PHYSICAL STUDIES OF LAKE TAHOE.—II.

Color of the Waters of Lake Tahoe.—One of the most striking features of this charming mountain lake is the beautiful hues presented by its pellucid waters. On a calm, clear, sunny day, wherever the depth is not less than from fifty to sixty metres, to an observer floating above its surface, the water assumes various shades of blue; from a brilliant Cyan blue (greenish-blue) to the most magnificent ultramarine blue or deep indigo blue. The shades of blue, increasing in darkness in the order of the colors of the solar spectrum, are as follows: Cyan-blue (greenish blue), Prussian-blue, Cobalt-blue, genuine ultramarine-blue, and artificial ultramarine-blue (violet blue). While traversing one portion of the lake in a steamer, a lady endowed with a remarkable natural appreciation and discrimination of shades of color declared that the exact tint of the water at this point was "Marie-Louise blue."

The waters of this lake exhibit the most brilliant blueness in the deep portions, which are remote from the fouling influences of the sediment-bearing affluents, and the washings of the shores. On a bright and calm day, when viewed in the distance, it had the ultramarine hue; but when looked fair down upon, it was of almost inky blackness—a solid dark blue qualified by a trace of purple or violet. Under these favorable conditions, the appearance presented was not unlike that of the liquid in a vast natural dyeing-vat.

A clouded state of the sky, as was to be expected, produced the well-known effects due to the diminished intensity of light; the shades of blue became darker, and, in extreme cases, almost black-blue. According to our observations, the obscurations of the sky by the interposition of clouds produced no other modifications of tints than those due to a diminution of luminosity.

In places where the depth is comparatively small and the bottom is visibly white, the water assumes various shades of green; from a delicate apple-green to the most exquisite emerald-green. Near the southern and western shores of the lake, the white, sandy bottom brings out the green tints very strikingly. In the charming *cul-de-sac* called "Emerald Bay," it is remarkably conspicuous and exquisitely beautiful. In places where the stratum of water covering white portions of the bottom is only a few metres in thickness, the green hue is not perceptible, unless viewed from such a distance that the rays of light emitted obliquely from the white surface have traversed a considerable thickness of the liquid before reaching the eye of the observer.

The experiments with the submerged white dinner-plate, in testing the transparency of the water, incidentally manifested, to some extent, the influence of depth on the color of the water. The white disk presented a bluish-green tint at the depth of from nine to twelve metres; at about fifteen metres it assumed a greenish-blue hue, and the blue element increased in distinctness with augmenting depth, until the disk became invisible or undistinguishable in the surrounding mass of blue waters. The water intervening between the white disk and the observer did not present the brilliant and vivid green tint which characterized that which is seen in the shallow portions of the lake, where the bottom is white. But this is not surprising, when we consider the small amount of diffused light which can reach the eye from so limited a surface of diffusion.

In studying the chromatic tints of these waters, a hollow paste-board cylinder, five or six centimeters in diameter, and sixty or seventy centimeters in length, was sometimes employed for the purpose of excluding the surface reflection and the disturbances due to the small ripples on the water. When quietly floating in a small row-boat, one end of this exploring-tube was plunged under the water, and the eye of the observer at the other extremity received the rays of light emanating from the deeper portions of the liquid. The light thus reaching the eye presented essentially the same variety of tints in the various portions of the lake as those which have been previously indicated.

Hence, it appears that under various conditions—such as depth, purity, state of sky and color of bottom—the waters of this lake manifest nearly all the chromatic tints presented in the solar spectrum between greenish-yellow and the darkest ultramarine-blue, bordering upon black-blue.

It is well known that the waters of oceans and seas exhibit similar gradations of chromatic hues in certain regions. Navigators have been struck with the variety and richness of the tints presented, in certain portions, by the waters of the Mediterranean Sea, the Atlantic and Pacific Oceans, and especially those of the Caribbean Sea. In some regions of the oceans and seas, the green hues, and particularly those tinged with yellow, are observed in comparatively deep waters, or, at least, where the depths are sufficiently great to prevent the bottom from being visible. But this phenomenon seems to require the presence of a considerable amount of suspended matter in the water. In no portion of Lake Tahoe did I observe any of the green tints, except where the light-colored bottom was visible. This was, probably, owing to the circumstance that no considerable quantity of suspended matter existed in any of the waters observed.

Physical Cause of the Colors of the Waters of Certain Lakes and Seas.—The study of the beautiful colors presented by the waters of certain lakes and seas has exercised the sagacity of a great number of navigators and physicists, without resulting in a perfectly satisfactory solution of the problem. And although recent investigations seem to furnish a key to the true explanation, yet the real cause of the phenomena appears to be very imperfectly understood even among physicists.

For example: some persons persist in assigning an important function to the blue of the sky in the production of the blue color of the water. Thus, as late as 1870, Dr. Aug. A. Hayes, in an article "On the Cause of the Color of the Water of the Lake of Geneva" (Am. J. Sci., 2d series, vol. 49, p. 186, *et seq.*, 1870), having satisfied himself by chemical analysis that no coloring matter existed in solution, distinctly ascribes the blue color of the water to "the reflection and refraction of an azure sky in a colorless water." He insists that the water of this lake "responded in unequal coloration" to the state of the sky, "as if the water mirrored the sky under this condition of beauty."

The question here presented is highly important in discussing the cause of the blue colors of the deep waters. For the first preliminary point to be established is, whether the colored light comes from the interior of the mass of water, or whether it is nothing more than the azure tint of the sky reflected from the surface of the liquid? In other terms, whether the water is really a colored body, or only mirrors the color of the sky? If the water merely performs the functions of a mirror, the explanation of the blue color of such waters is so simple and obvious that it is astonishing how it comes to pass that physicists have been so long perplexed in relation to the solution of this problem. This idea is susceptible of being subjected to decisive tests. It seems to me that the phenomena cannot be due to mirror-like reflections of the azure sky, for the following reasons:

(*a.*) If the blue color of the water is produced by the reflection of an azure sky, all tranquil waters should present this tint under an equally vivid blue sky. It is well known that this deduction is not confirmed by observation.

(*b.*) In looking vertically down into the blue waters—a condition rendering surface reflection very small—it is obvious that the tints emanate from the interior of the liquid.

(*c.*) When the sky is clear and the surface of the water is tranquil, the azure tint frequently far surpasses in vividness that of the sky itself. This would, of course, be impossible, if the color was nothing more than the reflected image of the azure sky; since the reflected image must be less brilliant than the object.

(*d.*) A clouded state of the sky does not, under ordinary circumstances, prevent the recognition of the blue tint of the waters; although, of course, it is of less intensity. This fact is attested by a number of observers in relation to the blue waters of both lakes and seas; and it is evidently inconsistent with the idea of a mirror-like reflection of an azure sky.

(*e.*) Tranquil waters sometimes reflect the warm colors of the horizon, representing all the tints of the luminous sky so exactly that sky and water appear to be blended with each other. Under these conditions, the blue tints from the interior of the liquid are overpowered by the more brilliant surface reflection; for, if a gentle breeze ruffles the surface with capillary waves, the bright surface tints vanish, and the blue from the interior immediately predominates.[1]

(*f.*) My experiments with the "pasteboard exploring-tube" seem to prove beyond question that the color-rays proceed from the depths of the water, and not from its surface; for, in this case, superficial reflection was eliminated.

(*g.*) Finally, the character of the polarization impressed upon the blue light emanating from the azure waters of the Lake of Geneva—first announced by J. L. Soret in the spring of 1869, and subsequently confirmed by other observers—affords a satisfactory demonstration that the blue rays are not reflected from the surface, but, on the contrary, are veritable luminous emanations from the interior of the liquid. This point will hereafter receive special consideration in connection with the cause of the blue color.

