the spring was colder in 1907.

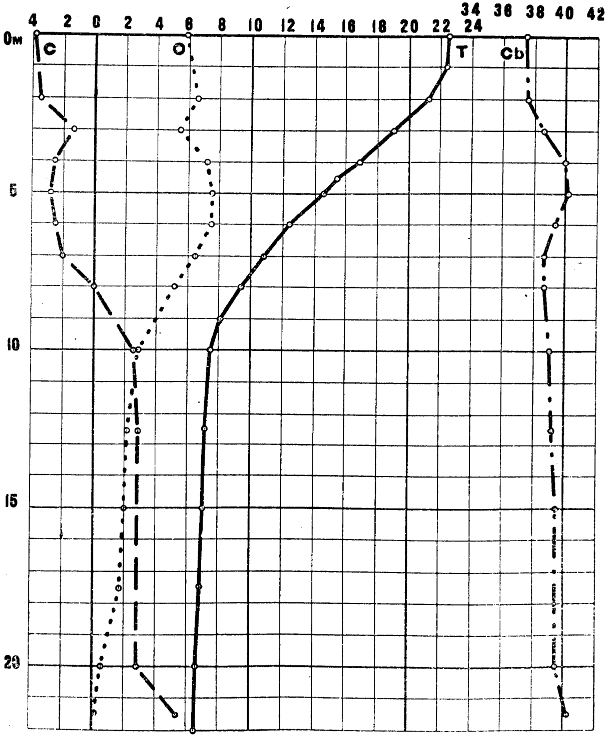

Fig. 95.—Long lake (Waupaca), June 24, 1907. Note the decrease in alkalinity and of oxygen at 3 m. Compare temperature and fixed carbon dioxid curves with those in fig. 93.

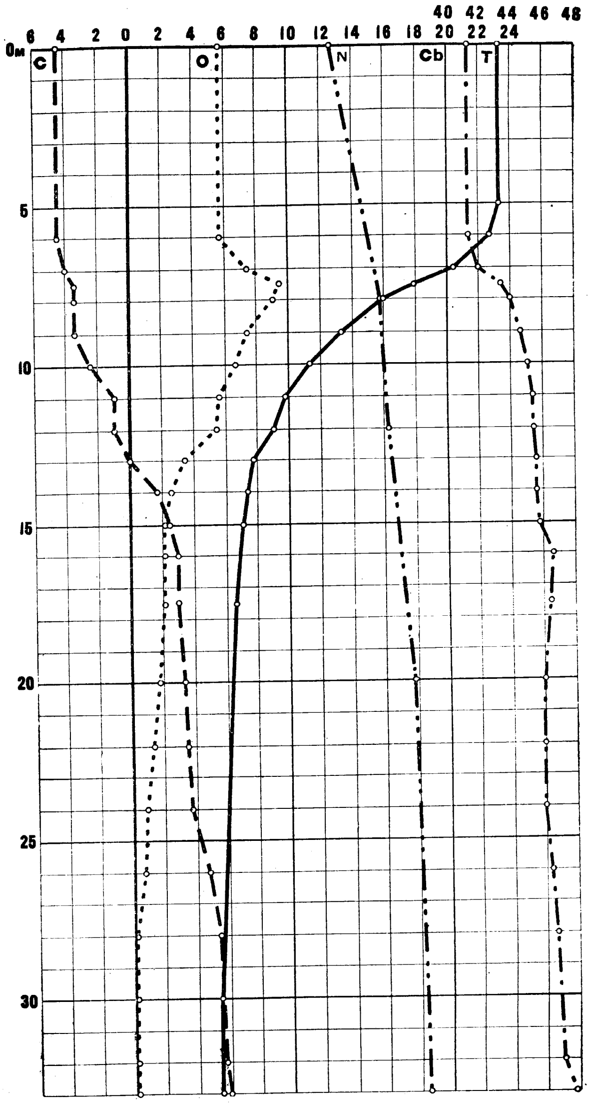

Fig. 96.—Elkhart lake, southeastern Wisconsin, L. (1.76 km., NW-SE; B. 1.26 km), August 9, 1906. Note the small excess of oxygen in the upper part of the thermocline. There was an excess of nitrogen at all depths; the amount at the surface was about 0.5 cc. above the saturation point and that at the bottom about 1.5 cc.

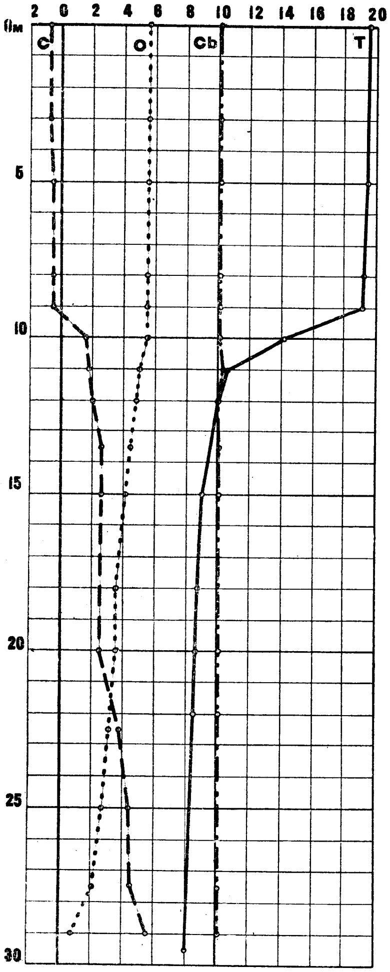

Fig. 97.—Trout lake, northeastern Wisconsin, (L. 7.2 km., N-S; B. 3.8 km.), September 7, 1906. Shows a fairly large amount of dissolved oxygen in the lower water.

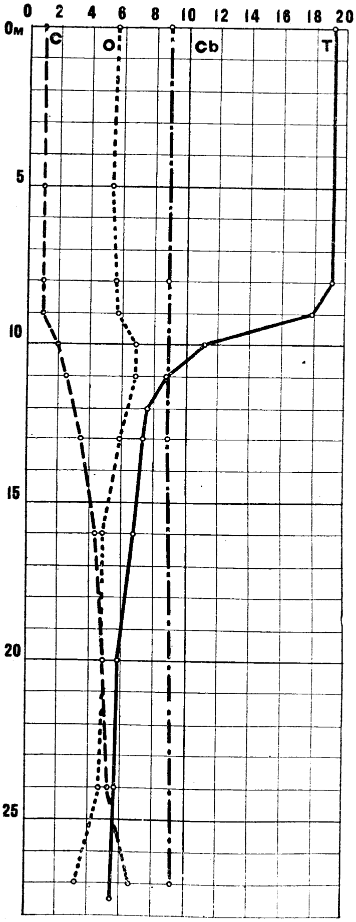

Fig. 98.—Trout lake, August 19, 1907. Compare with fig. 97 and note that the upper water was alkaline in 1906 but acid in 1907. See p. 77.

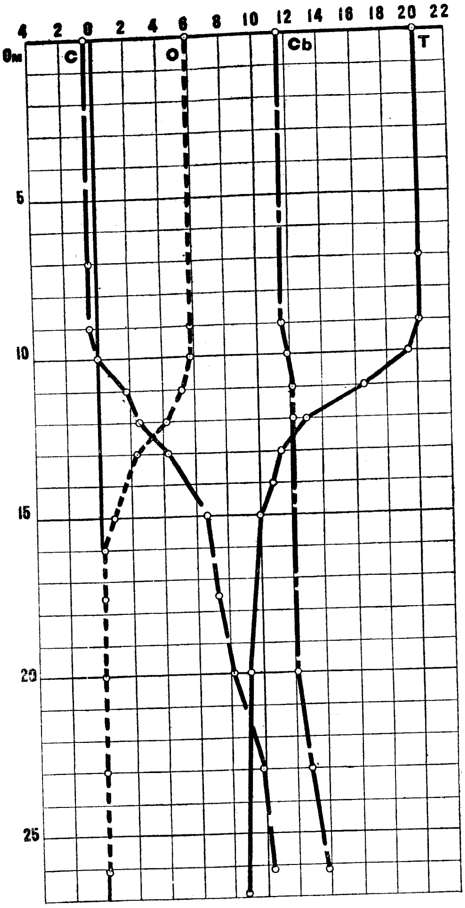

Fig. 99.—Lake Owen, northwestern Wisconsin (L. 10.0 km., NE-SW; B. 0.8 km.), August 20, 1908. Compare with fig. 97 and note the smaller amount of dissolved oxygen in the lower water of lake Owen.

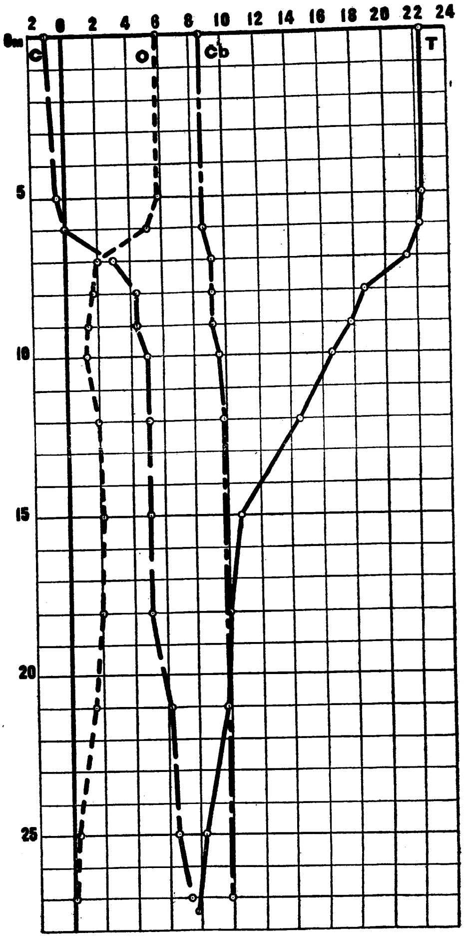

Fig. 100.—Beaver Dam lake, northwestern Wisconsin (L. 6.0 km., NW-SE; B. 1.2 km.), August 14, 1908. Note the peculiar thermocline and the decrease of oxygen in the 7-10 in stratum with a rise below. See p. 50.

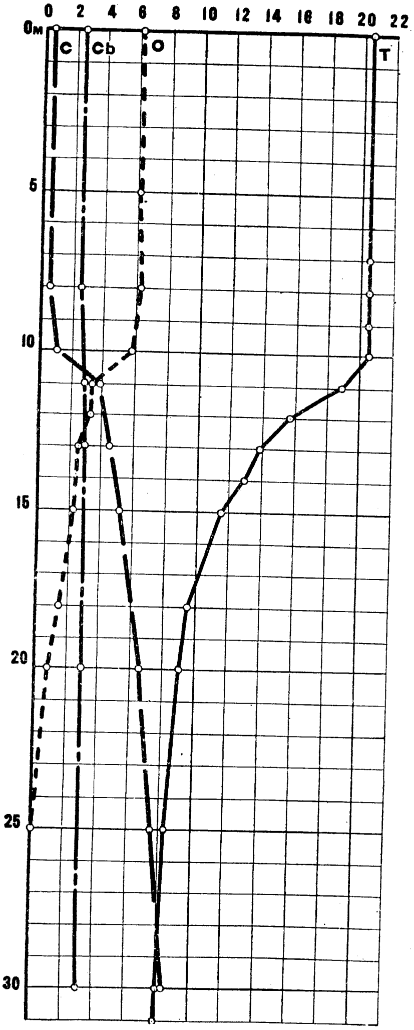

Fig. 101.—Bardon lake, northwestern Wisconsin (L. 4.2 km., NE-SW; B. 1.2 km.), August 20, 1908. Compare with figs. 99 and 100. All are situated in the same general region. Note the difference in dissolved oxygen and fixed carbon dioxid.

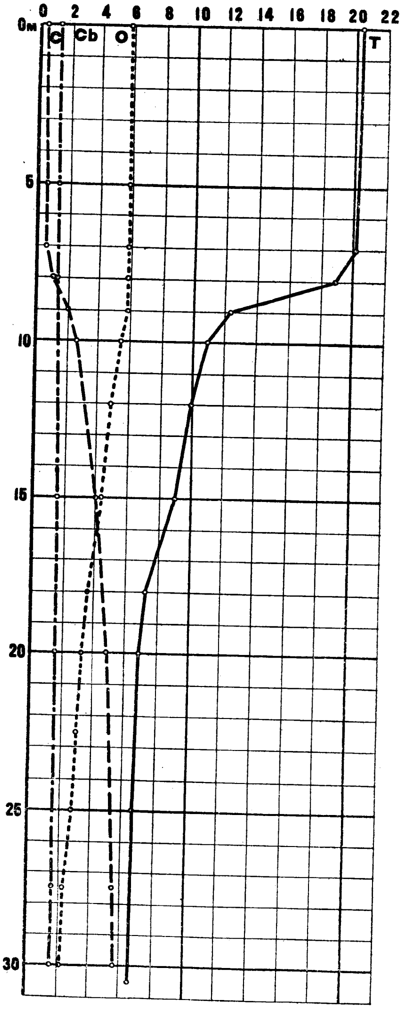

Fig. 102.—Pine lake (New Auburn district), northwestern Wisconsin. (L. 2.4 km., NE-SW; B. 1.0 km.) August 3, 1907.

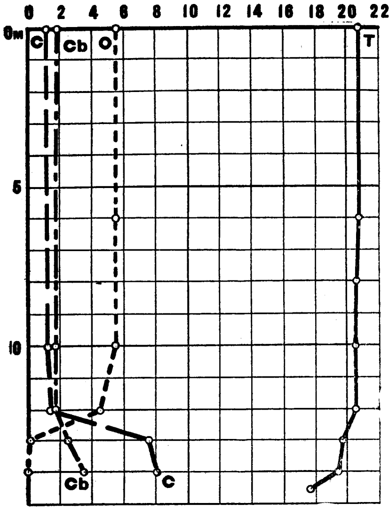

Fig. 103.—Shell lake, northwestern Wisconsin. (L. 5.2 km., NE-SW; B. 4.0 km.) August 18, 1908. Note the thin botton stratum that was not kept in circulation by the wind and by convection currents. See fig. 68.

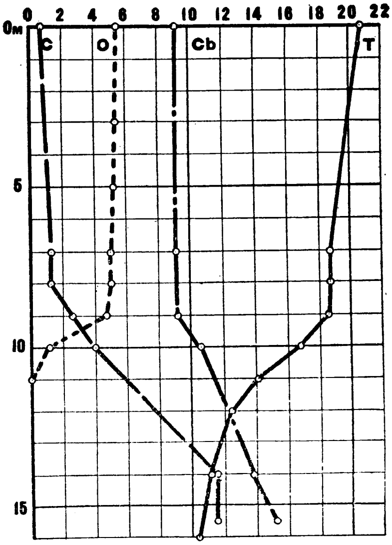

Fig. 105.—Kawaguesaga lake, northeastern Wisconsin. (L. 7.2 km., E-W; B. 1.0 km.) August 24, 1908. See fig. 106.

