PHYSICAL STUDIES OF LAKE TAHOE.—I.

HUNDREDS of Alpine lakes of various sizes, with their clear, deep, cold, emerald, or azure waters, are embosomed among the crags of the Sierra Nevada Mountains. The most extensive, as well as the most celebrated, of these bodies of fresh water is Lake Tahoe, otherwise called Lake Bigler.

This lake, the largest and most remarkable of the mountain lakes of the Sierra Nevada, occupies an elevated valley at a point where this mountain system divides into two ranges. It is, as it were, ingulfed between two lofty and nearly parallel ridges, one lying to the east and the other to the west. As the crest of the principal range of the Sierra runs near the western margin of this lake, this valley is thrown on the eastern slope of this great mountain system.

The boundary line between the States of California and Nevada makes an angle of about 131° in this lake, near its southern extremity, precisely at the intersection of the 39th parallel of north latitude with the 120th meridian west from Greenwich. Inasmuch as, north of this angle, this boundary line follows the 120th meridian, which traverses the lake longitudinally from two to four miles from its eastern shore-line, it follows that more than two-thirds of its area falls within the jurisdiction of California, the remaining third being within the boundary of Nevada. It is only within a comparatively recent period that the geographical co-ordinates of this lake have been accurately determined.

Its greatest dimension deviates but slightly from a meridian line. Its maximum length is about 21.6 miles, and its greatest width is about 12 miles. In consequence of the irregularity of its outline, it is difficult to estimate its exact area; but it cannot deviate much from 192 to 195 square miles.

The railroad surveys indicate that the elevation of the surface of its waters above the level of the ocean is about 6,247 feet.

Its drainage basin, including in this its own area, is estimated to be about five hundred square miles. Probably more than a hundred affluents of various capacities, deriving their waters from the amphitheater of snow-clad mountains which rise on all sides from 3,000 to 4,000 feet above its surface, contribute their quota to supply this lake. The largest of these affluents is the Upper Truckee River, which falls into its southern extremity.

The only outlet to the lake is the Truckee River, which carries the surplus waters from a point on its northwestern shore out through a magnificent mountain gorge, thence northeast, through the arid plains of Nevada, into Pyramid Lake. This river in its tortuous course runs a distance of over one hundred miles, and for about seventy miles (from Truckee to Wadsworth) the Central Pacific Railroad follows its windings. According to the railroad surveys, this river makes the following descent:

	Distance.		Fall.		Fall per Mile	
Lake Tahoe to Truckee....	14	Miles	401	Feet	28.64	Feet.
Truckee to Boca.............	8	"	313	"	39.12	"
Boca to State Line	11	"	395	"	35.91	"
State Line to Verdi..........	5	"	211	"	42 20	"
Verdi to Reno................	11	"	420	"	38 18	"
Reno to Vista	8	"	103	"	12.87	"
Vista to Clark's..............	12	"	141	"	11.75	"
Clark's to Wadsworth.......	15	"	186	"	12.40	"
Wadsworth to Pyramid Lake	18(?)	"	187(?)	"[1]	10 39	"
Lake Tahoe to Pyramid Lake	102	"	2357	"	23 11	"

[1] The elevation of Pyramid Lake above the sea-level has never, as far as we know, been accurately determined. Henry Gannet, in his "Lists of Elevations" (4th ed., Washington, 1877, p. 143), gives its altitude above the sea as 4,890 feet; and credits this number to the "Pacific Railroad Reports." But as this exact number appears in Fremont's "Report of Exploring Expedition to Oregon and North California in the years 1843–44" (Doc. No. 166, p. 217), it is probable that this first rude and necessarily imperfect estimate has been copied by subsequent authorities. This number is evidently more than 800 feet too great; for the railroad station at Wadsworth (about eighteen or twenty miles from the lake), where the line of the railroad leave the banks of the Truckee River, is only 4,077 feet above the sea-level. So that these numbers would make Pyramid Lake 813 feet above the level of its affluent at Wadsworth; which, of course, is impossible. Under this state of facts, I have assumed the elevation of this lake to be 3,890 feet.

There is little doubt but that this is the lake of which the Indians informed John C. Fremont, on the 15th of January, 1844, when he was encamped near the southern extremity of Pyramid Lake, at the mouth of Salmon-Trout, or Truckee, River. For he says, "They" (the Indians) "made on the ground a drawing of the river, which they represented as issuing from another lake in the mountains, three or four days distant, in a direction a little west of south; beyond which they drew a mountain; and farther still two rivers, on one of which they told us that people like ourselves traveled." (*Vide* "Report of Exploring Expedition to Oregon and North California in the years 1843–44." Document No. 166, p. 219.) Afterwards (February 14, 1844), when crossing the Sierra Nevada near Carson Pass, Fremont seems to have caught a glimpse of this lake; but deceived by the great height of the mountains on the east, he erroneously laid it down on the western slope of this great range, at the head of the south fork of the American River. It is evident, therefore, that the Indians had at that time a more accurate idea of the mountain topography than the exploring party. On Fremont's map the lake is laid down tolerably correctly as to latitude, but is misplaced towards the west about one-fourth of a degree in longitude; thus throwing it on the western slope of the Sierra Nevada, and making the head branches of the American River its outlets.