[1] Indeed, in many cases this surface reflection seriously interferes with the vivid perception of the blue tints from the interior. The beautiful blue light which illuminates the interior of the famous "Azure Grotto" on the shores of the Island of Capri, in the Bay of Naples, is of greater splendor because its waters, while receiving a full supply of the transmitted solar beams through the large subaqueous entrance, are protected from surface reflection by the smallness of the opening above the water-level.

The foregoing reasons appear to be abundantly sufficient to establish the fact that, in the blue waters of the lakes and seas, *the color-rays do actually come from the interior of the mass of liquid.* Moreover, the experiments of Soret and Tyndall prove, that when a beam of light thrown into an obscured chamber is concentrated by a lens and made to pass through small masses of the blue waters, taken from a number of the Swiss lakes, as well as from the Mediterranean Sea, the luminous cone which traversed the liquid, viewed laterally, was in all cases distinctly blue. These experimental results are absolutely demonstrative of the fact that the diffused blue light proceeds from the interior of the transparent liquid. (Soret, in "*Archives des Sci., Phys. et Nat.,*" tome 39, p. 357, Dec., 1870: Tyndall in *Nature,* vol. 2, p. 489, Oct. 20th, 1870.)

Colors of Transparent Liquids.—So far as known, the colors of transparent liquids are due to the modifications of white light produced in the interior of the substances traversed by the luminous rays. Besides the well-known chromatic phenomena, arising from the refraction and dispersion of light (which are out of the question in relation to the subject under consideration), there are, in this class of bodies, three recognized causes of coloration, viz.:

1st. *Selective Absorption of Transmitted Light;* by which, through the extinguishing of certain rays, the emergent light is colored.

2nd. *Selective Reflection of Light* from the interior of the liquid; by which both the transmitted and the reflected rays are colored.

3rd. *Fluorescence;* by which colors are manifested by a sort of selective secondary radiation, in which light-waves of greater length than those of the exciting rays are emitted from the interior of the liquid.

Although the admirable researches of G. G. Stokes, Edmond Becquerel, Alex. Lallemand, Hagenbach and others, on the "illumination of transparent liquids," prove that a greater number of such bodies possess the property of fluorescence than was formerly supposed; yet all investigators concur in classifying pure water among the non-fluorescent liquids. Hence, in the case of this liquid in a state of purity, the admitted causes of coloration are reduced to two, viz.: selective absorption, and selective reflection in the interior of the transparent mass.

If the liquid traversed by the light is so constituted that none of the rays are reflected from its interior parts, while selective absorption is active, then the transmitted light is alone colored, according to the rays that may be extinguished by absorption. On the other hand, in transparent liquids in which there is no absorption of light, both the transmitted and the reflected light may be colored by selective reflection. For it is evident that if some of the rays are selectively reflected in the interior of the transparent mass, the transmitted light and the reflected light must present different colors. It is likewise obvious that if all of the white light entering the transparent medium is thus disposed of, the transmitted light and the reflected light must present tints which are exactly complementary. In most cases, however, when selective reflection occurs, there will generally be some selective absorption; consequently, the color by transmission will not always be exactly complementary to the color by reflection. In fact, this exact complementary relation cannot be realized when any portion of the light is absorbed.

Moreover, in many cases in which there is a rapid absorption of particular rays, the transmitted and reflected lights are of the same color. For example: there are large classes of bodies (such as solutions of indigo, sulphate of copper, etc., and also various colored glasses), which are of the same color by reflection and transmission. In such cases the rays of all the other colors are speedily extinguished by absorption, while a portion of the incident characteristic color-rays are reflected, and the rest are transmitted. Thus, in many blue-colored solutions, not only is the transmitted light blue, but the blue tint is visible in all directions by means of the diffused light.

Opalescent Aqueous Media.—It is now well established, that fine-divided substances suspended in water impart to it the property of diffuse selective reflection, whereby certain chromatic phenomena are produced. It has been long recognized that if about one part of milk be added to fifty parts of distilled water, the presence of the diffused milk-globules in the midst of the liquid imparts to it a bluish tint by the *scattered reflected* light, while the *transmitted* light acquires a yellowish color. Similar phenomena are observed when delicate precipitates of magnesia or of amorphous sulphur are diffused in water; and, likewise, when weak alcoholic solutions of certain essential oils are mingled with this liquid. The admirable experiments of Ernest Brücke in 1852 (*Pogg. Ann.*, vol. 88, pp. 363–385), prove that mastic and other resins, which are soluble in alcohol, will be precipitated in a finely divided state when added to water; and that when such a precipitate is sufficiently diluted, it gives the liquid a soft sky-like hue by the diffuse reflected light, while the transmitted light is either yellow or red, according to the thickness of the stratum traversed. These results have been abundantly verified by more recent experiments; and notably by those of Tyndall (probably about 1857), and by those of the writer during the years 1878–1879. The suspended particles of resin are so extremely attenuated, that they remain mingled with the water for months without sensibly subsiding. In many instances they are so fine as to escape detection by the most powerful microscope; they are ultra microscopic in smallness.

Media which possess the property of decomposing compound white light by selective reflection have been characterized as opalescent. The distinguishing characteristics of opalescent liquids are: 1st. That the reflected and transmitted lights are different in color; and 2nd. That the tints of the two colors are more or less complementary. It is evident, however, that when the liquid exercises any selective absorptive action on light, the tints of both the reflected and transmitted lights will be more or less modified, according to the character of the rays which are withdrawn by absorption. Hence, it follows that the tints by diffuse reflection and by transmission may deviate more or less from the exact complementary relation.

Color of Pure Water.—In the investigation of the "Causes of the Colors of Waters of Certain Lakes and Seas," it is manifestly of primary importance to determine the color of pure water; for, if it is inherently colored, the tints afforded by impurities must be modified by the admixture of the hues proceeding from the liquid itself. Although pure water in small masses appears to be perfectly colorless, yet most physicists have been disposed to admit an intrinsically blue color as belonging to absolutely pure water, when viewed in sufficiently large masses. Thus, Sir I. Newton, Mariotte, Euler, Sir H. Davy, Count De Maistre, Arago, and others, ascribe the azure tints of the deep waters of certain lakes and seas to the selective reflection of the blue rays from the molecules of the liquid itself; while the green and other tints exhibited by other waters are due to impurities, or to various modifications and admixtures of reflected light from suspended materials and from the bottom.

More recent investigations seem to furnish some clew to the solution of this problem. R. W. Bunsen, in 1847, was the first to test the color of pure water by direct experiment. (*Ann. der Chem. und Pharm.*, vol. 62, pp. 44, 45.—1847.) He provided himself with a glass tube 5.2 centimeters in diameter and two metres long, which was blackened internally with lamp-black and wax to within 1.3 centimeters of the end, which was closed by a cork. The tube being filled with chemically pure water, and pieces of white porcelain being thrown into it, it was placed in a vertical position on a white plate. On looking down through the column of water at the bits of porcelain at the bottom, which were illuminated by the white light reflected from the plate through the rim of clear, uncoated glass at the lower extremity, he observed that they exhibited a pure blue tint, the intensity of which diminished as the column of water was shortened. The blue coloration was also recognized when a white object was illuminated through the column of water by direct sunlight, and viewed at the bottom of the tube through a small lateral opening in the black coating.