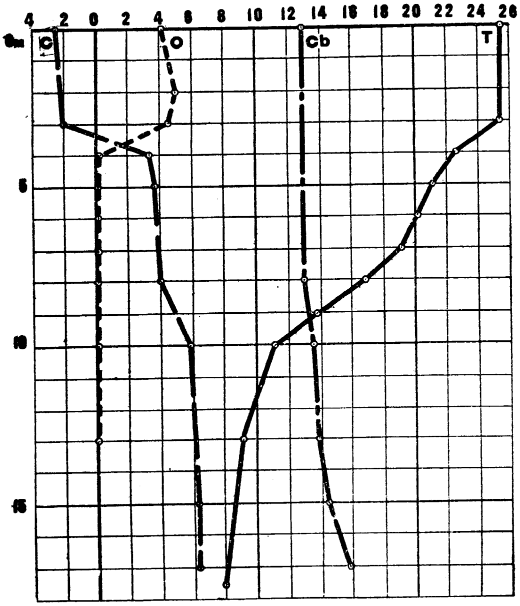

Fig. 104.—Nichols lake, northwestern Wisconsin. (L. 3.7 km., NE-SW; B. 0.7 km.) August 5, 1908. Compare with Pine lake (fig. 103) which is situated in immediate neighborhood and note differences in oxygen and fixed carbon dioxid.

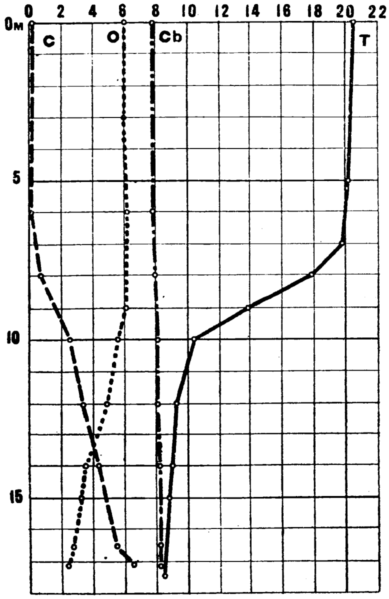

Fig. 106.—Tomahawk lake, northeastern Wisconsin. (L. 7.2 km., E-W; B. 2.0 km.) August 10, 1907. Compare with fig. 105 and note differences in oxygen and free and fixed carbon dioxid in lower water. These two lakes are only a few kilometers apart and have substantially the same maximum depth. The outlet of Tomahawk lake flows into Kawaguesaga which also receives other affluents.

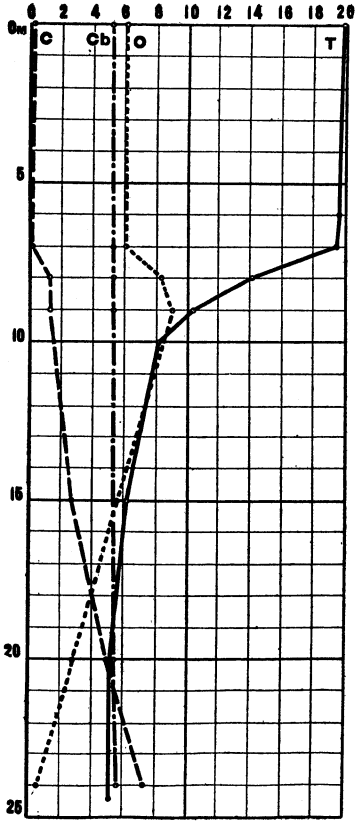

Fig. 107.—Black Oak lake, northeastern Wisconsin. (L. 3.7 km., E-W; B. 1.1 km.) August 14, 1907. Observe that an increase of free carbon dioxid in the thermocline is correlated with an increase of oxygen. See fig.. 64.

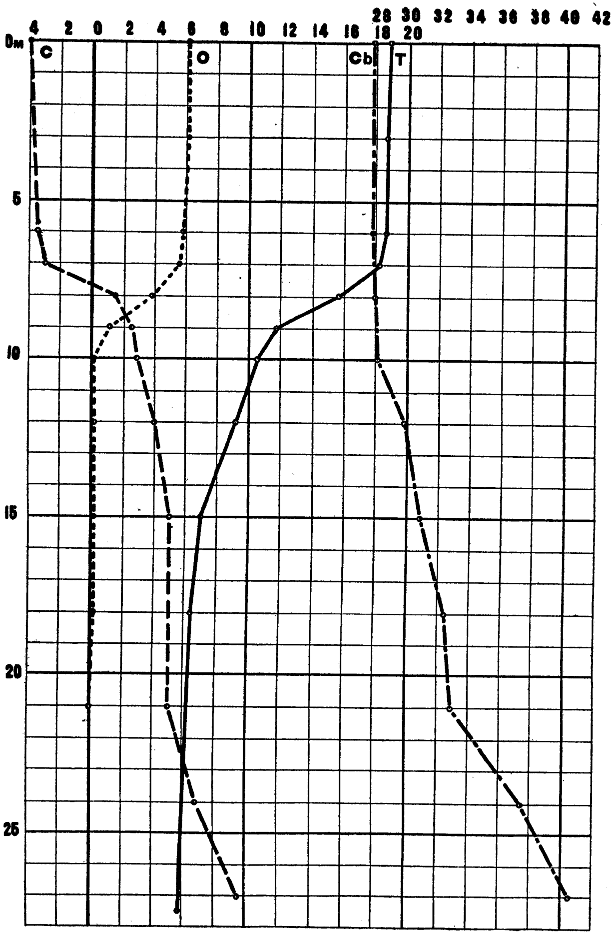

Fig. 108.—Rainbow lake, southeastern Wisconsin. (L. 1.25 km., NE-SW; B. 0.7 km.) September 10, 1907. Compare with fig. 28, lake Mendota, a shallower but much larger lake.

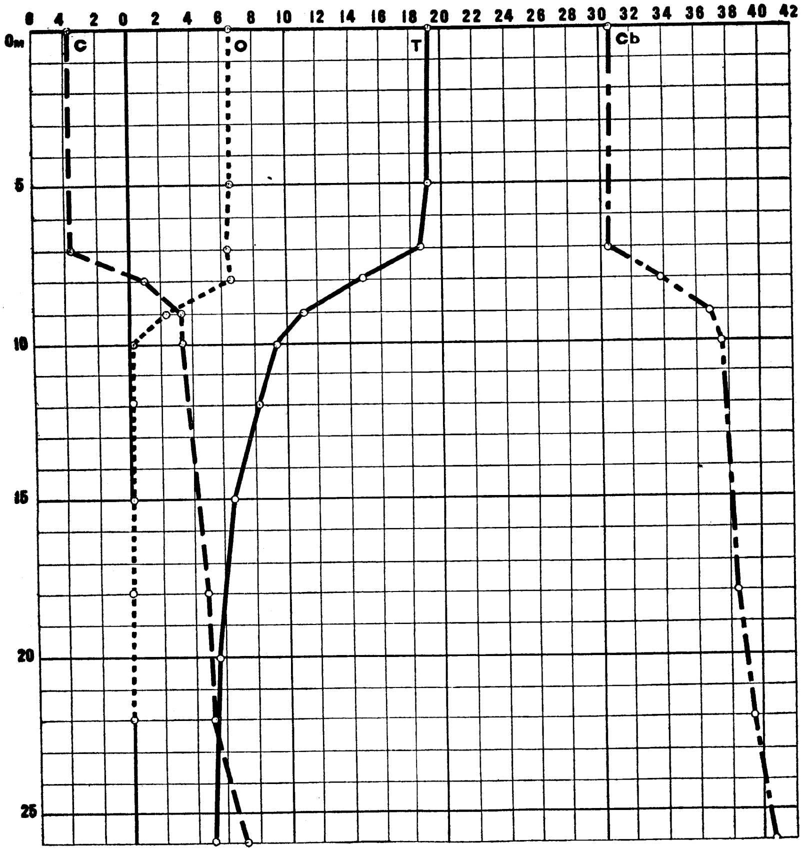

Fig. 109.—Rainbow lake, September 9, 1909. Compare with fig. 108. Note the difference in the fixed carbon dioxid.

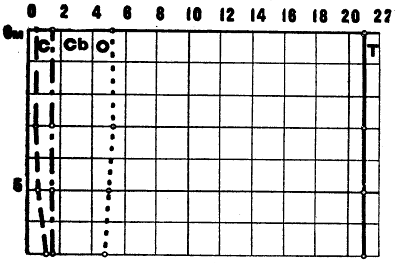

Fig. 110.—Bass lake (Minocqua), northeastern Wisconsin. (L. 0.9 km., NE-SW; B. 0.3 km.) September 6, 1906. Note the small amount of fixed carbon dioxid. Shows uniform conditions characteristic of a shallow lake. Figs. 32–35, 69–71, and 110 illustrate summer conditions in shallow lakes, ranging from those in which circulation is complete to those which possess a well defined thermocline but no hypolimnion.

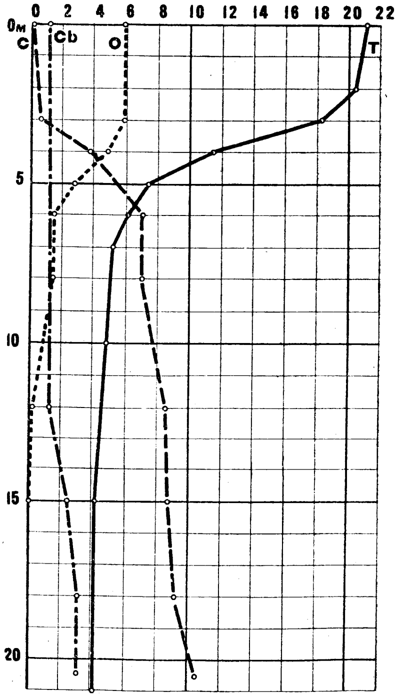

Fig. 111.—Adelaide lake, northeastern Wisconsin. (L. 0.6 km., N-S; B. 0.4 km.) August 10, 1907. A small, fairly deep lake situated in the midst of a forest. Only a thin upper stratum of water was disturbed by the wind and convection currents.

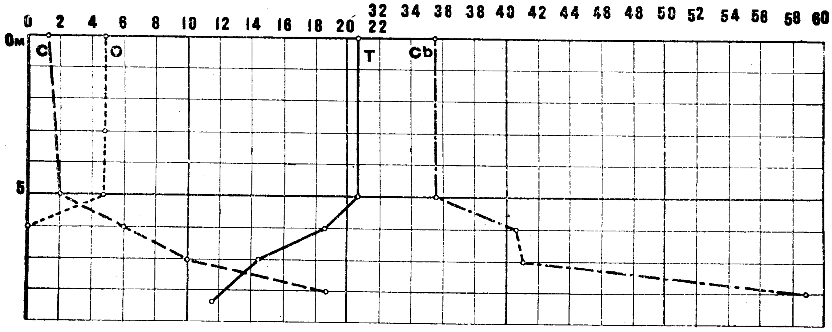

Fig. 112.—Holem lake, Indiana. (L. 1.2 km., NE-SW; B. 0.2 km.) September 23, 1907. Note the comparatively small amount of oxygen in the upper water and the marked rise of free and fixed carbon dioxid at the bottom. See figs. 52 and 53 and text, p. 94.

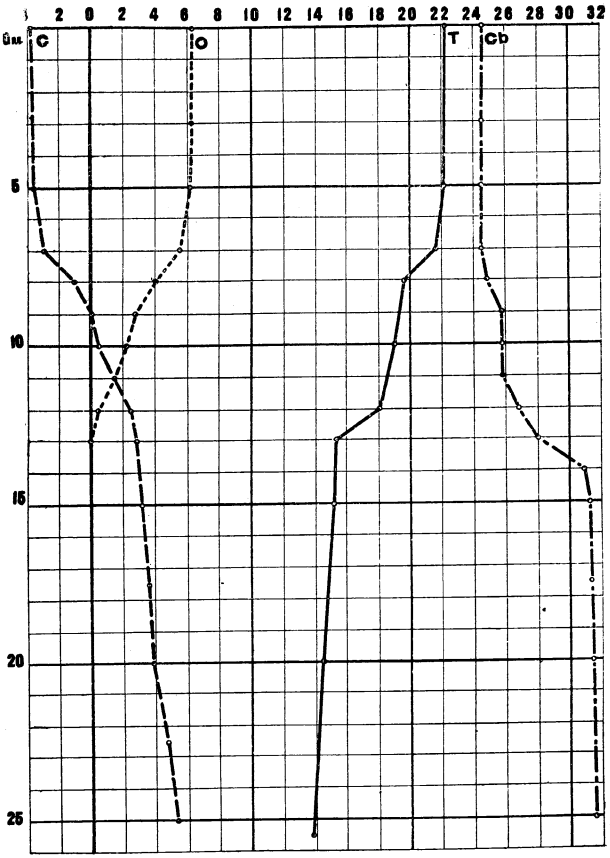

Fig. 113.—Lake Maxinkuckee, Indiana. (L. 2.7 km., N-S; B. 1.7 km.) September 20, 1907. Compare with fig. 28 and note the resemblance of the curves. See p. 93.

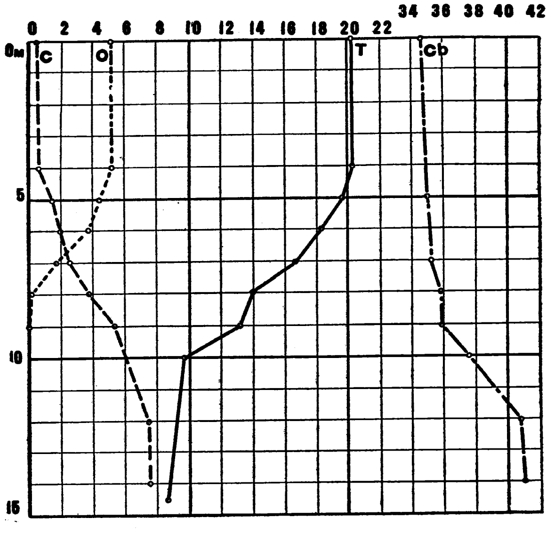

Fig. 114.—Cook lake, Indiana. (L. 1.6 km., NE-SW; B. 0.2 km.) September 23, 1907. Note the comparatively small amount of oxygen in the upper water. See p. 94.

