VII. *On an Artificial Substance resembling Shell: by* Leonard Horner, *Esq. F.R.SS. Lond. & Edinb. With an Account of an Examination of the same: by Sir* David Brewster, *LL.D. F.R.S. &c.*

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WHILE I was, some time ago, officially inspecting the cotton-factory of Messrs. J. Finlay and Co., at Catrine, in the county of Ayr, on going over the bleaching-establishment attached to it, I was struck with an unusual appearance of a part of the machinery, which, at a distance, looked as if it were made of brass. On a closer examination, I found that it was a large circular wooden box coated with an incrustation of a brown compact substance, having a highly polished surface, a metallic lustre, in some places beautifully iridescent, and when broken exhibiting a foliated texture*. This resemblance in structure and pearly lustre to some species of shells, such as the *Meleagrina, Malleus, Avicula, Ostrea, Pinna,* and others, induced me to examine the substance more closely, conceiving that it might possibly throw some light on the formation of shell.

The part of the machinery on which I observed the incrustation is called a Dash-wheel, and consists of a circular box, about seven feet in diameter and three feet in width, revolving upon a horizontal axis, and having its interior divided into four compartments, into each of which there is a circular opening on one side. The purpose of this wheel is to wash or rinse the cloth in pure water, after it has been boiled or steeped in the bleaching-liquors. It makes twenty-two revolutions in a minute, which is found to be the proper degree of speed, in order that the cloth may be tossed about and *dashed* against the sides as the wheel turns; a greater velocity causing it to keep at the circumference without shifting its position.

I was told that the incrustation was a deposit of carbonate of lime, and the source of the lime was mentioned. But whence the brown colour, and the metallic nacreous lustre? If the substance were analogous to shell, it ought to contain animal matter; and whence could that be derived? It was necessary to trace the operations from the beginning.

The cotton cloth is brought to the bleach-field in the state in which it is taken from the weaver's loom. The first process is to steep it in water for several hours, after which it is immersed in cream of lime. This is made in the following manner: fresh-burned lime is slaked and passed through a fine sieve, and added to water in the proportion

* Specimens are deposited at the British Museum.

of 38 lbs. of dry lime to 1000 lbs. of cloth. The cloth is boiled in this liquor from four to six hours, the lime acting as an alkali; and it is used only from being considerably cheaper than potash or soda. After this boiling, the cloth is taken to the dash-wheel to be thoroughly cleared of the lime, which is effected by its being tossed about for ten minutes in clear water in the interior of one of the compartments into which the wheel is divided. Here, then, is the source of the calcareous matter of the incrustation; and we have the lime dissolved or suspended in the water in a state of extremely minute division, and from which it is deposited, most probably, by a partial evaporation. It is difficult to say whether the deposit takes place while the wheel is revolving, by the water being broken into a kind of spray, and so presenting a greater surface for evaporation, or during the night, when the wheel is still: some of the properties, to be afterwards described, render the latter supposition the most probable. But in whatever way it takes place, the operation is an exceedingly gradual one; for the wheel had been in constant use for ten years, and the coating in the interior did not exceed one tenth of an inch in thickness. It had been in operation about two years before any perceptible deposit showed itself in the inside; but it had not been going half a year before an incrustation began to be formed on the outside of the wheel. I remarked that the deposit was in greatest quantity around the orifice where the cloth is put in and taken out. The deposit in the interior, and which coated the whole surface of the compartment, was of a darker brown colour, and was as smooth and splendent as a lining of highly polished bronze would have been. The high polish is no doubt partly produced by friction; and I observed that it was highest on that part of the outside nearest the opening.

So far we have *calcareous*, but no *animal*, matter; but in going a little further back in the history of the process to which the cotton had been subjected, before it came to the bleach-field, I discovered that animal matter might be contained in the incrustation. I learned that the cloth had been woven in power-looms; and on making inquiry as to the composition of the dressing or paste used to smooth and stiffen the warp before it is put into the loom, I was told that in the factory from whence the cloth had come, it is the practice to mix glue with the wheaten flour, generally in equal proportions by weight.