Few natural features of our country have enjoyed a greater diversity of appellations than this remarkable body of water. On Fremont's map it is called Mountain Lake; but on the general map of the explorations by Charles Preuss, it is named Lake Bonpland, in honor of Humboldt's companion. Under one of these names it appears, in its dislocated position, on all the maps published between 1844 and 1853. About the year 1850, after California began to be settled in its mountain districts, several "Indian expeditions" were organized by the military authorities of the State. It seems probable that this lake was first named Bigler by one of these "Parties of Discovery" (probably in 1851) from "Hangtown" (now Placerville), in honor of Governor John Bigler. Under the name of Lake Bigler it was first delineated in its trans-mountain position on the official map of the State of California, compiled by Surveyor-General William M. Eddy, and published in 1853; and thus the name became, for a time, established. From 1851 to 1863, this name seems to have been generally recognized; for it is so designated on the maps and charts of the United States prepared at Washington.

About the year 1862, the first mutterings of discontent in relation to the name by which this lake had been recently characterized came from the citizens of California. On two occasions it has been brought under the notice of the legislature of this State. During the thirteenth session (1862) of the legislature of California, Assemblyman Benton introduced a bill to change the name of "Lake Bigler." This bill was rejected. The friends of Governor Bigler did not hesitate to ascribe the desire to change the name of the lake to the inspiration of partisan animosity, intensified among the political opponents of the ex-governor by the state of feeling engendered during the progress of the Civil War.

During the session of the legislature of California for 1869–70, an act was passed to "legalize the name of Lake Bigler." (*Vide* "Statutes of California," 1869–70, p. 64.) Notwithstanding this statutory enactment, for the past ten years there has been a very strong tendency in the popular mind to call this lake by the name of Tahoe. On the map of California and Nevada published in 1874, it is still put down as Lake Bigler; but on the map of the same two States published in 1876, it has the double designation of "Lake Bigler or Tahoe Lake." At the present time this beautiful body of water seems to have entirely lost its gubernatorial appellation; for it is now almost universally called Lake Tahoe. It is so named on the "Centennial Map of the United States," compiled at the General Land Office at Washington, and likewise on the map of

California contained in the ninth edition of the "Encyclopædia Britannica," Article "California." Moreover, it is designated Lake Tahoe in the reports and maps of the Board of Commissioners of Irrigation, published in 1874, as well as in those of the "Water Supply of San Francisco," published in 1877. The cause of this change of name can hardly be sought for exclusively in the waning popularity of the worthy ex-governor, but rather in the following considerations: First, in the strong tendency of the American people to retain the old Indian names whenever they can be ascertained; second, in the instinctive aversion in the popular mind to the perpetuation of the names of political aspirants by attaching them to conspicuous natural features of our country; and third, in the fact that the State of Nevada designated its portion of said lake by the Indian name.

The meaning of the name Tahoe is by no means certain. It is usually said to be a Washoe Indian word, meaning, according to some, "Big-Water," according to others, "Elevated-Water," others, "Deep-Water," and others, "Fish-Lake." Whatever may be the meaning of this name, there can be no question but that the Washoe Indians designated this remarkable body of water by some characteristic name, long before the earliest pioneers of civilization penetrated into its secluded mountain recess.

During the summer of 1873, the writer embraced the opportunity afforded by a six weeks' sojourn on the shores of the lake to undertake some physical studies in relation to this largest of the "gems of the Sierra." Furnished with a good sounding-line and a self-registering thermometer, he was enabled to secure some interesting and trustworthy physical results.

(1.) *Depth.*—It is well known that considerable diversity of opinion has prevailed in relation to the actual depth of Lake Tahoe. Sensational newsmongers have unhesitatingly asserted that, in some portions, it is absolutely fathomless. It is needless to say that actual soundings served to dispel or to rectify this popular impression. The soundings indicated that there is a deep subaqueous channel traversing the whole lake in its greatest dimension, or south and north. Beginning at the southern end, near the Lake House, and advancing along the long axis of the lake directly north towards the Hot Springs at the northern end—a distance of about eighteen miles—we have the following depths:

Station.	Depth in Feet.	Depth in Meters.
1	900	274.32
2	1385	422.14
3	1495	455.67
4	1500	457.19
5	1506	459.02
6	1540	469.38
7	1504	458.41
8	1600	487.67
9	1640	499.86
10	1645	501.39

These figures show that this lake exceeds in depth the deepest of the Swiss lakes (the Lake of Geneva), which has a maximum depth of 334 meters. On the Italian side of the Alps, however, Lakes Maggiore and Como are said to have depths respectively of 796.43 and 586.73 meters. These two lakes are so little elevated above the sea that their bottoms are depressed 587 and 374 meters below the level of the Mediterranean.

