

XXX. *On the Change of Refrangibility of Light.* By G. G. STOKES, M.A., F.R.S.,  
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1. THE following researches originated in a consideration of the very remarkable phenomenon discovered by SIR JOHN HERSCHEL in a solution of sulphate of quinine, and described by him in two papers printed in the Philosophical Transactions for 1845, entitled ‘On a Case of Superficial Colour presented by a Homogeneous Liquid internally colourless,’ and ‘On the Epipolic Dispersion of Light.’ The solution of quinine, though it appears to be perfectly transparent and colourless, like water, when viewed by transmitted light, exhibits nevertheless in certain aspects, and under certain incidences of the light, a beautiful celestial blue colour. It appears from the experiments of Sir JOHN HERSCHEL that the blue colour comes only from a stratum of fluid of small but finite thickness adjacent to the surface by which the light enters. After passing through this stratum, the incident light, though not sensibly enfeebled nor coloured, has lost the power of producing the same effect, and therefore may be considered as in some way or other qualitatively different from the original light. The dispersion which takes place near the surface of this liquid is called by Sir JOHN HERSCHEL *epipolic*, and he applies the term *epipolized* to a beam of light which, having been transmitted through a quiferous solution, has been thereby rendered incapable of further undergoing epipolic dispersion. In one experiment, in which sun-light was used, a feeble blue gleam was observed to extend to nearly half an inch from the surface. As regards the dispersed light itself, when analysed by a prism it was found to consist of rays extending over a great range of refrangibility: the less refrangible extremity of the spectrum was however wanting. On being analysed by a tourmaline, it showed no signs of polarization. A special experiment showed that the dispersed light was perhaps incapable, at any rate not peculiarly susceptible, of being again dispersed.

2. In a paper ‘On the Decomposition and Dispersion of Light within Solid and Fluid Bodies,’ read before the Royal Society of Edinburgh in 1846, and printed in the 16th volume of their Transactions, as well as in the Philosophical Magazine for June 1848, Sir DAVID BREWSTER notices these results of Sir JOHN HERSCHEL’s, and states the conclusions, in some respects different, at which he had arrived by operating in a different way. The phenomenon of internal dispersion had been discovered by him some years before, and is briefly noticed in a paper read before the Royal Society

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of Edinburgh in 1833\*. It is described at length, as exhibited in the particular case of fluor-spar, in a paper communicated to the British Association at Newcastle in 1838†. In Sir DAVID BREWSTER's experiments the sun's light was condensed by a lens, and so admitted into the solid or fluid to be examined ; which afforded peculiar facilities for the study of the phenomena. On examining in this way a solution of sulphate of quinine, it was found that light was dispersed, not merely close to the surface, but at a long distance within the fluid : and Sir DAVID BREWSTER was led to conclude that the dispersion produced by sulphate of quinine was only a particular case of the general phenomenon of internal dispersion. On analysing the blue beam by a rhomb of calcareous spar, it was found that a considerable portion of it, consisting chiefly of the less refrangible rays, was polarized in the plane of reflexion, while the more refrangible of its rays, constituting an intensely blue beam, had a different polarization.

3. On repeating some of Sir JOHN HERSCHEL's experiments, I was immediately satisfied of the reality of the phenomenon, notwithstanding its mysterious nature, that is to say, that an epipolized beam of light is in some way or other qualitatively different from the light originally incident on the fluid. On making the observation in the manner of Sir DAVID BREWSTER, it seemed no less evident that the phenomenon belonged to the class of internal dispersion‡. Nevertheless, the singular phenomenon discovered by Sir JOHN HERSCHEL manifested itself even in this mode of observation. If indeed the vessel containing the solution were so placed that the image of the sun in the focus of the lens lay a little way inside the fluid, the phenomenon was masked, because the increase of intensity due to an increase of concentration in approaching the focus made up for the decrease of intensity due to passing out of the blue band. But when the vessel was moved so that the focus of the lens fell either further inside the fluid or else outside the vessel, the narrow blue band adjacent to the surface was seen *as well as* the blue beam which shot far into the fluid. Light which has been "epipolized" by transmission through a moderate thickness of the solution is indeed capable of undergoing further dispersion, but not *epipolic* dispersion, *if that term be restricted* to the dispersion by which the narrow blue band is produced. It was no doubt of great importance to assign to the phenomenon its true place as a member of the class of phenomena of internal dispersion. Nevertheless the mystery was by no means cleared up ; rather, we were prepared to expect something of the same sort

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

† Eighth Report.—Transactions of the Sections, p. 10.