We have thus lime and gelatine, the same materials which are employed by the molluscous animal in the formation of its covering, and apparently in the same degree of minute division as that in which they are exuded from its mantle.

Chemical examination of the Substance.

1. *The external deposit.*—Exposed to the flame of a wax candle, it blackens, and gives out the usual smell of burning animal matter, the thin laminæ of which it is composed separating and curling up like films of horn; appearances similar to those exhibited by membranous shells when heated. When the flame is urged by the blowpipe, the laminæ separate still more, and are changed into an extremely light and

brittle enamel, pure white, and having a pearly lustre. A fragment moistened on the back of the hand gives a sensation of heat, as quicklime does when so treated. The substance, when thrown into dilute muriatic acid, is entirely dissolved; the fluid is tinged yellow, and the effervescence produces a froth, like beer. When the acid is very much diluted, and a portion of the substance is suspended in it, the solution takes place gradually, minute flocculi of animal matter being separated, and floating in the fluid.

2. *The internal deposit.*—This is separable into extremely thin laminæ, and these, when in small fragments, are hardly distinguishable from scales of brown mica, showing also the most beautiful play of colours. The action of heat produces the same effect as on the external deposit, except that the separated laminæ are thinner. The action of muriatic acid is the same, but the yellow tinge is deeper, and the froth is more permanent, indicating a larger proportion of animal matter than in the other. The nacreous lustre is also much more conspicuous in this.

Mr. Gray, in his paper on the Structure of the Shells of Molluscous Animals, observes that the pearly or iridescent lustre appears to be confined to shells of the concretionary structure, which when broken exhibit a nearly uniform texture, but separate when heated into numerous thicker or thinner laminæ; and he adverts to the observation of Mr. Hatchett, that when they are digested in weak muriatic acid, the lime is dissolved, leaving a great number of thin plates of animal matter, which retain the original shape of the shell. He adds, "This variety of structure is found to constitute the whole shell of the *Anomiæ* and *Placunæ*, and to form the inner coat of those shells which have pearly insides, as the *Turbines*, *Haliotides*, *Uniones*, &c., as well as the laminar portion of the *Pinnæ* and Mother-of-pearl shells *."

Besides the laminated structure, there is, in the case of the Pinna and some other shells, a prismatic crystalline arrangement of the particles perpendicular to, and passing uninterruptedly through, the laminæ; but I have not discovered such an arrangement in any portion of the incrustation, even when examined by the microscope.

I felt very desirous that this singular deposit should be examined by Sir David Brewster; the more especially as he had long since directed his attention to the peculiar structure of mother-of-pearl †. On showing him the specimens in my possession he observed, that it was one of the most remarkable artificial productions he had seen; and he readily undertook to examine it carefully. He shortly afterwards sent me the particulars of that examination, which had afforded some curious and interesting results. Having subsequently visited Catrine, I procured more perfect specimens; and I sent these to Sir David Brewster, in order to ascertain whether they might not afford something new, in addition to the results he had obtained from the fragments he had formerly examined. They did so, and I now subjoin the very interesting account which Sir David has given me of the properties he has discovered in this new substance.

* Philosophical Transactions, 1833, p. 794.

† Id., 1814.

Belleville, January 1st, 1836.

My dear Sir,

In the communication which I had the pleasure of addressing to you on the 20th of January 1835, I gave a brief account of the observations I had made on the highly interesting substance which you had put into my hands; but as the specimens which you sent me a few days ago are so much superior to those with which I made my former experiments, and have led me to some new and I think rather extraordinary results, I shall include in the present letter all my former observations.

