XV. *On the Connexion between the Phenomena of the Absorption of Light, and the Colours of thin Plates.* *By Sir* DAVID BREWSTER, *K.H. LL.D. F.R.S.*

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SINCE the phenomena of the absorption of light by coloured media began to be studied with attention, various philosophers have regarded them as inexplicable by the theory of the colours of thin plates, and have consequently regarded Sir ISAAC NEWTON's theory of the colours of natural bodies as either defective in generality, or altogether unfounded. Mr. DELAVAL* was the first person who brought an extensive series of experiments to bear upon this subject. Dr. THOMAS YOUNG† considered it "impossible to suppose the production of natural colours perfectly identical with those of thin plates," unless the refractive density of the particles of colouring bodies was at least twenty or thirty times as great as that of glass or water, which he considered as "difficult to believe with respect to any of their arrangements constituting the diversities of material substances." Sir JOHN HERSCHEL has expressed a still more decided opinion upon this subject. He regards "the speculations of NEWTON on the colours of natural bodies" as only "a premature generalization," and "limited to a comparatively narrow range; while the phenomena of absorption, to which he considers the great majority of natural colours as referable, have always appeared to him to constitute a branch of photology *sui generis*‡."

The general opinion advanced by these three philosophers I have long entertained §; and with the view of supporting them I have analysed a great variety of colours which are exhibited by the juices of plants. In a paper "On the Colours of Natural Bodies ||," I have shown that the *green* colour of plants, the most prevalent of all the colours of natural bodies, in place of being a *green of the third order*, as NEWTON and his commentators assert, is a colour of no order whatever, and having in its composition no relation at all to the colours of thin plates.

In arriving at these conclusions, however, and drawing a distinct line between the phenomena of absorption and those of thin plates, two classes of facts are compared under very different circumstances. In the one case philosophers have studied *in cumulo* the result of the successive actions of an infinite number of the colorific particles upon the intromitted light, whereas in the other case they have observed only the

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* Manchester Memoirs, vol. ii. p. 131.

† Ed. Nat. Phil. vol. i. p. 469, 481. and vol. ii. p. 638.

‡ London and Edinburgh Philosophical Magazine, December 1833, vol. iii. p. 401. See also his Treatise on Light, Encyc. Metrop. p. 580, 581.

§ Life of NEWTON, chap. vii.

|| Edinburgh Transactions, vol. xii.

colour of a single particle, whose thickness is equal to that of the films of air, water, glass and mica submitted to experiment. The impracticability of combining a number of such films, and studying their united action upon light, was doubtless the reason which prevented natural philosophers from bringing the two series of facts under the same conditions. Sir Isaac Newton, indeed, had spoken so confidently of the result of such a combination, as to discourage any attempts to effect it; and it is a singular fact that his successors have never called in question his bold though ingenious assumption. "If a thinned or plated body," says he, "which being of an even thickness, appears all over of an uniform colour, shall be slit into threads or broken into fragments of the same thickness with the plate, I see no reason why every thread or fragment should not keep its colour, and by consequence why a heap of those threads or fragments should not constitute a mass or powder of the same colour which the plate exhibited before it was broken. And the parts of all natural bodies being like so many fragments of a plate, must on the same grounds exhibit the same colours."

This remarkable opinion I have often been desirous to submit to the test of direct experiment, in the conviction that the result would be different from what is here stated; but I have been baffled in every attempt to make such an experiment; and had not accidental circumstances placed in my hands two substances, in which thin plates were combined nearly in the very manner which I wished, and which I believe had never before been submitted to examination, the problem might have remained long without a solution.

The first of these substances to which my attention was called, is the remarkable nacreous body which Mr. Horner has described in the last volume of the Transactions, and whose singular optical properties I have explained in a letter which accompanies his paper. This substance consists of laminæ of considerable transparency, separated by extremely thin films, which exhibit in the most brilliant manner the colours of thin plates.

In order to compare the effect produced by a number of such films with that of a single film, we must either analyse the light reflected and transmitted by a single film by means of a fine prism placed in front of a telescope, or examine the prismatic spectrum produced by such an apparatus when it is reflected or transmitted by the film in question. When we thus examine the reflected tints of the three first orders of colours, we find them to consist of that part of the spectrum which gives the predominating colour of the tint mixed with the rays on each side of it. The reflected *green* of the *third* order, for example, consists of the green part of the spectrum, bounded on one side with some blue, and on the other side with some yellow rays, all the rest of the spectrum being wanting, having passed, as it were, into the transmitted beam. In analysing, therefore, the transmitted beam, its spectrum is found to consist only of the violet and blue, and the orange and red spaces, a dark band corresponding to the reflected spectrum separating it into two parts. In the higher orders of colours the reflected spectrum consists of two or more portions separated by perfectly dark bands, while the transmitted light exhibits analogous bands, which are much less dark in consequence of the tint being diluted with a portion of white light. The coloured bands of the reflected spectrum occupy the same place among the fixed lines of the spectrum as the dark bands of the transmitted one; and if the two spectra were superposed they would form a perfect spectrum, whose rays when united would form white light. Hence the reflected and the transmitted tints are complementary to each other.

