The Color of Water—I*

A Valuable Compendium of the Literature on a Neglected Subject

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THE literature on the color of water is widely scattered; it appears not to have been read by anybody; and it is somewhat contradictory. It has, therefore, seemed desirable to collect the material in an accessible form as it constitutes an interesting chapter in the general subject of the colors of colloids.

Tyndall¹ has discussed the blue color of turbid media with special reference to the color of the sky and of the sea. In Newton's rings the color nearest to the central black spot is a faint blue—blue of the first order—corresponding to the film of air when thinnest. "If a solid or liquid, of the thickness requisite to produce this color were broken into bits and scattered in the air, Newton inferred that the tiny fragments would display the blue color. Tantamount to this, he considered, was the addition of minute water-particles in the incipient stage of their condensation from aqueous vapor. Such particles suspended in our atmosphere ought, he supposed, to generate the serenest skies. Newton does not appear to have bestowed much thought upon this subject; for to produce the particular blue which he regarded as sky-blue, thin plates with parallel surfaces would be required. The notion that cloud-particles are hollow spheres, or vesicles, is prevalent on the Continent, but it never made any way among the scientific men of England. De Saussure thought that he had actually seen the cloud-vesicles, and Faraday, as I learned from himself, believed that he had once confirmed the observation of the illustrious Alpine traveler. During my long acquaintance with the atmosphere of the Alps I have often sought for these aqueous bladders, but have never been able to find them. Clausius once published a profound essay on the colors of the sky. The assumption of small water drops, he proved, would lead to optical consequences entirely at variance with facts. For a time, therefore, he closed with the idea of vesicles, and endeavored to deduce from them the blue of the firmament and the morning and evening red.

"It is not, however, necessary to invoke the blue of the first order to explain the color of the sky; nor is it necessary to impose upon condensing vapor the difficult, if not impossible, task of forming bladders, when it passes into the liquid condition. Let us examine the subject. Eau-de-Cologne is prepared by dissolving aromatic gums or resins in alcohol. Dropped into water, the scented liquid immediately produces a white cloudiness, due to the precipitation of the substances previously held in solution. The solid particles are, however, comparatively gross; but, by diminishing the quantity of the dissolved gum, the precipitate may be made to consist of extremely minute particles. Brücke, for example, dissolved gum-mastic, in certain proportions, in alcohol, and carefully dropping his solution into a beaker of water, kept briskly stirred, he was able to reduce the precipitate to an extremely fine state of division. The particles of mastic can by no means be imagined as forming bladders. Still, against a dark ground—black velvet for example—the water that contains them shows a distinctly blue color. The bluish color of many liquids is produced in a similar manner. Thin milk is an example. Blue eyes are also said to be simply turbid media. The rocks over which glaciers pass are finely ground and pulverized by the ice, or the stony emery imbedded in it; and the river which issues from the snout of every glacier is laden with suspended matter. When such glacier water is placed in a tall glass jar, and the heavier particles are permitted to subside, the liquid column, when viewed against a dark background, has a decidedly bluish tinge. The exceptional blueness of the Lake of Geneva, which is fed with glacier water may be due, in part, to particles small enough to remain suspended long after their larger and heavier companions have sunk to the bottom of the lake.

"We need not, however, resort to water for the production of the color. We can liberate, in air, particles of a size capable of producing a blue as deep and pure as the azure of the firmament. In fact, artificial skies may be thus generated, which prove their brotherhood with the natural sky by exhibiting all its phenomena. There are certain chemical compounds—aggregates of molecules—the constituent atoms of which