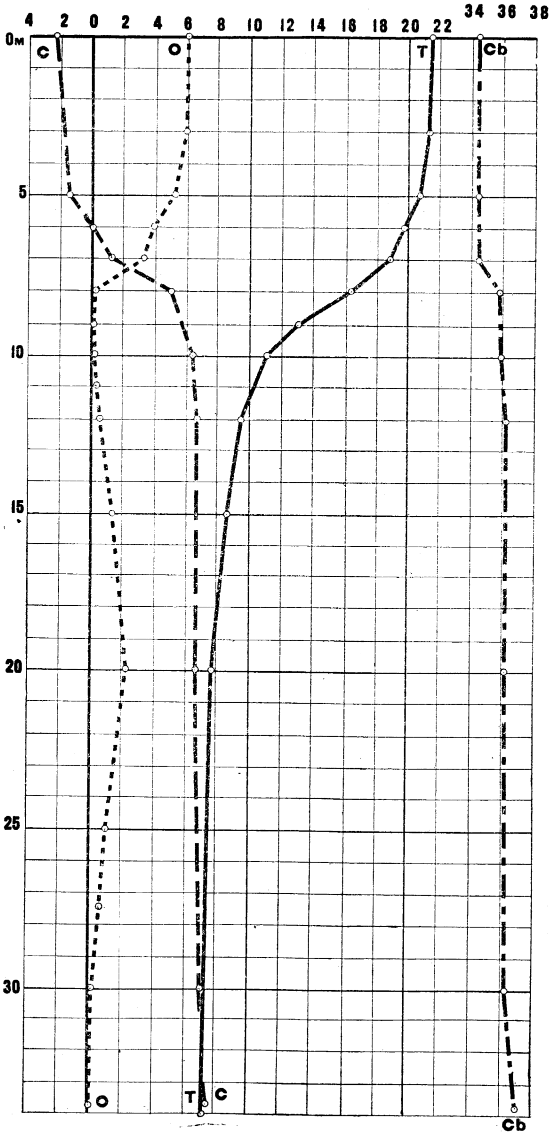

Fig. 115.—Tippecanoe lake, Indiana. (L. 4.0 km., NW-SE; B. 0.9 km.) September 17, 1909. Note the almost total disappearance of oxygen in the thermocline and the increase below. See figs. 40, 77, 84, 88, and 100. See text, pp. 50 and 94.

EXPLANATION OF FIGURES SHOWING VERTICAL DISTRIBUTION OF PLANKTON ORGANISMS.

In figures representing the distribution of the plankton organisms, the vertical spaces show the depth in meters; the curves to the left of the zero line indicate the number of crustacea, nauplii, and rotifers per liter of water, while those to the right show the number of algae per liter. The curve marked C = crustacea, N = nauplii, R = rotifers, D = diatoms, and A = all other algae. The small circles show the depths at which observations were made. The column of figures at the right margin marked T indicates the temperature of the water in degrees C. and that marked O shows the number of cc. of oxygen per liter of water at the various depths. The diatoms found in the various lakes are almost entirely colonial forms and no attempt has been made to indicate the number of individuals in these colonies. The curves, therefore, show only the number of colonies. Also, such forms as *Ceratium, Uroglena,* and *Dinobryon* have been included in the curve showing "all other algae."

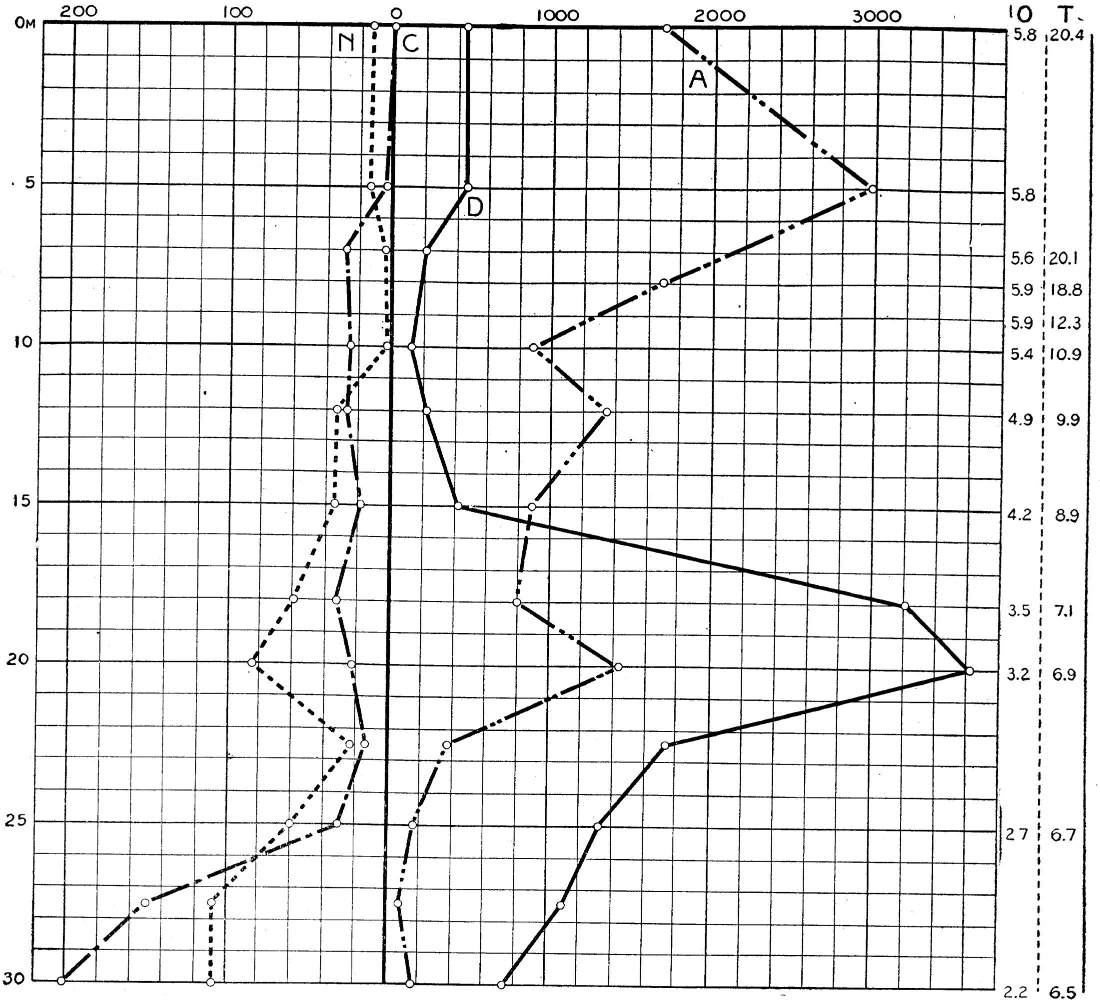

Fig. 116.—Distribution of plankton organisms in Pine lake (New Auburn), August 31, 1907. Scale, 1 vertical space = 1 m.; 1 horizontal space = 20 crustacea and nauplii per liter of water, and 200 algae and diatoms. The number of rotifers was too small to plat. Predominant forms: Aphanocapsa, Tabellaria, and Cyclops. See p. 116.

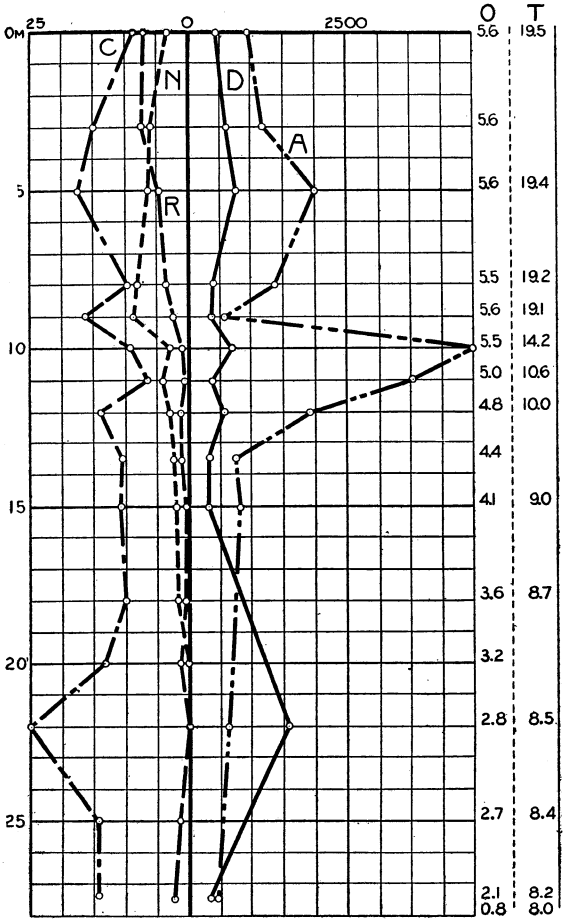

Fig. 117.—Vertical distribution of the plankton organisms in Trout lake, September 7, 1906. Scale, 1 horizontal space = 5 crustacea, nauplii, and rotifers per liter of water and 500 algae and diatoms. Oscillatoria was the predominant alga and Cyclops the predominant crustacean. Mastigocerca was the predominant rotifer. See p. 116.

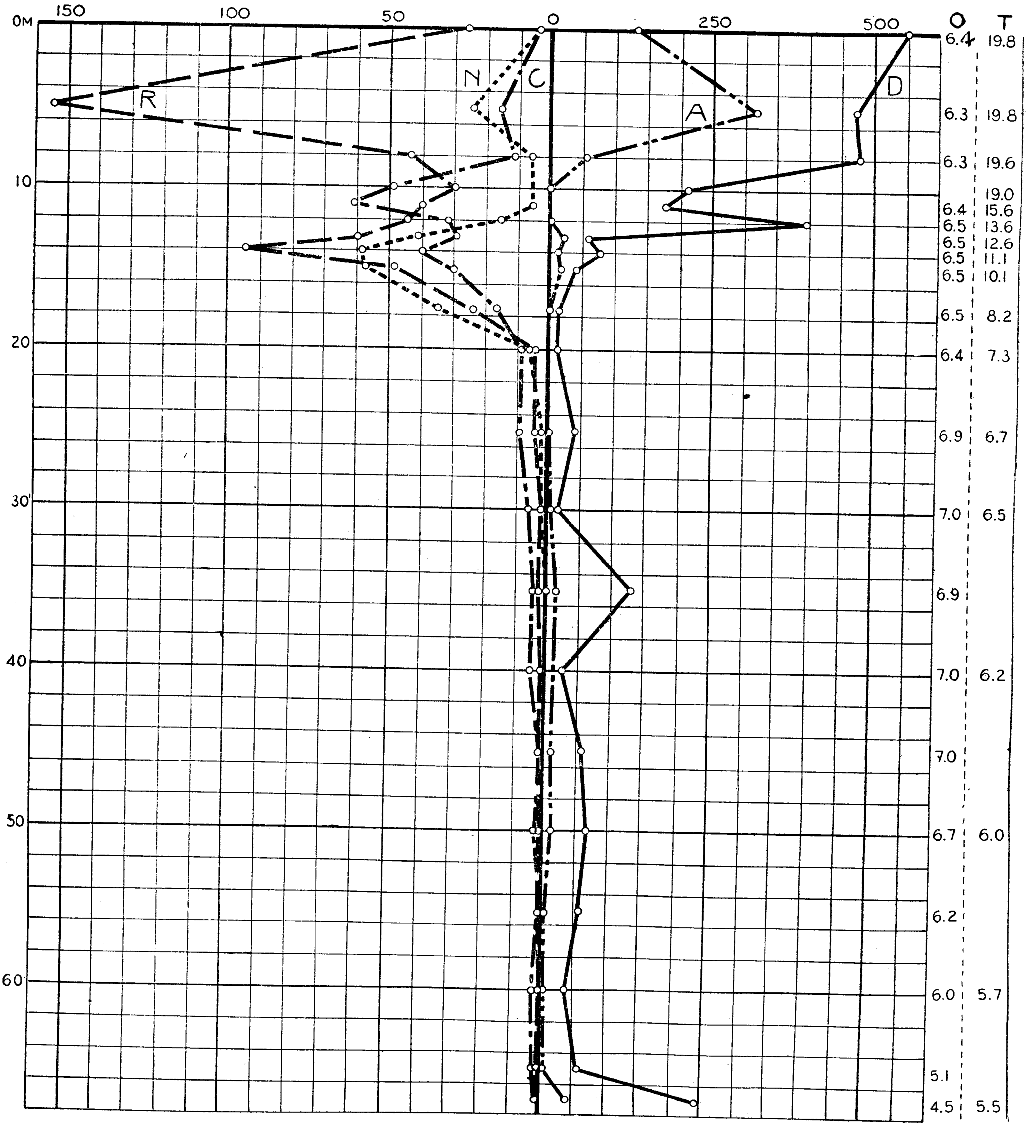

Fig. 118.—Vertical distribution of plankton organisms in Green lake, July 5, 1906. Scale, 1 horizontal space = 10 crustacea, nauplii, and rotifers per liter of water and 50 algae and diatoms. Synedra was the predominant diatom; Polyartha was by far the most abundant rotifer; and Diaptomus was the predominant crustacean. Note the small amount and uniform distribution of zooplankton below 20 m. See p. 117.