‡ By this, I merely mean that, to take a particular example, the exhibition of a blue light by a solution of sulphate of quinine appeared to be a phenomenon of the same nature as the exhibition of a red light by a solution of the green colouring matter of leaves, although the latter does not manifest the same singular concentration as the former in the neighbourhood of the surface by which the light enters ; and the latter had already been observed by Sir DAVID BREWSTER, and the phenomenon designated as *internal dispersion*. I make this remark because Sir DAVID BREWSTER has applied this same term to another class of phenomena which are totally different.

in other instances of internal dispersion. In fact, the mystery consisted, not in the narrowness of the stratum from which most of the blue light came, but in the circumstance that it was possible for light, by passing across such a stratum, to be deprived of the power of producing the same effect again, without, apparently, being altered in any other respect.

4. To one who regards light as a subtle and mysterious agent, of which the laws indeed are in a good measure known to us, but respecting the nature of which we are utterly ignorant, the phenomenon might seem merely to make another striking addition to the modes of decomposition with which we were already acquainted. But in the mind of one who regards the theory of undulations as being for light what the theory of universal gravitation is for the motions of the heavenly bodies, it was calculated to excite a much more lively interest. Whatever difficulty there might be in explaining how the effect was produced, we ought at least to be able to say what the effect was that had been produced; wherein, for example, epipolized light differed from light which had not undergone that modification.

In speculating on the nature of the phenomenon, there is one point which deserves especial attention. Although the passage through a thickness of fluid amounting to a small fraction of an inch is sufficient to purge the incident light from those rays which are capable of producing epipolic dispersion, the dispersed rays themselves traverse many inches of the fluid with perfect freedom. It appears therefore that the rays producing dispersion are in some way or other of a different nature from the dispersed rays produced. Now, according to the undulatory theory, the nature of light is defined by two things, its period of vibration, and its state of polarization. To the former corresponds its refrangibility, and, so far as the eye is a judge of colour, its colour\*. To a change, then, either in the refrangibility or in the state of polarization we are to look for an explanation of the phenomenon.

5. Regarding it at first as an axiom that the dispersed light of any given refrangibility could only have arisen from light of the same refrangibility contained in the incident beam, I was led to look in the direction of polarization for the required change in the nature of the light. Since a fluid has no axes, circular polarization is

\* It has been maintained by some philosophers of the first eminence that light of definite refrangibility may still be compound, and though no longer decomposable by prismatic refraction might still be so by other means. I am not now speaking of compositions and resolutions depending upon polarization. It has even been suggested by the advocates of the undulatory theory, that possibly a difference of properties in lights of the same refrangibility might correspond to a difference in the law of vibration, and that lights of given refrangibility may differ in tint, just as musical notes of given pitch differ in quality. Were it not for the strong conviction I felt that light of definite refrangibility is in the strict sense of the word homogeneous, I should probably have been led to look in this direction for an explanation of the remarkable phenomena presented by a solution of sulphate of quinine. It would lead me too far from the subject of the present paper to explain the grounds of this conviction. I will only observe that I have not overlooked the remarkable effect of absorbing media in causing apparent changes of colour in a pure spectrum; but this I believe to be a subjective phenomenon, depending upon contrast.

the only kind which can here come into play. As some fluids are doubly refracting, transmitting right-handed and left-handed circularly polarized light with different velocities, so, it might be, this fluid was doubly absorbing, absorbing say right-handed circularly polarized light of certain refrangibilities with great energy, and freely transmitting left-handed. The right-handed light, absorbed, in the sense of withdrawn from the incident beam, might have been more strictly speaking scattered, and thereby depolarized. The common light so produced would be equivalent to two streams, of equal intensity, one of right-handed, and the other of left-handed circularly polarized light. Of these the latter would be freely transmitted, while the former would be scattered anew, and so on. Yet this hypothesis, sufficiently improbable already, was not enough. New suppositions were still required, to account for the circumstance that an epipolized beam, when subjected to prismatic analysis with a low magnifying power, exhibited no bands of absorption in the region to which, as regards their refrangibility, the dispersed rays principally belong; so that altogether this theory bore not the slightest semblance of truth.