Systematic soundings, such as would be required to furnish contour sections of the bed of the lake along various lines, could not be executed in row-boat excursions; while the time of the small steamers which navigated the lake could not be controlled for such purely scientific purposes. Operations in small boats could be carried on only during calm weather, and it required from thirty to forty minutes to execute a single sounding of fifteen hundred feet.

(2.) *Relation of Temperature to Depth.*—By means of a self-registering thermometer (Six's) secured to the sounding-line, a great number of observations were made on the temperature of the water of the lake at various depths and in different portions of the same. These experiments were executed between the 11th and 18th of August, 1873. The same general results were obtained in all parts of the lake. The following table contains an abstract of the average results, after correcting the thermometric indications by comparison with a standard thermometer:

Obs.	Depth in Feet.	Depth in Meters.	Temp. in F.°	Temp. in C.°
1	0=Surface.	0=Surface.	67	19.44
2	50	15.24	63	17.22
3	100	30.48	55	12.78
4	150	45.72	50	10.00
5	200	60.96	48	8.89
6	250	76.20	47	8.33
7	300	91.44	46	7.78
8	330 (Bottom)	100.58	45.5	7.50
9	400	121.92	45	7.22
10	480 (Bottom)	146.30	44.5	6.94
11	500	152.40	44	6.67
12	600	182.88	43	6.11
13	772 (Bottom)	235 30	41	5.00
14	1506 (Bottom)	459 02	39.2	4.00

It will be seen from the foregoing numbers that the temperature of the water decreases with increasing depth to about 700 or 800 feet (213 or 244 meters), and below this depth it remains sensibly the same down to 1,506 feet (459 meters). This constant temperature which prevails at all depths below say 250 meters is about 4° Cent. (39.2° Fah.). This is precisely what might have been expected; for it is a well-established physical property of fresh water, that it attains its maximum density at the above-indicated temperature. In other words, a mass of fresh water at the temperature of 4° Cent. has a greater weight under a given volume (that is, a cubic unit of it is heavier at this temperature) than it is at any temperature either higher or lower. Hence, when the ice-cold water of the snow-fed streams of spring and summer reaches the lake, it naturally tends to sink as soon as its temperature rises to 4° Cent.; and, conversely, when winter sets in, as soon as the summer-heated surface water is cooled to 4°, it tends to sink. Any further rise of temperature of the surface water during the warm season, or fall of temperature during the cold season, alike produces expansion, and thus causes it to float on the heavier water below; so that water at 4° Cent. perpetually remains at the bottom, while the varying temperature of the seasons and the penetration of the solar heat only influence a surface stratum of about 250 meters in thickness. It is evident that the continual outflow of water from its shallow outlet cannot disturb the mass of liquid occupying the deeper portions of the lake. It thus results that the temperature of the surface stratum of such bodies of fresh water for a certain depth fluctuates with the climate and with the seasons; but at the bottom of deep lakes it undergoes little or no change throughout the year, and approaches to that which corresponds to the maximum density of fresh water.

From the thermometric soundings executed by J. Y. Buchanan in two of the Scotch lakes during the winter of 1879, while they were covered with ice ("Nature," vol. 19, p. 412), some doubt was cast upon the validity of the "classic theory," that the beds of all deep fresh-water lakes are filled with water at the temperature of 4° (C.). But the more recent thermometric soundings of Professor F. A. Forel, on the "Temperature of Frozen Lakes" in Switzerland (*Comptes Rendus de l'Acad. des Sciences*, tome 90, p. 322, February 16, 1880), prove conclusively that the depths of the Scotch lakes were not sufficiently great to show the limit of superficial cooling, which descends to much greater depth than was supposed. Forel obtained the following results:

Lake of Morat, Area=27.4 Sq. Kilometers. Max. Depth=45 Meters. Feb. 1, 1880. Thickness of Ice=36 Centim.		Lake of Zurich, Area=87.8 Sq. Kilometers. Max. Depth=143 Meters. Jan. 25. 1880. Thickness of Ice=10 Centim.	
Depth in Meters.	Temp. in C.°	Depth in Meters.	Temp. in C.°
0	0.35°	0	0.20°
5	1.90	10	2.60
10	2.00	20	2.90
15	2.45	30	3.20
20	2.50	40	3.50
25	2.50	50	3 60
30	2.40	60	3.70
35	2.55	70	3.70
40	2 70	80	3.80
		90	3.80
		100	3.90
		110	3 90
		120	4.00
		133	4 00

It will be seen that the vertical propagation of cold into the upper layers of water descends to a depth of 110 meters in Lake Zurich. In this respect, it is analogous to the superficial heating of Lake Tahoe in summer; excepting that in the latter case (as might be expected) the solar radiation appears to penetrate to the greater depth of about 250 meters. The deepest thermometric sounding obtained by Buchanan was 65 English feet, or less than 20 meters.