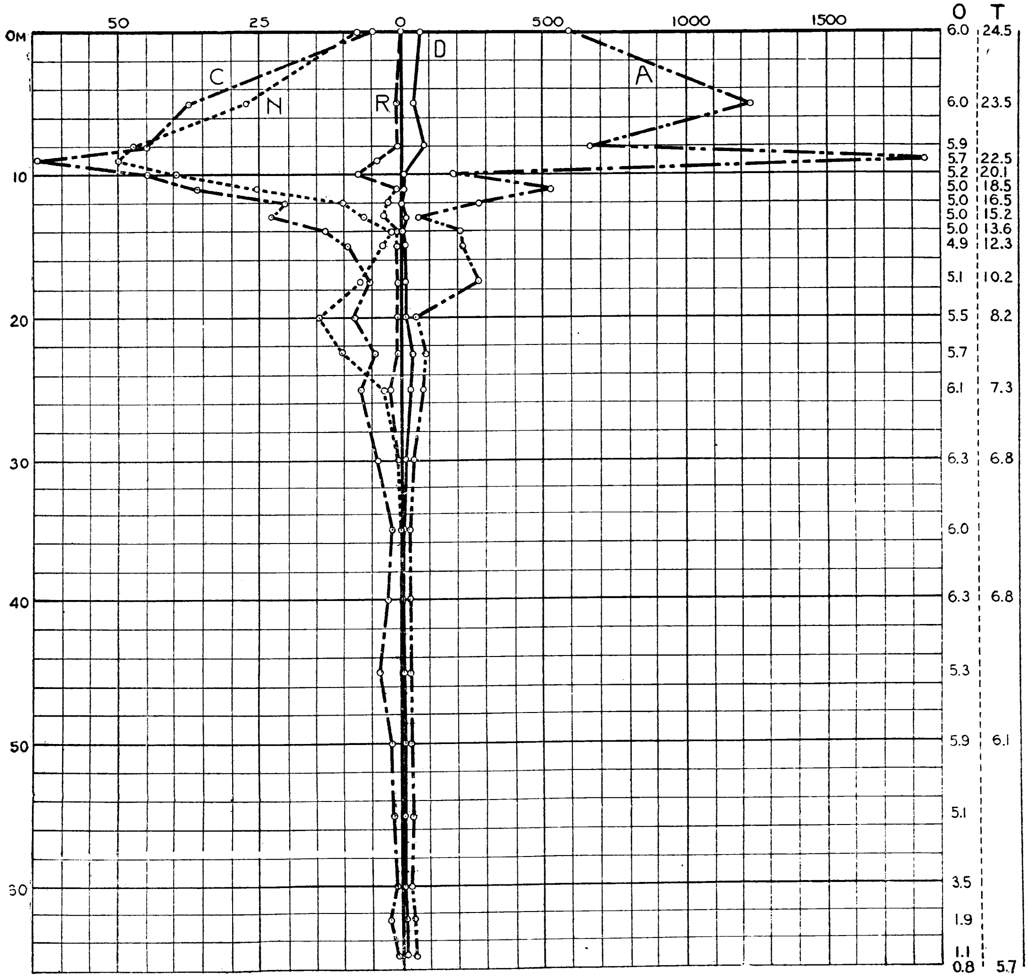

Fig. 119.—Vertical distribution of plankton organisms in Green lake, August 14, 1906, Scale, 1 horizontal space = 5 crustacea, nauplii, and rotifers per liter of water, and 500 algae and diatoms. The algae (besides diatoms) consisted almost entirely of Oscillatoria. Diaptomus was the predominant crustacean.

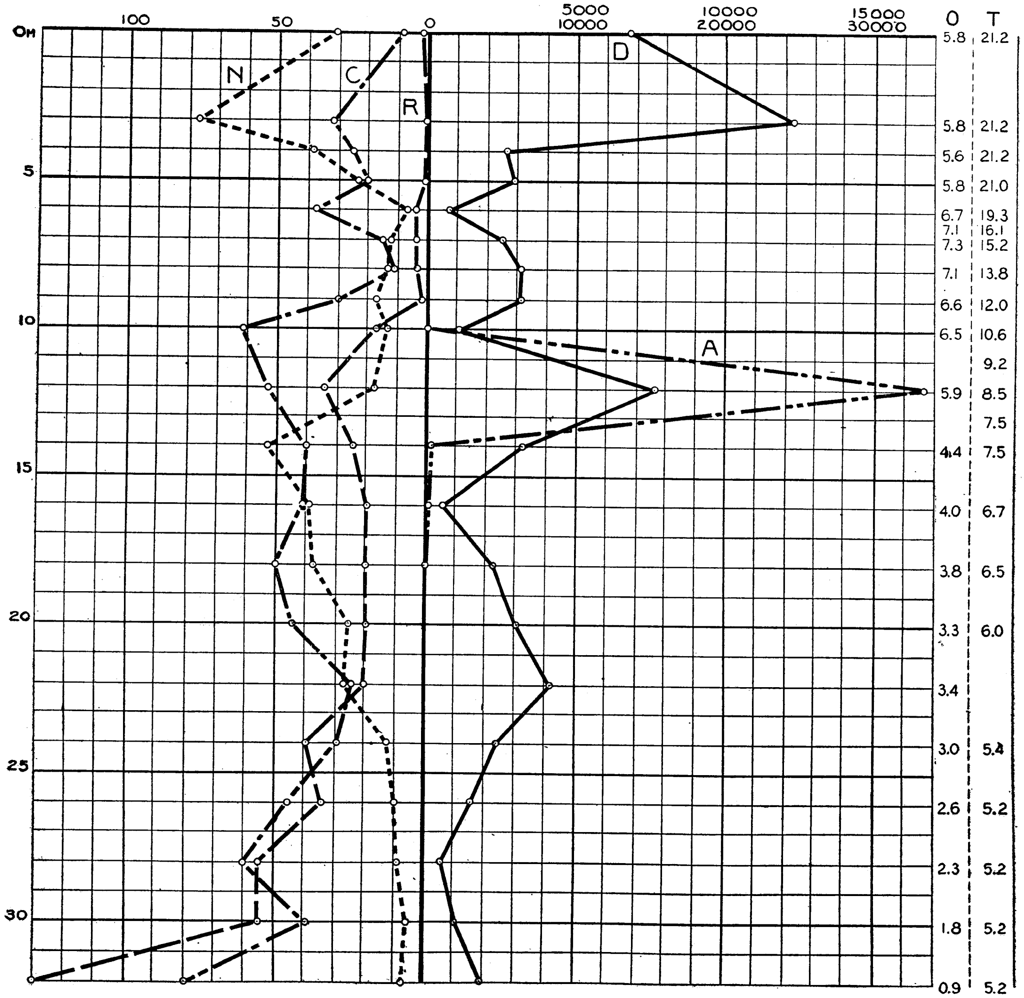

Fig. 120.—Vertical distribution of plankton organisms in Elkhart lake, July 3, 1906. Scale, 1 horizontal space = 10 crustacea, nauplii, and rotifers per liter of water, 2000 algae (practically all Oscillatoria) and 1000 diatoms. Predominant forms: Synedra, Notholca longispina, and Diaptomus. See p. 117.

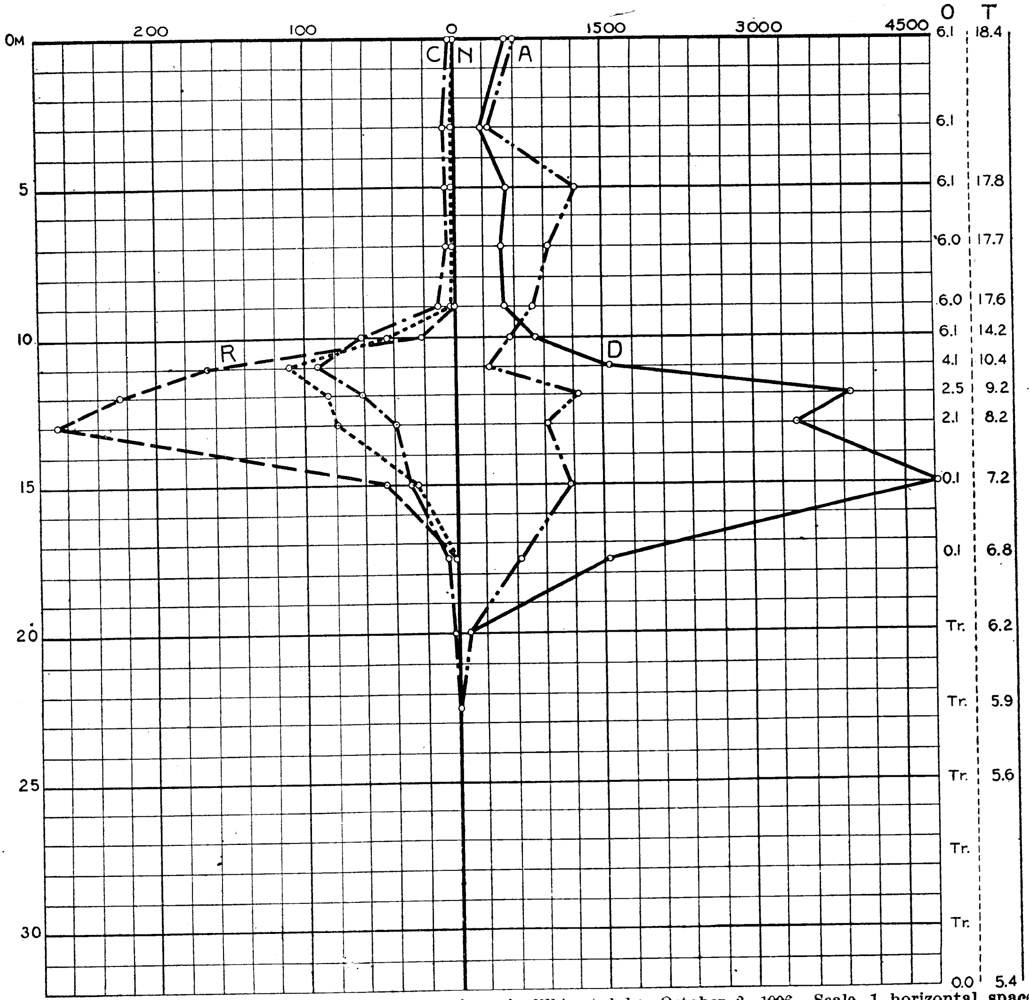

Fig. 121.—Vertical distribution of plankton organisms in Elkhart lake, October 2, 1906. Scale, 1 horizontal space = 20 crustacea, nauplii, and rotifers per liter of water and 300 algae and diatoms. Note the absence of plankton in the bottom water. Compare with fig. 120 both as to plankton and oxygen. Predominant forms: Microcystis, Synedra, Anuraea cochlearis, and Cyclops.

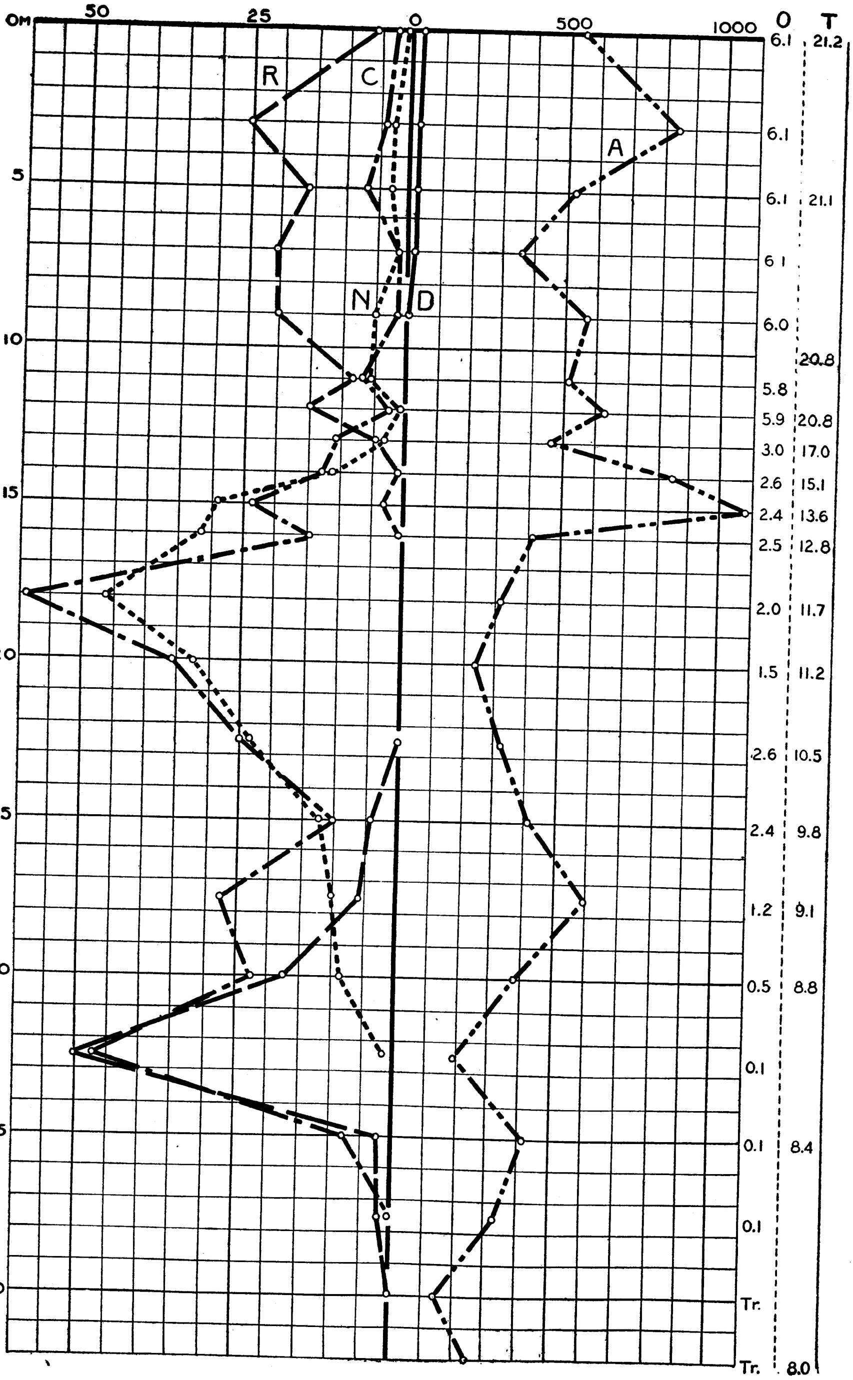

Fig. 122.—Vertical distribution of plankton organisms in lake Geneva, September 25, 1906. Scale, 1 horizontal space = 5 crustacea, nauplii, and rotifers per liter of water, and 100 algae. Note the absence of zooplankton in the bottom water. Predominant forms: Oscillatoria and Cyclops.. Asplanchna and Conochilus were the predominant rotifers in the upper water and Triarthra in the lower. See p. 117.