are readily shaken asunder by the impact of special waves of light. Probably, if not certainly, the atoms and the waves are so related to each other, as regards vibrating period, that the wave-motion can accumulate until it becomes disruptive. A great number of substances might be mentioned whose vapors, when mixed with air and subjected to the action of a solar or an electric beam, are thus decomposed, the products of decomposition hanging as liquid or solid particles in the beam which generates them. And here I must appeal to the inner vision already spoken of. Remembering the different sizes of the waves of light, it is not difficult to see that our minute particles are larger with respect to some waves than to others. In the case of water, for example, a pebble will intercept and reflect a larger fractional part of a ripple than of a larger wave. We have now to imagine light-undulations of different dimensions, but all exceedingly minute, passing through air laden with extremely small particles. It is plain that such particles, though scattering portions of all the waves, will exert their most conspicuous action upon the smallest waves—in other words, the color line—will be predominant in the scattered light. This harmonizes perfectly with what we observe in the firmament. The sky is blue, but the blue is not pure. On looking at the sky through a spectroscope, we observe all the colors of the spectrum; blue is merely the predominant color. By means of our artificial skies we can take as it were, the firmament in our hands and examine it at our leisure. Like the natural sky, the artificial one shows all the colors of the spectrum; but blue in excess. Mixing very small quantities of vapor with air, and bringing the decomposing luminous beam into action, we produce particles too small to shed any sensible light, but which may, and doubtless do, exert an action on the ultra-violet waves of the spectrum. We can watch these particles, or rather the space they occupy, till they grow to a size able to yield the firmamental azure. As the particles grow larger under the continued action of the light, the azure becomes less deep; while later on a milkiness, such as we often observe in nature, takes the place of the purer blue. Finally the particles become large enough to reflect all the light-waves, and then the suspended 'actinic cloud' diffuses white light. . . .

"In the harbor of Gibraltar, on the morning of our departure, I resumed a series of observations on the color of the sea. On the way out a number of specimens had been collected, with a view of subsequent examinations. But the bottles were claret bottles, of doubtful purity. At Gibraltar, therefore, I purchased fifteen white glass bottles, with ground-glass stoppers, and at Cadiz, thanks to the friendly guidance of Mr. Cameron, I secured a dozen more. These seven and twenty bottles were filled with water, taken at different places between Oran and Spithead. And here let me express my warmest acknowledgments to Captain Henderson, the commander of H. M. S. Urgent, who aided me in my observations in every possible way. Indeed, my thanks are due to all the officers for their unfailing courtesy and help. The captain placed at my disposal his own coxswain, an intelligent fellow named Thorgood, who skilfully attached a cord to each bottle, weighted it with lead, cast it into the sea, and, after three successive rinsings, filled it under my own eyes. The contact of jugs, buckets, or other vessels was thus avoided; and even the necessity of pouring out the water, afterward, through the dirty London air.

"The mode of examination applied to these bottles has been already described. The liquid is illuminated by a powerfully condensed beam, its condition being revealed through the light scattered by its suspended particles. Care is taken to defend the eye from the access of all other light, and, thus defended, it becomes an organ of inconceivable delicacy. Were water of uniform density perfectly free from suspended matter, it would, in my opinion, scatter no light at all. The track of a luminous beam could not be seen in such water. But 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, when examined by the method alluded to, produce not only sensible, but striking, effects upon the eye.

"The results of the examination of nineteen bottles filled at various places between Gibraltar and Spithead are tabulated in Table I.

"Here we have three specimens of water, described as green, a clearer green and bright green, taken in Gibraltar Harbor, and off Cabreta Point. The home examination showed the first to be thick with suspended matter, the second less thick, and the third still less thick. Thus the green brightened as the suspended matter diminished in amount.

TABLE I.			
No.	Location	Color of Sea	Appearance in Luminous Beam
1	Gibraltar Harbor.....	Green	Thick with fine particles.
2	Two miles from Gibraltar.....	Clearer green	Thick with very fine particles
3	Off Cabreta Point.....	Bright green	Still thick, but less so.
4	Off Cabreta Point.....	Black-indigo	Much less thick, very pure.
5	Off Tarifa.....	Undecided	Thicker than No. 4.
6	Beyond Tarifa.....	Cobalt-blue	Much purer than No. 5.
7	Twelve miles from Cadiz.....	Yellow-green	Very thick.
8	Cadiz Harbor.....	Yellow-green	Exceedingly thick.
9	Fourteen miles from Cadiz.....	Yellow-green	Thick, but less so.
10	Fourteen miles from Cadiz.....	Bright green	Much less thick.
11	Between Capes St. Mary and Vincent.....	Deep indigo	Very little matter, very pure.
12	Off the Burlings.....	Strong green	Thick, with fine matter.
13	Beyond the Burlings.....	Indigo	Very little matter, pure.
14	Off Cape Finisterre.....	Undecided	Less pure.
15	Bay of Biscay.....	Black-indigo	Very little matter, very pure.
16	Bay of Biscay.....	Indigo	Very fine matter. Iridescent.
17	Off Ushant.....	Dark green	A good deal of matter.
18	Off St. Catherine's.....	Yellow-green	Exceedingly thick.
19	Spithead.....	Green	Exceedingly thick.