Analogous results were obtained nearly a century ago (1779–84) from the observations of Horace Bénédict de Saussure, in the Swiss lakes, by means of a thermometer of his own invention. The following table contains De Saussure's results (*Ann. de Chim. et de Phys.*, 2d series, tome 5, p. 403, Paris, 1817):

Lake.	Month.	Temp. of Surface.	Depth in Meters.	Temp. at Depth.
Geneva........	August ..	21.20° C.	49	16.10° C.
"	February..	5.63 "	309	5.38 "
Constance.......	July	17.50 "	120	4.25 "
Brienz	July	20.00 "	162	4.75 "
Thun	July.....	18.75 "	114	5.00 "
Neufchatel......	July	23.10 "	106	5.00 "
Lucerne........	July	20.00 "	195	4.88 "
Bienne.........	July	20.70 "	71	6.37 "
Annecy	May......	14.38 "	53	5.63 "
Bourget........	October...	17 75 "	78	5.63 "
Maggiore	July.....	25.00 "	109	6.76 "

It is evident that the results of the experiments of the distinguished Swiss physicist, although executed with an imperfect thermometric instrument, in a general sense afford a striking confirmation of the deductions from my observations in relation to the distribution of temperature at different depths in the waters of Lake Tahoe.[1]

It will be observed, that most of the thermometric soundings of fresh-water lakes seem to indicate that the temperature of the deep waters—say below the depth of 150 to 200 meters—is from 1° to 1.5° (C.) above the point of maximum density of fresh water. Assuming these thermic determinations to be accurate, some physicists have speculated on the probable causes of this excess of temperature above that due to the well-known laws of density of fresh water. Two causes have been assigned to account for this presumed heating of the beds of deep lakes: (1) the internal heat of the earth, and (2) the direct and indirect influence of solar radiation. It seems to me, however, that the comparatively small excess of temperature of the deep waters above 4° (C.) is more probably due to the necessarily imperfect thermometric means of determining the temperatures of the deep-seated strata. It is well known that the disturbing influence of pressure frequently tends to render the indications of self-registering thermometers somewhat higher than they should be; and it is very difficult to apply the proper correction for the error due to pressure.

As we have already seen, the observations of H. B. de Saussure and of H. de la Bêche give temperatures at the greatest depths sensibly above 4° (C.). In like manner, the more recent thermometric soundings of C. de Fischer-Ooster and C. Brunner in the Lake of Thun, in 1848 and 1849, indicate in the deep layers an invariable temperature of about 5° (C.) (*Archives des Sci.*, tome 12, pp. 20 to 39, 1849). Similarly, the still more recent observations of F. A. Forel, in the Lake of Geneva in 1879, indicate an invariable deep-water temperature of about 5.2° (C.). The following table exhibits the details of Forel's thermometric soundings in this lake (*Archives des Sci. Phys. et Nat.*, 3d series, tome 3, pp. 501 to 516, June, 1880):

Thermometric Soundings of Forel in the Lake of Geneva in 1879.

Depth in Met'rs	Temp in May.	Temp in June.	Temp in July.	Temp in Aug.	Temp in Sept.	Temp in Oct.	Temp in Dec.	Tem. in Jan. 1880.
0	9.8° C	19.1°C	19.6°C	22.0°C	19.2°C	11.4°C	5.4° C	5.0°C
10	7.2	12.3	14 6	18.0	16.3	11.[illegible]	5.6	
20	7.0	8.7	13 8	12.7	12.2	11.0		
30	6.9	7.4	11.7	10.5	9.3	10.4		
40	6.8	6.6	7.9	7.6	7.6	8.4		
50	6.5	6.3	6.7	6.9	7.0	7.1		
60			6.3	6.2	6.4	6.6	5.6	
70	6.1	6.1	6.0	6.0	6.0			
80	5.9	5.8	5.8	5.8	5.7	6.2		
90	5.7	5.5	5.6	5.6	5.5	6.0		
100	5.5	5.4	5 5	5.5	5.4	5.8		
110	5.4	5.3	5.4			5.7	5.6	
120	5.3	5.3	5 3	5.4	5.3	5 6		
130		5.2	5 2	5 3	5.3	5.5		
140				5.3	5 3	5.4		
150					5.2	5.4	5.5	
160	5.2					5.3		
170						5.2		
200					5.2		5.3	
220	5.2							
240							5.3	
250							5.2	
260		5.2						
270							5.2	
300			5.2	5.2		5.2		

[1] Similar confirmatory results were obtained by Sir H. T. de la Bêche in 1819–20, by means of a self-registering minimum thermometer. Thus he found (*Ann. de Chim. et de Phys.*, 2d series, tome 19, p. 77 *et seq.*, Paris, 1821):