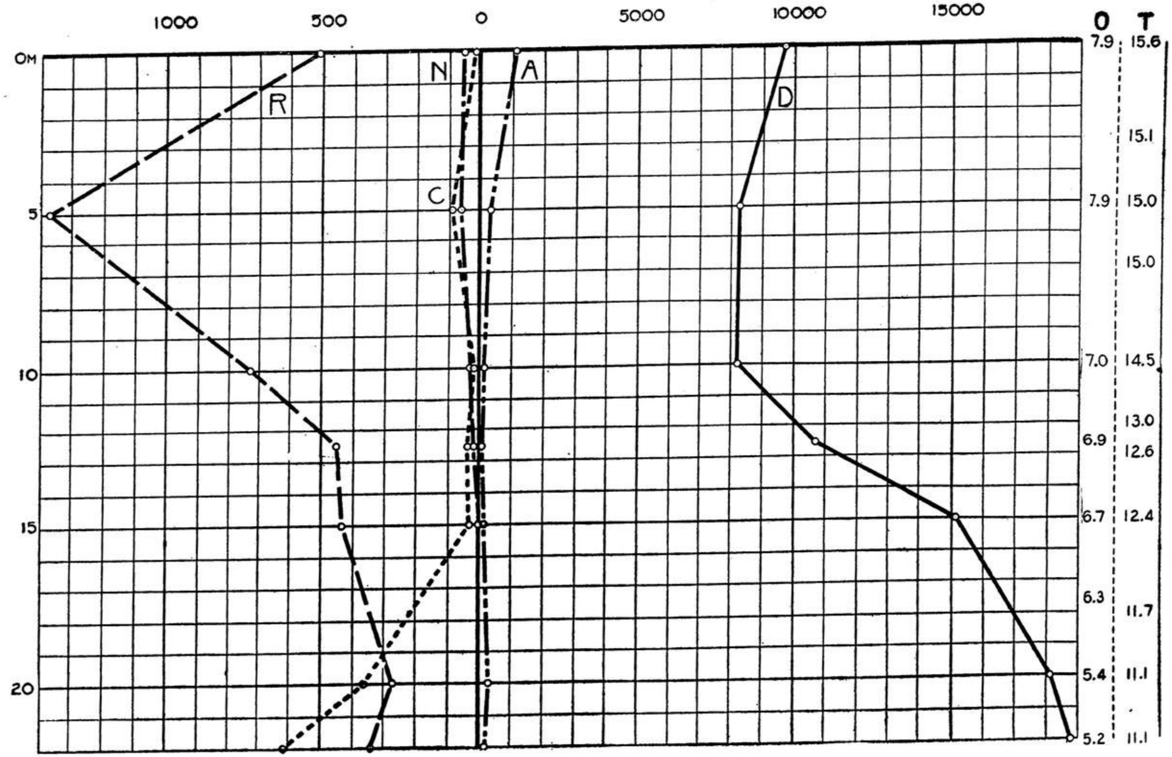

Fig. 123.—Vertical distribution of plankton organisms in lake Mendota, May 22, 1906. Scale, 1 horizontal space = 100 crustacea, nauplii, and rotifers per liter of water, and 1000 algae and diatoms. The following forms were most abundant: Tabellaria, Fragilaria, Cyclops, Anuraea aculeata, A. cochlearis, and Notholca longispina. See p. 118.

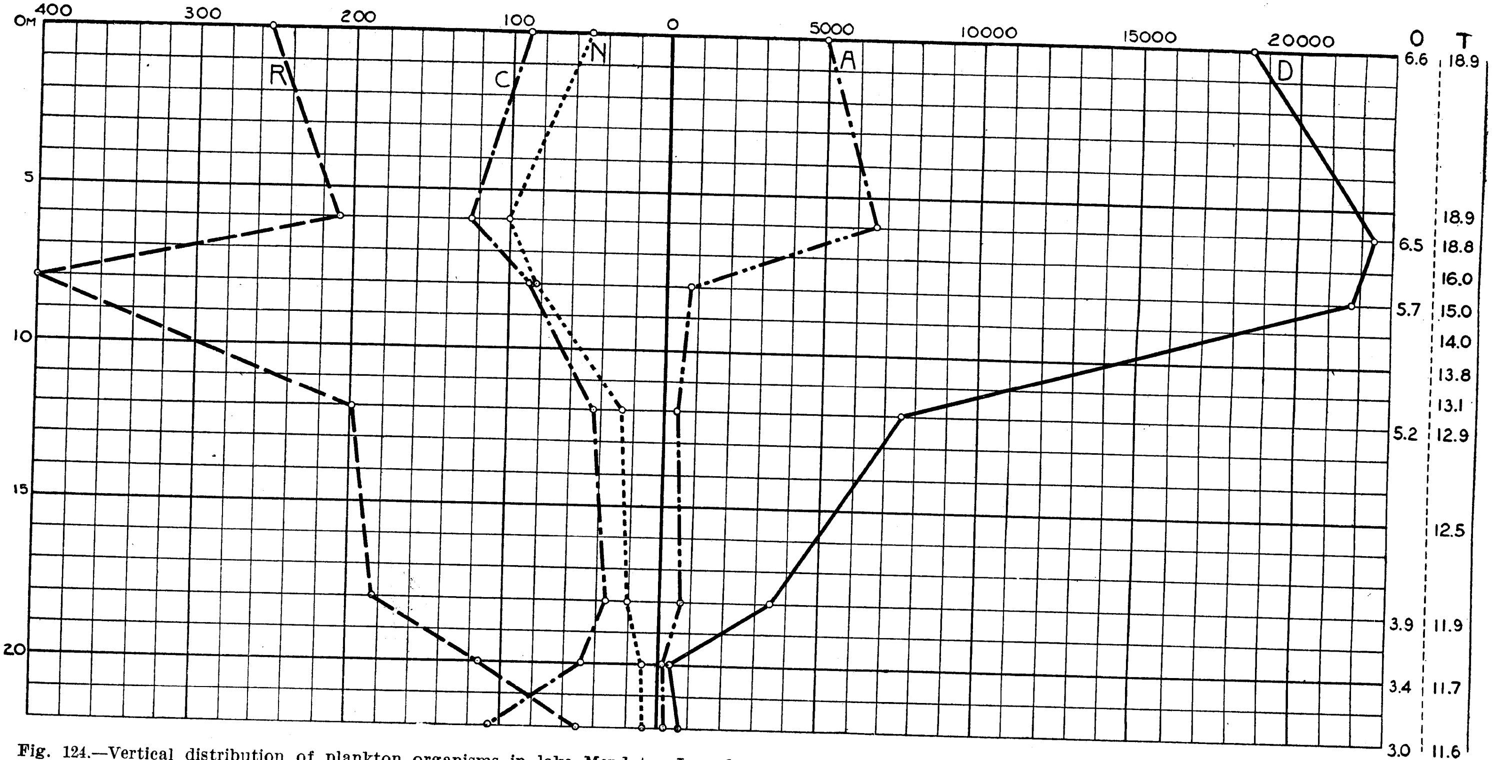

Fig. 124.—Vertical distribution of plankton organisms in lake Mendota, June 8, 1906. Scale, 1 horizontal space = 20 crustacea, nauplii, and rotifers per liter, and 1000 algae and diatoms. The predominant forms were Aphanizomenon, Melosira, Anuraea cochlearis; Daphne hyalina in the upper 8 m. and Cyclops below this depth.

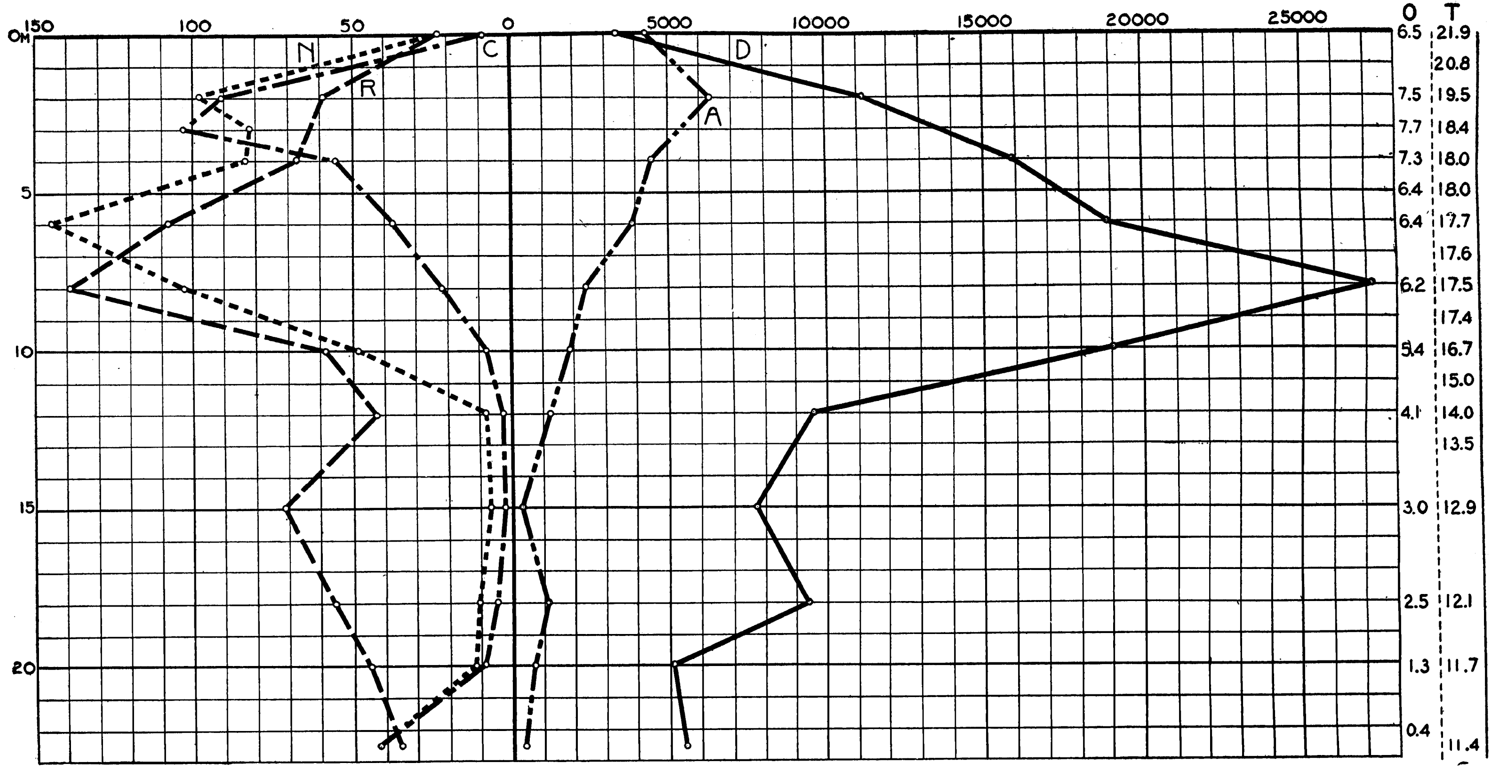

Fig. 125.—Vertical distribution of plankton organisms in lake Mendota, June 18, 1906. Scale, 1 horizontal space = 10 crustacea, nauplii, and rotifers per liter of water, and 1000 algae and diatoms. The predominant forms were Staurastrum, Fragilaria, Cyclops; Anuraea cochlearis in the upper 10 m. and Polyarthra thence to the bottom. See p. 118.

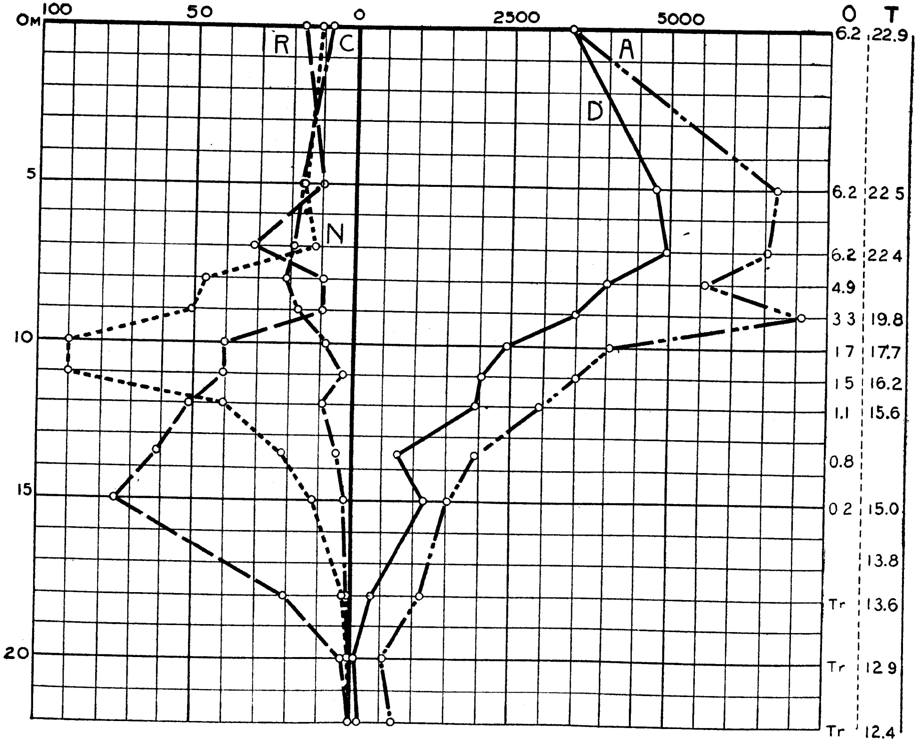

Fig. 126.—Vertical distribution of plankton organisms in lake Mendota, July 20, 1906. Scale, 1 horizontal space = 10 crustacea, nauplii, and rotifers per liter of water, and 500 algae and diatoms. Predominant forms: Staurastrum, Fragilaria, Cyclops, and Anuraea cochlearis which was responsible for the increased number of rotifers at 15 m.

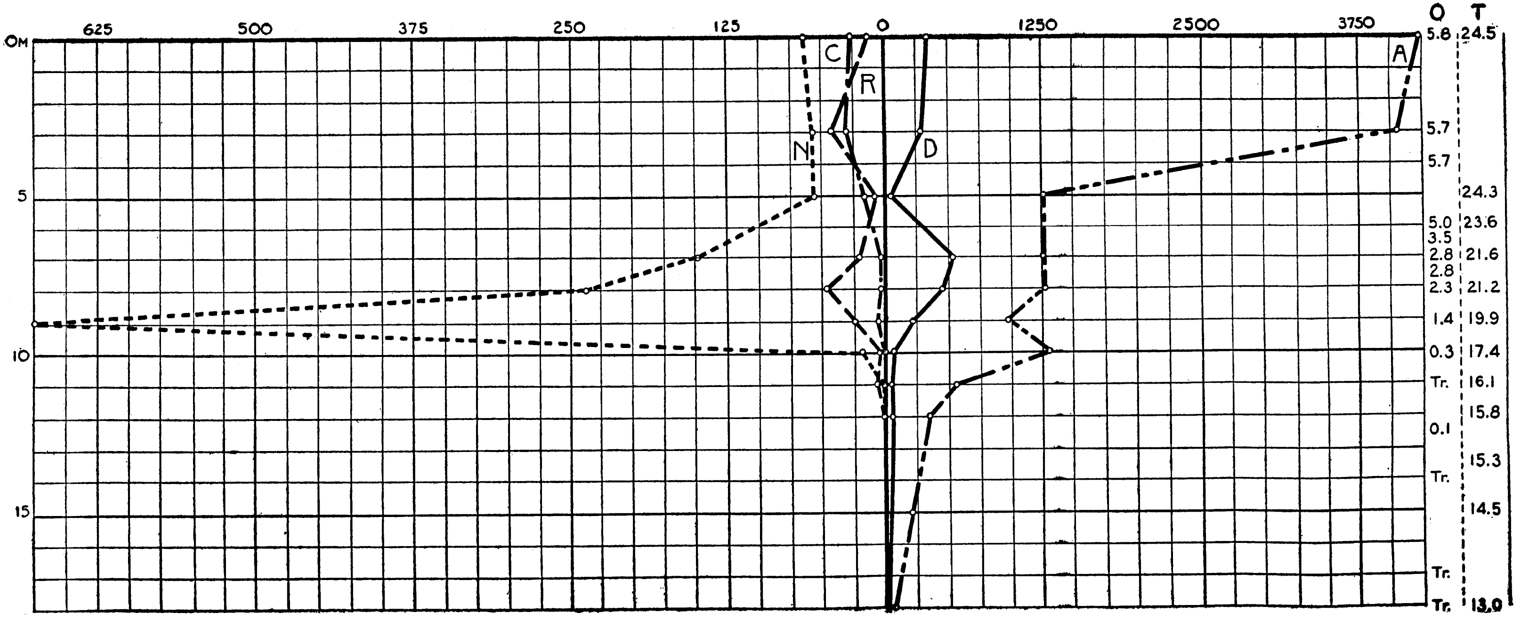

Fig. 127.—Vertical distribution of plankton organisms in lake Mendota, August 8, 1906. Scale, 1 horizontal space = 25 crustacea, nauplii, and rotifers per liter of water, and 250 algae and diatoms. Predominant algae: Lyngbya and Staurastrum. Note the large number of nauplii at 8 m. which was near the lower limit of habitable water for them. See p. 122.

