(28.)

ON THE DIATOM PRISM, AND THE TRUE FORM OF DIATOM MARKINGS.*

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The pages of our Transactions, from the commencement of our Society to the present time, bear ample evidence of the interest which is taken in the structure of the Diatom-valve, and of the Protean aspects which different observers have confidently recorded under different methods of illumination. In venturing to propose a new method of illumination and to describe new results, I must be permitted to copy the confidence of those who have preceded me, and to say that the usual methods of illumination are wrong in principle, and the consequent descriptions of the form of Diatom Markings are wrong in detail. But this, says one of my friends, is "a startler," and we all have to go to school again. I can only reply, that I have never left school, and the new lesson I have just learnt is not one of least interest, for it is admitted by those who have bestowed no unworthy labour on the minute structure of the diatom-valve, that the correct exposition of the structure involves a question quite as important, perhaps, as any we have to encounter in the whole course of vegetable physiology. It was only when I was imposed upon by lines, *i.e.* when I was taught to believe that on the valve of *P. angulatum*, for instance, there are sets of three lines in the direction of the sides of an equilateral triangle, and formed by probably elevated ridges, that I proposed to obtain their shadows, not by a circle of light, as in the common "stop lens," but by three separate points of light of proper intensity in the kettledrum, to be placed by the revolution of the sub-stage at right-angles to the lines to be resolved; and if this were the true structure, the principle of illumination is correct. The result also appeared to be satisfactory. The lines of shadows were readily made out, with the due arrangement of hexagonal markings, formed by the crossing of two equilateral triangles of these shadow-lines; but, after all, so far as the eye was concerned, there was only an illustration of Berkeley's theory of "No matter,"—shadow, without the substance. I have, however, at last seen the substance, and an

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exact knowledge of its form renders it absolutely necessary most materially to modify the mode of illumination.

I will state at once—and I hope to prove to the Society, as I have proved to others, the truth of what I affirm—that the outer surfaces of the two valves of diatoms in the family Naviculeæ are covered with rows of siliceous hemispheres, inclined at varying angles both to each other and to the longitudinal division of the valve. Hence, in scientific descriptions, the terms "striation and lineation" are no longer admissible, and the books we now have in our hands are not a mirror held up to nature, in which the members of this family could recognize themselves, for "striæ and lines" are just as little applicable to the rows of hemispheres on the surface of a diatom-valve as they would be to a hayfield with its rows of haycocks.

Further, with reference to structure, a vertical section of *P. Quadratum* reveals the fact that the siliceous hemispheres on the outer surfaces have corresponding hemispheres on the inner surfaces; in fact, we have perfect spheres of silica set equatorially in the siliceous tissue of the valve. That such arrangement is the law of the structure, does not admit of doubt. The silica is the solid material round which the carbonaceous portion of the living cell gathers, and thus it has its counterpart in every cell of every plant in the vegetable kingdom, for the varying solid material of the cells of plants is as necessary as the carbonaceous material for enabling them to perform their proper functions in the economy of vegetation. In this respect it may be said to correspond with the osseous system in animals. As a very different arrangement of the same solid materials is invariably found in the mineral kingdom, we cannot but recognize the action of different laws in the formation of the crystal and of the cell; for, if the soluble silica obeyed the same law during its solidification in the latter case as in the former, we should have examples of rock-crystal in the cell instead of a siliceous cell-wall. This consideration ought to be borne in mind when we treat of the important subject of cell-formation. Protoplasm alone is not to Nature's liking.

As I was a pupil, I may almost say a friend, of Ehrenberg, who named for me the Xanthidia which I found in flint, I have been for a long time unable to recognize the entire validity of the arguments which exclude the Diatomaceæ from the animal kingdom. But when I now see the form and arrangement of the silica on the cell-wall of the diatom to be so exactly like its form—and its arrangement in consecutive corpuscles—on the stomata of many plants that I have examined, and so exceedingly unlike any secretion of silica in any other kingdom than the vegetable, I find no difficulty whatever in placing the Diatomaceæ among the unicellular algæ.

On viewing the surface of different diatom-valves, we find a great difference in the diameter of the hemispheres, and in their distance from each other. We are told, popularly, and in sufficiently vague language, so far as structure is concerned, that the "*striæ*" range between about 30 and 100 in $\frac{1}{1000}$th of an inch, and, to adduce an example, that the striæ of *P. strigilis* are much closer than those of *P. formosum*—a statement which gives no idea of the fact that the diameters of their hemispheres are the same. Doubtless it would be more accurate to give the number of the hemispheres and the measure of the space between them, or the ratios of the diameter and the interval.