"Previous to the fourth observation our excellent navigating lieutenant, Mr. Brown, steered along the coast, thus avoiding the adverse current which sets in, through the Strait, from the Atlantic to the Mediterranean. He was at length forced to cross the boundary of the Atlantic current, which was defined with extraordinary sharpness. On the one side of it the water was a vivid green, on the other a deep blue. Standing at the bow of the ship, a bottle could be filled with blue water, while at the same moment a bottle cast from the stern could be filled with green water. Two bottles were secured, one on each side of this remarkable boundary. In the distance the Atlantic had the hue called ultra-violet; but looked fairly down upon, it was of almost inky blackness—black qualified by a trace of indigo.

"What change does the home examination here reveal? In passing the indigo, the water becomes suddenly augmented in purity, the suspended matter becoming suddenly less. Off Tarifa, the deep indigo disappears, and the sea is undecided in color. Accompanying this change, we have a rise in the quantity of suspended matter. Beyond Tarifa, we change to cobalt-blue, the suspended matter falling at the same time in quantity. This water is distinctly purer than the green. We approach Cadiz, and at twenty miles from the city get into yellow-green water; this the London examination shows to be thick with suspended matter. The same is true at Cadiz Harbor, and also of a point fourteen miles from Cadiz in the homeward direction. Here there is a sudden change from yellow-green to a bright emerald-green, and accompanying the change a sudden fall in the quantity of suspended matter. Between Cape St. Mary and Cape St. Vincent the water changes to the deepest indigo, a further diminution of the suspended matter being the concomitant phenomenon.

"We now reach the remarkable group of rocks called the Burlings, and find water between the shore and the rocks a strong green; the home examination shows it to be thick with fine matter. Fifteen or twenty miles beyond the Burlings we come again into indigo water, from which the suspended matter has in great part disappeared. Off Cape Finisterre, about the place where the Captain went down, the water becomes green, and the home examination pronounces it to be thicker. Then we enter the Bay of Biscay, where the indigo resumes its power, and where the home examination shows the greatly augmented purity of the water. A second specimen of water, taken from the Bay of Biscay, held in suspension fine particles of a peculiar kind; the size of them was such as to render the water richly iridescent. It showed itself green, blue or salmon-colored, according to the direction of the line of vision. Finally, we come to our last two bottles, the one taken opposite St. Catherine's lighthouse, on the Isle of Wight, the other at Spithead. The sea at both these places was green, and both specimens, as might be expected, were pronounced by the home examination to be thick with suspended matter.

"Two distinct series of observations are here referred to—the one consisting of direct observations of the color of the sea, conducted during the voyage from Gibraltar to Portsmouth, the other carried out in the

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¹"Fragments of Science: The Sky; Voyage to Algeria; Niagara."

laboratory of the Royal Institution. And here it is to be noted that in the home examination I never knew what water was placed in my hands. The labels, with the names of the localities written upon them, had been tied up, all information regarding the source of the water being thus held back. The bottles were simply numbered, and not till all of them had been examined, and described, were the labels opened, and the locality and sea-color corresponding to the various specimens ascertained. The home observations, therefore, must have been perfectly unbiased, and they clearly establish the association of the green color with fine suspended matter, and of the ultramarine color, and more especially of the black-indigo hue of the Atlantic, with the comparative absence of such matter.

"So much for mere observation; but what is the cause of the dark hue of the deep ocean? A preliminary remark or two will clear our way toward an explanation. Color resides in white light, appearing when any constituent of the white light is withdrawn. The hue of a purple liquid, for example, is immediately accounted for by its action on a spectrum. It cuts out the yellow and green, and allows the red and blue to pass through. The blending of these two colors produces the purple. But while such a liquid attacks with special energy the yellow and green, it enfeebles the whole spectrum. By increasing the thickness of the stratum we may absorb the whole of the light. The color of a blue liquid is similarly accounted for. It first extinguishes the red; then, as the thickness augments, it attacks the orange, yellow, and green in succession; the blue alone finally remaining. But even it might be extinguished by a sufficient depth of the liquid.