The substance in question does not resemble in its general aspect any natural or artificial production which I have seen. It is, generally speaking, brown where the surface is not iridescent, and in very thin plates: it is almost perfectly transparent, with a slight yellowish brown tinge like plates of glue or lac of the same thickness. The laminæ of which it is composed are sometimes separated by vacant spaces, at other times slightly coherent, but generally adhering to each other with a force greater than that of the laminæ of sulphate of lime or mica, and less than those of calcareous spar. When the adhering plates are separated, the separated surfaces are sometimes colourless, especially when these surfaces are corrugated or uneven; but they are almost always covered with an iridescent film of the most brilliant, and, generally, uniform tint, which exhibits all the variety of colours displayed by thin plates or polarizing laminæ.

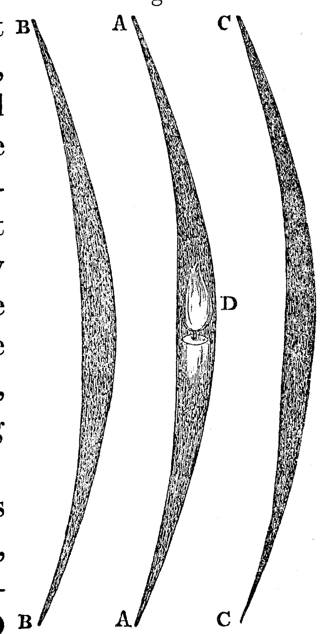
The substance is of intermediate hardness between calcareous spar and sulphate of lime. It scratches the latter easily, and is not scratched by mother-of-pearl. Its specific gravity is shown in the following Table, which indicates its relation to analogous substances.

Calcareous spar	2·72
Oriental pearls	2·68
New substance	2·44
Mother-of-pearl	2·19
Oyster-shell	2·02

The new substance has the property of refracting light doubly, like most crystallized bodies; and, as in agate, mother-of-pearl, &c., one of the two images is perfectly distinct, while the other contains a considerable portion of nebulous light, varying with the thickness of the plate and the inclination of the refracted ray. It has one axis of double refraction, like calcareous spar, which is negative, as in that mineral, and, like it also, it gives a beautiful system of coloured rings by polarized light. The double refraction of the substance is very considerable, though greatly less than that of calcareous spar. A plate, one seventy-fifth of an inch thick, makes the first red ring of the system *eight* inches in diameter at a distance of twenty-six inches from the eye. The substance belongs to the rhombohedral system, and, as in the *Chaux carbonatée basée* of Hauy, the axis of the rhombohedron, or that of double refraction, is perpendicular to the surface of the thin plates. As mother-of-pearl has two axes of double refraction like aragonite, this new substance may be considered as having the same optical relation to calcareous spar that mother-of-pearl has to aragonite.

When we look through a plate of this substance perpendicularly to its surface, or along the axis of double refraction, the flame of a candle is seen encircled with a nebulous haze like a halo. By the slightest inclination of the plate in any azimuth whatever, three elongated and curved nebulous images are seen, as in fig. 1., the central one, A A, having a distinct image, D, of the candle in the middle of it, and the other two, B B and C C, being equidistant from A A. These elongated images are parallel and concave towards the end of the plate nearest the eye. In the direction of the axis of double refraction, when all the nebulous light is in one mass, the distinct image, D, is redder than in any other direction; and by slightly inclining the plate the red light disappears, and the distinct image becomes brighter and whiter. All the three images, A A, B B, and C C, are united into a mass round D, at a perpendicular incidence, but they separate upon inclining the plate, and their distance increases with the inclination.

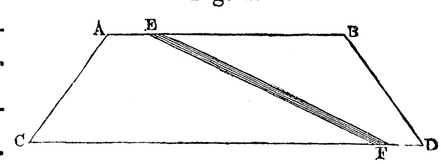
Fig. 1.



If we examine the nature of the light of which these images are composed, we shall find that the nebulous images, A A, B B, are wholly polarized in a plane passing through the direction of their length, while C C and the greater part of D are polarized in an opposite plane. As the thickness of the plate increases, more and more of the distinct image, D, is polarized in the same plane, as in mother-of-pearl*, till at a certain thickness the whole of it is thus polarized. In this case all the doubly refracted light which forms the nebulous image, A A, and the bright one, D, consists of two oppositely polarized pencils, the one forming the nebulous and the other the distinct image.