Lake.	Month.	Temp. of Surface.	Depth in Meters.	Temp. at Depth.
Geneva...	September..	19.5° Cent.	33	11 6° Cent.
" ...	"	19.5 "	52	7.3 "
" ...	"	19.5 "	62	6.6 "
" ...	"	19.5 "	146	6.4 "
" ...	"	19.5 "	241	6.4 "
" ...	"	19.5 "	300	6.4 "
Thun	....	15.6 "	192	5.3 "
Zug	....	14.4 "	70	5 0 "

On the other hand, some observers have found the deep waters of certain lakes to have temperatures as low as 4° (C.), and even lower. Thus, according to the observations of Professor F. Simony of Vienna, in two of the Alpine lakes of High Austria, from 1868 to 1875, at the depth of 190 meters, the temperature in the Lake of Gmünden varied from 4.75° to 3.95° (C.); and in the Lake of Atter, at the depth of 170 meters, the temperature varied from 4.6° to 3.7° (C.) (*Sitz. Ber. derk. Akad. d. Wiss. Wien*, 22 April, 1875, p. 104, as cited by Forel, *op. cit. supra*, p. 510). Moreover, we have already seen that the most recent observations of Professor Forel, on the "Frozen Lakes" in Switzerland in 1880, give the temperature of the deep strata as sensibly the same as that of the maximum density of fresh water.

It is evident that summer observations of Forel in the Lake of Geneva indicate a more rapid diminution of temperature with increasing depth in that lake than I found it to be in Lake Tahoe in the corresponding season of the year. This difference may possibly be due to the fact (which will hereafter appear) that the superior transparency of the waters of Lake Tahoe permits the heat-rays from the sun to penetrate to much greater depths than they do in the Lake of Geneva.

(3.) *Why the Water does not freeze in Winter.*—Residents on the shores of Lake Tahoe testify that, with the exception of shallow and detached portions, the water of the lake never freezes in the coldest winters. During the winter months, the temperature of atmosphere about this lake must fall as low, probably, as 0° Fah. (—17.78° Cent.). According to the observations of Dr. George M. Bourne, the minimum temperature recorded during the winter of 1873–74 was 6° Fah. (—14.44° Cent.). As it is evident that during the winter season the temperature of the air must frequently remain for days, and perhaps weeks, far below the freezing-point of water, the fact that the water of the lake does not congeal has been regarded as an anomalous phenomenon. Some persons imagine that this may be due to the existence of subaqueous hot springs in the bed of the lake—an opinion which may seem to be fortified by the fact that hot springs do occur at the northern extremity of the lake. But there is no evidence that the temperature of any considerable body of water in the lake is sensibly increased by such springs. Even in the immediate vicinity of the hot-springs (which have in summer a maximum temperature of 55° C. or 131 F.), the supply of warm water is so limited that it exercises no appreciable influence on the temperature of that portion of the lake. This is further corroborated by the fact that no local fogs hang over this or any other portion of the lake during winter, which would most certainly be the case if any considerable body of hot water found its way into the lake.

The true explanation of the phenomenon may, doubtless, be found in the high specific heat of water, the great depth of the lake, and in the agitation of its waters by the strong winds of winter. In relation to the influence of depth, it is sufficient to remark that, before the conditions preceding congelation can obtain, the whole mass of water—embracing a stratum of 250 meters in thickness—must be cooled down to 4° Cent.; for this must occur before the vertical circulation is arrested and the colder water floats on the surface. In consequence of the great specific heat of water, to cool such a mass of the liquid through an average temperature of 8° Cent. requires a long time, and the cold weather is over before it is accomplished. In the shallower portions, the surface of the water may reach the temperature of congelation, but the agitations due to the action of strong winds soon breaks up the thin pellicle of ice, which is quickly melted by the heat generated by the mechanical action of the waves. Nevertheless, in shallow and detached portions of the lake, which are sheltered from the action of winds and waves—as in Emerald Bay—ice several inches in thickness is sometimes formed.

The operation of similar causes prevents the deeper Alpine lakes of Switzerland from freezing under ordinary circumstances. Occasionally, however, during exceptionally severe and prolonged winters, even the deepest of the Swiss lakes have been known to be frozen. Thus, the Lake of Geneva (maximum depth 334 meters) was partially frozen in 1570, 1762, and 1805; the Lake of Constance (maximum depth 276 meters) was frozen in 1465, 1573, 1660, 1695, 1830, and 1880; the Lake of Neufchâtel (maximum depth 135 meters) was frozen in 1573, 1624, 1695, 1830, and 1880. The Lake of Zurich has been frequently frozen, and although its maximum depth is about 183 meters, yet it is well known that this narrow and elongated body of water is very shallow over a large portion of its area—a fact which sufficiently explains its greater liability to be frozen.