When this analysis is made with a highly magnified spectrum, the numerous lines of which are distinctly seen, it forms one of the most splendid experiments in optics. The spectrum is crossed throughout its whole extent with alternate dark and coloured bands, increasing in number and diminishing in magnitude with the thickness of the plate by which the tint is produced.

If we use a thin film of mica, of such a thickness as polarizes the *white* of the first order, the transmitted spectrum will be crossed by upwards of three hundred dark and three hundred luminous bands, thirty-four of each being included between the lines C and D of FRAUNHOFER, a space less than one tenth of the whole spectrum.

When we use polarized light, and interpose a doubly refracting plate, and subsequently analyse the transmitted beam, the spectrum is crossed with an analogous series of bands, which are still more splendid and more perfect than those given by a singly refracting film. The bands in the complementary spectra are equally and perfectly dark; and when the tints are pure as in calcareous spar, the colours are nearly identical with those of thin plates. Through the natural faces of a rhomb of calcareous spar about one sixth of an inch thick, I observed in the space C D above mentioned hundreds of the most minute lines almost as sharp and black as those in the solar spectrum.

In the phenomena of periodical colours which we have now described, there are three peculiarities which demand our attention. 1. The dark lines change their place by inclining the plate which produces them. 2. Two or more lines never coalesce into one, and one line of the series is never seen without all the rest being equally visible. 3. The colours of the luminous bands in the complementary spectra are the same as those of the original spectrum when the thin plate is perfectly colourless. In the case of polarized tints this similarity is not general.

In order to obtain a correct idea of the phenomena of absorption, I shall describe those which are exhibited by a solid, a fluid, and a gaseous body,—by the common smalt blue glass, by the green sap of vegetables, and by nitrous acid gas.

Dr. YOUNG has described the smalt blue glass as dividing the spectrum "into *seven* distinct portions." I have given in the Edinburgh Transactions* rude coloured drawings of the effect it produces on the spectrum, and Sir JOHN HERSCHEL† has represented its action in a different manner. Excepting in the single circumstance of the spectrum being divided into bands, there appears no analogy whatever between this

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* Vol. ix. p. 439. Plate XXVII.

† Ibid. p. 449. Plate XXVIII.

phenomenon and those of thin plates. The bands diminish in number as the thickness of the plate increases, and their colour suffers no other change by inclining the plate but that which arises from the small increase of thickness which the ray traverses. There is one remarkable point of difference between the two classes of phenomena which requires to be specially attended to. The *colours of some of the luminous bands are not the same as those of the spectrum*, and therefore the glass has removed certain colours while it has left others of exactly the same refrangibility. The *green*, for example, is changed into *yellow* by the removal of blue rays, and in certain glasses a band, *almost white*, is produced. The colours thus removed are said to be absorbed; and by an extensive series of experiments with such absorbing substances I have been able to insulate white light in the spectrum, which no prism can decompose, and to establish the existence of three equal and superposed spectra of red yellow and blue light.

Analogous phenomena are exhibited in an alcoholic solution of the colouring matter of the green leaves of vegetables. The spectrum which it forms consists of *six* luminous bands separated by *five* dark ones*, and the phenomena have the same character as those of the blue glass.

When the spectrum is viewed through nitrous acid gas the phenomena are still more remarkable. While the gas exerts a general absorbent action over the violet extremity of the spectrum, it attacks it when in a diluted state in definite lines as sharp and distinct as those in the solar spectrum; and what is still more important, it acts upon the same parts of light as the cause which produces the fixed lines in the sun's spectrum. In other respects the character of its action is similar to that of the blue glass and the green sap of plants.

In thus comparing the phenomena of absorption with those of thin plates, we find no connecting link but that of giving a divided or a mutilated spectrum; and even this common fact has not the same character in both. In coloured media the bands of light and darkness have no fixed relation, as in periodical colours; and the light removed from the dark portions, as well as the tints from some of the coloured spaces, have wholly disappeared, in place of being found in the reflected beam.

I have already mentioned that by the aid of two substances I have been able to study this subject under a new aspect, and that the nacreous substance described by Mr. Horner was the one which first exhibited to me the connexion between absorption and periodical action.