It is evident that the blue tints manifested in these experiments were those of the transmitted light; and they indicate that pure distilled water absorbs the luminous rays constituting the red end of the spectrum more copiously than those of the blue extremity. But they do not touch the question of the color of the diffused light reflected from the interior of the mass of water itself.

About 1857, John Tyndall confirmed the results of Bunsen's experiments, in the following manner: "A tin tube, fifteen feet long and three inches in diameter, has its ends stopped securely by pieces of colorless plate glass. It is placed in a horizontal position, and pure water is poured into it through a small lateral pipe, until the liquid reaches half-way up the glasses at the ends; the tube then holds a semi-cylinder of water and a semi-cylinder of air. A white plate, or a sheet of white paper, well-illuminated, is then placed a little distance from the end of the tube, and is looked at through the tube. Two semi-circular spaces are seen, one by the light which has passed through the air, the other by the light which has passed through the water. It is always found that while the former semi-circle remains white, the latter is vividly colored." Professor Tyndall was never able to obtain a pure blue, the nearest approach to it being a blue-green. When the beam from an electric lamp was sent through this tube, the transmitted image projected upon a screen was found to be blue-green when distilled water was used. ("Glaciers of the Alps," Part Second. (6.) "Color of Water and Ice," *Am. Ed.*, pp. 254, 255. Boston, 1861.) It will be noted that Professor Tyndall makes no allusion to the color of the diffused or scattered light; indeed, his tin tube rendered it impossible for him to observe it.

It is evident that at this time (1857) this sagacious physicist was disposed to ascribe the blue tints observed in purest natural waters, exclusively, to their absorbent action on the transmitted light. Thus, extending the analogy of the action of water on dark heat to the luminous rays of the solar spectrum, he says: "Water absorbs all the extra-red rays of the sun, and if the layer be thick enough it invades the red rays themselves. Thus, the greater the distance the solar beams travel through pure water, the more they are deprived of those components which lie at the red end of the spectrum. The consequence is, that the light finally transmitted by water, and which gives it its color, is blue." (*Op. cit., supra,* p. 254.) According to this view it would seem that pure water is really colored in the same sense as a weak solution of indigo; that is, it is blue both by reflected and transmitted light.

In December, 1861, W. Beetz, of Erlangen, obtained results analogous to those of Professors Bunsen and Tyndall, by the somewhat imperfect method of looking through considerable thickness of distilled water at the transmitted light made to pass by repeated reflections across a box ten inches long filled with this liquid. The transmitted light ultimately became dark blue, "with a very feeble tinge of green." (*Pogg. Ann.*, vol. 115, pp. 137–147, Jan. 1862; also, *Phil. Mag.*, 4th series, vol. 24, pp. 218–224, Sept. 1862.)

My own experiments, executed on various occasions in 1878–1879, afford complete verifications of the results obtained by the preceding physicists. My arrangements were similar to those of Professor Tyndall, except that a series of three glass tubes—of about three centimetres in clear internal diameter connected by india-rubber tubing, and having an aggregate length of about five meters, was employed instead of the tin tube used by him. Moreover, instead of the electric beam, I employed solar light thrown into a large, darkened lecture-room by means of a "Porte-Lumiére": the small beam passing through the first diaphragm at the window being rendered nearly uniform in diameter by the interposition of a secondary screen, with a small aperture in it, just before the light entered the end of the horizontally-adjusted series of tubes. By this arrangement, an approximate mathematical ray was obtained, which secured the transmission of the light along the axis of the column of water, without the possibility of the emergent beam being mixed with any light reflected from the internal surface of the glass tube. In every instance in which distilled water was used, the tint of the image of the emergent beam, received upon a white screen, was either greenish-blue or yellowish-green; the former tint seemed to characterize the summer, and the latter hue the winter experiments. Like Professor Tyndall, I failed to obtain a pure blue color in the transmitted light; the nearest approach to it being greenish-blue. Hence, it appears that, in a general way, my experiments confirm the opinion that pure water absorbs to a somewhat greater extent the solar rays constituting the red end of the spectrum; while at the same time they seem to indicate—in accordance with the deductions of Wild—that the absorption is more active at elevated temperatures. It must be borne in mind that these results relate to the tints of the transmitted light.

Has Pure Water any Color by Diffuse Reflection?—In relation to the colors observed in the deep waters of certain lakes and seas, it is evident that the transmitted light cannot reach the eye of the observer. Hence, it is plain that if such waters were perfectly free from all foreign materials—in solution or mechanically suspended—there are only two methods by which colored tints can emanate from the interior of such a transparent liquid. These are for pure water:

1st. Color tints by diffuse selective reflection from the aqueous molecules.

2nd. Color tints produced by selective absorption, and the diffuse reflection of the unabsorbed light.

In the first case, the tints of pure water would be analogous to those of opalescent liquids.

In the second case, the hues would be analogous to those of weak-colored solutions, in which the colors by transmission and reflection are the same. In both cases it is absolutely essential, in order that the color tints should reach the eye of the observer, floating on the surface of deep waters, that the aqueous molecules should possess the property of reflection. The only difference being, that in the first case the reflection is selective, while in the second case all of the unextinguished rays are more or less reflected. So that the primary question which is to be settled is: "Whether perfectly pure water has any color by diffuse reflection of light from the interior of the liquid?" This being a question of fact can only be settled by observation and experiment.

We have already seen that Sir I. Newton and many of his successors thought that water exercised a selective reflection on the rays of the sun-light which traversed it. In proof of this, he records an observation related to him by his distinguished contemporary and friend, Dr. Edmund Halley. Having descended under sea-water many fathoms deep in a diving-bell, Halley found, in a clear sun-shine day, a crimson color (like a damask rose) on the upper part of his hand, on which fell the solar rays after traversing the stratum of water above him and a glass aperture; whereas, the water below him and the under part of his hand, illuminated by light coming from the water beneath, appeared green. From which Newton concluded that the sea water reflects the violet and blue rays most easily, and allows the red rays to pass most freely and copiously to great depths. Hence, the direct light of the sun must appear red at all great depths, and the greater the depth the fuller and more intense must the red be; and at such depths as the violet rays scarcely reach the blue, green and yellow rays, being reflected from below more copiously than the red ones, must make a green. (Newton's Optics, book 1, part 2, prop. 10, exp. 17.) At a later date J. H. Hassenfratz verified Newton's explanation by means of a long tube blackened inside, closed at the ends by glasses, and filled with pure water, through which the solar rays were made to pass. The transmitted light became successively white, yellow, orange or red, as the length of the column of water traversed was augmented. Annular diaphragms placed at different points in the tube appeared black on the side of the observer, at the point where the transmitted light was white; a feeble violet where it was yellow; blue where it was orange; and green where it was red. The diaphragms being illuminated by the rays reflected from the interior portions of the water, the light presented a color complementary to that which was transmitted.[1]

It is evident, therefore, that both Newton and Hassenfratz regarded pure water as possessing the properties of an opalescent medium. On the other hand, we have already shown that distilled water really absorbs the solar rays constituting the red end of the spectrum more copiously than those of the blue end; so that the transmitted light comes out greenish-blue. The discrepancy thus indicated is, doubtless, due to the circumstance that in the older observations and experiments the water employed was not sufficiently free from mechanically suspended materials. For the presence of an extremely minute quantity of suspended matter in distilled water is sufficient to change the color of the transmitted solar light from greenish-blue to yellow, orange or red, according to the amount of foreign ma-