(4.) *Why Bodies of the Drowned do not Rise.*—A number of persons have been drowned in Lake Tahoe—some fourteen between 1860 and 1874—and it is the uniform testimony of the residents, that in no case, where the accident occurred in deep water, were the bodies ever recovered. This striking fact has caused wonder-seekers to propound the most extraordinary theories to account for it. Thus one of them says, "The water of the lake is purity itself, but on account of the highly rarefied state of the air it is not very buoyant, and swimmers find some little fatigue; or, in other words, they are compelled to keep swimming all the time they are in the water; and objects which float easily in other water sink here like lead." Again he says, "Not a thing ever floats on the surface of this lake, save and except the boats which ply upon it."

It is scarcely necessary to remark that it is impossible that the diminution of atmospheric pressure, due to an elevation of 6,250 feet (1,905 meters) above the sea-level, could sensibly affect the density of the water. In fact, the coefficient of compressibility of this liquid is so small that the withdrawal of the above-indicated amount of pressure (about one-fifth of an atmosphere) would not lower its density more than one one-hundred-thousanth part! The truth is, that the specific gravity of the water of this lake is not lower than that of any other fresh water of equal purity and corresponding temperature. It is not less buoyant nor more difficult to swim in than any other fresh water; and consequently the fact that the bodies of the drowned do not rise to the surface cannot be accounted for by ascribing marvelous properties to its waters.

The distribution of temperature with depth affords a natural and satisfactory explanation of this phenomenon, and renders entirely superfluous any assumption of extraordinary lightness in the water. The true reason why the bodies of the drowned do not rise to the surface is evidently owing to the fact that when they sink into water which is only 4° Cent. (7.2° Fah.) above the freezing temperature, the gases usually generated by decomposition are not produced in the intestines; in other words, at this low temperature the bodies do not become inflated, and therefore do not rise to the surface. The same phenomenon would doubtless occur in any other body of fresh water under similar physical conditions.

(5.) *Transparency of the Water.*—All visitors to this beautiful lake are struck with the extraordinary transparency of the water. At a depth of 15 or 20 meters (49.21 or 65.62 feet), every object on the bottom—on a calm sunny day—is seen with the greatest distinctness. On the 6th of September, 1873, the writer executed a series of experiments with the view of testing the transparency of the water. A number of other experiments were made August 28 and 29, under less favorable conditions. By securing a white object of considerable size—a horizontally adjusted dinner-plate about 9.5 inches in diameter—to the sounding-line, it was ascertained that (at noon) it was plainly visible at a vertical depth of 33 meters, or 108.27 English feet. It must be recollected that the light reaching the eye from such submerged objects must have traversed a thickness of water equal to at least twice the measured depth; in the above case, it must have been at least 66 meters, or 216.54 feet. Furthermore, when it is considered that the amount of light regularly reflected from such a surface as that of a dinner-plate, under large angles of incidence in relation to the surface, is known to be a very small fraction of the incident beam (probably not exceeding three or four per cent), it is evident that solar light must penetrate to vastly greater depths in these pellucid waters.[1]

Moreover, it is quite certain that if the experiments in relation to the depths corresponding to the limit of visibility of the submerged white disk had been executed in winter instead of summer, much larger numbers would have been obtained. For it is now well ascertained, by means of the researches of Dr. F. A. Forel of Lausanne, that the waters of Alpine lakes are decidedly more transparent in winter than in summer. Indeed, it is reasonable that when the affluents of such lakes are locked in the icy fetters of winter, much less suspended matter is carried into them than in summer, when all the sub-glacial streams are in active operation.

The experimental investigations of Professor F. A. Forel on the "Variations in the Transparency of the Waters" of the Lake of Geneva (*Archives des Sci. Phys. et Nat.*, tome 59, p. 137 *et seq.*, Juin, 1877), show that the water of this famous Swiss lake is far inferior in transparency to that of Lake Tahoe. Professor Forel employed two methods of testing the transparency of the waters of the Lake of Geneva at different seasons of the year. First, the direct method by letting down a white disk 25 centimeters in diameter (about the size of the dinner-plate used by me) attached to a sounding-line, and finding the depth corresponding to the limit of visibility. For the seven winter months, from October to April, he found from forty-six experiments, in 1874–75, a mean of 12.7 meters, or 41.67 English feet. And for the five summer months, from May to September, he found during the same years a mean of 6.6 meters, or 21.65 feet. The maximum depth of the limit of visibility observed by him was 17 meters, or 55.88 English feet, being a little more than half the depth found by me in Lake Tahoe early in the month of September.