In investigating the cause of these phenomena, we must take as our guide the analogous facts presented by certain composite crystals of calcareous spar. Having long ago described this class of phenomena very fully†, I shall only state at present the general fact. Let A B C D, fig. 2., be a section of a rhomb of calcareous spar having its axis perpendicular to the faces A B, C D, and let E F be another crystal, or vein of the same substance crossing it according to the law of crystallographic composition.

Fig. 2.



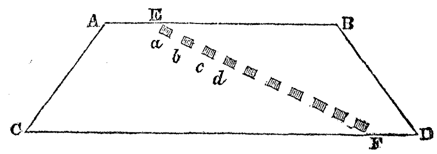
If we now look at a candle through this compound crystal, it will appear single in the direction of the axis of A B C D; but if we incline the plate in a plane passing through A B, we shall see two images together as at A and D, fig. 3., and other two, namely one at B

Fig. 3.

* See Philosophical Transactions, 1814. † Id., 1815. Edinburgh Encyclopedia, art. Optics.

and the other at C. These images B, C, separate by the inclination of the plate exactly like those in fig. 1., and all the four, A, B, C, and D, have the same absolute and relative polarization as the four analogous images seen through the new substance, with this difference only, that none of them are nebulous.

Fig. 4.



If we conceive the vein E F to consist, as in fig. 4., of a great number of small crystals, *a*, *b*, *c*, *d*, &c. in place of one, the very same effects will be produced.

When we look through the new substance, the multiplication of images takes place *in whatever azimuth* we incline the plate, the elongated images being always perpendicular to the azimuth of inclination. Hence it follows, that these images are produced by *numbers of minute crystals* lying in or near the azimuth in which the plate is inclined; and that these crystals have their axes all inclined to that of the plate which contains them, at the same angle as the vein E F, figg. 2. & 4., is inclined to the axis of the rhombohedron of Iceland spar. But the remarkable result of these observations is, that in place of one set of crystals, or sometimes three sets, which occur in calcareous spar in three different azimuths, we have here *an infinite number of them* lying in every possible azimuth, and these so small in their dimensions that they cannot be recognised by the most powerful microscopes, except as dark specks disseminated through the general mass; and yet they indicate by their action on light, not only their existence, but the position of their axes, and their doubly refracting and polarizing structure, as unequivocally as if we could handle them, and cleave them, and place them upon the goniometer.

It may now be asked why the images are nebulous, and not distinct as in calcareous spar. The reason is, that the substance is imperfectly crystallized like the agate, mother-of-pearl and other bodies in which the doubly refracting force separates the incident light into two oppositely polarized pencils, which are not perfectly equal and similar, but which differ from each other, sometimes in the intensity of their light, sometimes in the distinctness of the image, sometimes in the nature or brightness of the colour, and sometimes in more than one of these characters. But though the new substance resembles the crystals above mentioned in giving dissimilar pencils of doubly refracted light, it stands unique among all bodies with which I am acquainted in possessing the extraordinary system of composite crystallization, in which an infinite number of crystals are disseminated equally in every possible azimuth through a larger crystalline plate, having their axes all inclined at the same angle to that of the larger plate, and producing similar phenomena in every direction, and through every portion of the plate; or we may describe this remarkable structure by saying that the minute elementary crystals form the surfaces of an infinite number of cones whose axes pass perpendicularly through every point of the larger plate*.

* A rude idea of this structure is given by the beautiful cones, or rather pyramids of microscopic crystals of titanium which I have somewhere described as existing within the pyramids of many crystals of amethyst from the Brazils.

The iridescent phenomena exhibited by the new substance are extremely interesting, and I have been at much pains to examine them in a great number of specimens. The plates into which the substance is divisible have been formed in succession, and certain intervals of time have elapsed between their formation. In general every two contiguous laminæ are separated by a thin iridescent film, varying from the three to the fifty millionth part of an inch in thickness, and producing all the various colours of thin plates which correspond to intermediate thicknesses. Between some of the laminæ no such film exists, probably in consequence of the interval of time between their formation being too short; and between others the film has been formed of unequal thickness, as happens in the oxidations upon steel when they are formed upon or around hard parts of the metal called *pins* by the workmen.