1 The above account of Hassenfratz's experiments is taken from Daguin's "*Traité de Physique*," 3rd edition, Tome 4, Article 2,056, p. 217.—Paris, 1868. Not being able to find any reference to Hassenfratz's original paper, I wrote to Prof. P. A. Daguin of Toulouse, and ascertained that the details given in his treatise were taken from the grand "Encyclopedie Methodique" 1816, "Dictionnaire de Physique," word "Couleur," page 610. He further informs me, that he has never seen the original memoir, and doubts whether it was ever published *in extenso*. The details given by Daguin are said by him to be scarcely less full than those given in the "Dictionnaire de Physique." I have not been able to find a copy of the "Encyclopedie Methodique" on this coast.

terial present. Thus, Tyndall found that when an alcoholic solution of mastic and other resins is added to water a finely-divided precipitate is formed, which, when sufficiently diluted, gives the liquid a blue color by reflected light, and yellow by transmitted light. Hence, he maintains "that, if a beam of white light be sent through a liquid which contains extremely minute particles in a state of suspension, the short waves are more copiously reflected by such particles than the long ones: blue, for example, is more copiously reflected than red." "When a long tube is filled with clear water, the color of the liquid (blue-green), as before stated, shows itself by transmitted light. The effect is very interesting when a solution of mastic is permitted to drop into such a tube, and the fine precipitate to diffuse itself in the water. The blue-green of the liquid is first neutralized, and a yellow color shows itself; on adding more of the solution, the color passes from yellow to orange, and from orange to blood-red." Again, he says, "It is evident, this change of color must necessarily exist; for the blue being partially withdrawn by more copious reflection, the transmitted light must partake more or less of the character of the complementary color." ("Glaciers of the Alps."—"Colors of the Sky." Edition *cit. ante*, pp. 259–261.)

My own experiments, by means of the series of glass-tubes already described, strikingly confirm the foregoing deductions. Indeed, I was unable to find any natural water, however clear, which did not contain a sufficient amount of finely-divided particles in a state of suspension to impart the opaline characters to the transmitted solar light. The purest hydrant water, as well as the water taken from the Pacific Ocean in latitude 39° 17′ North, and longitude 123° 58′ West from Greenwich, did not manifest the greenish-blue tint of distilled water by transmitted light, but exhibited colors of the emergent beam, which varied from yellowish-orange to green, according to the amount of suspended matter present in the column of liquid.

As early as 1857, Professor Tyndall seems to have fully recognized the important function of finely-divided suspended matter in imparting the blue tints to the light reaching the eye by diffuse reflection from the interior of masses of water. This is distinctly indicated in the account of his experiments already quoted. Again, in speaking of the bluish appearance of thin milk, he says, "Its blueness is not due to absorption, but to separation of the light by the particles suspended in the liquid." In reference to blue color of the waters of the Lake of Geneva, on the 9th of July, 1857, he remarks: "It may be that the lake simply exhibits the color of pure water." ("Glaciers of the Alps." Edition *cit. ante*, pp. 33, 34.) But a little later, and after making the experiments previously noted, he very significantly asks, "Is it not probable that this action of finely-divided matter may have some influence on the color of some of the Swiss lakes—on that of Geneva for example?" Again, in speaking of the color of the water of this lake, he says, "It seems certainly worthy of examination whether such particles, suspended in the water, do not contribute to the production of that magnificent blue which has excited the admiration of all who have seen it under favorable circumstances." (*Op. cit. supra*, p. 261.) Nevertheless, it is quite evident that, at this time, Professor Tyndall regarded the suspended particles as playing a comparatively secondary part in the production of the blue tints of the natural waters; for he clearly intimates that pure water has an inherently blue color in the same sense as a weak solution of indigo.

It was not until nearly twelve years later that the beautiful experimental investigations of Professor Tyndall, in January, 1869, in relation to the "blue color of the Sky, the Polarization of Skylight, and on the Polarization of light by cloudy matter, generally," ("Proceedings of Royal Society," vol. 17, No. 108, pp. 223–233. Jan. 14th, 1869)—first suggested to J. L. Soret, of Geneva, the analogy which exists, in regard to polarization, between the light of the sky and the blue light coming from the water of the Lake of Geneva. In a letter addressed to Professor Tyndall, dated Geneva, March 31st, 1869, M. Soret maintains that the blue color of the water of this lake is due exclusively to the suspended solid particles, from the fact, which he established by direct experiments, that this light presents phenomena of polarization identical with those of the light of the sky. For, his experiments show: 1st. That the plane of polarization is coincident with the plane of incidence; and 2nd. That the polarization is a maximum, when the light received by the eye is emitted at right angles to the direction of the refracted solar rays in the water. (*Phil. Mag*, 4th series, vol. 37, p. 345. May, 1869. Also "*Comptes Rendus*," tome 68, p. 911. April 19th, 1869. Also, "*Archives des Sci. Phys. et Nat.*," tome 35, p. 54. May, 1869.)

During the year 1869, and soon after the publication of these investigations of the Swiss physicist, Alexander Lallemand made a number of interesting communications to the French Academy of Sciences on the "Illumination of Transparent Bodies," in which he attempted to controvert the deductions of Soret, and attributed the diffuse illumination of such media—as well as the peculiar phenomena of polarization above noticed—to the action of the molecules of water, and not to the presence of foreign corpuscles in suspension. The French physicist bases his conclusions mainly upon the phenomena manifested in transmitting beams of solar light through clear glass and distilled water; which he assumed to be optically homogeneous media. (For full text of Lallemand's Memoirs, *vide*, "*Ann. de Chim. et de Phys.*, 4th series, tome 22, pp. 200–234, Feb., 1871: and "*Ann. de Chim. et de Phys.*, 5th series, tome 8, pp. 93–136. May, 1876.) But the views of Soret were very soon abundantly verified by additional and more refined experimental researches, by which it was proved that under the searching test of a concentrated beam of light traversing such media in a darkened room, none of them manifested anything approaching to absolute homogeneousness in relation to light. Under the hypothesis that the illumination of such bodies is due exclusively to the presence of foreign corpuscles suspended in them, it is evident that the more a non-fluorescent liquid (as water) is deprived of heterogeneous particles, the less must be its power of diffuse illumination; and if we could secure a complete elimination of the particles in suspension, a concentrated luminous beam would produce no laterally visible trace in traversing the liquid. Accordingly, in relation to water, the experiments of Soret, in Jan. and Feb. 1870, show that the most careful distillation does not entirely remove the suspended matter; although in proportion to the care with which the distillation was made, the less was the light scattered in traversing the liquid. Moreover, he found that the scattering power of the waters of the Lake of Geneva was diminished by allowing the liquid to repose long enough (many months) to permit the suspended matter to partially subside.

Conversely, the experiments of the same physicist prove conclusively that when the number of particles in suspension is augmented—provided they are sufficiently attenuated—the power of illumination in the water was considerably increased, without modifying the phenomena of polarization. Thus it was found that very diluted precipitates formed in distilled water gave rise to considerable augmentation in the power of diffuse illumination, and the light emitted transversely to the traversing luminous beam presented the same characters of polarization as have been previously indicated. For example, in a flask filled with water from the Lake of Geneva, which, after long repose, manifested a very feeble power of illumination when a drop of solution of nitrate of silver was introduced, the presence of a trace of some the chlorides gave rise to a delicate precipitate, which was invisible in diffused light; but in a darkened room it exhibited a notable augmentation in the brightness of the trace produced by the passage of a concentrated beam of solar light; and the phenomena of polarization were complete. The addition of a second drop of the solution of nitrate of silver augmented the power of illumination, the trace of the beam appeared distinctly blue, and the polarization became more complete. ("*Archives des Sci. Phys. et Nat.*," tome 37, pp. 145–155. Feb., 1870.)