The other method employed by Professor Forel was the indirect or photographic method. This consisted in finding the limiting depth at which solar light ceased to act on paper rendered sensitive by means of chloride of silver. If we assume that the same laws which regulate the penetration of the actinic rays of the sun are applicable to the luminous rays, this method furnishes a much more delicate means of testing the transparency of water; and especially of determining how deep the direct solar rays penetrate. Forel found the limit of obscurity for the chloride of silver paper in winter to be about 100 meters, and in summer about 45 meters; numbers (as we should expect) far exceeding those furnished by the limit of visibility of submerged white disks.[2] Assuming that the index of transparency of the water of Lake Tahoe is in winter no greater than twice that of the Lake of Geneva, it follows that during the cold season the solar light must penetrate the waters of the former to a depth of at least 200 meters.

From his admirable photometrical investigations, Bouguer estimated (*Traité d'Optique sur la Gradation de la Lumiere*, La Caille's ed., Paris, 1760) that in the purest sea-water, at the depth of 311 Paris feet, or 101 meters, the light of the sun would be equal only to that of the full moon, and that it would be perfectly opaque at the thickness of 679 Paris feet, or 220.57 meters. In relation to the comparative transparency of different waters, we may be permitted to cite a few results obtained by the method of depths

[1] According to the experiments of Bouguer, out of one thousand rays of light incident upon polished black marble, the following were the proportional numbers reflected at the several angles, measured from the surface of the marble:

At angle of 3° 35′	600	were reflected.
" 15°	156	" "
" 30°	51	" "
" 80°	23	" "

(*Traité d'Optique*, p. 125.)

[2] By employing paper prepared by means of the more sensitive bromide of silver, Asper found, in August, 1881, that the actinic rays of the sun were active in the Lake of Zurich even to the depth of 90 meters or more. This would extend the limit of obscurity for the bromide of silver paper in winter to about 200 meters.

corresponding to the limit of visibility of white disks. Even absolutely pure water is not perfectly transparent; it absorbs a certain amount of light, so that at a determinate depth it is opaque. The following table presents us comparative results, which may be of some interest:

Water.	Season.	Depth of visibility in Meters.		Observer.
Lake of Geneva	Summer.	5.30	Minimum	F. A. Forel.
" "	"	8.20	Maximum	"
" "	"	6.60	Mean	"
" "	Winter.	10.20	Minimum	"
" "	"	17.00	Maximum	"
" "	"	12.70	Mean	"
Lake Tahoe..	Summer.	33.00	Maximum	Nobis.
Pacific Ocean Wallis Island..	Summer.	40.00		Capt. Berard
Mediterranean near Civita Vecchia.	....	42.50		P. A. Secchi.
Atlantic	....	49.50		L. F. dePourtales.[1]

Inasmuch as our observations on the water of Lake Tahoe were made during the latter portion of August and the beginning of September, it seems probable, from Forel's results in the Lake of Geneva, that winter experiments would place the limit of visibility as deep if not deeper than Pourtalés found in the Atlantic Ocean. It may be proper to add that Professor Forel does not ascribe the variations in the transparency of the water of the Swiss lake with the season exclusively to the greater or less abundance of suspended matter; but also to the fact (which seems to be confirmed by the experiments of H. Wild) that increase of temperature augments the absorbing power of water for light. It is evident that this cause is more efficient in summer than in winter.

But the transparency of the waters occupying pools in certain limestone districts unquestionably far surpasses that of any of the Alpine lakes or any of the intertropical seas. The observations and experiments executed by the writer during his investigations in the month of December, 1859, in relation to "The Optical Phenomena Presented by the Silver Spring," in the State of Florida (*Vide Proc. Am. Assoc. Adv. of Sci.*, vol. 14, p. 33–46, Aug., 1860; also, *Am. Jour. Sci.*, 2nd series, vol. 31, p. 1–12, Jan., 1861), indicated a degree of transparency in the water surpassing anything which can be imagined. The depth of this remarkable pool varied, in different portions, from 30 to 36 English feet, or from 9.14 to 10.97 meters. Yet "every feature and configuration of the bottom of this gigantic basin was almost as distinctly visible as if the water was removed and the atmosphere substituted in its place"! "The sunlight illuminated the sides and bottom of this remarkable pool nearly as brilliantly as if nothing obstructed the light. The shadows of our little boat, of our overhanging heads and hats, of projecting crags and logs, of the surrounding forests, and of the vegetation at the bottom were distinctly and sharply defined." The experiments in relation to the vertical depth at which printed cards could be read when viewed vertically afforded a good illustration of the extraordinary transparency of these waters. Comparative experiments in relation to the distances at which the same cards could be read in the air showed that, when the letters were of considerable size—say six to seven millimeters or more in length—on a clear and calm day they could be read at about as great a vertical distance beneath the surface of the water as they could be in the atmosphere. But it would be a grave error to imagine that these results indicate that sunlight undergoes no greater diminution in traversing a given thickness of this water than in passing through an equal stratum of air. For, in both cases, when the cards are strongly illuminated, the reading distance is limited by the smallness of the images of the letters on the retina, and not by the amount of light reaching the eye. Never-

[1] So few exact observations have been made on the transparency of sea-water that it may be proper to add the following results obtained by Captain Duperrey during the "Voyage de la Coquille." The apparatus employed consisted of a circular board sixty-six centimeters in diameter, painted white, to which a weight was attached and so adjusted that when let down by a line the white disk descended horizontally in the water. (*Vide Œuvres Complètes de François Arago*, 2d ed., tome 9, p. 203, Paris, 1865.)