"And now we are prepared for a brief, but tolerably complete, statement of that action of sea-water upon light to which it owes its darkness. The spectrum embraces three classes of rays—the thermal, the visual and the chemical. These divisions overlap each other; the thermal rays are in part visual, the visual rays in part chemical and vice-versa. The vast body of thermal rays lies beyond the red, being invisible. These rays are attacked with exceeding energy by water. They are absorbed close to the surface of the sea, and are the great agents in evaporation. At the same time the whole spectrum suffers enfeeblement; water attacks all its rays, but with different degrees of energy. Of the visual rays, the red are first extinguished. As the solar beam plunges deeper into the sea, orange follows red, yellow follows orange, green follows yellow and the various shades of blue, where the water is deep enough, follow green. Absolute extinction of the solar beam would be the consequence if the water were deep and uniform. If it contained no suspended matter, such water would be as black as ink. A reflected glimmer of ordinary light would reach us from its surface, as it would from the surface of actual ink; but no light, hence no color, would reach us from the body of the water. In very clear and deep sea-water this condition is approximately fulfilled, and hence the extraordinary darkness of such water. The indigo, already referred to, is, I believe, to be ascribed in part to the suspended matter, which is never absent, even in the purest natural water; and in part to the slight reflection of the light from the limiting surfaces of strata of different densities. A modification of light is thus thrown back to the eye, before the depth necessary to absolute extinction has been attained. An effect precisely similar occurs under the moraines of glaciers. The ice here is exceptionally compact, and, owing to the absence of the internal scattering common in bubbled ice, the light plunges into the mass, where it is extinguished, the perfectly clear ice presenting an appearance of pitchy blackness."

"The green color of the sea has now to be accounted for; and here, again, let us fall back upon the sure basis of experiment. A strong white dinner-plate had a lead weight securely fastened to it. Fifty or sixty yards of strong hempen line were attached to the plate. My assistant, Thorgood, occupied a boat, fastened as usual to the davits of the *Urgent*, while I occupied a second boat nearer the stern of the ship. He cast the plate as a mariner heaves the lead, and by the time it reached me it had sunk a considerable depth in the water. In all cases the hue of this plate was green. Even when the sea was of the darkest indigo, the green was vivid and pronounced. I could notice the gradual deepening of the color as the plate sank, but at its greatest depth, even in indigo water, the color was still green."

"Other observations confirmed this one. The *Urgent* is a screw steamer, and right over the blades of the

screw was an orifice called the screw-well, through which one could look from the poop down upon the screw. The surface-glimmer, which so pesters the eye, was here in a great measure removed. Midway down, a plank crossed the screw-well from side to side; on this I placed myself and observed the action of the screw underneath. The eye was rendered sensitive by the moderation of the light; and, to remove still further all disturbing causes, Lieutenant Walton had a sail and tarpaulin thrown over the mouth of the well. Underneath this I perched myself on the plank and watched the screw. In an indigo sea the play of color was indescribably beautiful, and the contrast between the water, which had the screw blades, and that which had the bottom of the ocean, as a background, was extraordinary. The one was of the most brilliant green, and the other of the deepest ultramarine. The surface of the water above the screw-blade was always ruffled. Liquid lenses were thus formed, by which the light was withdrawn from some places and concentrated upon others, the water flashing with metallic lustre. The screw-blades in this case played the part of the dinner-plate in the former case, and there were other instances of a similar kind. The white bellies of porpoises showed the green hue, varying in intensity as the creatures swung to and fro between the surface and the deeper water. Foam, at a certain depth below the surface, was also green. In a rough sea the light which penetrated the summit of a wave sometimes reached the eye, a beautiful green cap being thus placed upon the wave, even in indigo water.

"But how is this color to be connected with the suspended particles? Take the dinner-plate which showed so brilliant a green when thrown into indigo water. Suppose it to diminish in size, until it reaches an almost microscopic magnitude. It would still behave substantially as the larger plate, sending to the eye its modicum of green light. If the plate, instead of being a large coherent mass, were ground to powder sufficiently fine, and in this condition diffused through the clear sea-water, it would also send green to the eye. In fact, the suspended particles which the home examination reveals act in all essential particulars like the plate, or like the screw-blades, or like the foam, or like the bellies of the porpoises. Thus I think the greenness of the sea is physically connected with the matter which it holds in suspension. . . .

"At some distance below the Whirlpool Rapids we have the celebrated whirlpool itself. Here the river makes a sudden bend to the northeast, forming nearly a right angle with its previous direction. The water strikes the concave bank with great force, and scoops it incessantly away. A vast basin has been thus formed, in which the sweep of the river prolongs itself in gyratory currents. Bodies and trees which have come over the falls are stated to circulate here for days without finding the outlet. From various points of the cliffs above this is curiously hidden. The rush of the river into the whirlpool is obvious enough; and though you can imagine the outlet must be visible if one existed, you cannot find it. Turning, however, round the bend of the precipice to the northeast, the outlet comes to view.