In like manner, the experiments of Tyndall in October, 1870, prove that while, as a general fact, the concentrated beam of light may be readily tracked through masses of the purest ice, when made to traverse them in various directions; yet there were remarkable variations in the intensity of the scattered light, and in some places the "track of the beam wholly disappears." In relation to water, Tyndall was also unsuccessful in entirely removing the suspended particles by the most careful and repeated distillations. His experiments on water taken from the Lake of Geneva and from the Mediterranean Sea, off the coast of Nice, show that the concentrated beam of light traversing each of them manifested a distinctly blue color when viewed laterally. 'Viewed through a Nicol's prism the light was found polarized, and the polarization along the perpendicular to the illuminating beam was a maximum." He adds: "In no respect could I discover that the blue of the water was different from that of the firmament." (Nature, vol. 2, pp. 489, 490. Oct. 20, 1870.)

Professor Ed. Hagenbach confirmed Soret's views in relation to the polarization of the blue light emanating from the waters of lakes, by a series of observations on the Lake of Lucerne. Without contesting the fact that the polarization of the diffused light emitted from such water is produced by reflection from minute particles held in suspension; he, nevertheless, suggests that a certain want of homogeneousness due to differences of temperature in the layers of water might, likewise, give rise to similar phenomena of polarization. But Soret has shown, by direct experiments, that it is not possible to attribute the illumination and polarization to the reflections from the layers of water of unequal density. Moreover, even if these reflections contribute something, in certain cases, to the production of the phenomena, it is evident that, under ordinary circumstances, their influence must be insignificant. ("*Archives des Sci. Phys. et de Nat.*," tome 37, pp .176–181. Feb., 1870.)

In the light of the results afforded by the preceding experimental investigations, we are now prepared to give a definite and intelligible answer to the question, "Whether perfectly pure water has any color by diffuse reflection of light from the interior of the liquid?" It seems to me that the evidence leading to a negative answer to the foregoing question is overwhelming. Professor Tyndall's conclusion, in relation to this point, appears to be a perfectly legitimate induction from the ascertained facts. In speaking of the water obtained from the fusion of selected specimens of ice, in which extraordinary precautions were taken for excluding impurities, and which were regarded as the purest samples of the liquid hitherto attained, this sagacious physicist remarks: "Still I should hesitate to call the water absolutely pure. When the concentrated beam is sent through it the track of the beam is not invisible, but of the most exquisitely delicate blue. This blue is purer than that of the sky, so that the matter which produces it must be finer than that of the sky. It may be, and indeed has been, contended that this blue is scattered by the very molecules of the water, and not by matter suspended in it. But when we remember that this perfection of blue is approached gradually through stages of less perfect blue; and when we consider that a blue in all respects similar is demonstrably obtainable from particles mechanically suspended; we should hesitate, I think, to conclude that we have arrived here at the last stage of purification. The evidence, I think, points distinctly to the conclusion that, could we push the process of purification still further, even this last delicate trace of blue would disappear." ("Fragments of Science": "Dust and Disease," pp. 319, 320, Am. ed., N. Y., 1875.) In other terms, "Water optically homogeneous would have transmitted the beam without revealing the track." "In such water, the course of the light would be no more seen than in optically pure air." Hence, the scattering of the light is not molecular; but is evidently due to the presence of finely-divided matter in a state of suspension, whereby the shorter waves of the beam are intercepted and diffused more copiously than the longer ones; thus rendering the trace of the light visible in the liquid, and imparting a blue tint to the laterally scattered polarized light. The conclusion seems, therefore, to be inevitable, that if water were perfectly free from all foreign materials, either in solution or mechanically suspended, both chemically and optically pure, it would have no color at all by diffusion of light: in fact, inasmuch as no scattered light would be emitted from the traversing beam, it would show the darkness of true transparency.[1]

Cause of the Blue Color of Certain Waters.—The preceding considerations very clearly indicate that the real cause of the blue tints of the waters of certain lakes and seas is to be traced to the presence of finely-divided matter in a state of suspension in the liquid. We have seen that Sir I. Newton and most of his successors, as late as 1869, ascribed the blue color of certain deep waters to an inherent selective reflecting property of its molecules, by which they reflected the blue rays of light more copiously than the other rays of the solar spectrum. Since the researches of Soret, Tyndall and others, this selective reflection has been transferred to finely-divided particles, which are known to be held in suspension in greater or less abundance, not only in all natural waters, but even in the most carefully distilled water. When the depth of water is sufficiently great to preclude any solar rays reaching the bottom, then the various shades of blue which are perceived under similar conditions of sunshine will depend upon the attenuation and abundance of the materials held in suspension—the purity and delicacy of the tint increasing with the smallness and the degree of diffusion of the suspended particles. Moreover, it is evident that Tyndall is quite correct in assigning to "true molecular absorption" some agency in augmenting "the intense and exceptional blueness" of certain waters; for it is obvious that the "blue of scattering by small particles" must be purified by the abstraction of the less refrangible rays, which always accompany the blue during the transmission of the scattered light to the observer.

It seems to be very certain that, were water perfectly free from suspended matter and coloring substances in solution, and of uniform density, it would scatter no light at all. "But," as Tyndall remarks, "an amount of impurity so infinitesimal as to be scarcely expressible in numbers, and the individual particles of which are so small as wholly to elude the microscope," may be revealed in an obvious and striking manner when examined by a powerfully concentrated beam of light in a darkened chamber. If the waters of the lakes and seas were chemically pure and optically homogeneous, absolute extinction of the traversing solar rays would be the consequence, if they were deep enough. So that to an observer, floating on the surface, such waters would appear as black as ink; and, apart from a slight glimmer of ordinary light reflected from the surface, no light, and hence no color, would reach the eye from the body of the liquid. According to Tyndall, "In very clear and very deep sea-water, this condition is approximately fulfilled, and hence the extraordinary darkness of such water." In some places, when looked down upon, the water "was of almost inky blackness—black qualified by a trace of indigo." But even this trace of indigo he ascribes to the small amount of suspended matter, which is never absent even in the purest natural water—throwing back to the eye a modicum of light before the traversing rays attain a depth necessary for absolute extinction. He adds: "An effect precisely similar occurs under the moraines of the Swiss glaciers. The ice is

[1] The presence of colorless salts in solution does not seem to impair the transparency of water, or to have any influence on the phenomena of coloration by scattered light. As previously intimated, there is no improbability in the supposition that the existence of certain salts in solution might augment its transparency.

here exceptionally compact, and, owing to the absence of the internal scattering common in bubbled ice, the light plunges into the mass, is extinguished, and the perfectly clear ice presents an appearance of pitchy blackness." ("Hours of Exercise in the Alps," "Voyage to Algeria to observe the Eclipse." Am. ed., N. Y., 1871, pp. 463–470.) In like manner the waters of certain Welsh tarns, which are reputed bottomless, are said to present an inky hue. And it is more than probable that the waters of "Silver Spring"—whose exceptional transparency has been previously indicated—would, if they were sufficiently deep, present a similar blackness or absence of all color by diffuse reflection.[1]

[1] Several more recent investigations relative to the colors of water, inasmuch as they refer to the tints of the transmitted light, have not contributed anything towards the real solution of the problem of the physical causes of the coloration of natural waters.