This substance when it contains no thin plates acts generally in absorbing the violet and blue end of the spectrum; but when it includes within it, or has on its surface thin films which act like thin plates, it exercises an additional action upon the spectrum. In some cases when the thickness of the plate is small, it produces bands perfectly identical with those of thin plates, but in other cases the bands are

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* A full account of this experiment, and a coloured drawing of the divided spectrum, will be found in the Edinburgh Transactions, vol. xii.

exactly similar to those of coloured media. In one specimen I obtained a dark and distinct band in the orange space at D, with another faint band in the red. These bands were parallel to the fixed line D at a vertical incidence, but by inclining the plate the bands moved towards the green space, and became inclined to the line D. In a recent specimen I obtained the darkest band in the green space, with other lesser bands of unequal size and breadth in the other spaces, all of which moved along the spectrum, while new ones advanced from the red extremity during the inclination of the plate. In a third specimen the phenomena were still more varied, and what was a new feature in the results, the *colour* of the tints was changed exactly as in the phenomena of absorption. It is very obvious that these results are not produced by the same action which causes the orange colour of the substance, for this action could not vary by the inclination excepting in producing a greater absorption of the more refrangible rays; but in order to place this beyond a doubt, I detached a film which had none of the colours of thin plates, and which, as I expected, produced none of the bands above described. In these experiments the nacreous plate was placed in Canada Balsam to remove the imperfect smoothness of its surface, but the phenomena were essentially the same with plates surrounded by air. I now divided the first of the plates above mentioned into two, and having viewed the spectrum through both, I found the principal black band considerably widened, as happens with absorbent media.

When the light reflected from the nacreous plates is examined in a similar manner, the division of the spectrum into bands is extremely brilliant and beautiful, and the phenomena the same; but owing to the light having entered the substance to different depths before it was reflected, the spectrum is by no means complementary to the one seen by transmission.

Satisfactory as these experiments are, I was still desirous of obtaining similar results with perfectly transparent plates, but after failing in every attempt to combine them, I thought of trying the iridescent films of decomposed glass*. This idea succeeded beyond my most sanguine expectations. I obtained combinations of films which gave me by transmitted light the most rich and splendid colours, surpassing anything that I had previously seen either among the colours of nature or of art. I obtained the deepest and richest blues shading off into the palest, and the finest reds and yellows, with all those intermediate and mixed tints which are seen only in the vegetable kingdom. The reflected tints had quite a different character. They possessed all the brilliancy of metallic reflexion, like the colours in the Diamond Beetle and other insects, and the tints varying within a considerable range were disposed in straight lines and bands, as if the film had formed part of a regularly organized body†.

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* For a very fine collection of these films I have been indebted to the kindness of Mrs. Buckland, the Marquis of Northampton, and Mr. Children.

† The surface of these films is beautifully mammillated, the parts that are curves on one side being concave on the other.

The reflected tints of course vary with the obliquity of the incident light; and at great incidences the transmitted ones, however splendid and varied, all become pale yellow. When these combinations of glass films are immersed in a balsam or an oil, their colours whether transmitted or reflected all disappear, excepting a pale yellow light like that which is transmitted at great incidences. These facts prove, beyond a doubt, that the transmitted colours, though wholly unlike to those of thin plates, are yet produced by the same cause and are residuary, and generally complementary to the hue of the reflected tints.

The analysis of these colours by the prism affords a series of most beautiful and instructive phenomena, and it is only by coloured drawings that any adequate idea of them can be conveyed. All the phenomena of coloured media, with bands of various breadths and various intensities of illumination, are exhibited in great perfection, so as to identify completely *in this feature* the two classes of facts. But what is still more striking, the colours of the bands are changed, and we thus find that the characteristic phenomenon of absorption is produced by the action of thin plates. To such a degree indeed is the change of tint carried, that I have insulated a white band in the orange part of the spectrum.

Notwithstanding this identification of absorption and periodical action in their primary features, there are two points of difference which separate widely the two classes of phenomena. The first of these is, that the bands and tints of absorbing media are not changed by obliquity, and the second, that the reflected tints are not visible in such media. Sir ISAAC NEWTON endeavoured to remove the first of these difficulties by supposing that the particles of bodies on which their colours depended have an enormous refractive power; and M. BIOT* has endeavoured to meet it more effectually by introducing two new suppositions, viz. that the particles are capable of transmitting light *only through their centre of gravity*, and that the lateral transmissions may be prevented or turned aside by the inflecting forces which act at a distance on the luminous molecules which approach them.