In my own microscope, with Ross's $\frac{1}{12}$th and a double D eyepiece, the diameter of the field of view at the distance of the stage from the eye is 12 inches, and this space represents the magnified image of $\frac{1}{1000}$th of a inch, on a micrometer-slide ruled by Mr. Waterhouse. The magnifying power is therefore 12,000 linear. Using this arrangement, *P. Quadratum* has 40 hemispheres and 40 intervals in the diameter of the field, *i.e.* in 12 inches, which cover $\frac{1}{1000}$th of an inch on the micrometer-slide, and as each interval is equal to a radius of a hemisphere, the magnified diameter of each hemisphere covers $\frac{2}{10}$ths, and the interval $\frac{1}{10}$th of an inch. Therefore, the real diameter of the hemispheres is $\frac{1}{60000}$th, and of each interval $\frac{1}{120000}$th of an inch. The rows of hemispheres cross each other at an angle of 60°, as in *P. angulatum*, and are therefore arranged in the order of the sides of an equilateral triangle. Hence, under the illusion of the common methods of illumination, which deal with shadows only, and under deep powers, the markings of these diatoms are described and figured as hexagons, with the sides and centre light and dark, or *vice versâ*, and PHOTOGRAPHY stands by as an attesting witness. But this illusion arises from causing either the illuminated or the shaded portions of the hemispheres to run into each other, and so to form hexagons with either dark or light centres.

In a valuable paper by Dr. Wallich, "On the Development and Structure of the Diatom-valve," communicated to the Microscopical Society in March, 1860, it is stated that "in *P. formosum* there exists good evidence to prove that the interlinear spaces are occupied by elevated rhomboidal papillæ, which present facetted surfaces, whereas in *P. balticum*, instead of rhomboidal elevations, we have four-sided flattened pyramids, presenting, as in the former case, four sets of lines, of which those bounding the spaces, and not crossing them, are the predominant ones." No one will be more pleased than Dr. Wallich with the very different, but more truthful representation of these valves when illuminated by the *diatom-prism* which I will presently describe. In both valves we have rows of siliceous hemispheres. Those in *P. formosum* are at right-angles to each other, and meet the longitudinal division of the valve at an angle of 45°. In one direction there are 24 hemispheres and intervals in the 12-inch diameter of the field already described, and in the direction at right-angles to it there are 30 diameters and intervals, so that the rows of equal hemispheres are rather closer together in one direction than in the other. Here, under the magnifying power of 12,000 linear, one hemisphere and interval occupy half-an-inch, the apparent diameter of the hemisphere being $\frac{3}{10}$ths, and of the interval $\frac{2}{10}$ths of an inch; this, of course, makes the real diameter of the hemisphere $\frac{1}{40000}$th of an inch, and therefore, with *strigilis*, among the largest in the range of valvular structure. The "stout costæ" of Pinnularia major also follow the law of structure, and consist of very closely-packed spheres. When Mr. Sheppard, of Canterbury, saw these and other diatoms under the new illumination, he felt obliged to say that the microscope makes a new start on the Queen's birthday, 1869; and a young friend of mine, under fourteen years of age, exclaimed, when he saw the *formosum*, that "it looked like a plate of marbles." This, at all events, may be adduced as the evidence of an unprejudiced witness to the truthfulness of my story. *Pleurosigma balticum*, which we have all looked upon as presenting four-sided flattened pyramids, as described by Dr. Wallich, follows the same law of cell-formation as its congeners, the only modification being the cropping out of a rather larger portion of the sphere above the surface of the valve.

It is amusing now to read of ingenious modes of playing with the illuminating rays, so that the eye, fortified by a little previous theory, may see at will, either elevations or depressions, triangular, quadrangular, or hexagonal dots, with rhomboids, pyramids, or spheres. But *Truth* is not so many-faced as this, and it is, therefore, very satisfactory to find at the conclusion of Dr. Wallich's paper in the Transactions, that the editors have added an important note, which more than justifies my confidence in the accuracy of my descriptions. It is as follows:—"In the discussion which followed the reading of Dr. Wallich's paper, Mr. Wenham stated that, with an object-glass of his own construction, having a focal distance of about $\frac{1}{50}$th of an inch and a large aperture, he had ascertained, beyond doubt, that in *Pleurosigma angulatum*, and some others, the valves are composed wholly of spherical particles of silex, possessing high refractive properties. And he showed how all the various optical appearances in the valves of the Diatomaceæ might be reconciled with the supposition that their structure was universally the same." Mr. Wenham will be glad to learn that, while the true valvular structure was revealed to him by the $\frac{1}{50}$th of an inch, a power which few hands besides his own can make, and few observers can ever hope to possess, the diatom-prism, as an educational adjunct, will enable all observers to see the exquisite structure of the coarser valves, for even a $\frac{2}{3}$rds of an inch by Wray, with the D and double D eye-piece, shows "the plate of marbles" on *P. formosum* with abundant light and perfect achromatism.