(1) The experiments of F. Boas of Kiel (Wiedemann's "Beiblätter zu den Ann. der Phys. und Chem.," Band V. [1881] p. 797), made by transmitting light through water contained in a zinc tube fourteen meters long, as far as they go confirm the deductions given in the text. (2) So likewise do the experiments executed in 1881 by Dr. A. C. Peale, in his researches in relation to the colors of the waters of the Thermal Springs of the Yellowstone National Park. (Hayden's 12th Report of the U. S. Geological and Geographical Survey for 1878, vol. II., p. 373, *et seq.*) (3) In like manner, the results secured by the experiments of John Aitken, communicated to the "Royal Society of Edinburgh," Feb. 6th, 1882 (Nature, vol. 25, p. 427), fall under the same category. (4) Even the more elaborate researches of W. Spring, of the University of Liége, ("*Revue Scientifique.*" Transl. in "Popular Science Monthly" for May, 1883) while they clear up some points in relation to the origin of the green tints which are mingled with blue in the light transmitted through a column of distilled water, do not, in reality, touch the question of colors seen by *diffused reflected* light; which, of course, alone can furnish the tints appearing in the natural waters. Like myself, he employed glass tubes closed at the end with glass plates; but a black sheathing was used, which necessarily cut off the laterally diffused light emanating from the interior of the contained liquid. Moreover, the arrangement was otherwise defective in that his source of light was a ground-glass pane in the window of his laboratory; for it is evident, that the light emerging from the tube, under these conditions, would necessarily be mingled with the light modified by reflections from the interior surface of the glass tubing.

One of the results, however, of the experimental investigations of the Belgian physicist is a very interesting contribution to our knowledge in relation to this subject. He found that the addition of one-ten-thousandth of bichloride of mercury to the distilled water in his tubes, enabled him to obtain a *pure sky-blue* by transmitted light. The blue-green tints obtained by his predecessors, he ascribes to the speedy development of *living organisms* in the purest distilled water. The poisonous qualities of this salt of mercury prevented the development of the organisms.

Cause of the Green Color of Certain Waters.—It remains for us to explain the cause of the green tints which the waters of certain lakes and seas assume under peculiar circumstances. These green colors manifest themselves under the following conditions, viz.:

(*a.*) In the finest blue water, when the depth is so small as to allow the transmitted light to be reflected from a bottom which is more or less white. Thus, a white sandy bottom, or white rocks beneath the surface of the Lake of Geneva, or of the Bay of Naples, or of Lake Tahoe, will, if the depth is not too great or too small, impart a beautiful emerald-green to the waters above them.

(*b.*) In the finest blue water, when a white object is looked at through the intervening stratum of water. In the blue waters of the sea, this is frequently seen in looking at the white bellies of the porpoises, as they gambol about a ship or steamer. In a rough sea, the light which has traversed the crest of a wave, and is reflected back to the observer from the white foam on the remote side, sometimes crowns it with a beautiful green cap. In March, 1869, I observed this phenomenon in the magnificent ultramarine waters of the Caribbean Sea. A stout white dinner-plate secured to a sounding-line presents various tints of green as it is let down into the blue water. Such experiments were made by Count Xavier De Maistre in the Bay of Naples, in 1832; by Professor Tyndall in the Atlantic Ocean, in December 1870; and by the writer in Lake Tahoe, in August and September, 1873.

(*c.*) In waters of all degrees of depth, when a greater amount of solid matter is held in suspension than is required to produce the blue color of the purer deep waters of lakes and seas. Thus Tyndall, in his "Voyage to Algeria to observe the Eclipse," in December, 1870, collected nineteen bottles of water from various places in the Alantic Ocean between Gibraltar and Spithead. These specimens were taken from the sea at positions where its waters presented tints varying from deep indigo-blue, through bright green, to yellow-green. After his return to England, he directed the concentrated beam from an electric lamp through the several specimens of water, and found that the blue waters indicated the presence of a small amount of suspended matter; the bright green a decidedly greater amount of suspended particles; and the yellow-green was exceeding thick with suspended corpuscles. He remarks: "My home observations, I think, clearly established the association of the green color of sea water with fine suspended matter, and the association of the ultramarine color, and more especially of the black-indigo hue of sea water, with the comparative absence of such matter." ("Hours of Exercise in the Alps": "Voyage to Algeria to observe the Eclipse." Ed. *cit. ante*, pp. 464, 467.)

There is one feature which is common to all of the three above-indicated conditions under which the green color manifests itself in the waters of lakes and seas, viz.: when a white or more or less light-colored reflecting surface is seen through a stratum of intervening water of sufficient purity and thickness. Condition (*c*) is obviously included; for it is evident that a back-ground of suspended particles may, under proper conditions, form such a reflecting surface.

Inasmuch as under these several conditions more or less of the transmitted light is reflected back to the eye of the observer, it is evident that the rays which reach him carry with them the chromatic modifications due to the combined influence of the selective absorption of the water itself, and the selective reflection from the smaller suspended particles. Hence the chromatic phenomena presented, being produced by the mingling of these rays in various proportions, must manifest complex combinations of tints, under varying circumstances relating to color of bottom, depth of water, and the amount and character of the suspended matter present.

In the explanations of the green color of certain waters by the older physicists, we recognize the full appreciation of the influence of selective reflection in the production of the phenomena; but they seem to have overlooked the important effects of molecular absorption. We have seen that Sir I. Newton regarded the green tints of sea-water as due to the more copious reflection of the violet, blue and green rays, while those constituting the red end of the spectrum are allowed to penetrate to greater depths. (Optics., *Loc. cit. ante.*) Sir H. Davy ascribes it, in part at least, to the presence of iodine and bromine in the waters, imparting a yellow tint, which, mingled with the blue color from pure water, produced the sea-green. ("Salmonia." "Collected Works," vol. 9, p. 201.) In like manner, Count Xavier De Maistre ascribes the green tints to the yellow light, which, penetrating the water and reaching the white bottom, or other light-colored submerged object, and being reflected and mixed with the blue which reaches the eye from all quarters, produces the green. (Bibl. Univ., vol. 51, pp. 259–278. Nov. 1832: also Am. J. Sci., 1st. series, vol. 26, pp. 65–75.—1834.)[1]

On the other hand, after Bunsen, in 1847, had established that chemically pure water extinguished the rays of light constituting the red end of the solar spectrum more copiously than those of the blue extremity—so that the transmitted tints were more or less tinged with blue—some chemists were inclined to attribute the green color of certain waters to the presence of foreign coloring substances. Thus, Bunsen himself explained the brown color of many waters, especially of the North-German inland lakes, as produced by an admixture of *humus*; but he considers the green tints of the Swiss lakes and the silicious springs of Iceland, as aris-

[1] Similarly, Arago has very ingeniously applied the same principles to the explanation of the varying colors of the waters of the ocean under different circumstances—showing that when calm, it must be blue by the reflected light, but when ruffled, the waves acting the part of prisms, refract to the eye some of the transmitted light from the interior, and it then appears green. ("*Comptes Rendus*," tome 7, p. 219. July 23rd, 1838.)

ing from the color of the yellowish bottom. (*Vide Loc. cit. ante*, p. 44, *et. seq.*) Similarly, we find that Wittstein, in 1860, from chemical considerations, concluded that the green color derives its origin from organic admixtures, because the less organic substance a water contains, the less does the color differ from blue; and with increase of organic substances the blue gradually passes into green, and ultimately into brown. This is, likewise, the view taken in 1862 by Beetz; for he insists that in all waters the observed color of the liquid is that of the transmitted light, and not, in any case, of the reflected light. Moreover, he maintains that Newton, De Maistre, Arago and others were mistaken in classifying water among those bodies which have a different color by transmitted light to that which they have by reflected light. (*Loc. cit. ante.*)

Leaving out of consideration, for the present, those natural waters in which the colors are obviously due to various coloring substances (usually organic) in solution, or to the presence of minute colored vegetable and animal organisms diffused in them; modern researches point to selective molecular absorption of the water itself, and selective reflection from finely-divided solid particles held in suspension, as the real cause of the pure and rich blue and green tints presented by certain lakes and seas. The combined influence of these two causes seems to be fully adequate to explain all the tints characterizing such waters as are destitute of organic coloring matters.