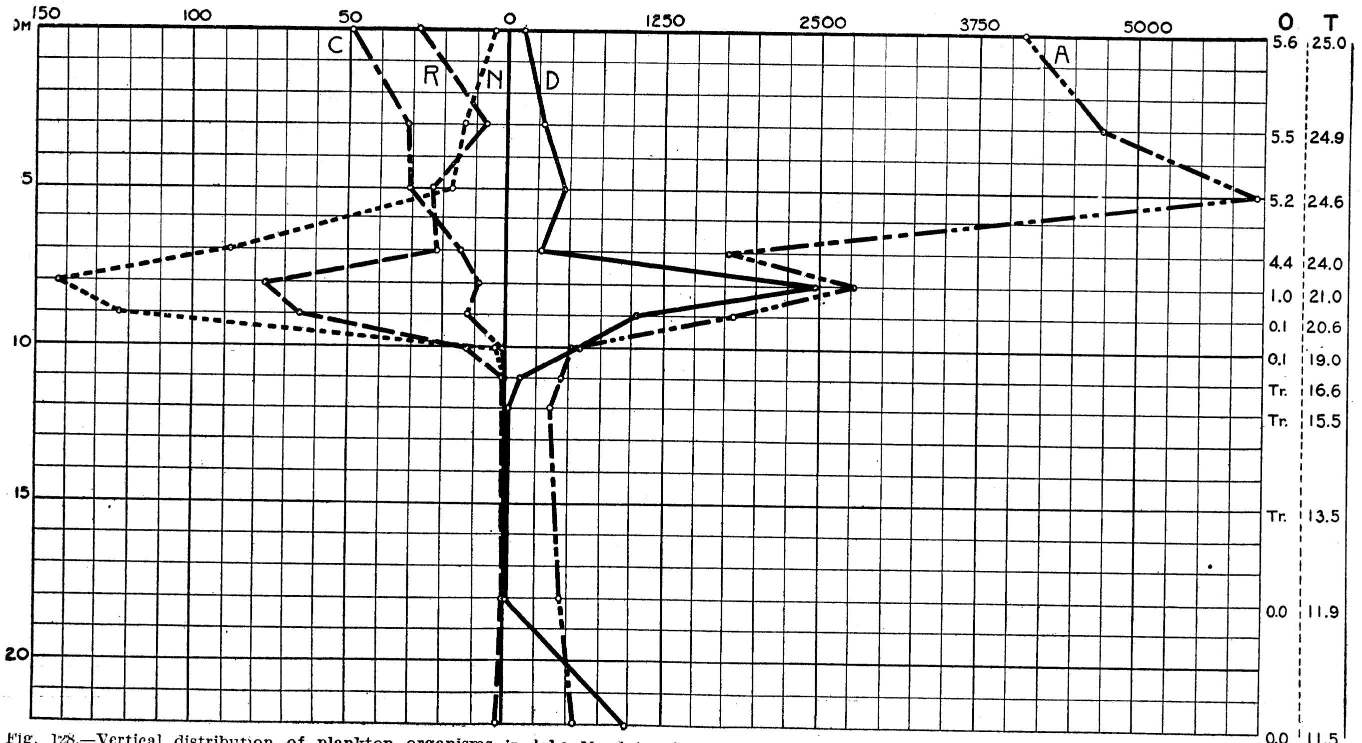

Fig. 128.—Vertical distribution of plankton organisms in lake Mendota. August 24, 1906. Scale, 1 horizontal space = 10 crustacea, nauplii, and rotifers per liter of water, and 250 algae and diatoms. Predominant forms: Ceratium, Staurastrum, Melosira, Anuraea cochlearis; Daphne hyalina in the upper 5 m. and Cyclops thence to the bottom.

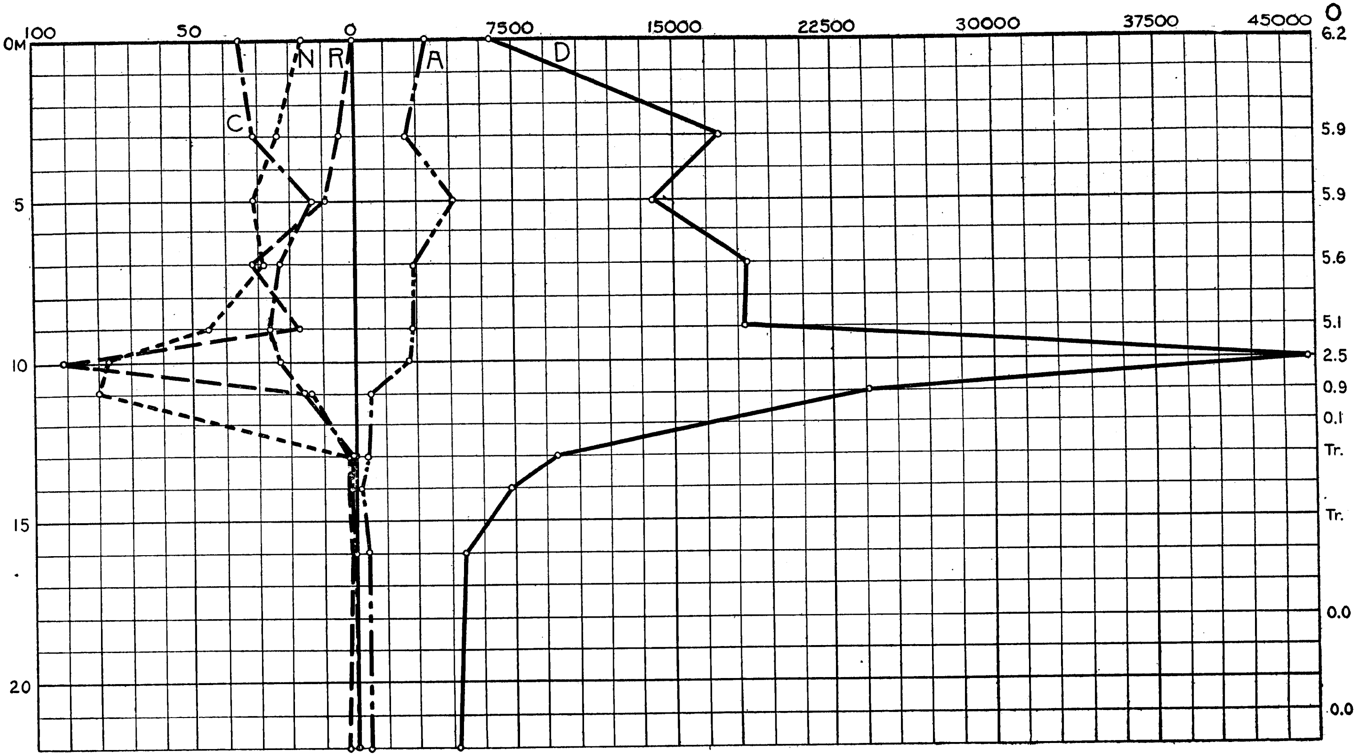

Fig. 129.—Vertical distribution of plankton organisms in lake Mendota, September 14, 1906. Scale, 1 horizontal space = 10 crustacea, nauplii, and rotifers per liter of water, and 1500 algae and diatoms. Predominant forms: Microcystis, Melosira (practically the only diatom), Polyarthra in the upper 7 m. and Anuraea cochlearis below this depth. The latter rotifer was responsible for the increase at 10 m. The crustacea were fairly evenly divided among the several forms represented. Note the increased number of nauplii at 10 m. and 11 m.

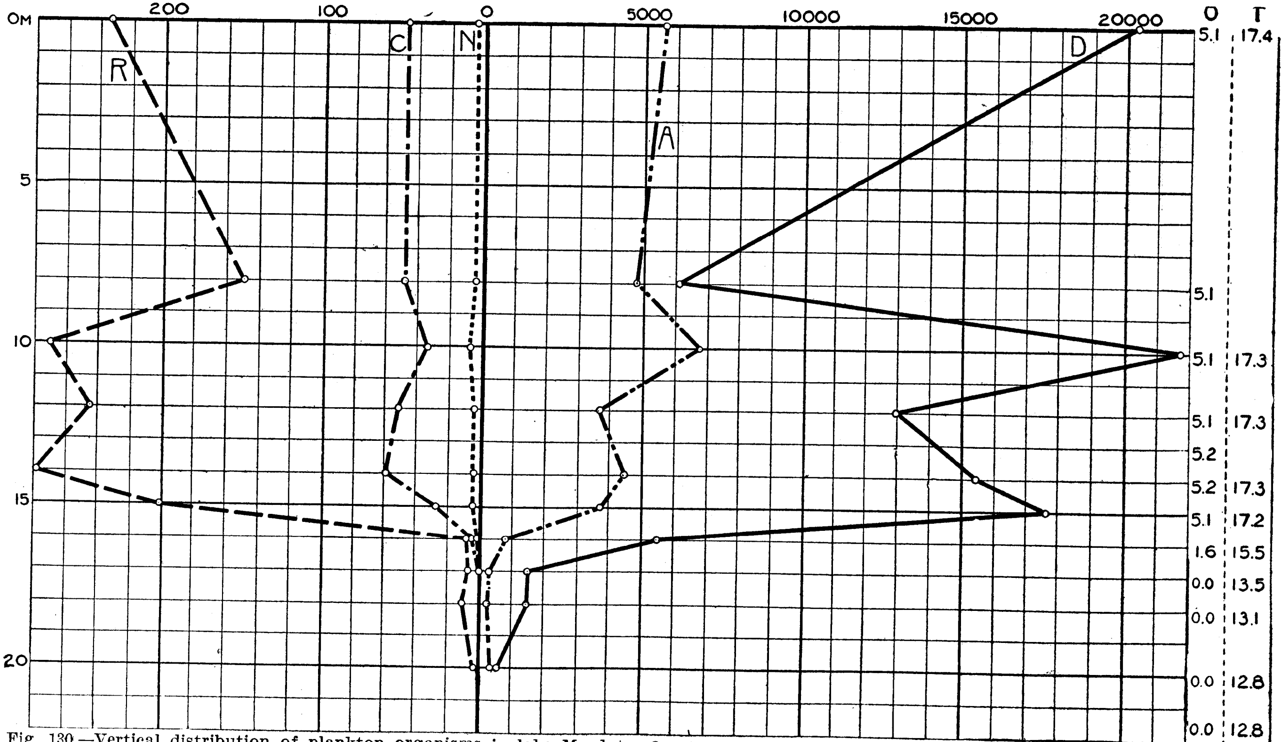

Fig. 130.—Vertical distribution of plankton organisms in lake Mendota, October 6, 1906. Scale 1 horizontal space = 20 crustacea, nauplii, and rotifers per liter of water, and 1000 algae and diatoms. Predominant forms: Coelosphaerium, Melosira, Anuraea cochlearis and Cyclops. Compare with figs. 128 and 129 and note that the habitable zone has advanced to a depth of about 16 m. See p. 120.

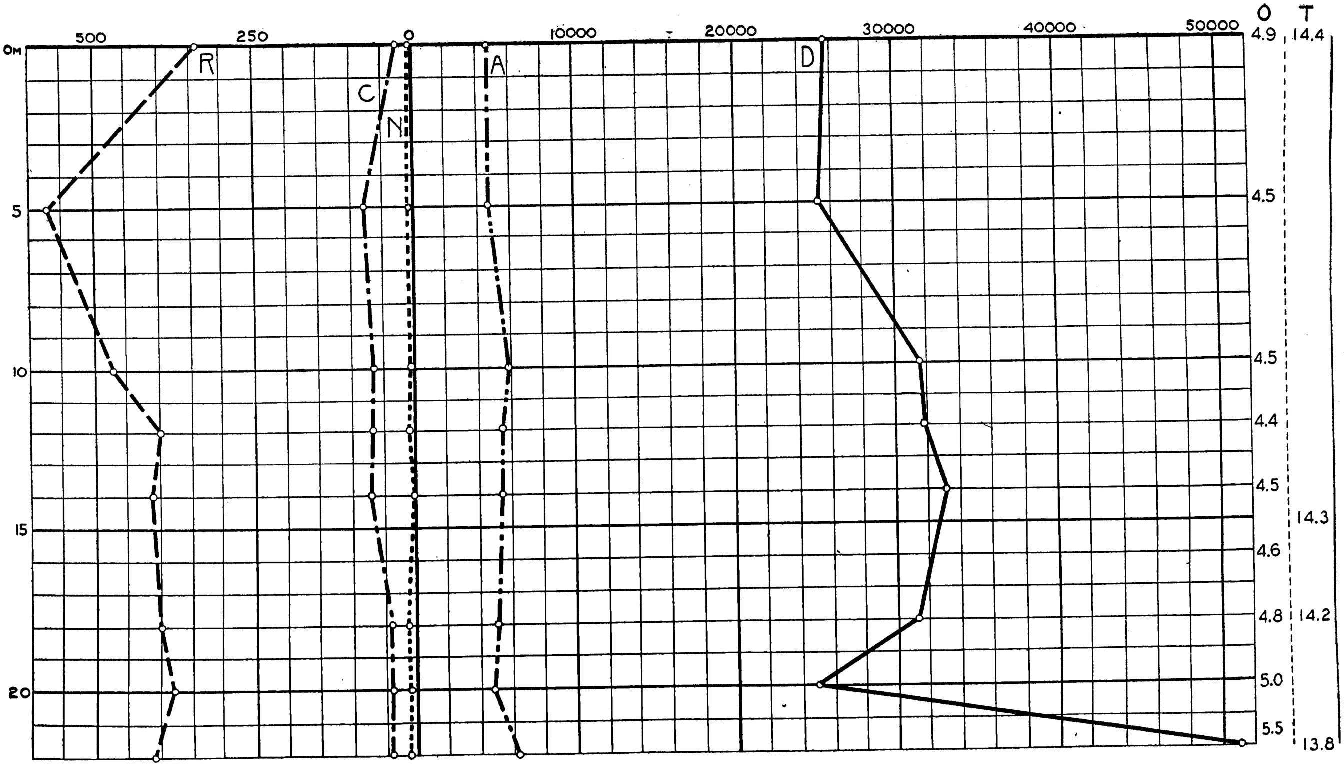

Fig. 131.—Vertical distribution of the plankton organisms in lake Mendota, October 11, 1906. Scale, 1 horizontal space = 50 crustacea, nauplii, and rotifers per liter of water, and 2000 algae and diatoms. This diagram shows the vertical distribution immediately after the autumnal overturn. The predominant forms were the same as in fig. 130.