"The Niagara season was over; the chatter of sight-seers had ceased, and the scene presented itself as one of holy seclusion and beauty. I went down to the river's edge, where the weird loneliness seemed to increase. The basin is enclosed by high and almost precipitous banks—covered, at the time, with russet woods. A kind of mystery attaches itself to gyrating water, due perhaps to the fact that we are to some extent ignorant of the direction of its force. It is said that, at certain points of the whirlpool, pine-trees are sucked down, to be ejected mysteriously elsewhere. The water is of the brightest emerald-green. The gorge through which it escapes is narrow, and the motion of the river swift though silent. The surface is steeply inclined, but it is perfectly unbroken. There are no lateral waves, no ripples with their breaking bubbles to raise a murmur, while the depth is here too great to allow the inequality of the bed to ruffle the surface. Nothing can be more beautiful than this sloping liquid mirror formed by the Niagara in sliding from the whirlpool.

"The green color is, I think, correctly accounted for in the last Fragment. While crossing the Atlantic, in 1872-1873, I had frequent opportunities of testing the explanation there given. Looked properly down upon, there are portions of the ocean to which we should hardly ascribe a trace of blue; at the most, a mere hint of indigo reaches the eye. The water, indeed, is practically black, and this is an indication both of its depth and of its freedom from mechanically suspended matter. In small thicknesses water is sensibly transparent to all kinds of light; but, as the thickness increases the rays of low refrangibility are first

absorbed, and after them the other rays. Where, therefore, the water is very deep and very pure, all the colors are absorbed, and such water ought to appear black, as no light is sent from its interior to the eye. The approximation of the Atlantic Ocean to this condition is an indication of its extreme purity.

"Throw a white pebble into such water; as it sinks it becomes greener and greener, and before it disappears, it reaches a vivid blue-green. Break such a pebble into fragments, each of these will behave like the unbroken mass; grind the pebble to powder, every particle will yield its modicum of green; and if the particles be so fine as to remain suspended in the water, the scattered light will be a uniform green. Hence the greenness of shoal water. You go to bed with the black Atlantic around you. You rise in the morning, find it a vivid green, and correctly infer that you are crossing the bank of Newfoundland. Such water is found charged with fine matter in a state of mechanical suspension. The light from the bottom may sometimes cross into play, but it is not necessary. A storm can render the water muddy, by rendering the particles too numerous and gross. Such a case occurred toward the close of my visit to Niagara. There had been rain and storm in the upper lake-regions, and the quantity of suspended matter brought down quite extinguished the fascinating green of the Horseshoe.

"Nothing can be more superb than the green of the Atlantic waves, when the circumstances are favorable to the exhibition of the color. As long as a wave remains unbroken no color appears; but when the foam just doubles over the crest, like an Alpine snow-cornice, under the cornice we often see a display of the most exquisite green. It is metallic in its brilliancy. But the foam is necessary to its production. The foam is first illuminated, and it scatters the light in all directions; the light which passes through the higher portion of the wave alone reaches the eye, and gives to that portion its matchless color. The folding of the wave, producing as it does a series of longitudinal protuberances and furrows which act like cylindrical lenses, introduces variation in the intensity of the light and materially enhances its beauty."

The question of the color of the Mediterranean and of other waters has been studied with a good deal of care by Aitken, whose work seems not to have received the attention which it deserves. Only a lengthy abstract of his paper is available and I quote from that."

"The experiments were made with a special view of determining whether the selective reflection or the selective absorption theory gave the correct explanation of the blueness seen in water. According to the selective reflection theory the color is due to the light reflected by extremely small particles of matter suspended in the water, these particles being so small they can reflect only the short waves of light, or those which belong to the blue end of the spectrum. The other theory explains the color by supposing that water has a selective absorption for the rays of the red end of the spectrum—that water is in fact a blue transparent medium. Three different methods were adopted of testing the correctness of these rival theories, and all three proved the water of the Mediterranean to be blue by selective absorption, and show that light in passing through the water has the rays of the red end of the spectrum absorbed, and only those of the blue end transmitted. The first method tried was to find out what is the color of the illumination of submerged objects. This was done by taking a long metal tube, closed at the end with a glass plate, sinking it vertically in the water, and looking through it at white and different colored objects fixed near the end of the tube. When this was done, it was found that a white object appeared of a most beautiful deep and delicate blue at a depth of 6 m. If the selective reflection theory was true, submerged objects would be illuminated with a color complementary to that reflected by the fine particles, and would therefore appear orange or yellow, the exact color depending on the amount of green in the reflected blue. If the blue color of the sky, as generally supposed, is due to the reflection of the blue rays by small particles of matter suspended in the air, it obviously follows that light in passing through our atmosphere must become of a color complementary to the blue of the sky; and it is asked, may not this be one of the reasons why the sun near the horizon, and all artificial lights when seen at a great distance, appear more or less yellow?"