We have already shown that if the waters were chemically pure and perfectly free from suspended particles, the red rays of the traversing solar light would be first absorbed and disappear, while the other colored rays pass to greater depths, one after the other being extinguished in their proper order, viz.: red, orange, yellow, green, blue and violet, until at last there is complete extinction of the light in the deeper mass of the liquid. But the presence of suspended particles causes a part of the traversing solar light to be reflected, and according as this reflected light has come from various depths, so will the color vary. If, for example, the particles are large or are abundant, and freely reflect from a moderate depth, while they prevent reflection from a greater depth, the color will be some shade of green.

When the water is shallow, and a more or less light-colored bottom or submerged object reflects the transmitted light to the observer through the intervening stratum of liquid, it is evident that the chromatic tints presented must be due to the combined influence of the selective absorption of the water itself and the selective reflection from the smaller suspended particles. In other terms, under these conditions, the tints are produced by the mingling of the blue rays with the yellow, orange, or red, so that the resulting hues must generally be some shade of green. In short, all the facts established by modern investigations seem to converge and point to the admixture of the blue rays reflected from the smaller suspended particles, with the yellow, orange and red rays reflected from the grosser matters below, as the true physical cause of the green tints of such waters.

Harmony of Views.—The establishment of the very important function of solid particles held in suspension in water, in producing chromatic modifications, both in the scattered light and in the transmitted light, serves to reconcile and to harmonize the apparent discrepancies and contradictions in the views of physicists who have investigated the color of water. We have already seen that Sir I. Newton and most of his successors, as late as 1847, regarded water as belonging to the opalescent class of liquids, in which the diffuse reflected light and the transmitted light present more or less complementary tints; the former partaking more of the colors constituting the blue end of the solar spectrum, while the latter presented more of the hues belonging to the red extremity. On the contrary, the more recent and more accurate experiments render it quite certain that in distilled water the rays of the red end of the spectrum are more copiously absorbed than those of the blue extremity; so that the emergent transmitted tint is yellowish-green or greenish-blue. At first view, these results appear to be discordant and irreconcilable. But it will be recollected, that while even the most carefully distilled water contains a sufficient amount of suspended matter to scatter enough light to render the track of traversing concentrated solar beams visible, yet in this case, the selective reflection of the blue rays, due to the suspended particles, is not adequate to neutralize the selective molecular absorption of the rays towards the red end of the spectrum. Nevertheless, as has been previously shown, the addition of very minute quantities of diffused suspended matter confers on distilled water the dichroitic properties of an opalescent liquid. The presence of an exceedingly small amount of suspended solid corpuscles, by selectively reflecting the shorter waves of light, is sufficient to neutralize and overcome the selectively absorbent action of the molecules of water on the longer waves; and thus to impart yellow, orange or red tints to the transmitted beam. Moreover, it is very questionable whether any natural waters are sufficiently free from suspended matter to deprive them of these dichroitic characteristics. Under this aspect of the subject, the views of Newton derived from the observations of Halley, those of Hassenfratz deduced from his own experiments, as well as the explanations of the green tints of certain waters given by De Maistre, Arago and others, completely harmonize with the conclusions deducible from modern researches, provided the property of selective reflection is transferred from the aqueous molecules to the finely-divided particles held in suspension.

As a striking illustration of the slight causes which sometimes transform the purest water into an opalescent or dichromatic liquid, it may be interesting to detail one of my own experiences. On the 21st of December, 1878, the series of glass tubes employed in my experiments (as previously indicated) being filled with distilled water, the transmitted solar beam presented, when received upon a white screen in a darkened room, the usual yellowish-green tint of my winter observations. On the 24th of December, or after an interval of three days, during which all parts of the apparatus had remained *in situ*, I was much surprised to find that the transmitted solar beam was enfeebled, and presented an orange-red color with no tinge of green. Puzzled to discover what could have produced so marked a change in the optical properties of the liquid, the "scientific use of the imagination" pictured the possible development of ultra-microscopic germs, infusoria, bacteria, confervæ, etc. The next day (Dec. 25th) the same phenomenon presented itself, when I called the attention of my assistant, Mr. August Harding (who had kindly prepared the arrangement of tubes), to the anomalous change that had taken place in the color of the transmitted beam. He suggested that as he had used alcohol in cleaning the glass plates closing the end of the tubes, and as the plates were secured to corks by means of Canada balsam, the alcohol absorbed by the corks, being gradually diffused, dissolved some of the balsam, which solution mingling with the water might produce a fine resinous precipitate, which might stifle the transmitted beam and scatter the rays of shorter wave lengths, thus leaving the orange-red rays predominant in the emergent light. This view was speedily verified by a critical examination of the track of the traversing beam. A sensible turbidity was visible (in the darkened room) at the extremities of the column of water adjacent to the corks securing the glass plates; and the light diffused laterally at these portions, when examined by a Nicol's prism, was found to be distinctly polarized. The emergent beam examined by the spectroscope exhibited orange and red in full intensity; but the yellow and green were greatly diminished. Ten days later (Jan. 2nd, 1879), the solar beam traversing the same column of water emerged much brighter than on Christmas day, and the tint was orange, tinged with yellow and red. This long repose caused, doubtless, some of the resinous precipitate to become more generally diffused or to subside, and thus diminished the turbidity of the liquid.

The recognition of the dichroism imparted to water by the presence of finely divided particles in suspension, serves, likewise, to harmonize the conflicting views promulgated by physicists who have studied the chromatic phenomena presented by this liquid. Some claim that the rays of higher refrangibility are more copiously withdrawn by absorption; while others maintain that the rays of longer wave-lengths are more absorbed. In many cases, the chromatic tints ascribed to selective molecular absorption are, unquestionably, due to selective diffuse reflection from the ultra-microscopic corpuscles which are held in suspension. (*Vide* Jamin's "*Cours de Physique*," 2nd ed., tome 3, p. 447, *et seq.*)

Colors of Sky and Water.—The consideration of the dichroitic properties imparted by the presence of finely divided matter in a state of suspension likewise harmonizes the views of the older physicists with the deductions from modern investigations. It was long ago insisted that there existed a complete analogy between the tints of the sky and those of the purest natural waters: indeed, that the causes of the blue color of the sky and the red tints of sunrise and sunset were identical with those of the pure natural waters under corresponding circumstances. In other terms, that in both cases the blue tints are due to reflection, and the red to transmission. In relation to the sky, these have been long recognized as the true causes of its variable tints. Now we have shown that the light transmitted by a column of natural water is in reality "yellow, orange or red, like the light of sunrise or sunset"; while the light reflected from the attenuated suspended particles partakes of the various shades of blue, like the hues of the sky. Hence, the analogy is completely verified upon the sure basis of experiment.

Moreover, the thermotic researches of Prof. Tyndall and others seem to demonstrate that liquids which possess absorbing qualities for radiant heat preserve these properties in the gaseous or vaporous states. In other words, when a liquid assumes the vaporous state, its power of absorbing heat-rays follows it in its change of physical condition. Hence, it appears that the absorption of the thermal-rays seems to depend upon the individual molecules of the compound, and not upon their state of aggregation; for the change into vapor does not alter their relative powers of absorption. This power asserts itself correspondingly in the liquid and in the gaseous states.