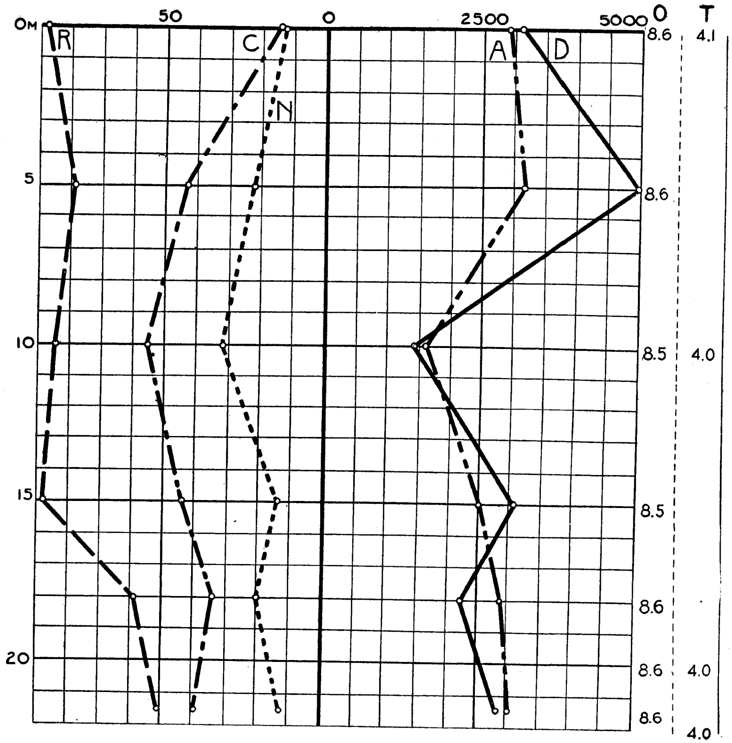

Fig. 132.—Vertical distribution of plankton organisms in lake Mendota, April 10, 1907. Scale, 1 horizontal space = 10 crustacea, nauplii, and rotifers per liter of water, and 500 algae and diatoms. Note the fairly uniform distribution produced by the vernal circulation of the water. Predominant forms: Aphanizomenon, Asterionella, Anuraea cochlearis, and Cyclops.

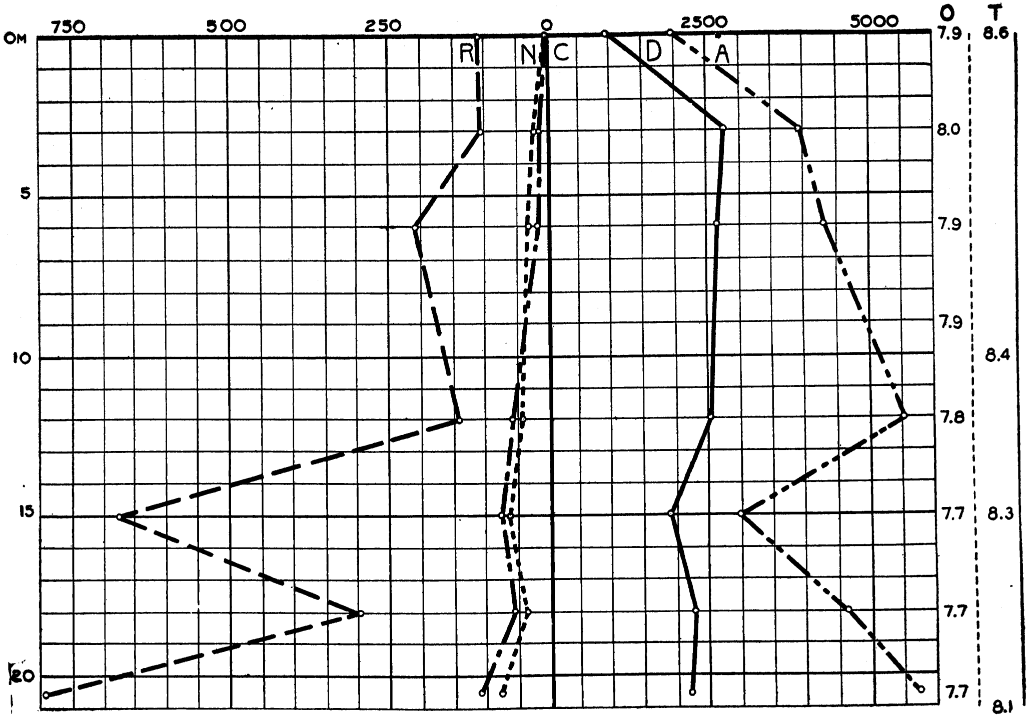

Fig. 133.—Vertical distribution of plankton organisms in lake Mendota, May 16, 1907. Scale, 1 horizontal space = 50 crustacea, nauplii, and rotifers per liter of water, and 500 algae and diatoms. Predominant forms: Aphanizomenon, Fragilaria, Anuraea cochlearis, and Cyclops. Compare with fig. 123 and note the difference in the number of algae and diatoms.

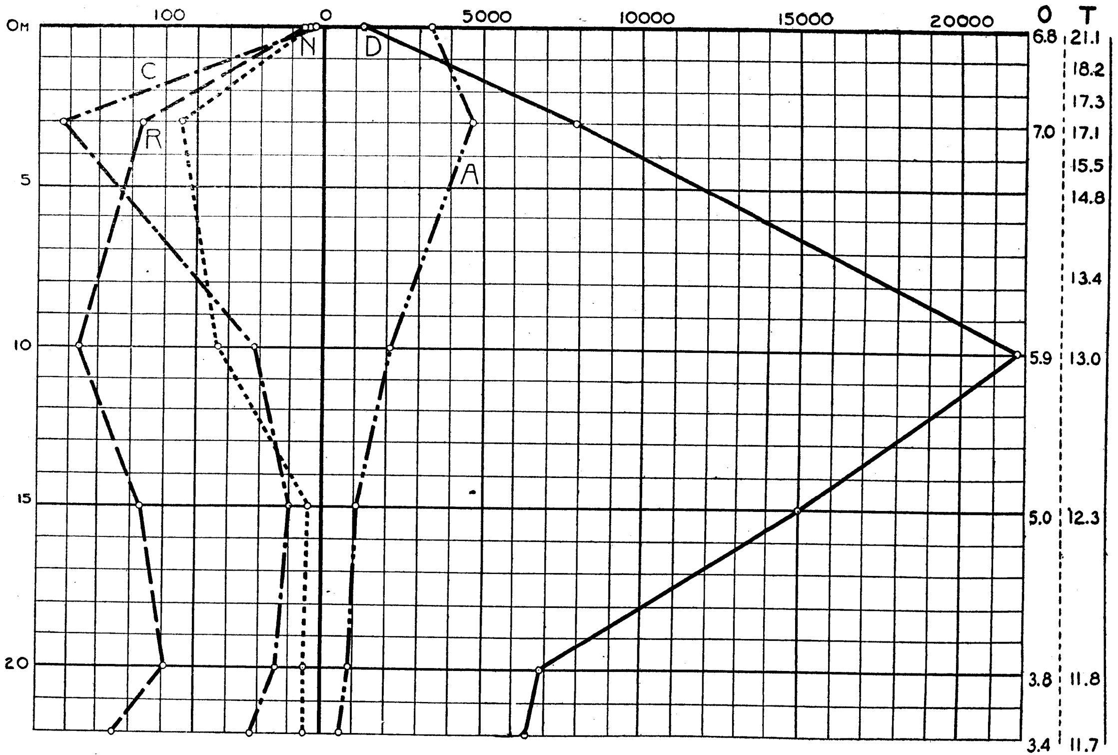

Fig. 134.—Vertical distribution of plankton organisms in lake Mendota, June 18, 1907. Scale, 1 horizontal space = 20 crustacea, nauplii, and rotifers per liter of water, and 1000 algae and diatoms. Predominant forms: Aphanizomenon, Pandorina, Tabellaria, Anuraea cochlearis, and Cyclops. Compare with fig. 125.

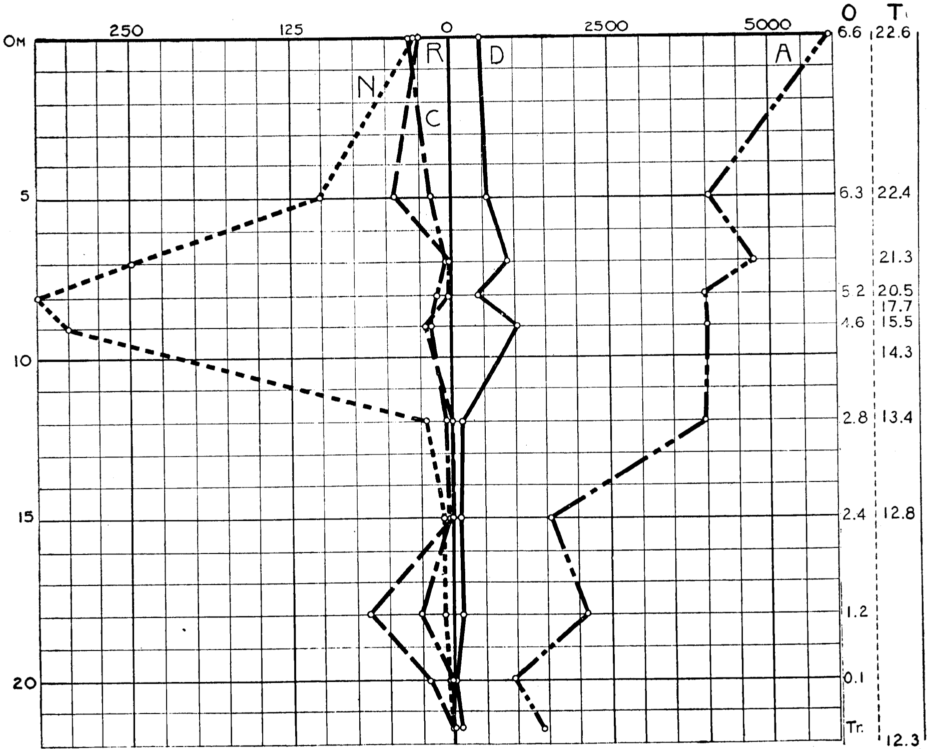

Fig. 135.—Vertical distribution of plankton organisms in lake Mendota, July 16, 1907. Scale, 1 horizontal space = 25 crustacea, nauplii, and rotifers per liter of water, and 500 algae and diatoms. Predominant forms: Coelosphaerium, Aphanizomenon, Tabellaria, Anuraea cochlearis, and Cyclops. Compare with fig. 134 and note decrease of diatoms.

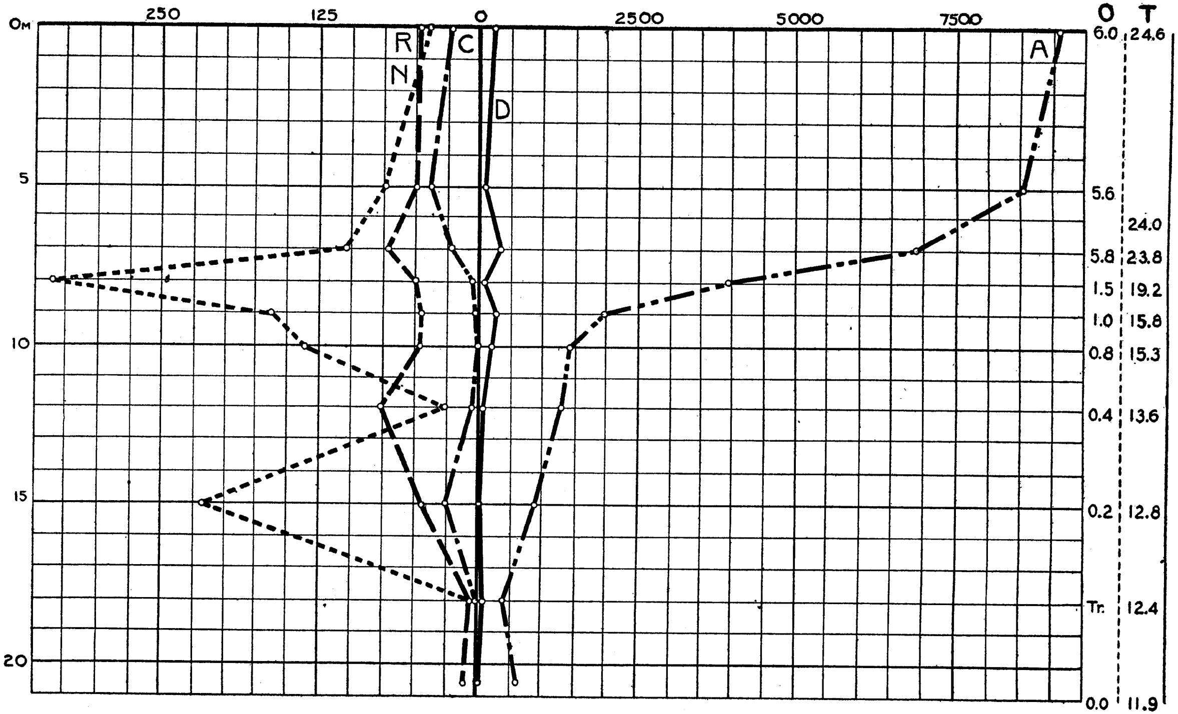

Fig. 136.—Vertical distribution of plankton organisms in lake Mendota, July 30, 1907. Scale, 1 horizontal space = 25 crustacea, nauplii, and rotifers per liter of water, and 500 algae and diatoms. Predominant forms: Lyngbya, Anuraea cochlearis, and Cyclops. Compare with fig. 126 and note the difference in the number of diatoms.