Place.	State of Weather.	Date of Obs.	Limit of Visibility.
Offak.	Calm and Cloudy	Sept. 13.	18 Meters.
Offak.	Calm and Clear	Sept. 14.	23 "
Port Jackson.	Calm	Feb. 12 and 13	12 "
Island Acension	Favorable	Jan. (11 Expts)	9 to 12 "

theless, these experiments prove conclusively that at the depth of ten meters the illumination was sufficiently intense to secure this limiting condition, and thus serve to convey a more distinct idea of the wonderful diaphanous properties of these waters than any verbal description. The experiments were executed about noon at the winter solstice (lat. 29° 15′ north), and were made on various sized letters, and at depths varying from two to ten meters.

It would be exceedingly interesting to test the transparency of the waters of similar springs in limestone districts, by the limit of visibility of white disks, where the depth is sufficiently great to admit of the application of this method. The famous fountain situated about ten or fifteen miles south of Tallahassee, in the State of Florida, called Wakulla Spring, is represented to be deeper than the Silver Spring, and to be equally transparent. But we have as yet no trustworthy measurements or observations in relation to the comparative diaphanous properties of the waters of other limestone pools.[1]

It only remains to indicate the causes which produce the extraordinary transparency of the waters occupying the Silver Spring. It may be remarked that these diaphanous properties are perennial; they are not in the slightest degree impaired by season, by rain or drought. The comparatively slight fluctuations in the level of the water in the pool, produced by the advent of the rainy season, are not accompanied by any turbidity of its waters. At first sight it may seem paradoxical that, in a country where semi-tropical rains occur, the waters of this spring should not be rendered turbid by surface drainage. But the whole mystery vanishes when we consider the peculiar character of the drainage of this portion of Florida. Although the surface of the country is quite undulating, or rolling, the summits of many of the hills being thirty or forty feet above the adjacent depressions, yet there is no surface drainage; there is not a brook or rivulet to be found in this part of the State. The whole drainage is subterranean; even the rain-water which falls near the banks of the pool, and the bold stream constituting its outlet, pass out by underground channels. There is not the slightest doubt but that all of the rain-water which falls on a large hydrographic basin passes down by subterraneous channels, and boils up and finds an outlet by means of the Silver Spring and the smaller tributary springs which occur in the coves along the margin of its short discharging stream. The whole surface of the country in the vicinity, and probably over the area of a circle of ten or fifteen miles radius whose center is the Silver Spring, is thickly dotted with lime-sinks, which are the points at which the surface water finds entrance to the subterranean passages. New sinks are constantly occurring at the present time. The beautiful miniature lakes, whose crystal waters are so justly admired, which occur in this portion of Florida, are doubtless nothing more than lime-sinks of ancient date. Under this aspect of the subject, it is obvious that all the rain-fall on this hydrographic basin boils up in the Silver Spring, after having been strained, filtered, and decolorized in its passage through beds of sand and tortuous underground channels. It thus comes out, not only entirely free from all mechanically suspended materials, but completely destitute of every trace of organic coloring matter. For this reason, there is a striking contrast between the color and transparency of the waters of the Silver Spring stream and those of the Ochlawaha River at their junction; the latter draining a country whose drainage is not entirely subterraneous.

The above-mentioned conditions seem to

[1] There are numerous lakes in the Scandinavian peninsula whose waters are said to be very transparent; objects on the bottom being visible at depths of from 30 to 37 meters. More specifically in Lake Wetter, in Sweden, a farthing is said to be visible at a depth of twenty fathoms, or 36.575 meters. But such vague popular estimates are scarcely worthy of consideration. Still less trustworthy are the unverified accounts we have, that in some parts of the Arctic Ocean shells are distinctly seen at the depth of eighty fathoms; and that among the West India Islands, in eighty fathoms of water, the bed of the sea is as distinctly visible as if seen in air (Somerville's Phys. Geog., Am. ed. 1858, p. 199). Perhaps it should have been feet instead of fathoms.

be fully adequate to persistently secure the waters of this spring from the admixture of insoluble and suspended materials, as well as from the discoloration of organic matters in solution. But, inasmuch as these waters appear to be *more diaphanous than absolutely pure water*, it is possible that the minute quantity of lime which they hold in solution may exercise some influence in augmenting their transparency. There is nothing *à priori* improbable in the idea that the optical as well as the other physical properties of the liquid may be altered by the materials held in solution. This is an interesting physico-chemical question, which demands experimental investigation.

John LeConte.