There can be no doubt that these iridescent films are formed when the dash-wheel is at rest during the night, and that when no film exists between two laminæ, an interval too short for its formation (arising perhaps from the stopping of the work during the day,) has elapsed during the drying or induration of the one lamina and the deposition of the other.

That these iridescent films are not thin films of the substance itself, may be inferred from the fact that light is reflected from their surfaces when they firmly adhere to the laminæ which inclose them. If, for example, we remove or raise up from a piece of mica a thin film which gives a bright green tint, and press it again into optical contact with the surface from which it was separated, it will then cease to exhibit any colour, because no light is reflected from its posterior surface; but if we press it into optical contact with another surface which has a different refractive power, its green colour will still be exhibited. It is owing to this cause that the colours of the oxidations on steel are so distinctly visible, and that the analogous oxidations are seen upon glass even before the film has begun to separate into coloured scales.

The iridescent films in the new substance possess another source of interest, in so far as they promise to throw a new light on the origin of the *incommunicable* colours of mother-of-pearl, which arise from the interior structure of the shell, and which cannot therefore be communicated to wax. These colours have frequently occupied my attention since the year 1814, when I described the phenomena of the colours communicable to wax*; but though I have devoted much time to the inquiry, I never could obtain a single result worthy of being communicated to the public. I took plates of mother-of-pearl that exhibited different bright colours through different parts of their surface, and by getting the mother-of-pearl ground away in different places by the seal-engraver's wheel, I endeavoured to discover the thicknesses at which the colours were produced, and the cause of the capricious variation of tints which arose from every inclination of the plate: but all my experiments were fruitless, and I abandoned the subject as beyond my reach. The phenomena, however, presented by the new substance seem to me to disclose the secret of which I was in

* Philosophical Transactions, 1814.

quest. The layers of mother-of-pearl are deposited in succession like those which are formed upon the dash-wheel; and there can be no doubt that the animal whose mucous secretions form the shell that incloses it, rests occasionally from its toils, and affords a sufficient interval for the formation of an iridescent film upon the surface of the plate of shell which it daily deposits. Owing to the firm adhesion of the successive layers of the shell, we cannot, as in the more imperfectly formed new substance, separate each stratum in order to see the iridescent film upon their surfaces; but we can easily determine what phenomena would be produced if the layers of the new substance were as transparent as those of mother-of-pearl. If this were the case, we should see, both by reflected and transmitted light, the combined colours of all the iridescent films in the plate. When these films are numerous and flat, and of various thicknesses, the union of all their colours would form a pearly whiteness by reflected light, and when films of a particular colour predominate, both the reflected and the transmitted light would exhibit that prevailing colour; but if their surfaces are undulated as in mother-of-pearl, from the form of the shell and other causes,—if the iridescent films vary in thickness, and consequently in colour,—if they are wanting in some parts of the shell, and abound in others,—and if films of equal thicknesses occur in several laminæ in succession, and films of other thicknesses in other laminæ, which must necessarily take place from the varying and remitting action of the animal agent, then we shall have the very structure which is necessary for the production of the incommunicable colours of mother-of-pearl.

I have no doubt that this is the true cause of the phenomena which had so long perplexed me; and the results which I formerly obtained, though I could then attach no meaning to them, are in perfect unison with the preceding views. In order, however, to obtain something like an experimental confirmation of this opinion, I have examined the *fracture* of a mother-of-pearl shell where the laminæ have been all deposited with considerable regularity, and where their overlying edges are exhibited, and I find distinct and positive proofs of the existence of iridescent films, sometimes green, and sometimes red in several successive strata.

I am, my dear Sir,

Ever most truly yours,

D. Brewster.

To Leonard Horner, Esq.