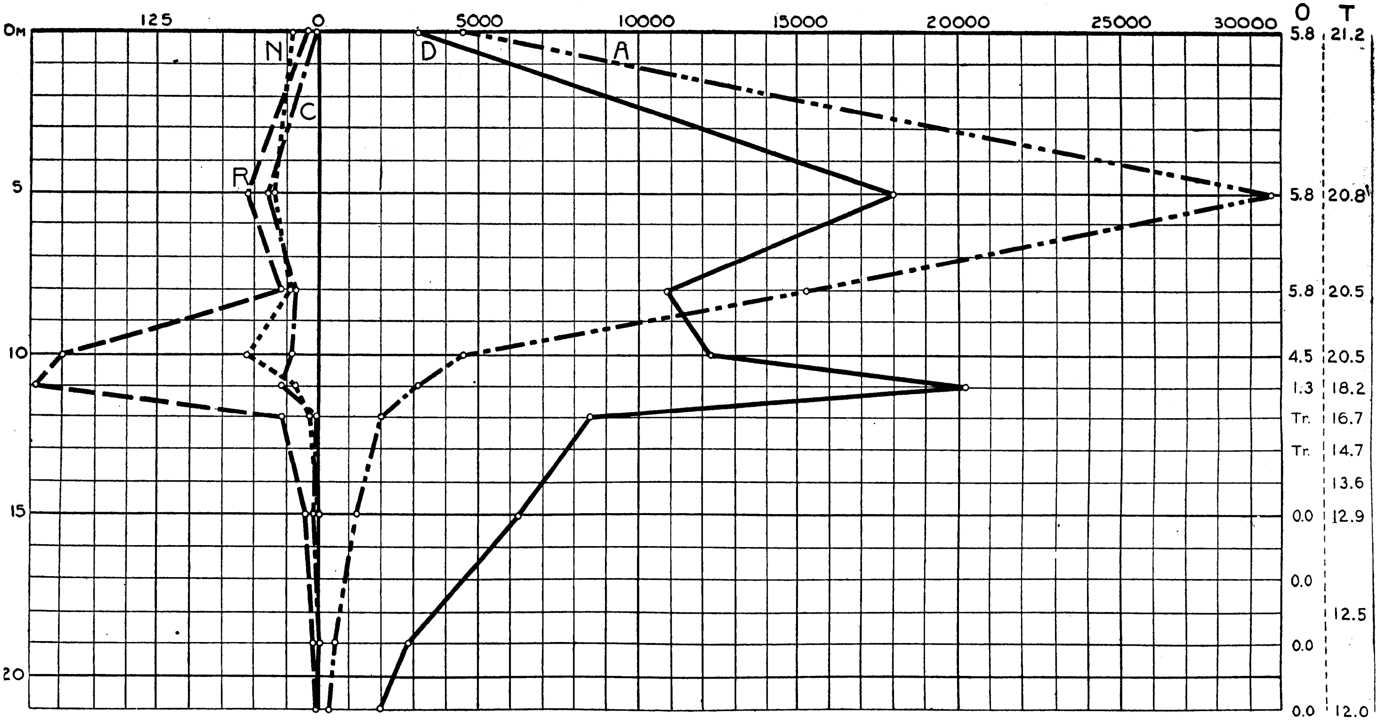

Fig. 137.—Vertical distribution of plankton organisms in lake Mendota. September 6, 1907. Scale, 1 horizontal space = 25 crustacea, nauplii, and rotifers per liter of water, and 1000 algae and diatoms. Predominant forms: Ceratium, Coelosphaerium, Anuraea cochlearis, Cyclops and Chydorus. Note the marked decrease in the number of diatoms in the 5-11 m. stratum, but no evidence of such a decrease appears in the other curves. Melosira was the predominant diatom and it was present in much smaller number at 8 m. and 10 m. than either above or below. See p. 120.

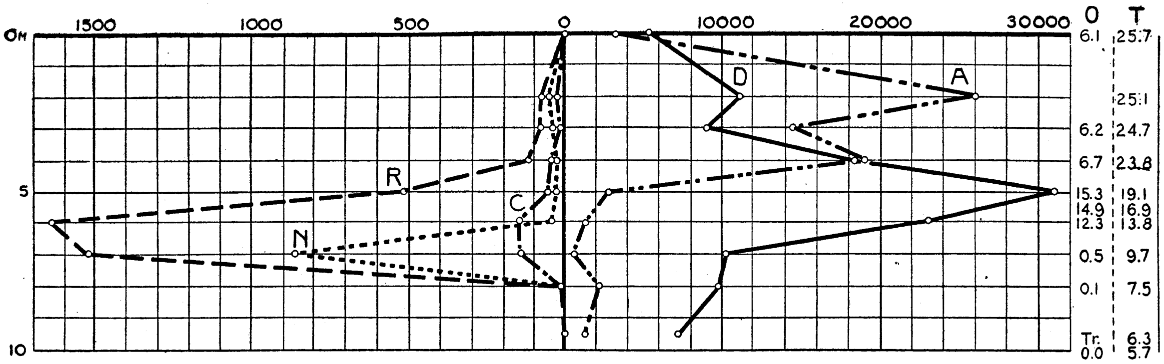

Fig. 138.—Vertical distribution of plankton organisms in Beasley lake, August 3, 1908. Scale, 1 horizontal space = 100 crustacea, nauplii, and rotifers per liter of water, and 2,000 algae and diatoms. Predominant forms: Aphanocapsa, Fragilaria, Dinobryon, Uroglena, Polyarthra, and Cyclops. The large number of rotifers at 6 m. and 7 m. consisted almost wholly of Polyarthra. See p. 120.

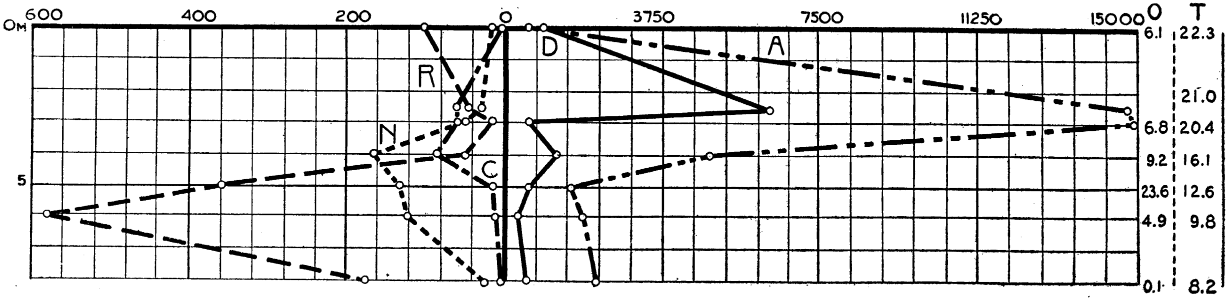

Fig. 139.—Vertical distribution of plankton organisms in Knights lake, August 14, 1909. Scale, 1 horizontal space = 40 crustacea, nauplii, and rotifers per liter of water, and 750 algae and diatoms. Predominant forms: Oscillatoria, Ceratium, Uroglena, and Tabellaria. Cyclops and Diaptomus averaged about the same in number and the marked rise in the number of rotifers at 6 m. was due chiefly to the presence of a large number of Polyarthra. See p. 129.

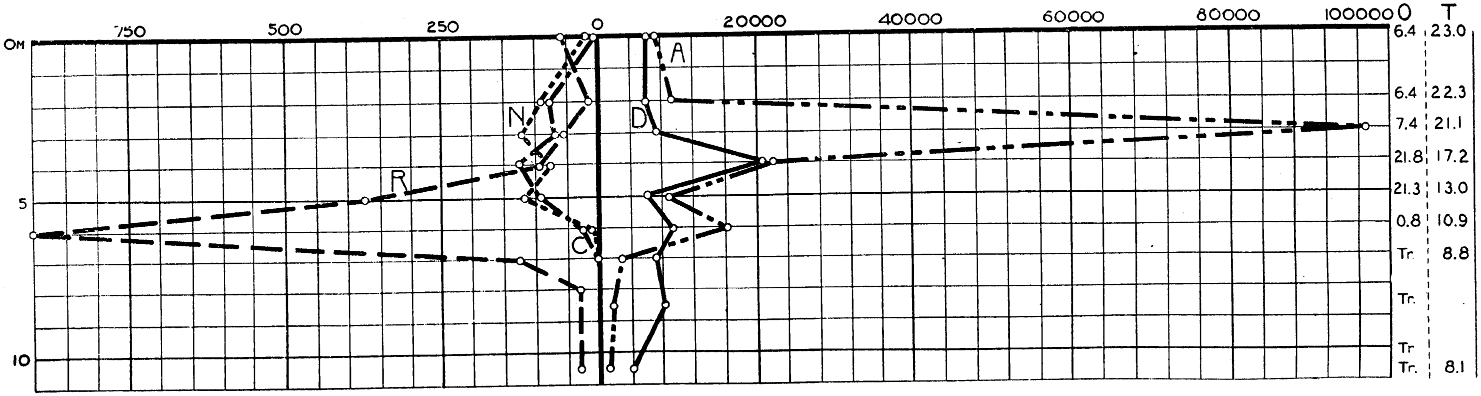

Fig. 140.—Vertical distribution of plankton organisms in Knights lake, August 25, 1909. Scale, 1 horizontal space = 50 crustacea, nauplii, and rotifers per liter of water, and 4,000 algae and diatoms. Predominant forms: Dinobryon, Uroglena, Tabellaria, and Cyclops. The rise in the rotifer curve at 6 m. was due to a marked increase in the number of Polyarthra, Anuraea aculeata, and A. cochlearis. Compare with fig. 139 and note the much larger number of algae. The maximum quantity of dissolved oxygen is correlated in depth with the maximum number of diatoms, but the maximum number of other algae is 1 m. above this depth.

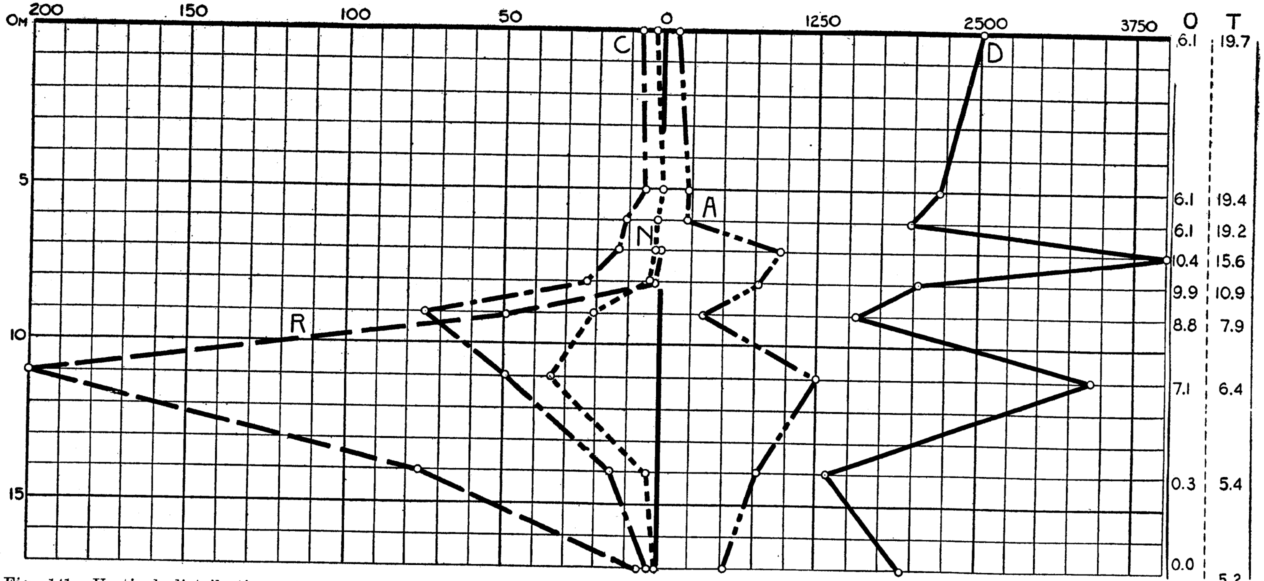

Fig. 141.—Vertical distribution of plankton organisms in Silver lake, August 21. 1907. Scale, 1, horizontal space = 10 crustacea, nauplii, and rotifers per liter of water, and 250 algae and diatoms. Predominant forms: Aphanocapsa, Ceratium, Asterionella, Anuraea cochlearis ,and Cyclops. See p. 54.

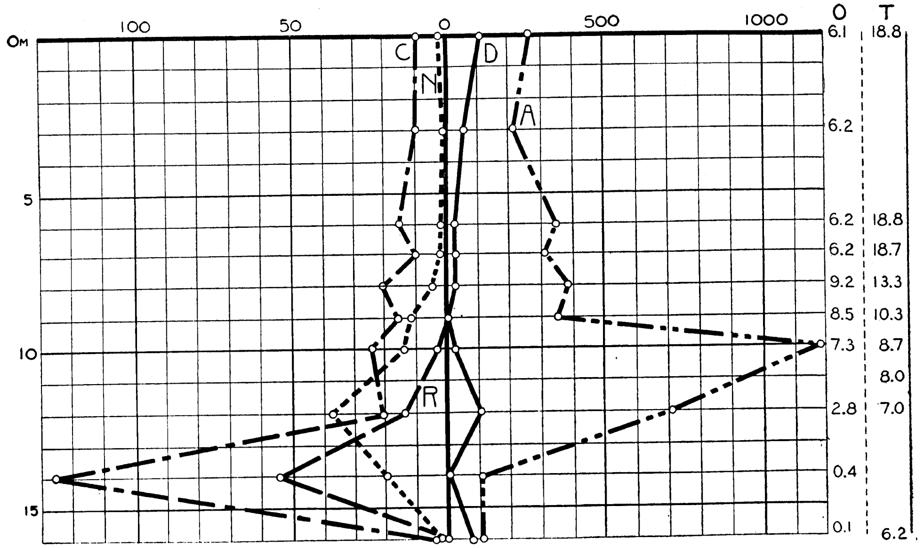

Fig. 142.—Vertical distribution of plankton organisms in Silver lake, August 28, 1908. Scale, 1 horizontal space = 10 crustacea, nauplii and rotifers per liter of water, and 100 algae and diatoms. Throughout most of the depth of the lake Aphanocapsa was the predominant alga. Dinobryon was chiefly responsible for the rise in the curve for algae at 10 m. Diaptomus was the predominant crustacean down to a depth of 12 m. and Cyclops below. Cyclops was responsible for the marked increase of crustacea at 14 m. Rotifers were not found in the upper water and the maximum number at 14 m. consisted chiefly of Anuraea brevispina. Compare with fig. 141 and note difference in the proportion of algae and diatoms.

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