6. I found myself thus fairly driven to suppose that the change of nature consisted in a change of refrangibility. From the time of NEWTON it had been believed that light retains its refrangibility through all the modifications which it may undergo. Nevertheless it seemed to me less improbable that the refrangibility should have changed, than that the undulatory theory should have been found at fault. And when I reflected on the extreme simplicity of the whole explanation if only this one supposition be admitted, I could not help feeling a strong expectation that it would turn out to be true. In fact, we have only to suppose that the invisible rays beyond the extreme violet give rise by internal dispersion to others which fall within the limits of refrangibility between which the retina of the human eye is affected, and the explanation is obvious. The narrowness of the blue band observed by Sir JOHN HERSCHEL would merely indicate that the fluid, though highly transparent with regard to the visible rays, was nearly opaque with regard to the invisible. According to the law of continuity, the passage from almost perfect transparency to a high degree of opacity would not take place abruptly; and thus rays of intermediate refrangibilities might produce the blue gleam noticed by Sir JOHN HERSCHEL, or the blue cylinder, or rather cone, observed by Sir DAVID BREWSTER. We should thus, too, have an immediate explanation of a remarkable circumstance connected with the blue band, namely that it can hardly be seen by strong candle-light, though readily seen by even weak daylight. For candle-light, as is well known, is deficient in the chemical rays situated beyond the extreme violet.

7. My first experiments were made with coloured glasses. A test tube was about half filled with a solution consisting of disulphate of quinine dissolved in 200 times its weight of water acidulated with sulphuric acid. The tube, having been first covered with black paper, with the exception of a hole by which the light might enter, was placed in a vertical position in front of a window, the hole being turned

towards the light. On looking down from above, in a direction nearly parallel to the surface of the glass, a blue arc was well seen, extending only a very short distance into the fluid, and situated immediately behind the hole. As this arc, though extremely distinct, was not of course what could be called brilliant, I did not at first venture, for the experiment I had in view, to use any but pale glasses. Having no direct means of determining which were opaque with regard to the invisible rays situated beyond the extreme violet, I sought among a collection of orange, yellow, and brown glasses, which, from transmitting mainly the less refrangible rays, seemed the most likely to absorb the chemical rays. I presently found a pale smoke-coloured glass, which, when placed immediately in front of the hole, prevented the formation of the blue arc, although when placed immediately in front of the eye it transmitted a large proportion of the light of which the arc consisted. The colour of the arc was of course modified, and rendered more nearly white.

On trying other pale glasses, I found one of a puce colour, which, when placed in front of the hole, allowed the arc to be formed, though it absorbed it when placed in front of the eye. A yellow, and likewise a yellowish green glass allowed the arc to be seen in both positions; but its colour was decidedly different according as the glass was placed in front of the hole or in front of the eye. The breadth, too, of the arc was differently affected by different coloured glasses placed in front of the hole, some causing the light to be more, and others less concentrated towards the surface of the test tube than when the incident light was unimpeded.

8. The sun's light was next reflected horizontally into a darkened room, and allowed to pass through a hole in a vertical board which was placed in the window. The hole contained a lens of rather short focus. On placing a test tube containing the solution, in a vertical position, in front of the lens, at such a distance that the focus lay some way inside the fluid, the narrow blue band described by Sir JOHN HERSCHEL and the blue beam mentioned by Sir DAVID BREWSTER were seen independently of each other. On trying different coloured glasses, which were placed, first in front of the fluid, and then in front of the eye, it was found that the blue beam, as had previously proved to be the case with the narrow band, was for the most part differently affected according as the glass was placed so as to intercept the incident or the dispersed light. Moreover, the long blue beam and the narrow band did not behave in the same manner under the action of the same coloured glass.

9. To my own mind these experiments were conclusive as to the fact of a change of refrangibility. Admitting that the effect of a coloured glass is simply to stop a certain fraction of the incident light, that fraction being a function of the refrangibility, it is plain that the results can be explained in no other way. It must be confessed however that these results are merely an extension of that which precisely constitutes the peculiarity of the phenomenon. For, take the case of the narrow blue band formed by ordinary daylight. Imagine a glass vessel with parallel sides to be filled with a portion of the solution, and placed so as to intercept, first the incident,

and then the dispersed light. In the first position the light incident on the fluid under examination would be "epipolized" by transmission through the fluid contained in the vessel, and therefore the blue band would be cut off, whereas when the vessel was held in front of the eye the blue band would be freely transmitted. Hence the effects of the coloured glasses are analogous to, but less striking than, the effect of a stratum of the solution of sulphate of quinine in the imaginary experiment above described. There is to be sure one important difference in the two cases, namely, that in the case of the stratum of fluid the epipolic dispersion which is prevented in the fluid under examination is produced near the first surface of the stratum, whereas no such dispersion is produced, or at any rate necessarily produced, in the coloured glasses. Whatever the reader may think of the results obtained with coloured glasses, the next experiment it is presumed will be deemed conclusive.

10. The board in the window containing the lens having been replaced by a pair of boards adapted to form a vertical slit, the sun's light was reflected horizontally through the slit, and transmitted through three Munich prisms placed one after the other close to it. A tolerably pure spectrum was thus formed at the distance of some feet from the slit. A test tube containing the solution was then placed vertically a little beyond the extreme red of the spectrum, and afterwards gradually moved horizontally through the colours. Throughout nearly the whole of the visible spectrum the light passed through the fluid as it would have done through so much water; but on arriving nearly at the violet extremity a ghost-like gleam of pale blue light shot right across the tube. On continuing to move the tube, the blue light at first increased in intensity and afterwards gradually died away. It did not however cease to appear until the tube had been moved far beyond the violet extremity of the spectrum visible on a screen. Before disappearing, the blue light was observed to be confined to an excessively thin stratum of fluid adjacent to the surface by which the light entered, whereas when it first appeared, namely when the tube was placed a little short of the extreme violet, the blue light had extended completely across it. It was certainly a curious sight to see the tube instantaneously lighted up when plunged into the invisible rays: it was literally *darkness visible*. Altogether the phenomenon had something of an unearthly appearance.

11. Since the fluid is so intensely opaque with regard to rays of extreme refrangibility, it might be expected, that, though it appears transparent and colourless when examined merely by viewing a white object through it, it would yet exhibit a very sensible absorbing action with regard to the extreme violet rays when subjected to prismatic analysis. To try whether such were really the case, I reflected the sun's light horizontally through a slit, at which was placed a test tube filled with the liquid, and analysed the line of light by a prism, the eye being defended by a deep blue glass. I was barely able to make out the fixed line H in Plate XXV., that is, the less refrangible band of the pair, although in similar circumstances I can generally see about as far beyond the more refrangible band as it is beyond H. However, to make the result

more decisive by using a greater thickness, as well as to render the observation strictly differential, I placed a tumbler filled with water behind the slit, the blue glass before it, and then viewed the slit through the prism. I saw as far as usual into the violet. The water was then poured out and replaced by the solution of sulphate of quinine, which, when viewed by transmitted light, appeared as transparent as the water which it had replaced. When the tumbler was now placed behind the slit, the blue beam of dispersed light was observed to extend quite across it, a distance of about three inches, and would evidently have gone much further. On viewing the slit through the prism, the spectrum was found to be cut off about half-way between the fixed lines G and H. The termination was pretty definite, which indicates that, at least for that part of the spectrum, the absorbing energy of the fluid rapidly increased with the refrangibility of the light; there was, however, an evident diminution of intensity produced by the fluid, extending from the termination of the spectrum to near G.

12. There could no longer be any doubt, either as to the fact of a change of refrangibility, or as to the explanation thereby of the remarkable phenomenon exhibited by sulphate of quinine. Epipolized light is merely light which has been purged of the invisible, or at most feebly illuminating rays more refrangible than the violet; and the term itself, which in fact was only adopted provisionally by Sir JOHN HERSCHEL, and which has now served its purpose, may henceforth be discarded, especially as it is calculated to convey a false impression respecting the cause of the phenomenon. It remained to examine other instances of internal dispersion, of which, according to Sir DAVID BREWSTER'S observations, the dispersion produced by sulphate of quinine is only a particular case; to endeavour to make out the laws according to which a change of refrangibility takes place; and, if possible, to account for these laws on mechanical principles.

13. In giving an account of my further experiments, I think it best to describe in detail the phenomena observed in some of the more remarkable instances of internal dispersion before attempting to draw any general conclusions. It will save repetition to explain in the first instance the methods of observation employed, which on the whole may very fairly be divided into four, though occasionally it was convenient to employ intermediate methods, or a combination of two of them. Of course I frequently availed myself of Sir DAVID BREWSTER'S method of observation, in which the effect of the incident light is studied as a whole; but the methods here referred to relate to an investigation of the separate offices of the portions of light of different degrees of refrangibility which are found in the incident beam. As my researches proceeded, new methods of observation suggested themselves, but these will be described in their place.

*Methods of Observation employed.*

FIRST METHOD.—The sun's light was reflected horizontally through a small lens, which was fixed in a hole in a vertical board. The cone of emergent rays was

allowed to enter the solid or fluid examined. A coloured glass or other absorbing medium was then placed, first so as to intercept the incident rays, and then between the substance examined and the eye. For shortness' sake these positions will be designated as *the first* and *the second*. Sometimes a coloured glass was allowed to remain in front of the hole, and a second glass was added, first in front of the hole and then in front of the eye.

SECOND METHOD.—The sun's light, reflected as before, was transmitted through a series of three or four Munich prisms placed one immediately after the other, and each nearly in the position of minimum deviation. It was then transmitted through a small lens in a board close to the last prism, and so allowed to enter the body to be examined, which was generally placed so that the first surface coincided, or nearly so, with the focus of the lens. The diameter of the lens was much smaller than the breadth or height of the prisms, so that the lens was completely filled with white light, the component parts of which however entered in different directions. Regarding the image of the sun in the focus of the small lens as a point, we may conceive the light incident on the body under examination as consisting of a series of cones, corresponding to different refrangibilities, the axes of which lay in a horizontal plane and intersected in the centre of the lens, the vertices being arranged in a horizontal line near the surface of the body examined.

THIRD METHOD.—The sun's light was reflected horizontally through a vertical slit, and received on the prisms, which were arranged as before, but placed at the distance of several feet from the slit. A large lens of rather long focus was placed immediately after the last prism, with its plane perpendicular, or nearly so, to the beam of light which had passed through the prisms, and with its centre about the middle of this beam. The body examined was placed at the distance of the image of the slit, or nearly so.

FOURTH METHOD.—Everything being arranged as in the third method, a board with a small lens of short focus was placed at the distance of the image of the slit, or between that and the image of the sun, which was a little nearer to the prisms, inasmuch as the focal length of the large lens commonly employed, though much smaller, was not incomparably smaller than the distance of the lens from the slit. A second slit was generally added immediately in front of the small lens. The body examined was placed at the focus of the small lens. The dispersed light was viewed from above, and analysed by a prism, being refracted sideways.

The object of these several arrangements will appear in the course of the paper. The prisms employed consisted, three of them of flint glass and one of crown. The refracting angles of the former were about  $43^\circ$ ,  $33^\circ$ , and  $24^\circ$ , and that of the latter about  $45^\circ$ . The refracting faces of the smallest of the prisms (the flint of  $43^\circ$ ) were 1.35 inch high and 1.60 long. The small lens used was one or other of a pair of which the apertures were 0.34 inch and 0.22 inch, and the focal lengths 0.75 inch and 0.50 inch. The focal length of the large lens generally used was about twelve inches.



Once or twice a lens was tried which had a focal length about three times as great, but the light proved too faint for most purposes. In the third method it was sometimes convenient to employ a lens of only  $6\frac{1}{2}$  inches focal length, but the 12-inch lens was employed in the fourth method, except on a few occasions, when the lens of 36 inches focal length was used. With the 12-inch lens the length of the spectrum from the fixed line B to H was usually about an inch and a quarter.

It will be convenient for the purposes of this paper to employ certain terms in a particular sense, but as some of these terms relate to phenomena which have not yet been described, it will be well previously to relate in detail what was observed in one remarkable instance of internal dispersion.

*Solution of Sulphate of Quinine.*

14. The effects of some pale coloured glasses in the case of this fluid have already been mentioned. But there is one glass of which the effect is still more striking. It is well known that a deep cobalt blue glass is highly transparent with regard to the chemical rays. Accordingly I found that a blue glass, so deep that only the brighter objects in a room could be seen through it, produced but very little effect when placed so as to intercept the light incident on the fluid. When placed immediately in front of the eye, at first everything disappeared except the light reflected from the convexities of the glass tube; but when the eye became a little accustomed to the darkness it was possible to make out the existence of the band. The contrast between the effects of this glass and of the pale brown glass already mentioned was most striking.

15. When the fluid was examined by the second method, the dispersed light was found to consist of two beams, separated from each other at their entrance into the fluid, that is, at the vertical surface of separation of the fluid and the containing vessel, and afterwards still further separated by divergence. Of course each beam must have been made up of a series of cones having their axes diverging from the centre of the lens, and their vertices situated at its focus. The first beam, or that which was produced by light of less refrangibility, consisted of the brighter colours of the spectrum in their natural order. It had a discontinuous, sparkling appearance, and was plainly due merely to motes which were suspended in the fluid. On being viewed from above through a NICOL'S prism, it was found to consist chiefly of light polarized in the plane of reflexion. Taken as a whole, it served as a fiducial line to which to refer the position of the second beam, and thereby judge of the refrangibility of the rays by which it was produced.

This second beam was a good deal the brighter of the two. Its colour was a beautiful sky-blue, which was nearly the same throughout, but just about its first border, that is, where it arose from the least refrangible of those rays which were capable of producing it, the colour was less pure. It had a perfectly continuous appearance. When viewed from above through a doubly refracting achromatic prism of quartz,

which allowed a direct comparison of the two images, it offered no traces of polarization. It was produced by light polarized in a vertical or horizontal plane as well as by common light, and in that case, as well as in the former, manifested no traces of polarization\*.

The short distance that the more refrangible rays were able to penetrate into the fluid might readily be perceived in this experiment, but the second method of observation was not adapted to bring out this part of the phenomenon.

16. On examining the fluid by the third method, the result was very striking, although of course only what might have been anticipated. The principal fixed lines of the violet, and of the chemical parts of the spectrum beyond, were seen with beautiful distinctness as dark planes interrupting an otherwise perfectly continuous mass of blue light. To see any particular fixed line with most distinctness, it was of course necessary to hold the eye in the corresponding plane, when the dark plane was foreshortened into a dark line. From the red end of the spectrum, as far as the line G, or thereabouts, the light passed freely through the fluid, or at least was only reflected here and there from motes held in mechanical suspension. About G the dispersion just commenced to be sensible, and there were traces of that line seen as a dark plane interrupting a mass of continuous but excessively faint light. For some distance further on the dispersed light remained so faint that it might have been passed over if not specially looked for. It was about half-way between G and H, or a little before, that it first became so strong as to arrest attention, and a little further on it became very conspicuous, the tint meanwhile changing to a pale sky-blue. The light was very copious about the two broad bands of the group H, and for some distance from H towards G. Some of the fixed lines less refrangible than H were very plain, and beyond H a good number were visible, which will presently be further described. The whole system of fixed lines thus visible as interruptions in the dispersed light had a resolvable appearance; but with a very narrow slit and a lens of long focus at the prisms the light would have been too faint for convenient observation.

The dispersed light about G, and for some distance further on, was so very faint that I might have overlooked it had it not arrested my attention when observing by the fourth method; indeed, I have sometimes specially looked for it in the third arrangement without having been able to see it. Practically speaking, the dispersion might be said to commence about half-way between G and H.

\* These two results, namely, that the blue beam which constitutes the greater part of the light dispersed by a solution of sulphate of quinine is unpolarized, or according to his expression possesses a *quaquaversus* polarization, and that that still remains the case when the incident light is polarized, have been already announced by Sir DAVID BREWSTER, who appears to have been led to attend to the polarization of the light from Sir JOHN HERSCHEL'S observation, that the blue light arising from epipolic dispersion in a solution of sulphate of quinine was unpolarized. It seemed important however to repeat the observation on the blue beam obtained in a state of isolation.

17. On refracting the whole system sideways through a prism of moderate angle held in front of the eye, the fixed lines became confused, and the finer ones disappeared. The edges of the broad bands H were tinged with prismatic colours, like the edges of two slips of black velvet placed on a sheet of pale blue paper, and viewed through a prism. This experiment exhibits the compound character of the dispersed light, notwithstanding the perfect homogeneity of the incident light.

18. The third method of observation is well adapted to bring into view the variation in the absorbing energy of the medium corresponding to a variation in the refrangibility of the incident rays. When the eye is placed vertically over the vessel containing the solution, so that the dark planes corresponding to the fixed lines of the spectrum are projected into dark lines, of which the length is not exaggerated by obliquity, the boundary of the dispersed light is projected into a curve, which serves to represent to the eye the relation between the absorbing power of the medium and the refrangibility of the incident light. This curve is not exactly that which Sir JOHN HERSCHEL has treated of in the theory of absorption, and considered as the type of the absorbing medium to which it is applied, but nevertheless it serves much the same purpose. It is true, that, independently of any change in the absorbing energy of the medium, an increasing faintness in the dispersed light would produce to a certain extent an approximation of the curve to its axis; but practically, in the case of sulphate of quinine, as well as in a great many others, the appearance is such as to leave no doubt as to the existence of a most intense absorbing energy on the part of the medium with respect to rays of very high refrangibilities\*.

In the case of a solution of sulphate of quinine of the strength of one part of the disulphate to 200 parts of acidulated water, it has been already stated that a portion of the rays which are capable of producing dispersed light passed across a thickness of 3 inches. On forming a pure spectrum, the fixed line H was traced about an inch into the fluid. On passing from H towards G, the distance that the incident rays penetrated into the fluid increased with great rapidity, while on passing in the contrary direction it diminished no less rapidly, so that from a point situated at no great distance beyond H to where the light ceased, the dispersion was confined to the immediate neighbourhood of the surface. When the solution was diluted so as to be only one-tenth of the former strength, a conspicuous fixed line, or rather band of sensible breadth, situated in the first group of fixed lines beyond H, was observed to penetrate about an inch into the fluid. On passing onwards from the band above-mentioned in the direction of the more refrangible rays, the distance that the incident rays penetrated into the fluid rapidly decreased, and thus the rapid increase in the absorbing energy of the fluid was brought into view in a part of the spectrum in

\* I should here remark, that, after the researches described in this paper had far advanced, I met accidentally with a passage in the *Comptes Rendus*, tom. xvii. p. 883, in which M. ED. BRUQUEREL mentions a solution of acid sulphate of quinine as a medium eminently remarkable for its absorbing power with respect to the rays more refrangible than H.

which, with the stronger solution, it could not be so conveniently made out, inasmuch as the posterior surface of the space from which the dispersed light came almost confounded itself with the anterior surface of the fluid.

The high degree of opacity with regard to rays of great refrangibility which the addition of so small a proportion of sulphate of quinine is sufficient to produce in water is certainly very remarkable; nevertheless it is only what I have constantly observed while following out these researches.

19. In observing by the fourth method, the part of the spectrum to which the incident light belonged was determined sometimes by the colour, sometimes by means of the fixed lines of the spectrum. It almost always happened that there were motes enough suspended in the fluid to cause a portion of the dispersed beam to consist merely of light which had undergone ordinary reflexion. When the whole dispersed beam was analysed by a prism, the beam which consisted of light reflected from motes was separated from the rest; it was in general easily recognised by its sparkling appearance, but at any rate was known by its consisting almost wholly of light polarized in the plane of incidence, whereas the truly dispersed light was unpolarized. It consisted of course of light of definite refrangibility, the same as that of the incident light, and thus served as a fiducial line to which to refer by estimation the refrangibilities of the component parts of the dispersed light. Of course this part of the observation was possible only when the incident rays belonged to the visible part of the spectrum.

On moving the lens horizontally through the colours of the spectrum, in a direction from the red to the violet, it was found that the dispersion was first perceptible in the blue. When the dispersed light was separated by a prism from the light reflected from motes, it was found to consist of an exceedingly small quantity of red; further on some yellow began to enter into its composition; further still, perhaps about the junction of the blue and indigo, the dispersed beam began to grow brighter, and was found on analysis to contain some green in addition to the former colours. In the indigo it got still brighter, and when viewed as a whole was somewhat greenish. Further still it became something of a pale slaty blue, and was found on analysis to contain some indigo, or at least highly refrangible blue. On proceeding further the dispersed light became first of a deeper blue and then, a little short of the fixed line H, whiter. At a considerable distance beyond H the dispersed light was if anything a shade more nearly white.

By this method of observation the dispersion can be detected earlier in the spectrum than by the third method, and moreover the change in the colour of the dispersed light is much more easily perceived; indeed the most striking part of this change takes place while the dispersed light is so very faint that it can hardly be seen in observing by the third method; moreover, even in the bright part of the dispersed beam, it is not at all easy by the latter method to make out the change of tint corresponding to a change in the refrangibility of the incident rays, because the tint

changes so gradually and so slightly that the eye glides from one part of the dispersed beam to another without noticing any change.

20. It has been already mentioned that the blue beam of dispersed light seen in a solution of sulphate of quinine was produced whether the incident light was polarized in or perpendicularly to the plane of reflexion, or more properly plane of dispersion, that is, the plane containing the incident ray and that dispersed ray which enters the eye. A question naturally presents itself, whether the intensity of the dispersed light is strictly the same in the two cases. By combining a lens of rather short focus and a doubly refracting prism with the four prisms, I satisfied myself that the difference of intensity, if there were any, was not great, but the experiment presented some practical difficulties. However, the result of the following experiment appeared to be as decisive as a negative result could well be.

The arrangement being the same as in the third method, but the lens in front of the prisms having a focal length of only 6·5 inches, the incident light was polarized in a vertical plane previously to passing through the slit, by transmission through a pile of plates. The two beams of light were seen as usual in the fluid, namely, the blue beam due to internal dispersion, and the fainter coloured beam due to motes. The former of these, which was quite separate from the latter, exhibited the principal fixed lines belonging to the highly refrangible part of the spectrum. A plate of selenite was then interposed immediately in front of the vessel, so as to modify the polarization of the light entering the fluid. This plate was obtained by an irregular natural cleavage, and was cemented with Canada balsam between two discs of glass. When examined by polarized light it exhibited a succession of beautiful and varied tints, according to the various thicknesses of the different parts. Now when the plate was moved about in front of the vessel, without altering its perpendicularity to the incident light, different portions of the beam due to motes were observed to disappear and reappear, or at least to become faint and then bright again, so that a person ignorant of the cause, and not looking at the disc, might have supposed that the observer had been holding in front of the vessel a piece of dirty glass, having the dirt laid on in patches; but in whatever manner the disc was moved in its own plane without rotation, or turned round an axis perpendicular to its plane, not the slightest perceptible change was produced in any part of the blue beam.