It is needless to observe that deeper powers are required when attacking a valve like *N. rhomboides.* Here the $\frac{1}{12}$th is used, and I am sure that the exquisite beauty of this valve will be a treat to critical eyes. The acknowledged difficulty of resolving it arises from the extreme closeness of the very minute hemispheres in the longitudinal rows. Round the valve, and forming an elegant border, are three rows of beads or hemispheres gradually decreasing in size—then, on the semi-diameter of the valve through the centre, 14 rows of much smaller beads, numbering at least 80 in $\frac{1}{1000}$th of an inch—and then the two "median lines," which consist of hemispheres as large as those in the outer row of the border. In the centre of the valve the boss or *umbilicus* pushes out the adjacent beads of the median rows into an oval form. Powell's immersion lens would bear with admirable effect upon this exquisite object, and bring out the wondrous structure which, without the aid of the microscope, must have remained among the invisible things of Him who created all things. This lens would no doubt show also an exactly similar structure on the still more difficult valve *Amphipleura acus,* the shadows of the beads being already seen as apparent lines.

Such and so satisfactory is the work of the diatom-prism, which has made the microscope, old observer as I am, quite a new instrument *to me.* This is evident from the curious coincidence of my having given such a different description of *rhomboides* at the last meeting of the Society. In then describing the markings as brought out by a supposed improvement of the double hemispherical condenser, I used the language of the craft, and spoke of "dots as black as jet;" but this mere silhouette representation of *rhomboides,* an unnatural distortion of light and shade, I never wish to see again.

A single sentence will be sufficient to describe the diatom-prism illumination. I place *an equilateral* prism below the stage of the microscope, and the light, either of the sun or of a lamp, after being totally reflected, is made to fall obliquely on the valve to be examined. The light of a lamp is condensed in parallel rays by means of a bull's-eye lens. This is all. But why never used! Is it possible that, without making the trial, a supposed deficiency of the power of a few parallel rays could prove a bar to the experiment? Yet it would almost seem as if such were the case, since Newton, Chevalier, Amici, Brewster, and Abraham have suggested different modes of obtaining condensed and convergent reflected light, and their prisms have frequently formed adjuncts for microscopical examination. But, be this as it may, the fact remains that we are still without any authoritative recommendation to adopt the method I have described. Its advantages, however, are great and obvious. I have no longer two suns in my firmament, shining at right-angles to each other, but one source of proper light properly placed; and therefore, instead of the false appearance of lines and striæ, rectilineal and oblique under low powers, and of hexagons and other fancies, under high powers, I see what really does exist, *viz.* a series of beautiful hemispheres placed in their due order on the siliceous tissue of the valve. The kettledrum with its double pencil of light is therefore, *quoad hoc*, a thing of the past. If the hemisphere on the stage were really the size which our powers make it, nearly half an inch in diameter, it would be seen by unassisted vision, and we should smile at a supposed necessity of forming its shadow by two sources of light, just as an artist would smile if he were advised to have two windows in his studio at right-angles to each other, for the more artistic illumination of his sitter. The moon, as shown by the sun's illumination, is a fair illustration of diatom-illumination. Light, virtually parallel, falling obliquely on one side only of its mountains and craters, produces *natural* light and shade. Any other arrangement would fail, and for this reason right-angled apertures either with the kettledrum or the prism lead to illusions. The kettledrum, however, with one aperture properly placed, is still a serviceable condenser, and brings out the hemispheres remarkably well. Still, refracted light has not the power and purity of reflected light; and converging rays, whether reflected from a convex prism or refracted through a lens, must yield the palm to parallel light, which is obtained by Newton's plane prism as from the sun. The truth of this remark will be obvious if we place the smaller hemisphere of the kettledrum at right angles to its present position, and use it for obtaining condensed, reflected, and convergent rays from its flat surface, as proposed by Brewster. In this case, the object, being in a cone of converging rays, is virtually under the influence of more than one source of light, and its character is lost amid the intense illumination. It would be easy, by means of a double concave lens placed within the focus of the converging cone, to produce an intense beam of parallel light without any assistance from the bull's-eye lens, and this might enable us to detect more accurately the structure of such unapproachable fineness as obtains in *Aphipleura pellucida.* The direct light of the sun, when reflected by the plane prism, would thus be represented by a very close approximation.

In the mechanical adjustment of the prism to the sub-stage, I would suggest a cradle above a ball-and-socket joint, as prisms are often mounted, with the addition of a jointed arm, as used for the extension of the mirror of our microscopes sideways, and, if necessary, a clamping-screw to keep the prism in position. At present, I fix the prism on the sub-stage with an india-rubber band. All that is required is the power of turning the prism on its axis, and also of placing it over any diameter or any chord of the sub-stage. In the latter position, the prism lying over a chord from 30° east of the vertex of the stage to 30° west of south, and its face slightly inclined to the upper stage, very effective obliquity is obtained. The lamp, of course, stands to the west. We must rotate the valve by the circular motion of the upper stage, till the hemispheres are not obscured by the parallel lines of their own shadows. When they reach their proper place they seem to start into existence, and the degree of elevation is conferred *per saltum*. By this perfect command over its movements, the "diatom-prism" (thus named from its first application) will meet every requirement for oblique, direct, and dark-ground illumination, while its simplicity and independence of harness, in the shape of diaphragms or stops, is a chief characteristic. The light being nearly parallel, the prism may be moved, by the rackwork adjustment of the sub-stage, to a considerable distance below the object without materially weakening the illumination—and the slight diminution of light thus obtained is advantageous when using low powers.

It is impossible to avoid noticing the remarkable stereoscopic effect of this parallel reflected light. On a Barbadoes slide, for instance, the objects are seen under an inch power and on a dark ground in very striking relief; and the same effect is remarkably visible when viewing the proboscis of the blow-fly on a light ground. The peculiar character of muscular fibre is also well displayed, new beauty is seen in the Podura scale, and infusoria and portions of insects may be examined with additional interest.

It seems to be owing to this stereoscopic effect of parallel light and natural shadows, that the hemispheres of diatom-valves are seen beyond all doubt as elevations. We seem to be looking at an opaque body illuminated from above, and the appearance in the microscope is exactly similar to a model, made to scale, in plaster of Paris. On the other hand, when we have anything approaching to depressions, as in the markings of *Triceratium* and *Isthmia*, these depressions are, as it were, palpably felt. The hexagonal markings in *Triceratium* are of special interest. At every angle of the hexagon there is a hemisphere of larger size, and smaller hemispheres, in contact with each other, form the sides, so that it is questionable whether the depression is deeper than the radius of the hemispheres themselves. A similar inquiry also presents itself when viewing the irregular though somewhat circular markings formed by an arrangement of small hemispheres on the surface of *Isthmia*.

I felt unwilling that the present session should close without giving some account of my observations to those who have more leisure than myself for pursuing these interesting researches. That the hemispheres which Mr. Wenham speaks of generally, and Mr. Hogg figures in the case of *P. formosum*, are such as I have described is, I hope, satisfactorily proved. There they are. I can number them, I can weigh them, I can measure them—and number, measure, and weight may be justly represented as the three rectangular co-ordinates of all accurate knowledge of matter.

In the discussion on this paper, Mr. Wenham said: Some time since he had determined the markings on some diatoms to be spherical, and that this discovery had not been made by any special mode of illumination, but by the examination of fractured specimens. In one of the fragments of *Quadratum* a line of spherules had been detached like a row of beads. At the extreme end a single spherule had separated sufficiently to enable it to be examined in an isolated state. In another case a small piece of the scale had been broken out and laid over close to the opening, thus affording an immediate comparison of both sides of the scale at the same time, and clearly proving the appearance to be exactly similar on either. The diatoms in question are exceedingly brittle; and if some of them are placed on a slide with water, and a thin glass cover pressed hard down, and the whole left till dry, on slightly moving the cover some of them will be broken, a portion of the fragments adhering to each glass surface in various forms of dissection. The President confirmed in a remarkable way the views which he (Mr. Wenham) had entertained. An item of great value in the mode of illumination used by the President was the length of the prism, which threw a line of light from the condenser; and he thought that, by using a shorter prism of only one-fourth of the length, the same effect would not be produced. The relief in which the object was seen was very remarkable. In fact, it had all the appearance of a solid body illuminated from above.

Mr. Browning said it was gratifying to know, that after having bestowed so much labour on the attempt to resolve the markings on diatoms, the President was able to exhibit the real facts by so simple a method.

Mr. Slack said it was very interesting to find that the deposition of silica in the living diatom takes place under purely physical laws; and the appearances which had been described as occurring on the diatom-valves are exactly what can be produced in making artificial diatoms by Max-Schultze's process. The structure of the diatom-valve shows that the so-called "vital forces" do not trouble themselves to interfere with the deposition of silica, according to chemical and physical laws. He had never seen the markings on diatoms so well and clearly shown as by the President's method, though he had long distrusted any mode of displaying them that did not lead to the same results.

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