Now, although we have as yet no direct experimental evidence in regard to the relative powers of absorption of various vapors for the different luminous rays, yet these thermotic results render it analogically probable that vapors carry with them the same relative absorbing powers for the different rays of light which their liquids enjoyed. Hence we may conclude, that if the mixture of air and aqueous vapor constituting our atmosphere were perfectly free from suspended particles (ultra-microscopic globules of water no less than solid corpuscles), it would probably, like distilled water, absorb more copiously the rays forming the red end of the solar spectrum than those of the blue extremity; so that the green-blue tints would appear by transmitted light. But as in the case of natural waters, the presence of finely divided matter in a state of suspension in the atmosphere, by scattering the shorter waves of light, neutralizes and overcomes the effects of selective molecular absorption; so that, in reality, yellow, orange and red are the tints transmitted at sunrise and sunset; while the light reflected from the attenuated suspended particles gives us the blue color of the sky. It thus appears to be in the highest degree probable, that the dichromatic properties of the atmosphere are due to the same physical causes as those of the waters of lakes and seas.[1]

[1] Since the above was written, Prof. S. P. Langley has published the results of his refined and admirable experiments at Alleghany in the spring of 1881, by means of his "*bolometer.*" The title of his paper is, "The Selective Absorption of Solar Energy," (*Vide* Am. Journ. Sci. 3d. S., vol. 25, p. 169, *et seq.* March, 1883.) but, when properly interpreted, they seem to fortify the view above expressed. They indicate that

Cause of Other Colors of Certain Waters.—Besides the rich blue and green tints which we have been considering, the waters of lakes and seas in some places present various other hues. From the preceding discussion it is evident that the shades of color presented to the observer will depend upon several circumstances, viz.: (*a*) The presence of coloring matters in solution; (*b*) The color of the bottom; (*c*) The depth of water; and (*d*) The amount and character of the suspended matter present.

(*a*.) There are certain natural waters which obviously derive their colors from the presence of coloring substances in solution. In most cases various organic matters seem to be coloring agents. Thus, the waters of pools, ponds, and small lakes, as well as those of their tributaries, in certain level forest-clad regions, frequently exhibit various shades of brown, and sometimes present a rich sherry color when viewed in considerable masses. These tints, doubtless, arise from the diluted colored infusions produced by the percolation of the meteoric waters through decaying leaves and other organic substances.

(*b*). The color of the bottom, when the water is sufficiently shallow to reflect back to the observer more or less of the transmitted light, must evidently modify the resultant tint presented to the eye. According as the bottom exhibits various shades of white, green, yellow, brown or red, the mingling of these tints with the blue reflected from the suspended particles in the intervening stratum of water must give rise to various chromatic hues, from bluish-green to yellowish-red. There is much uncertainty in relation to the origin of the color-designation of the Red Sea; but it is by no means improbable that it arose from the abundance of red coral found in it, which imparts a reddish tint to the waters occupying the shallow portions. The waters of the Bay of Loango, on the western coast of tropical Africa, have been observed to be always strongly reddish, as if mixed with blood, and Captain Tuckey assures us that the bottom of this bay is very red.

(*c*.) It is scarcely necessary to remark that, as the tint of the light coming from the bottom to the observer is modified by the thickness of the intervening stratum of liquid, the color due to the mingling of it with the blue reflected from the suspended particles must depend, to some extent, upon the depth of water as well as the hue of the bottom.

(*d*.) Lastly, it is very obvious that the amount and character of the suspended matter existing in the water must, more or less, modify the color presented to the observer. Near the mouths of rivers the sea exhibits tints evidently depending upon the color of the suspended materials discharged into it. Thus, the Yellow Sea derives its name from the hue imparted to its waters by the large amount of yellow sediment discharged into it by the Hoang Ho and Yang-tse-Kiang.

Moreover, the variety of colors of the waters of the seas may, in many instances, be traced to myriads of living vegetable and animal organisms diffused in the liquid. The unfortunate Captain Tuckey, while navigating the seas on the western coast of tropical Africa, found that the waters began to grow white on entering the Gulf of Guinea; and in the

some fifty-four per cent. of the long-wave (infra-red) solar energy is transmitted through the air at low-sun; and only about eight per cent. of short-wave (ultra-violet) radiation reaches us under similar circumstances. Prof. Langley ascribes this difference to the greater "*selective absorption*" of the short-waves by the atmosphere; but it is obvious that the greater *selective reflection* of these waves would produce identical phenomena. In fact, as we have seen, Tyndall's experiments seem to show that these short-waves are *not absorbed* by the atmosphere, but are *selectively reflected* from the ultra-microscopic corpuscles which are held in suspension. Hence, we conclude that the results recorded by Langley are not due to selective absorption, but to selective reflection: so that a slight freedom of interpretation brings these experimental results into harmony with those deduced from experiments on the natural waters.

The *green sun* occasionally seen in India (or elsewhere) just preceding the beginning of the rainy season, (Nature, vol. 28, p. 575 and p. 588. Oct., 1883) may be due to the selectively absorbent action of the enormous quantity of aqueous vapor in the atmosphere on the red end of the spectrum, *neutralizing* and *overcoming* the effect of the removal of the short-waves by selective reflection from the suspended matter. In other cases, the phenomenon may be due to volcanic products projected into the atmosphere.

vicinity of Prince's Island his vessel appeared to be moving in a sea of milk. He ascribed this white color of the water to the multitude of minute animals (many of them phosphorescent) diffused near the surface, which completely masked the natural tint of the liquid. In like manner, according to the observations of Captain Scoresby, the olive-green waters of certain portions of the Arctic Seas owe their color to the presence of myriads of medusæ and other animalcules.

The illustrious Ehrenberg having observed that the waters of the Gulf of Tor, in the Gulf of Suez, were colored blood-red, subjected a portion of them to microscopic examination, and found the color to be due to the presence of a minute, thread-like, dark red oscillatoria or alga. The same alga was observed by Dupont and by Darwin as imparting a similar tint to certain areas of the oceanic waters. In other cases the sea is colored red by animals of different kinds, as by minute crustaceans or infusoriæ. Thus in the Gulf of California two distinct shades of red are produced by the presence of different microscopic infusoriæ. Again, the presence of diatoms frequently gives rise to various colorings in the waters in certain regions of the sea; and the local development of bacteria has often given origin to the apparently mysterious appearance of bloody spots extending over very limited areas.

John Le Conte.

LEISURE.

Written in La Paz, Mexico.

Sweet Leisure, welcome! Lo! I run to thee,
  Fall at thy feet and kiss them o'er and o'er;
Not since my childhood's hours have I been free
  To lay my cheek to thine, or hold thee more
Than one short moment in a fond embrace:
Can it be true I meet thee face to face?
  And stranger, if 'tis true that thou art mine,
Hard to believe, and harder still to doubt
  When thy soft arms so tenderly entwine
My weary, languid form around about;
  And thy calm voice rehearses in mine ear
  The love of him who gently bore me here
  To meet thee, 'neath the palms beside the sea,
That I my fevered, restless feet might lave
  (Thy magic hand all gently soothing me)
In the cool waters of the crystal wave,
  Far from the world, apart, with thee to rest,
  Yet in a world complete—supremely blest.

Sweet Leisure! while within my soul the bliss
  Of meeting thee stirs every pulse and thought;
While nerve elated, and from happiness
  To rhapsody the senses high are wrought;
Ere yet within thy atmosphere they gain
A mood too tranquil, listen to my strain: