

*Tincture of Turmeric.*

42. This fluid is very sensitive, and exhibits a pretty copious dispersive reflexion of a greenish light. In its mode of internal dispersion it strongly resembles a solution of guaiacum, but the final tint of the dispersed light does not correspond to so high a mean refrangibility. When the fluid was examined by the third method, the true dispersion appeared to commence about *b*. The absorbing power was so great for the rays of high refrangibility, that from a little above F (in the case of tincture not diluted with alcohol) to the end the dispersed light seemed to be confined to the mere surface. By the fourth method the dispersion was as usual traced a little lower down in the spectrum. When the dispersed beam was first perceived it was nearly homogeneous, and its refrangibility was only a very little less than that of the active light. As the refrangibility of the active light increased, new colours, in the order of their refrangibility, entered into the dispersed beam, which became more and more composite, while at the same time its upper limit became distinctly separated from the beam of falsely dispersed light, which, when the whole dispersed beam was analysed by a prism, was always found in advance of the other. The tint of the dispersed beam passed from orange through yellow to yellowish green, which was its final tint. Tincture of turmeric is well adapted for exhibiting the fixed lines in the invisible part of the spectrum, though perhaps not quite so well as a solution of sulphate of quinine.

*Alcoholic Extract from the Seeds of the Datura Stramonium.*

43. This fluid, which I was led to try in consequence of Sir DAVID BREWSTER'S paper, proved to be remarkably sensitive, and exhibited a copious dispersive reflexion of a pale but lively green. The general phenomena are so nearly the same as in a solution of sulphate of quinine that there is no need of a separate description. The principal difference consists in the tint, which is green instead of blue. In the present case, however, the fluid, in addition to its dispersion of green, dispersed a red beam under the influence of certain red rays. As the lens employed in the fourth method of examination was moved from the extreme red onwards, the light was at first inactive, but when the lens reached a certain point of the spectrum, a red beam of truly dispersed light suddenly appeared, which disappeared with almost equal suddenness as the lens moved on. In this mode of observation the refrangibility of the dispersed could hardly be distinguished from that of the active light; but on combining the first and third methods, by removing the lens, placing the vessel truly in focus, and holding a blue glass alternately in front of the vessel and in front of the eye, I satisfied myself that the truly dispersed beam, taken as a whole, was of lower refrangibility than the light by which it was produced. The utility of the blue glass depended upon the circumstance that the upper extremity of the extreme red which it transmitted nearly coincided with the point of the spectrum at which the red beam occurred. This red beam was doubtless due to the presence of a small quantity of

chlorophyll, or one of its modifications. The light transmitted by the fluid exhibited on prismatic analysis the absorption band in the red which is so characteristic of that substance.

The colour of the solution was a pale brownish yellow; it would no doubt have been still paler, and perhaps nearly colourless, had the sensitive principle to which the green dispersion was due been present in equal quantity but in a state of purity. As it was, the fluid was pale enough to exhibit well, when poured into a test tube and held in front of a window, a narrow arc on the side of the incident light, like sulphate of quinine, only in this case the arc was green instead of blue.

*Frequency of the occurrence of true internal dispersion having the same general character as that which takes place in the cases above described.*

44. If we except the red dispersed beam produced by red rays in the crystal of fluor-spar and in the stramonium extract, a strong similarity may be observed in the mode of internal dispersion which takes place in the cases hitherto described. As the refrangibility of the incident light continually increases, the rays are at first inactive. At a certain point of the spectrum, varying according to circumstances, the true dispersion begins to be sensible, but is faint at first. After remaining faint for some distance it presently becomes more copious. It remains very conspicuous through the whole of the violet and beyond, and then gradually dies away. It consists at first of light of comparatively low refrangibility, and then new colours in the order of their refrangibility enter into it. Frequently the greater part of the change of prismatic composition takes place while the dispersed light is very faint, so that practically speaking we may almost say that the tint is uniform. Sometimes, when the dispersion just commences, the dispersed light is nearly homogeneous, and has a refrangibility so nearly equal to that of the active light that the beams due to true and false dispersion can hardly be separated.

45. Now this, so far as I have observed, is much the commonest kind of true internal dispersion, although sometimes the phenomenon presents very striking singularities. In the paper in which Sir DAVID BREWSTER first announced the discovery of internal dispersion, he remarks "that it is a phenomenon which occurs almost always in vegetable solutions, and almost never in chemical ones or in coloured glasses\*." For my own part, I have rarely met with a vegetable solution which did not exhibit more or less the phenomenon of *true* internal dispersion. Its existence may in general be easily detected in the following manner. The sun's light being reflected horizontally through a lens, a deep blue glass is left in such a position as to intercept the light incident on the vessel containing the fluid, which is placed at the focus of the lens. A pale brown glass of the proper kind is then placed so as to intercept, first the incident, and then the dispersed light. A vessel with flat sides filled with a solution of sulphate of quinine would be better, and then the placing of the

\* Edinburgh Transactions, vol. xii. p. 542.

medium in the second position might be dispensed with, the medium being sensibly transparent. Sometimes it is useful to have recourse to analysis through a doubly refracting prism, or a rhomb of calcareous spar. In this way true internal dispersion may often be detected in a fluid which is actually muddy, in which case, were the effect of the incident light observed as a whole, the true would be masked by the enormous quantity of false dispersion which such a medium would offer.

46. The fluids obtained by treating the leaves and other parts of plants with alcohol or hot water are almost always sensitive, so far as I have observed. The solutions in water presently ferment, and are frequently highly sensitive in the early stages of fermentation; they are usually more or less sensitive in all stages. Different kinds of fungus furnish very sensitive solutions. When aqueous solutions become muddy by decomposition, other clear and often highly sensitive liquids may be obtained from them by various chemical processes. Port and sherry are decidedly sensitive. In such cases the fluid is a mixture of several substances, of which some may be sensitive and others insensible. When vegetable substances are isolated they are frequently insensible, or else so very slightly sensitive when examined under great concentration of the highly refrangible rays, that it is quite impossible to say whether the sensibility thus exhibited may not be due to some impurity: thus, several solutions containing sugar, salicine, morphine, or strychnine were found to be insensible. A solution of veratrine in alcohol proved to be sensitive in a pretty high degree, dispersing internally a bluish light. Sir DAVID BREWSTER has remarked that a solution of sulphate of strychnine in alcohol dispersed light *after it had stood for some days*. This observation I have verified with reference to *true* dispersion, which the solution exhibits, though not very copiously, after it has been made some time. There can be little doubt that the sensitive principle in this case is not strychnine, but some product of its decomposition. I now come to some instances of internal dispersion which are far more striking.

#### *Solution of Leaf-Green in Alcohol.*

47. It was in this very remarkable fluid that the phenomenon of internal dispersion was first discovered by Sir DAVID BREWSTER, while engaged in researches relating to absorption. The character of the internal dispersion of a solution of leaf-green is no less remarkable than the character of its absorption. On account of the close connexion which seems to exist between the two phenomena, it will be requisite first to say a few words about the latter.

When green leaves are treated with alcohol, a fluid is obtained which is of a beautiful emerald-green in moderate thicknesses, but red in great thicknesses, and which has a very remarkable effect on the spectrum. A good number of the following observations on the internal dispersion of leaf-green were made with a solution obtained from the leaves of the common nettle, by first boiling them in water and then treating them with cold alcohol, the leaves having previously been partially

dried by pressing them between sheets of blotting paper. Nettle was chosen partly because it stands boiling without losing its green colour, and partly for other reasons. My object in boiling the leaves was to obtain the green colouring matter more nearly in a state of isolation, but it seems to have the additional advantage of giving a solution less liable to decomposition. Indeed, this fluid seemed disposed to remain permanently unchanged when kept in the dark; but a small portion of it which was exposed to strong light had its colour rapidly discharged.