"The second method of experimenting was by looking at a white surface through a considerable length of water contained in a blackened tube. The light transmitted was found to be blue, thus showing the water to have a selective absorption for the rays of the red end of the spectrum.

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*Aitken: Proc. Roy. Soc. Edin. 11, 472 (1882).

²I learn from a correspondent that certain Welsh tarns, which are reputed bottomless, have this inky hue.

³In no case, of course, is the green pure, but a mixture of green and blue.

Influence of Magnetic Field on the Initial Phase of the Electric Discharge

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In the particular case of the influence of the field on the potential of discharge, we must also take into consideration, besides the magnetic field, the electric field due to the difference of potential of the electrodes. For certain reasons it can be predicted that the influence of the magnetization is most evident when the two fields lie in a rectangular direction. M. Righi's experiments prove, in fact, that the magnetic field causes the potential of discharge to be lowered precisely at the moment when it lies in a direction perpendicular to the lines of electric force, i. e. when it tends to prevent the positive ions as well as the electrons from moving in the direction which runs from one electrode to the other as required by the mechanism of the discharge. There can be no doubt according to M. Righi that the current explanation is insufficient and that it is necessary to assume a special action of the field tending to favor the discharge which would be magneto-ionization. —*Revue Scientifique* (Paris).

A Unique Form of Prehistoric Pottery

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was used as a receptacle for sacred water. It is not unusual for the Hopi priests today to make long pilgrimages to distant springs to procure water to use in their rites. The medicine vessels of Hopi priests are, however, smaller and simpler than that here considered, although some of these sacred vessels are furnished with handles. The size of the two members of the prehistoric vessels are about the same; both are almost spherical, slightly flattened on their upper side where they are decorated with parallel lines distributed in four blocks. Both have an unusual feature in prehistoric pottery—a concave basal depression. This unique form of pottery belongs to the black-and-white ware which is regarded as archaic and characteristic of the most ancient pueblo ruins.—J. W. FEWKES, in *Journ. Wash. Acad. Sci.*

The Color of Water—I

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"The third method was by sinking white and different colored surfaces under water, and noting the change which took place in the colors. The colors selected were red, yellow, and purple. It was found that these colors when seen through the water changed in the same way as when seen through a blue transparent medium, such as a piece of glass. The white changed to blue. The red darkened very rapidly as it descended, a very small depth of water being sufficient to destroy all the color. At a depth of about 2 m. a very brilliant red was so darkened as to appear a dark brick red. Yellow changed to green by the water absorbing the red component of the yellow. An orange, as it sank in the water, appeared to become more and more unripe, while a lemon became quite green. The purple surface quickly changed to a dark blue or violet by the selective absorption of the water. These changes, being all due to the cutting out of the red component of the colors, showed the water to have a selective absorption for the rays of the red and of the spectrum. If the water had been colored blue by selective reflection, then those test colors would all have appeared deficient in blue when sunk in the water, as the fine particles would reflect and scatter the blue rays. Experiments are described which show that when these colors are sunk in water colored blue by reflection from small particles, white changes to yellow, while yellow simply deepens in color, and purple grows redder.

"All these different methods of experimenting show this water to be a blue transparent medium, and that it acts in the same way as a solution of a blue salt or as a blue tinted glass. It is then shown that this selective absorption theory is not enough to account for the different color phenomena seen in water. A piece of blue glass or a blue solution have but little color when viewed from the side on which the light is falling, and it seems certain that light will penetrate pure water till it is all absorbed, and the water will look dark and colorless. Something more, and that of great importance, is obviously necessary to explain the different color phenomena seen in different waters, and in the same water at different times.