These explanations of the uniformity of the tints at all incidences have been rendered necessary, not perhaps by the real difficulties of the case, but in consequence of Sir ISAAC NEWTON and his followers taking it for granted that the colours of natural bodies were pure tints of a particular order. Hence it becomes a necessary assumption in the theory that the particles had sizes corresponding to these pure tints, and that the light which composed them should not pass through different thicknesses of these particles. As I have demonstrated, however, in a paper already referred to, that the tint which NEWTON reckoned one of the third order, has no connexion whatever with that or with any other order, and that all other tints of absorbent media are in the same predicament, we are not only free from the difficulty which embarrassed NEWTON; but it is actually necessary to have recourse to particles of an ordinary refractive power, and having such forms and occupying such positions as will

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* Traité de Physique, tom. iv. p. 126.

permit lateral transmissions and thus produce compound tints, such as we actually observe in natural bodies, and as we have shown to be produced by thin plates.

Now if we suppose the colouring particles to be spherical, or to have the form of plates or cubes, or other solids disseminated through the fluid or solid bodies which they colour, the tints would be permanent and compound as we find them in nature.

The second point of difference to which I have referred, namely the absolute disappearance of the reflected tints in several coloured solids, fluids, and gases, is one of great magnitude. Newton has evaded this difficulty in his theory; but from the manner in which he gets rid of the intromitted light in black bodies, it is obvious that he would ascribe the disappearance of the reflected tints to their being "variously reflected to and fro until they happened to be stifled and lost."

As I shall have occasion to discuss this subject experimentally in a paper on the permanent colours of natural bodies, I shall only state at present that I have succeeded by particular methods in rendering reflected tints visible in many coloured fluids and glasses, but I cannot consider them as equivalent to the reflexions of thin plates.

I have endeavoured to corroborate the views contained in the preceding pages by a series of collateral experiments on the periodical colours of polarized light. When we divide the spectrum into bands by doubly refracting plates, the phenomena are beautiful beyond all description. If we dissect or subdivide the luminous bands in the spectrum, as seen by one analysing prism, by means of successive plates and prisms, the result is very remarkable; and if the doubly refracting plates are inclined to each other or to the incident beam, the black bands will also be inclined to each other, and the luminous spaces have the form of a triangle either complete or truncated at its apex. By using plates of the same or of various substances*, and placing their axes in different azimuths to the plane of primitive polarization, we obtain extremely singular spectra, in which the bands approximate to those of absorbing media.

But there is another result of this class of experiments to which I would especially call the attention of philosophers. The colours of the bands thus produced have no

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* I have constructed apparatuses of this kind made out of composite crystals of calcareous spar, including one and more thin plates of its own substance. The beautiful and apparently capricious tints which such crystals exhibit when properly cut into prisms, or when prisms are applied to their surface, are nothing more than the luminous bands of the spectrum subdivided by one or more dissections. I have now before me such a crystal, in which a prism cemented externally brings out the spectrum, which would otherwise have suffered total internal reflexion. A virtual prism forming part of the rhomb polarizes the incident light, an included hemitrope plate affords the polarized tints, and a second virtual prism analyses the light which the plate transmits. In some parts of the rhomb there are plates of different thickness, by which the luminous bands are beautifully subdivided. In this manner by the slight aid of an applied prism we are furnished with a complicated optical apparatus. Such a combination, which it is easy to make artificially by inclosing thin doubly refracting plates between prisms of calcareous spar, affords an ocular explanation of those beautiful forms of the system of polarized rings which are produced in composite crystals of calcareous spar. These subdivided bands, indeed, are portions of that system seen obliquely by prismatic refraction.

resemblance to those of the original spectrum, so that the spectrum has actually been analysed by dissection. This effect is so decided, that even by a single subdivision of a banded spectrum I have succeeded in insulating a band nearly white, and of course incapable of being decomposed by the prism.

Hence we deduce from the phenomena of thin plates, and polarized tints, the existence of a new property of light, in virtue of which the reflecting force selects, as it were, out of differently coloured rays of the same refrangibility rays of a particular colour, allowing the others to pass into the transmitted beam; or to use the language of the undulatory theory, the colour produced by the interference of homogeneous pencils reflected from the first and second surfaces of thin plates, is different from the colour produced by the interference of the transmitted light with that which has suffered two internal reflexions within the plate. If, for example, we use the greenish yellow light of the spectrum between the lines D and E, the system of reflected rings will be more yellow than the transmitted rings towards E, and more *green* than the same rings towards D, a result which in so far as the transmitted tints are concerned, is seen in the colours of smalt blue glass.

Here then we have a principle not provided for in either of the theories of light to which the phenomena of absorption, produced by nacrite, by decomposed films of glass and by polarizing plates are distinctly referable. Here also we have the probable cause of certain remarkable phenomena of dichroism in doubly refracting bodies, in which rays of the same refrangibility but of different colours pass into the ordinary and extraordinary pencils.

Allerly by Melrose,
May 5*th*, 1837.