48. When fresh leaves are left in contact with alcohol in the dark, or in only weak light, the colour of the fluid changes by degrees, and it seems to approximate (making allowance for impurities) to a type which is nearly represented by the fluid obtained in this manner from laurel leaves, or that obtained by treating with alcohol tea leaves from which a good deal of brown colouring matter has first been extracted by water. This type was rather ideal than actual, being derived from a comparison of different cases, until it seemed to be realized in the case of a fluid obtained by re-dissolving in alcohol a crust which had formed itself at the bottom of a test tube containing leaf-green. The principle to which the peculiar absorption and internal dispersion of such a fluid seems due may be called modified leaf-green. The fluid itself is not green but olive-coloured, becoming red at great thicknesses.

49. When solutions of leaf-green, and of its various modifications, are examined in different thicknesses by the light of a candle, there are five bands of absorption which may be observed in the spectrum. These will be called, in the order of their refrangibility, Nos. 1, 2, 3, 4 and 5, the bright bands below the respective dark bands being also numbered in the same manner. Of the dark bands, Nos. 1, 2, 3 and 5, are the first four in Sir DAVID BREWSTER'S plate\*. No. 4 is mentioned in the memoir, but not represented in the plate, which corresponds to a thickness not sufficient to bring out this band. The last band in the plate could not be seen without strong light. The dark bands Nos. 1 and 2 are situated in the red, No. 3 about the yellow or greenish yellow, No. 4 in the green, and No. 5 early in the blue. Of these, No. 1 is in small thicknesses by far the most intense, and it may be readily seen even in a very dilute solution; it might apparently be used as a chemical test of chlorophyll, or one of its modifications. The test would be of very easy application, since it would be sufficient to hold a test tube with the liquid at arm's length before a candle at a little distance, and view the linear image of the flame through a prism applied to the eye.

50. Fresh and modified leaf-green differ much in the order in which the bright bands are absorbed, and in the degree to which the dark bands are developed before they cease to be visible by the absorption of the part of the spectrum in which they are situated. In the green fluid, the dark band No. 5 is not usually seen, because the spectrum is there cut off, unless a very small thickness be used. With a moderate thickness, Nos. 2 and 3, especially the former, are well seen, and No. 1 is very intense. As the absorption goes on, the bright bands Nos. 2 and 3 are absorbed,

\* Edinburgh Transactions, vol. xii.

and there is left the red band No. 1, and a double green band, consisting of the bright bands Nos. 4 and 5, separated by the dark band No. 4, which by this time has come out. In modified leaf-green, the dark bands Nos. 4 and 5 are much more conspicuous than in the green fluid, but No. 3 is wanting, or all but wanting. With a thickness by which the absorption is well developed, the conspicuous bright bands are in this case Nos. 1 and 3, and next to them No. 2, whereas in the green fluid Nos. 2 and 3 were quickly absorbed, or at least the whole of No. 2, and the greater part of No. 3.

51. It seems worthy of remark, that, especially in the case of the green fluid, the absorbing power alters with the refrangibility of the light at a very different rate on the two sides of the intense dark band No. 1. This might be inferred from the order in which the bright bands disappear; but it was rendered visible to the eye by the following easy experiment. A narrow test tube was partly filled with a solution of leaf-green, and then a few drops of alcohol were added, which remained at the top, and there diluted the solution. The tube was then held before a candle, and the linear image of the flame was viewed through a prism. In the under part the dark band No. 1 was broad, the bright band No. 2 being narrow, and almost obliterated, but in the upper part the dark band No. 1 was very narrow. Now on tracing upwards the sides of this dark band, it was found that the less refrangible side was almost straight, and the diminution in the breadth of the band was produced by the encroachment of the bright band No. 2. Speaking approximately, we may say that in proceeding from the extreme red onwards, at a certain point of the spectrum the fluid passes abruptly from transparent to opaque, and then gradually becomes almost transparent again.

52. It may here be remarked, that although the absorption produced by leaf-green is best studied in a solution, its leading characters may be observed very well by merely placing a green leaf behind a slit, as near as possible to the flame of a candle, and then viewing the slit through a prism.

53. After this digression relating to the absorption of leaf-green, it is time to come to its internal dispersion. And first, when a cone of white light coming from the sun is admitted horizontally into the fluid, as close as possible to its upper surface, and the beautiful red beam of dispersed light is analysed by a prism, the spectrum is found to consist of a bright red band of a certain breadth, followed by a dark interval, and then a much broader green band not near so brilliant. There is usually but little false dispersion, and what there is may be almost entirely got rid of by analysing the beam by a NICOL'S prism, so as to view it by light polarized in a plane perpendicular to the plane of dispersion. Now on raising the vessel without removing the prism from the eye, it was found that a dark band, which was in fact the absorption band No. 1, appeared almost exactly in the middle of the bright red band. On continuing to raise the vessel, so as to make the dispersed rays pass through a still greater thickness of the medium before reaching the eye, the dark

band increased in width, and when the red beam was almost absorbed, the part that was left consisted of two cones of red, one at each side of the dark band, which by this time had become broad. The whole appearance seemed to indicate that the bright red beam of dispersed light had a very intimate connexion with the intense absorption band No. 1.

54. Among coloured glasses, there is one combination which produces a very striking effect. When a deep blue glass is placed in the first position, the dispersed light, if the solution be at all strong, is confined to a very thin stratum adjacent to the surface, and is best seen by placing the vessel so that the surface of the fluid at which the light enters is situated at a little distance on either side of the focus of the lens, when there is seen a bright circle of a most beautiful crimson colour. It might be supposed that the red of which this circle mainly consists was nothing but the extreme red transmitted by the blue glass. But it is readily shown that such is not the case. For in the first place, the fluid transmits pretty freely the red transmitted by the blue glass, whereas the red light found in this circle is almost confined to the surface of the fluid. Again, it was found that a pale brown glass, which transmitted freely the extreme red, almost entirely cut off the bright circle, when placed in the first position without removing the blue glass, although it freely transmitted it when placed in the second position. It appears, therefore, that the bright circle is due, not to the red, but to the highly refrangible rays transmitted by the blue glass.

55. When a solution of leaf-green was examined by the third method, the appearance as seen from the outside was very singular. The fixed lines in all the more refrangible part of the spectrum were seen as interruptions in a bright red ground verging to crimson. The beauty and purity of the tint, and the strange contrast which it presented to the colours belonging to that part of the spectrum, were very striking. About H the tint began to verge towards brown, and the fixed lines beyond H were seen on a brownish red ground. That the ground on which the fixed lines of somewhat less refrangibility were seen was rather crimson than red, arose, no doubt, from the mixture of a little blue or violet light due to false dispersion, and to the scattering which took place at the surface of the glass.

56. On looking down from above, the places of the more conspicuous bands of absorption were indicated by dark teeth, with their points turned towards the incident light, interrupting the dispersed light. It is to be understood that the light was transmitted as close as possible to the upper surface, so that the absorption by which these teeth were formed took place *before* dispersion. In this way the places of the absorption bands Nos. 1, 2 and 4, were perfectly evident. No. 3, it will be remembered, was by no means conspicuous. When the solution is of convenient strength, the absorption is so rapid beyond the bright band No. 5, that the dispersion is confined to a thin stratum close to the surface by which the light enters, and therefore no dark tooth would be seen corresponding to the dark band No. 5.

57. On following the active light through the spectrum, in the direction of increasing refrangibility, the dispersion was found to commence with a bright, but narrow tail of pure red light, which shot right across the vessel. The light by which this tail was produced belonged to the more refrangible part of the extreme red band which is transmitted by a moderate thickness of the fluid. The activity of the incident light commenced almost abruptly: the same, it will be remembered, was the case with the absorbing power of the medium. After the tail of red light came the intense absorption band No. 1, where the dispersed light was confined to the immediate neighbourhood of the surface by which the active light entered. At this place a very bright band of dispersed light was visible on looking at the vessel from the outside. In this part of the spectrum the active and the dispersed light were both red; but that dispersion was accompanied by a change of refrangibility, was shown by the effect of absorbing media. Thus the long red tail and the bright band adjacent to the surface were differently affected by a blue glass, according as it was held in the first or the second position; and the bright band, though much enfeebled, was still plainly visible through a considerable thickness of the fluid, although a stratum having a thickness of only a very small fraction of an inch was sufficient to absorb the rays by which the band was produced. Although the dispersion continued throughout the whole of the visible spectrum and beyond, it was comparatively feeble in the brightest part of the spectrum. It became pretty copious again in the neighbourhood of the dark band No. 4, and remained copious throughout the blue and violet. In the green, the dispersed light was red, slightly verging towards orange, and in the blue and violet it was red verging a little towards brown.

58. It may seem superfluous, after what precedes, to bring forward any further proof of the reality of a change of refrangibility. Nevertheless the following experiment, which was in fact performed at an early stage of these researches, may not be deemed wholly unworthy of notice, as not involving the use either of absorbing media or of false dispersion.

A small narrow triangle of white paper was stuck on to the outside of the vessel containing the leaf-green, in such a manner that its axis was vertical, and its vertex, which was uppermost, was situated at the height of the middle of the spectrum. A narrow vertical slit was then placed at the distance of the image of the first slit, where the fixed lines were formed, and moved sideways till the light immediately beside the fixed line G passed through it. The vessel was then placed a few inches behind the slit, and moved sideways till the riband-shaped beam of homogeneous light, which passed through the second slit, was incident on the vertex of the triangle. On looking at the vessel from the front, as nearly as was convenient in the direction of the incident light, there appeared a bright vertical bar corresponding to a section of the incident beam. This bar was of two colours, namely, red in the upper half, where the light fell on the fluid, and indigo in the under half, where it fell on the paper. On refracting the whole system sideways,

through a prism of moderate angle applied to the eye, the objects appeared in the following order as regards refrangibility. First came the upper half of the bright bar, which was only a very little widened by refraction, so that it consisted of red light which was approximately homogeneous. Next came the triangle, with its vertex a little rounded, and its edges tinged with prismatic colours. The vertex, which had formerly coincided with the bright bar, now lay a little to one side of its upper half. The triangle was of course seen by means of the diffused light of the room, which was not perfectly dark, and therefore its refrangibility must have corresponded to the brightest part of the spectrum, or nearly so. Lastly came the under half of the bright bar, which was much more refracted than the triangle, so as to be shifted almost completely off it. The paper triangle was far too close to the first surface of the fluid to allow of attributing the dislocation of the bright bar to any error depending upon parallax; but to prevent all possible doubts on this score, I took care to refract the system both right and left, and the result was the same in the two cases. The conclusion is therefore inevitable, that the indigo light which had changed its colour by dispersion from leaf-green had changed its refrangibility at the same time.

59. In viewing a solution of leaf-green in a pure spectrum, I noticed a phenomenon which further indicates the close connexion which seems to exist between the absorption and internal dispersion of this fluid. On holding the eye vertically over the fluid, and looking down at the dispersed light through a red glass, I observed five minima of illumination, having for the most part the shape of teeth with their bases situated at the surface by which the light entered, and their points turned inwards. These minima occupied positions intermediate between the bands of absorption, so far at least as the positions of the latter were indicated by dark teeth pointing in the contrary direction. The first minimum was situated a little beyond the intense absorption band No. 1, and corresponded in position to the bright band No. 2. The second was situated a little further on. The maximum intervening between this and the third was but slight, so that the second and third together formed pretty nearly one broad minimum. The third and fourth were situated one at each side of the dark band No. 4, so as to correspond in position to the bright bands Nos. 4 and 5. The fifth was situated a little way beyond the bright band No. 5. This last minimum was not tooth-shaped, inasmuch as it occurred at a part of the spectrum where the dispersed light was almost confined to the surface of the fluid. These minima are best seen when the solution is rather weak. They may be perceived without using a red glass, though not so easily as with its assistance. With a stronger solution it was observed that the first minimum ran obliquely into the dark tooth corresponding to the absorption band No. 1.

60. The reason of the occurrence of these minima appears to be simply this, that the more copiously dispersed light is produced, the more rapidly the incident light is used up in producing it, so that minima of activity correspond to points of the



spectrum at which the incident light penetrates to comparatively great distances into the fluid before it is absorbed. The oblique position observed in the first minimum is readily explained by considering that the illumination at any point of the field of view depends conjointly upon the activity of the incident light, which is a function of its refrangibility, and upon the fraction of the incident light left unabsorbed, which last is a function both of the refrangibility and of the distance from the first surface.

61. It seems worthy of remark, that while the quantity of dispersed light is liable to fluctuations having an evident relation to the bands of absorption which occur throughout the spectrum, the quality of the light dispersed, as regards its refrangibility, appears rather to have reference to the intense absorption band No. 1.

*Extract from blue leaves of the Mercurialis perennis.*

62. The juice of this plant has the property of turning blue by exposure to the air. Some leaves and stalks which had turned blue were treated with alcohol, and a green fluid was thus obtained much resembling in colour the ordinary solutions of leaf-green, but I think of a rather bluer green than usual. In its mode of absorption, too, it much resembled ordinary solutions of leaf-green, to which substance no doubt the greater part of its colour was due. Its internal dispersion however was very peculiar, for it dispersed a copious orange in place of a blood red like the extracts from fresh green leaves in general, those of the *Mercurialis perennis* included. On analysis the dispersed beam was found to consist chiefly of a red band, similar to that which occurs in solutions of leaf-green, and of a yellow or orange and yellow band, a good deal brighter than the former, from which it was separated by an intervening dark band. When the fluid was examined by the second method, it was found that the yellow dispersion was produced principally by the brightest part of the spectrum. After a considerable time the fluid lost its fine green colour, as is very often the case with solutions of leaf-green, and became yellowish brown, but the red and yellow dispersions still continued.

When the fluid was examined by the fourth method, it was found that the red rays dispersed a red, just as in a solution of leaf-green. The additional dispersion which was so conspicuous in this fluid began almost abruptly about the fixed line D. When it was first observed, the refrangibility of the orange dispersed light could hardly, if at all, be separated from that of the active light. As the lens moved on, the orange beam rapidly grew brighter, and yellow entered into it; and now it was easy to see that the beam of falsely dispersed light lay at its more refrangible limit. The orange and yellow dispersed beam was brightest at about  $D\frac{2}{3} E$ ; but though it decreased in intensity it could be traced far beyond that point, in fact, throughout the spectrum.

63. I have generally found that when a copious dispersion commences almost abruptly at a certain point of the spectrum, it is followed by a band of absorption in

the transmitted light. This law did not seem applicable to the orange dispersion exhibited by the solution just mentioned; but then it is to be remembered that the solution contained a quantity of chlorophyll, which produces absorption bands with such energy that it would naturally mask the bands which might be due to another colouring principle with which it was mixed. To try whether the law would be obeyed if the chlorophyll were got rid of, I boiled in water some portions of the root and young shoots which had turned blue, chlorophyll being insoluble in water. The solution thus obtained was red, in small thicknesses pink, and dispersed copiously a yellow or rather orange light. On subjecting the fluid to prismatic analysis, a band of absorption was seen at the place expected. Since aqueous solutions of this nature are liable to decomposition, frequently decomposing before sunlight can be obtained by which to examine them, the red solution was concentrated by evaporation and purified by alcohol, in which the orange-dispersing principle is soluble, as had already appeared from the properties of the alcoholic solution. The alcoholic solution thus obtained remained unchanged, at least for a long time, and had the further advantage over the aqueous solution of presenting the sensitive principle more nearly in a state of isolation, though it was still contaminated by some principle which dispersed a whitish light under the influence of rays of high refrangibility.

64. The blue colouring matter may be readily extracted by cold water, but is decomposed by boiling. The blue solution dispersed an orange light like the other, but the dispersed light could not be nearly so well seen, just as would be the case were the red orange-dispersing fluid mixed with an insensible blue fluid of a much deeper colour, so that the mixture of the two would be blue. And in fact when the blue fluid was changed to red by boiling the colour became far less intense.

*Archil and Litmus.*

65. It is stated by Sir DAVID BREWSTER that a very remarkable example of internal dispersion, which had been pointed out to him by Mr. SCHUNK, is exhibited in an alkaline or in an alcoholic solution of a resinous powder produced from orcein by contact with the oxygen of the air. Not being able readily to procure a specimen of orcein, I tried archil, and obtained from it and litmus some very remarkable solutions.

In the fluid state in which archil is sold, the colour is much too deep for convenient optical examination. When a small quantity of archil is diluted with a great deal of water, the diluted fluid is very sensitive. It is red by transmission, or in small thicknesses purple, but exhibits by dispersive reflexion a pretty copious but rather sombre green.

66. When the fluid was examined by different methods, it was found to disperse a little red, some orange, and a great deal of green. The red dispersion was so slight, that in observing by the third method it appeared doubtful whether there was any except false dispersion. It commenced in the red, when the active and dispersed lights had the same refrangibility, or nearly so. The orange dispersion commenced

about the fixed line D, the dispersed light being at first nearly homogeneous, and of the same refrangibility as the active light. On proceeding onwards in the spectrum, in observing by the fourth method, the orange beam became brighter, and yellow entered into it, but no colour beyond that, so that the orange and yellow beam was left behind by the beam of falsely dispersed light, from which it was separated by a perfectly dark interval. The green dispersion began about *b*, or a little beyond, coming on almost abruptly. The manner of its commencement was best observed by the fourth method, by holding a prism to the eye while the lens was moved through the spectrum. In this way it was found that on arriving at the point of the spectrum above mentioned, a gleam of green light shot across the dark space which before separated the beam of falsely dispersed light from the orange beam of truly dispersed light. As the lens moved on, the green dispersed light grew brighter, but its more refrangible limit did not seem to pass, or at least much to pass, the refrangibility it had at first; so that the green beam of truly dispersed light was almost immediately left behind by the beam of falsely dispersed light. The former, on being left behind, soon died away.

67. We might suppose either that the red, orange and green dispersions are due to the same sensitive principle, or that they are produced by three distinct sensitive principles mixed together in the solution. The latter would appear the more probable supposition, to judge by the apparent want of connexion between the three dispersions. This view is strongly confirmed by the following results. Some ether was poured on archil in the fluid state, and after being gently moved about and allowed to stand, a little was withdrawn without agitation. A purplish rose-coloured fluid was thus obtained, which was highly sensitive, exhibiting the orange and green dispersions but not the red. The orange dispersion was far more copious, in proportion to the whole quantity of dispersed light, than had been the case with archil diluted with water.

Some archil was violently agitated with ether, and after subsidence the ether was withdrawn. This ethereal solution was much deeper in colour than the former, and exhibited the red dispersion in addition to the orange and green. On adding a small quantity of water, and agitating, a separation, or at least partial separation, of the sensitive principles took place; for the upper fluid exhibited the orange dispersion abundantly, but none of the red, and little or none of the green, while the under fluid exhibited the green and red dispersions with little, if any, of the orange. The upper fluid exhibited a pretty copious dispersive reflexion of reddish orange, and the under fluid a remarkably copious reflexion of a fine green. A similar separation, more or less perfect, took place in other cases, the dispersion of orange bearing to that of green a greater ratio in the ether than in the water. Some of the green-dispersing fluids thus obtained were most remarkable on account of the extraordinary copiousness of the reflected green, and the strange contrast which it presented to the transmitted tint, which was a purplish red.

The red dispersion in the second ethereal solution, though decided, was by no means copious. In the case of archil merely diluted with water, it had been so slight that its existence might have been considered doubtful. It might be supposed that the first solution was not sufficiently concentrated to exhibit the red dispersion, in which case the red and green dispersions might have been due to the same sensitive principle. But an ethereal extract from dried archil, which was plainly concentrated enough, did not exhibit the red dispersion, although it did exhibit the orange and green dispersions. None of the sensitive principles appear to constitute the chief part of the colouring matter of this dye-stuff.

68. When some of these ethereal solutions were examined by the third method, with a lens of shorter focus than usual, the appearance was very singular. At the less refrangible end of the spectrum the incident light was quite inactive; and then, on reaching a certain point, a copious dispersion of orange commenced abruptly. This continued with no particular change for some distance further on, when it passed abruptly into green. The fourth method showed however that the former dispersion continued, and was only masked, in the third method of observation, by a new and more powerful dispersion of green which then commenced. And in fact when the green-dispersing principle was separated, or partially separated, by water, the orange dispersion was seen to continue where before it appeared to have been exchanged for green.

69. I ought here to mention that a similar separation did not take place on the addition of water only to an ethereal extract from archil previously dried. The condition which determined the separation in the first case appeared to be the presence of a small quantity of ammonia, which would evaporate on drying the archil. And in fact when a small quantity of ammonia was added to the extract from dried archil, a partial separation was effected. I do not here enter into the question whether one of the sensitive principles may be obtained from the other, whether, for example, a chemical combination of the orange-dispersing principle with ammonia might disperse a green, or a green with a little orange. A solution containing a mixture of the same substance in two different states of chemical combination, both compounds being sensitive, is not the less justly regarded as containing two distinct sensitive principles.

70. The preceding results are mentioned, not for their own sake, but merely for the sake of the method of examination employed. The results indeed are so imperfect as to be worthless on their own account. A complete optico-chemical examination of archil and litmus would itself alone furnish a subject for research of no small extent; but it belongs rather to chemistry than to general physics. It is quite possible that internal dispersion may turn out of importance as a chemical test. The dispersing such a tint, and the having the dispersed light produced by light of such a refrangibility, form together a double character of so peculiar a nature that it enables us, so to speak, *to see* a sensitive principle in a solution containing many sub-

stances, some of them, perhaps, coloured, so that the colour of the solution may be very different from what it would be if the sensitive principle were present alone.

71. The law mentioned at the beginning of art. 63 did not seem very applicable to archil when the fluid was merely diluted with water. But when the orange-dispersing and green-dispersing principles were obtained, as it would appear, more nearly in a state of isolation, by means of ether and water, the law was found to be obeyed. Thus, when the ethereal solution which exhibited the orange dispersion and little else was examined by the third method, the dispersion was found to commence with a tail of light followed by a dark tooth, indicating the position of a band of absorption. When the light transmitted by a certain thickness of this fluid was subjected to prismatic examination, it was found to consist of red followed by some orange, when the spectrum was cut off with unusual abruptness. After a broad dark interval came the most refrangible colours faintly appearing. Those solutions which exhibited a copious dispersion of green gave, in addition to a band obliterating the yellow, a very distinct band separating the green from the blue. A similar band, but by no means distinct, might be seen in archil merely diluted; and it is particularly to be observed that this band, which occurred a little above the point of the spectrum where the green dispersion commenced, became more conspicuous when the green-dispersing principle was present more nearly in a state of isolation.

72. Two portions of litmus were treated, one with ether and the other with alcohol, which were allowed to remain in contact with the solid. Both extracts, but especially the latter, were highly sensitive, exhibiting dispersions of orange and green similar to archil, and due apparently to the same sensitive principles. The ethereal extract dispersed chiefly orange, while the alcoholic extract dispersed orange and green in nearly equal quantities. The latter extract exhibited a remarkably copious dispersive reflexion of a colour nearly that of mud, and was altogether one of the strangest looking fluids that I have met with. On viewing it in such a manner that no transmitted light entered the eye, one might almost have supposed that it was muddy water taken from a pool on a road. But when the bottle containing it was held between the eye and a window the fluid was found to be perfectly clear, and of a beautiful purple colour.

#### *Canary Glass.*

73. Among media which possess the property of internal dispersion in a high degree, Sir DAVID BREWSTER mentions a yellow Bohemian glass, which dispersed a brilliant green light. This led me to seek for such a glass, and it proved to be pretty common in ornamental bottles and other articles. The colour of the glass by transmitted light is a pale yellow. Its ornamental character depends in a great measure upon the internal dispersion, which occasions a beautiful and unusual appearance in the articles made of it. The commercial name of the glass is canary glass. The following observations were made with a small bottle of English manufacture.

74. When the sun's light was admitted without decomposition the dispersed beam

was yellowish green. The dispersion was so copious that when a large lens was used the dispersed beam approached to dazzling. The prismatic composition of this beam was extremely remarkable. The beam was found on analysis to consist of five bright bands, which were equal in breadth and equidistant, or at least very nearly so, and were separated by narrow dark bands. The first bright band was red, the second reddish orange, the third yellowish green, the fourth and fifth green. I have very frequently observed dark bands, or at least minima, in the spectrum resulting from the prismatic analysis of dispersed beams, but I have not met with any example so remarkable as this, except in a class of compounds which the properties of canary glass led me to examine.

75. On analysing a beam of sun-light transmitted through a certain thickness of the glass, there was found to be a dusky absorption band a little below F, another less distinct at  $F\frac{1}{2}G$ , and the spectrum was cut off a little below G.

76. When the glass was examined by the third method, the dispersion was found to commence abruptly about the fixed line *b*. It remained remarkably copious throughout the whole of the visible spectrum and far beyond, with the exception of a band beginning a little above F, and having its centre at about  $F\frac{1}{3}G$ , where there was a remarkable minimum of activity. This band, it will be observed, was situated between the bands of absorption already mentioned. The tint of the dispersed light appeared to be uniform throughout, except perhaps where the dispersion was just commencing. This was the best medium I have met with for showing the fixed lines of extreme refrangibility, though some others were nearly as good.

77. On examining the glass by the fourth method, it was found that the dispersion commenced nearly where the dispersed light ended, that is, the lowest refrangibility of the rays capable of being dispersed was nearly the same as the highest refrangibility of the rays constituting the dispersed beam exhibited by white light as a whole. The dispersion appeared indeed to commence a little earlier, at about the refrangibility of the fourth dark band in the spectrum of the entire dispersed beam. When the small prism was held to the eye with one hand, while the small lens in the board was gradually moved with the other, in a direction from the red to the violet, through the part of the spectrum where the dispersion commenced, it was found that the region of the first four bands was lighted up almost simultaneously, the whole field of view having been previously dark. When the lens was moved a very little further on the dispersed beam with its five bands was formed complete. Indeed the whole five appeared almost simultaneously. Speaking approximately, and in fact with almost perfect accuracy, we may say that if white light be conceived to be decomposed into two portions, the first containing rays of all refrangibilities up to that of the fixed line *b*, or thereabouts, and the second containing rays of all greater refrangibilities, the dispersed light produced by white light as a whole belongs exclusively to the first portion; and yet, were the bottle illuminated by the first portion alone, no dispersion whatsoever would be produced, whereas were it illuminated by the second portion

alone, which contains not a ray having the same refrangibility as any one of the dispersed rays, the dispersion would be exhibited in full perfection.

*Common Colourless Glasses.*

78. SIR DAVID BREWSTER states that he has met with many specimens, both of colourless plate and colourless flint glasses, which disperse a beautiful green light. All the colourless glasses which I have examined dispersed light internally to a greater or less extent, with the exception of some few specimens belonging to Dr. FARADAY'S experiments. A beautiful green seems to be the commonest tint of the dispersed beam, and this I have found in wine glasses, decanters, apothecaries' bottles, pieces of unannealed glass, &c.; also in many specimens of plate and crown glass. The green was generally of a finer tint than that dispersed by the canary glass, but was not near so copious. On analysis it was found to consist usually of red and green separated by a dark band, or rather a minimum of brightness. Those specimens which were examined by the third and fourth methods were found to exhibit a little false dispersion, produced chiefly in the brightest part of the spectrum, but the greater part was true dispersion. This dispersion was produced chiefly by a rather narrow band, comprising the fixed line G, where there appeared to be a remarkable maximum of sensibility. The line G lay a little above the lower limit of the band. Below the band dispersion also took place, though not near so copiously, and there appeared to be another maximum of sensibility some way further down in the spectrum; but above the band dispersion almost entirely ceased of a sudden; a very unusual circumstance when the active and the dispersed light are well separated in refrangibility. The position of the band in the spectrum, and the distribution of the illumination in it, which are very peculiar, were the same in all the specimens which were sufficiently sensitive to admit of being examined by the third method, but the tint of the dispersed light was not quite the same.

79. Orange-coloured glasses are frequently met with which reflect from one side, or rather scatter in all directions, a copious light of a bluish-green colour, quite different from the transmitted tint. In such cases the body of the glass is colourless, and the colouring matter is contained in a very thin layer on one face of the plate. The bluish green tint is seen when the colourless face is next the eye. As this phenomenon was supposed by Sir JOHN HERSCHEL to offer some analogy with the reflected tints of fluor-spar and a solution of sulphate of quinine, I was the more desirous of determining the nature of the dispersion. It proved on examination to be nothing but false dispersion, so that the appearance might be conceived to be produced by an excessively fine bluish-green powder contained in a clear orange stratum, or in the colourless part of the glass immediately contiguous to the coloured stratum. The phenomenon has therefore no relation to the tints of fluor-spar or sulphate of quinine. It is true that the very same glass which displayed a superficial reflexion of bluish green, when examined by condensed sun-light exhibited also, in its colour-

less part, a little true dispersion, just as another colourless glass would do. But this has plainly nothing to do with the peculiar reflexion which attracts notice in such a glass.

*Observations on the preceding results.*

80. There is one law relating to internal dispersion which appears to be universal, namely, that when the refrangibility of light is changed by dispersion it is *always lowered*. I have examined a great many media besides those which have been mentioned, and I have not met with a single exception to this rule. Once or twice, in observing by the fourth method, there appeared at first sight to be some dispersed light produced when the small lens was placed beyond the extreme red. But on further examination I satisfied myself that this was due merely to the light scattered at the surfaces of the large prisms and lens, which thus acted the part of a self-luminous body, emitting a light of sufficient intensity to affect a very sensitive medium.

81. Consider light of given refrangibility incident on a given medium. Let some numerical quantity be taken for a measure of the refrangibility, suppose the refractive index in some standard substance. Let the refrangibilities of the incident and dispersed light be laid down along a straight line AX (fig. 2) taken for the axis of abscissæ; let AM represent the refrangibility of the incident light, and draw a curve of which the ordinates shall represent the intensities of the component parts of the truly dispersed beam. According to the law above stated, no part of the curve is ever found to the right of the point M; but in other respects its form admits of great latitude. Sometimes the curve progresses with tolerable uniformity, sometimes it presents several maxima and minima, or even appears to consist of distinct portions. Sometimes it is well separated from M, as in fig. 2; sometimes it approaches so near to M that the most refrangible portion of the truly dispersed beam is confounded with the beam due to false dispersion.

82. Let  $f(x)$  be the ordinate of the curve corresponding to the abscissa  $x$ ,  $a$  the abscissa of the point M. Since  $f(x)$  is equal to zero when  $x$  exceeds  $a$ , the curve must reach the axis at the point M at latest, unless we suppose the function capable of altering abruptly, as is represented in fig. 3. I do not think that such an abrupt alteration, properly understood, is necessarily in contradiction with the law of continuity. For the sake of illustration, let us consider the phenomenon of total internal reflexion. Let P be a point in air situated at the distance  $z$  from an infinite plane separating air from glass. Conceive light having an intensity equal to unity, and coming from an infinitely distant point, to be incident internally on this plane at an angle  $\gamma + \theta$ , where  $\gamma$  is the angle of total internal reflexion. The intensity at P is commonly, and for most purposes correctly, considered as altering abruptly with  $\theta$ , having, so long as  $\theta$  is negative, a finite value which does not vanish with  $\theta$ , but being equal to zero when  $\theta$  is positive. The mode in which the law of continuity is in this case obeyed is worthy of notice. In the analytical expression for the vibration, when  $\theta$  passes from negative to positive, the coordinate  $z$  passes from under a



circular function into an exponential with a negative index, containing in its denominator  $\lambda$ , the length of a wave of light. As  $\theta$  increases through zero, the expression for the vibration alters continuously; but if  $x$  be large compared with  $\lambda$  it decreases with extreme rapidity when  $\theta$  becomes positive. On account of the excessive smallness of  $\lambda$ , it is sufficient for most purposes to consider the intensity as a function of  $\theta$  which vanishes abruptly; and indeed it would be hardly correct to consider it otherwise. For the use of the term *intensity* implies that we are considering light as usual, whereas those phenomena which require us to take into account the disturbance in the second medium which exists when the angle of incidence exceeds that of total internal reflexion, lead us to consider the nature as well as the magnitude of that disturbance, which no longer consists of a series of plane waves constituting light as usual. It is in some similar sense that I mean to say that we may suppose the function  $f(x)$ , which expresses the intensity of the truly dispersed light, to alter abruptly, without thereby implying any violation in the law of continuity. In observing by the fourth method, the portion of the spectrum operated on, though it may be small, is necessarily finite, and in some cases no separation could be made out between the beams of truly and falsely dispersed light. Hence I cannot undertake to say from observation, whether the variation of  $f(x)$  be always continuous, though sometimes very rapid, or be in some cases actually abrupt. I think, however, that observation rather favours the former supposition, a supposition which, independently of observation, seems by far the more likely.

83. Although the law mentioned in Art. 80 is the only one which I have been able to discover, relating to the connexion between the intensity and the refrangibility of the component parts of the dispersed beam, which appears to be always obeyed, and which admits of mathematical expression, there are some other circumstances usually attending the phenomenon which deserve notice.

When dispersion commences almost abruptly on arriving at a certain point of the spectrum, the dispersed beam is very frequently almost homogeneous at first, and of the same refrangibility as the active light. If the dispersed beam, when first perceived, be decidedly heterogeneous, its refrangibility extends almost, if not quite, to that of the active light, so that it is difficult, if not impossible, to separate the beams of truly and falsely dispersed light. On the other hand, when dispersion comes on gradually, it is generally found that the refrangibility of even the most refrangible part of the dispersed beam does not come up to that of the active light.

Thus in the cases of the red dispersion exhibited by a solution of leaf-green, and of the orange dispersions exhibited by solutions obtained from archil and from the *Mercurialis perennis*, the dispersed light was at first nearly homogeneous, and of the same refrangibility as the active light. In the case of the green dispersions shown by a solution obtained from archil, and by canary glass, the dispersed light was heterogeneous from the first; but still, when it first commenced, a portion of it had nearly the same refrangibility as the active light. In a solution of sulphate of quinine

the dispersion came on gradually, being perceptible when the active light belonged to the middle of the spectrum; and in this case the dispersed light consisted of colours of low refrangibility. The bright part of the dispersion however came on pretty rapidly, when the active light approached the extreme limit of the visible spectrum, and accordingly the dispersed beam consisted in that case chiefly of light of high refrangibility.

84. The mode of absorption of any medium may very conveniently be represented by a curve, as has been done by Sir JOHN HERSCHEL. To represent geometrically in a similar manner the mode of internal dispersion, would require a curved surface. Let the refrangibility of light be measured as before, and suppose for simplicity's sake the intensity of the incident light to be independent of the refrangibility, so that  $dy$  may be taken to represent the quantity of incident light of which the refrangibility lies between  $y$  and  $y+dy$ . Considering the effect of this portion of the incident light by itself, let  $x$  be the refrangibility of any portion of the dispersed light, and  $zdx dy$  the quantity of dispersed light of which the refrangibility lies between  $x$  and  $x+dx$ . Then the curved surface, of which the coordinates are  $x, y, z$ , will represent the nature of the internal dispersion of the medium. We must suppose the intensity of the incident light referred to some standard independent of the eye, since the illuminating power of the rays beyond the violet, and even of the extreme violet, is utterly disproportionate to the effect which in these phenomena they produce.

From the nature of the case, the ordinate  $z$  of the surface can never be negative. The law mentioned in Art. 80 may be expressed by saying, that if we draw through the axis of  $z$  a plane bisecting the angle between the axes of  $x$  and  $y$ , at all points on the side of this plane towards  $x$  positive, the curved surface confounds itself with the plane of  $xy$ .

85. Let us consider the form of this surface in two or three instances of internal dispersion. For facility of explanation, suppose the plane of  $xy$  horizontal, let  $x$  be measured to the right,  $y$  forwards, and  $z$  upwards. Let a line drawn in the plane of  $xy$  through the origin, and bisecting the angle between the axes of  $x$  and  $y$ , be called for shortness the line L. In all cases the surface rises above the plane of  $xy$  only to the left of the line L.

In the case of a solution of leaf-green, the surface consists as it were of two mountain ranges running in a direction parallel to the axis of  $y$ , or nearly so. The first range, if prolonged, would meet the axis of  $x$  at a point corresponding to the place of the dark band No. 1 in the red, or nearly so. The second would meet it somewhere in the place corresponding to the green. The green range is much broader than the red, but very much lower, and is comparatively insignificant. The ridge of the red range is by no means uniform, but presents a succession of maxima and minima. The range commences at the end nearest to the axis of  $x$  with a very high peak, by far the highest in the whole surface. In following the ridge forwards,

five minima or passes may be observed, with hills intervening. The ordinates  $y$  of the first four of these minima correspond to the refrangibilities of the bright bands Nos. 2, 3, 4 and 5. The last minimum lies a little further on. Whether similar minima exist in the green range is not decided by observation, on account of the faintness of the green dispersed light.

In the case of canary glass, the surface consists of five portions like mountain ranges running parallel to the axis of  $y$ , and having abscissæ belonging to the red, reddish orange, yellowish green, green, and more refrangible green, respectively. These ranges do not all start from the immediate neighbourhood of the line L, but on the side towards the axis of  $x$  end almost in cliffs, at points at which the ordinate  $y$  is nearly equal to the abscissa of the fifth range, perhaps a little less. Thus the first three ranges are well separated from the line L. The ranges are intersected by a sort of valley running parallel to the axis of  $x$ , and having for its ordinate  $y$  the refrangibility of  $F\frac{1}{3}G$ . With the exception of the minima which occur where the ranges are intersected by this valley, the ridges run on very uniformly, and it is only very gradually that the ranges die away.

The form of the surface which expresses the internal dispersion of a solution of sulphate of quinine, may be gathered from the description of that medium. In this case the surface resembles a rising country, not intersected by any remarkable mountain ranges or valleys.

Fig. 4 is a rude representation of the internal dispersion in a solution of leaf-green. The curves represented in the figure must be supposed to be turned through  $90^\circ$  about the lines on which they stand, and will then represent sections of the surface already described, made by vertical planes parallel to the axis of  $x$ . OL is the straight line bisecting the angle  $xOy$ . The figure is merely intended to assist the reader in forming a clear conception of the general nature of the phenomena, and must not be trusted for details. No attempt is made to represent the several maxima and minima in the intensity of the red beam of dispersed light. In any such figure, if we suppose homogeneous light to be incident on the medium, and wish to lay down the place of the falsely dispersed beam, we have only to draw a straight line parallel to the axis of  $x$ , through the point in the axis of  $y$  which corresponds to the refrangibility of the incident light, and find where this line cuts the straight line OL which bisects the angle  $xOy$ .

*On the cause of the clearness of fluids, notwithstanding a copious internal dispersion which they may exhibit.*

86. It has been already remarked, that though water holding a water colour in suspension makes an admirable imitation of a highly sensitive fluid, when the latter is viewed by dispersive reflexion alone, the two fluids have a totally different appearance when viewed by transmitted light. The cause of this difference appears to be plain enough. The light due to internal dispersion emanates from each portion of

the fluid which is under the influence of the active light, and emanates apparently in all directions alike. I have not attempted to determine experimentally whether the intensity is strictly the same in all directions. The experiment would be very difficult, especially for directions nearly coinciding with that of the active light, because in that case the light which was really due to internal dispersion would be mixed up with the glare which is always found in the neighbourhood of light of dazzling brightness. However, I have seen nothing which led me to suppose that the intensity was different in different directions. We may express the results of observation extremely well, by saying that the fluid or solid medium is self-luminous so long as it is under the influence of the active light.

Accordingly, when a bright object, such as the sky, or the flame of a candle, is viewed through a highly sensitive fluid, the regularly transmitted light is accompanied by some side light due to internal dispersion. The latter, however, emanating in all directions alike from the influenced particles, is too faint, when contrasted with the regularly transmitted light, to make any sensible impression on the eye. But when a fluid, itself insensible, holds in suspension a great number of solid particles of finite size, the light reflected from such particles is reinforced, in directions nearly coinciding with that of the incident light, by a great quantity of diffracted light, so that a bright object viewed through such a fluid is surrounded by a sort of nebulous haze, giving the fluid a milky appearance.

#### *Washed Papers.*

87. In a paper "On the Action of the Rays of the Solar Spectrum on Vegetable Colours," Sir JOHN HERSCHEL mentions a peculiarity which he had observed in paper washed with tincture of turmeric, which consists in its being illuminated, when a pure spectrum is thrown on it, to a much greater distance at the violet end than is the case with mere white paper\*. This phenomenon was attributed by Sir JOHN to a peculiarity in its reflecting power, and was considered as a proof of the visibility of the ultra-violet rays. The colour of the prolongation of the spectrum was yellowish green. Sir JOHN appears to have been in doubt whether the greenish yellow colour was to be attributed to the mixture of the true colour of the ultra-violet rays with the yellow of the paper due to diffused light, or to the real colour of the ultra-violet rays themselves, which on that supposition would have been incorrectly termed "lavender."

88. The fact of the change of refrangibility of light having been established, there could be little doubt that the true cause of the extraordinary prolongation of the spectrum on paper washed with tincture of turmeric, was very different from what Sir JOHN HERSCHEL had supposed, and that it was due to a change of refrangibility in the incident light, which was produced by the medium in a solid state. Tincture of turmeric has already been mentioned as a medium which possesses in a high

\* Philosophical Transactions for 1842, p. 194.

degree the property of internal dispersion. It was the observation of Sir JOHN HERSCHEL's already mentioned, which led me to try this medium. But it is by no means essential that a sensitive substance should be in solution, or in the state of a transparent solid, in order that the change of refrangibility which it produces should admit of being established by direct experiment, although of course the mode of observation must be changed.

89. A piece of paper was prepared by pouring some tincture of turmeric on it, and allowing it to dry. In this way the part which was deeply coloured by turmeric was in juxtaposition with the part which remained white, which was convenient in contrasting the effects of the two portions. The sun's light being reflected horizontally into a darkened room through a vertical slit, the paper was placed in a pure spectrum formed in the usual manner. On the coloured part the fixed lines were seen with the utmost facility far beyond the line H, on a yellowish ground. The colours too of all the more highly refrangible part of the spectrum were totally changed. From the red end, as far as the line F, or thereabouts, there was no material change of colour; but a little further on a very perceptible reddish tinge came on, which was quite decided at  $F\frac{1}{2}G$ , where it was mixed with the proper colour of that part of the spectrum. About  $G\frac{4}{7}H$  the colour became yellowish. The reality of a change of refrangibility was easily proved by refracting the spectrum on the screen by a prism applied to the eye. When the refraction took place in a plane parallel to the fixed lines, they were seen distinctly throughout the spectrum; but when it took place in a plane perpendicular to the former, the fixed lines in the less refrangible part of the spectrum, and as far as F, were distinctly seen; but in the rest of the spectrum they were more or less confused, or even wholly obliterated, according to their original strength, the refracting angle and dispersive power of the prism, and its distance from the paper. With a prism of small angle the edges of the broad bands H were seen tinged with prismatic colours.

90. The change of refrangibility was further shown by the following observation. The paper was placed in the pure spectrum in such a manner that the line of junction of the coloured and uncoloured parts ran lengthways through the spectrum, so that the same fixed line was seen partly on the coloured and partly on the uncoloured portion. On viewing the whole through a prism of moderate angle applied to the eye, and so held as to refract the system in a direction perpendicular to the fixed lines, the line F was seen uninterrupted, but G was dislocated, the portion formed on the yellow part of the paper being a good deal less refracted than that formed on the white. The latter was indeed faintly prolonged into the yellow part of the paper, so that on this part G was seen double; but the image which was by far the more intense of the two was less refracted than that formed on the white paper. The whole appearance was such as to create a strong suspicion of some illusion, as if some other group of fixed lines formed on the yellow part of the paper had been mistaken for G, though certainly no reason appears why such a group should not have had its coun-

terpart on the white part. However, to remove all doubts, I refracted the system in the direction of the fixed lines, and then turned the prism round the axis of the eye through  $90^\circ$ , when the plane of refraction was situated as before. At first the two portions of the line G were of course seen in the same straight line; and the perfect continuity with which, as the prism turned round, the appearance changed into what had been first seen, left not the shadow of a doubt as to the reality of the dislocation.

91. The cause of the whole appearance is plain enough. The light coming from the illuminated part of the yellow paper consisted, in the neighbourhood of G, of two portions; the first, indigo light, which had been scattered in the ordinary way; the second and larger portion, heterogeneous light having a mean refrangibility a good deal less than that of G, which had arisen from homogeneous light of higher refrangibility. The absence of the first occasioned the faint prolongation of the more refracted part of the line G; the absence of the second gave rise to the less refracted part.

92. The broad bands H were seen faintly but quite distinctly on the white paper. On refracting them sideways by a prism of moderate angle held to the eye, they became confused, and tinged with prismatic colours. The confused images of these bands, seen in the white and coloured parts, were nearly continuous. It thus appears that the visibility of the bands H on the white paper was due to a change of refrangibility which that substance had produced in violet light of extreme refrangibility.

93. Effects similar to those produced by paper coloured by tincture of turmeric are also produced by turmeric powder, or even by the root merely broken across. Notwithstanding the roughness of the latter, the bands H and fixed lines far beyond are seen with the utmost facility.

94. These phenomena are much better observed by covering the slit with a deep blue glass, which absorbs all the bright part of the spectrum, while it freely transmits the violet and invisible rays, which are mainly efficient in this class of phenomena. In this way fixed lines may be seen on common white paper far beyond H. These lines may be seen without the use of the blue glass, by allowing the bright colours to pass by the edge of the paper, and receiving on it only the extreme violet and invisible rays.

95. Paper coloured by turmeric having exhibited so well the sensibility of that substance, I was induced to try various other washed papers, in fact, papers washed with most of the fluids with which I had made experiments. I found almost always that sensitive solutions gave rise to sensitive papers, exhibiting a change of refrangibility of the same character as that shown by the solution. Besides the turmeric paper, the two most remarkable were paper washed with a pretty strong solution of sulphate of quinine, and paper washed with the extract from the seeds of the *Datura stramonium*. I should here observe, that it was not till long after the time when these experiments were made that I was acquainted with the high sensibility of a decoction of the bark of the horse-chestnut. The former of the papers just mentioned ex-

hibited the fixed lines of the invisible rays on a blue, and the latter on a green ground. The dispersion produced by the quinine paper was not exhibited so early in the spectrum as in the case of turmeric, nor was it so copious in the extreme violet rays, and for some distance further on, but the quinine paper seemed superior to the other for showing the fixed lines of extreme refrangibility. With the turmeric paper the group  $n$  was plain enough, but with the quinine paper I have seen some fixed lines of the group  $p$ . The stramonium paper was, on the whole, I think superior to the quinine paper in point of the copiousness of the dispersed light, but seemed hardly equal to it for showing the fixed lines of extreme refrangibility. However, it is likely that paper washed with a solution of the sensitive principle in a state of purity would have been quite equal to the quinine paper in this respect.

96. A washed paper is a little more convenient for use than a solution, but, as might be expected, it does not show the fixed lines with quite as much delicacy, nor is it quite so good for tracing the spectrum to the utmost limits to which it can be traced with the substance employed.

97. The sensibility of fresh leaf-green could not be made out on a washed paper by this mode of observation, but the sensibility of the substance extracted by alcohol from black tea, from which the brown colouring matter had been removed by hot water, was plainly exhibited by the redness which it produced in the highly refrangible part of the spectrum.

98. Paper washed with a solution of guaiacum seemed an exception to the general rule; but this is not to be wondered at, since a paper prepared in this manner is turned green when exposed to the light, and it is difficult to prevent some degree of discoloration. That the fluid state is not essential to the exhibition of the sensibility of this substance, was however plainly shown by the high degree of sensibility of the solid resin from which the solution was made. In this case the bands H were seen on a greenish ground. The dispersion of a fine blue light under the influence of rays of still higher refrangibility was hardly, or not at all, exhibited by the solid resin.

99. Shell-lac, common resin, glue, are all highly sensitive. The ground on which the fixed lines in the neighbourhood of H are seen is brown in the case of shell-lac, and greenish in the case of resin and glue. The sensibility of glue is evidently not due to gelatine, for isinglass is almost, if not quite, insensible. These are merely a few instances of sensibility: I shall defer further mention of the subject till I have described a better mode of observation. I will merely observe for the present, that several washed papers proved not greatly inferior to turmeric paper for showing the fixed lines about and beyond H.

*Effect of refracting a Narrow Spectrum in a Vertical Plane.*

100. In the arrangement last described, when a short slit is used, the spectrum received on the washed paper or other substance is of course narrow, so that the fixed lines formed on the paper are but short, and may roughly be regarded as mere

points. If, now, the whole be viewed through a prism, so as to be refracted in a vertical plane, the effect is very striking. For facility of explanation suppose the red to be to the left, and the rays to be refracted upwards, so that to the observer the image is thrown downwards. The original spectrum on the screen is decomposed by the prism held to the eye into two spectra, which diverge from each other. The first of these runs obliquely downwards from left to right, and contains the natural colours of the spectrum from red to violet. It consists of light which has been scattered in the ordinary way by the substance on which the primary spectrum is received, and the cause of its obliquity is evident. The second spectrum is horizontal, that is to say, it approximates to the form of a long rectangle having its longer sides horizontal. Of course it would be theoretically possible to render the vertical sides the longer, but when the whole arrangement of the apparatus is such as to be convenient for observation, the horizontal sides are much longer than the others. In this second spectrum the colours run *horizontally*, that is to say, the lines of equal colour are horizontal. The interruptions of the primary spectrum corresponding to fixed lines, almost reduced to points, are now elongated, so that in this strangely formed spectrum the principal fixed lines of the solar spectrum are seen running *across* the colours.

101. It will be convenient to have a name for the second of the two spectra above mentioned. As the term *secondary spectrum* is already appropriated to something altogether different, I shall call it the *derived spectrum*. The first of the diverging spectra may be called the *primitive spectrum*, while the original spectrum, considered as not yet decomposed by the prism held to the eye, may be called, for distinction, as in fact it has been already called, *primary*.

102. In accordance with the law enunciated in Art. 80, it is found that the derived spectrum appears *always on one and the same side* of the primitive, being *less refracted*.

103. The brilliancy of the derived spectrum, its extent, both vertically and horizontally, the colours of which it mainly consists, the distribution of its illumination in a horizontal direction, all depend upon the nature of the substance upon which the primary spectrum is received. As a general rule, it may be stated that it starts from the neighbourhood of the brightest part of the primitive spectrum, and extends from thence onwards to a good distance beyond the extreme violet; and that with a given substance its colour is pretty uniform, that is, does not much change in passing from one vertical section to another. Sometimes the derived spectrum remains very bright up to its junction with the primitive, or at least till it gets so near that the superior brilliancy of the primitive spectrum prevents all observation on the derived; sometimes it remains dull to a considerable distance from the primitive spectrum, and then, opposite a highly refrangible part of the primitive spectrum, a strong illumination comes on in the derived, lasts for some distance, and afterwards gradually dies away. Many of the results mentioned in this paragraph are better observed by a somewhat different method, which will shortly be described.