"If the water of the Mediterranean, when brilliantly colored, is examined by means of a concentrated beam of light, it is found to be full of fine solid particles in suspension. It is shown that it is to this dust of the sea—so to speak—that the Mediterranean owes its fine and varied coloring. The particles of this aquatic dust are large, and reflect not only the blue rays, like

the supposed particles of the selective reflection theory, but they reflect rays of all colors, and the water, by its selective absorption, strikes down the red rays, and only the blue rays are reflected to the surface and to the eye. These solid particles determine the brilliancy, and the selective absorption of the water determines its color. The color and the amount of the suspended particles is then considered. It is shown that the color of the particles will have a marked influence in the appearance of the water. If the particles are yellow—sand particles, for instance—then a blue colored water will appear to be green, as the light reflected by the yellow particles is deficient in the rays of the violet end of the spectrum.

"In the Mediterranean the solid particles are whitish and all the different color phenomena are easily explained by the different amounts of the reflecting particles at the different places. Where the color is deep blue there are few particles in the water, and but little light reflected; and, further, the light passes through a great amount of water, and undergoes a great amount of selective absorption before it is reflected to the surface and to the eye. But if there are many particles in the water much light is reflected, and the color is chalky blue-green, as the light does not pass through so great a depth of water, and is therefore not so deeply colored, nor has it so many of the green rays cut out as in the water where the particles are few and far separated.

"Color experiments on a small scale with a solution of Prussian blue and a fine white powder are described. If the solution of Prussian blue is placed in a vessel, the bottom and sides of which are dark and reflect no light, then the colored solution appears dark and colorless; but if a little of the white powder is added then the solution at once becomes brilliantly colored. By varying the amount of the powder in the water all the varied color effects of the Mediterranean can be reproduced, a little powder causing the solution to appear deep blue, and as more powder is added the brilliancy of the water increases, and its color changes from blue to chalky blue-green.

"The presence and the abundance of white reflecting particles is shown to be a characteristic of all finely colored waters, and the wave-washed shores of the Mediterranean are shown to be the factories in which are prepared its reflecting particles. The waves, as they beat on the shore, grind up the stones and rocks, and stir up a great amount of fine whitish solid matter, which gives the water along the shore a milky appearance.

"With the assistance of these whitish particles, we understand how it is that the brilliant blue-green of this sea depends so much on the continuance of sea-breezes. The longer the wave-mills have been at work the more fine powder has been produced along the shore, and more time given for the particles to be carried seaward, by the wave-mixed and wind-driven waters, and the blue-green which only extended in a narrow band along the shore, when the wind began to blow, is, after a few days of inshore wind, seen to extend far to sea. We also understand how it is that the color near shore is so brilliant and so much greener than outside. Near the shore there is a greater quantity of white solid matter in suspension; there is therefore more light reflected, and further, the light does not penetrate through so great a depth of water, and has not so much of the light of the red end of the spectrum cut out, and therefore looks greener than the water outside, the light from which has to penetrate a greater depth of the absorbing medium. The blueness and beauty of the Mediterranean would thus appear to be due to the blue transparency of its waters, coupled with the presence of white reflecting particles, and the variety in its coloring to the amount of the suspended particles at different places and at different times.

"From this we see the important influence which the geological formation of the shore has on the appearance of the water of a sea, as it determines the nature of the solid suspended particles. This is beautifully illustrated by the difference of coloring in the Mediterranean at Mentone and at Cannes. At Mentone, limestone is everywhere abundant along the shore, and this limestone, when ground up by the waves, produces an extremely fine and white powder, which mixed with the water, causes the sea at Mentone to be far more brilliantly colored than it is at Cannes, where there is but little limestone, and the shore is almost everywhere covered with sand, the debris of the surrounding rocks.

"In the experiments in the Mediterranean it was found that the solid particles were so abundant that they prevented the sun's rays penetrating in a direct line to any great depth. This was shown by the illumination of the white surface placed at some distance under the water, and seen through the empty tube,

being the same, whether the surface was turned towards the sun or away from it. It was also shown by the fact that at a depth of 6 m. these solid particles were found to reflect about as much light as a white surface did. These solid particles act like a fog, and, while they stop the light penetrating in a direct line, yet allow it to penetrate much further by internal reflection. The sun's rays get entangled—so to speak—among the particles, and are reflected from particle to particle, becoming a deeper blue with each reflection, so that the particles become illuminated with blue light. From this it is obvious that the more transparent the water, and the greater the reflecting power of the particles, the more deeply colored will the water appear.

(To be continued)

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