#### *Explanation of Terms.*

21. In all the experiments described in this paper in which a spectrum was formed for the sake of examining the separate action of portions of light of different refrangibilities, the length of the spectrum was horizontal, so that the fixed lines were vertical. Nevertheless it will be convenient, for the sake of shortness, to use the prepositions *above* and *below* to signify respectively *on the more refrangible side of* and *on the less refrangible side of*.

The principal fixed lines of the visible spectrum will be denoted by letters in ac-

cordance with FRAUNHOFER'S admirable map. These lines are now too well known to need description.

The only map of the fixed lines of the chemical spectrum which I had for a good while after these researches were commenced is PROFESSOR DRAPER'S, which will be found in the twenty-second volume of the Philosophical Magazine (1843). Of course this map cannot be compared for accuracy of detail with FRAUNHOFER'S map of the visible spectrum, nor does it profess to give more than some of the most conspicuous lines selected from among a great multitude. The suppression of so many lines, without any representation by shading of their general effect, renders it difficult to identify those which are laid down, at least if I may judge from my own observations; besides, PROFESSOR DRAPER'S spectrum was so much purer than the one with which I found it most convenient to work, that the two are not comparable with each other.

22. I have made a sketch of the fixed lines from H to the end, which accompanies this paper. The fixed lines of the visible spectrum are so well known that I thought it unnecessary to begin before H. A solution of sulphate of quinine is a very good medium for showing the lines, but a yellow glass, which will be mentioned presently, is quite as good, or rather better. The map represents the spectrum as seen with the lens of 12 inches focal length in front of the prisms. The breadth of the slit was not always quite the same: it may be estimated at about the  $\frac{1}{20}$ th of an inch. The map contains 32 fixed lines or bands more refrangible than H, which is the utmost that I have been able on different occasions to see with this lens, though with a lens of longer focus and a narrower slit the number of fixed lines which might be counted was, as might be expected, a good deal larger. As I have not yet identified these lines, except in certain cases, with those which had previously been represented by means of photographic impressions, I have thought it advisable not to attempt an identification, but to attach letters to the more conspicuous lines in my map without reference to former maps. As the capitals L, M, N, O, P have already been appropriated to designate certain fixed lines, I have made use of the small letters *l, m, n, o, p*, to prevent confusion.

In drawing the map, I have endeavoured to preserve the character of the lines with respect to blackness or faintness, sharpness or diffuseness. The distances were not laid down by measurement, except here and there, and they are not, I fear, quite so accurate as might be desired; still, I feel assured that no one viewing the actual object would feel any difficulty in identifying the lines with those in my map, provided the circumstances under which his spectrum was formed at all approached to those under which mine was seen when the arrangement as to focal length of the lens, &c. was that most convenient for general purposes.

The more conspicuous lines in the part of the spectrum represented in the map may conveniently be arranged in five groups, which I will call the groups H, *l, m, n, p*. The group H consists chiefly of the well known pair of bands of which the first contains FRAUNHOFER'S line H; the second band I have marked *k*, in accordance with

Professor DRAPER's map. The most conspicuous object in the next group consists of a broad dark band, *l*. This band is between once and twice as broad as H, and is darker in the less refrangible half than in the other. With a lens of 3 feet focal length and a narrow slit it was resolved into lines, which is probably the reason why it is altogether omitted in Professor DRAPER's map, while the first three lines of the group (if I do not mistake as to the identification) are represented, forming his group L. Under the circumstances to which the accompanying map corresponds, the band *l* appears as a very striking object, perhaps, with the exception of the bands H, *k*, the most conspicuous in the whole spectrum. With a still lower power it appears as a very black and conspicuous line. A double line beyond *l* completes the group *l*, after which comes another remarkable group *m*, consisting of five lines or bands. Of these the first is rather shady, though sharply cut off on its more refrangible side, but the others, and especially I think the second and third, are particularly dark and well-defined. I have marked the middle line *m*, not because it is more conspicuous than its neighbours, but on account of its central situation. After a very faint group, consisting apparently of four lines, comes another very conspicuous group *n*, consisting of two pairs of dark bands followed by another pair of bands which are broad and very dark. The first of these is a good deal broader than the second, but is not so broad as the band H; the second is followed by a fine line. This is as far as it is easy to see; but when the sunshine is clear, and the arrangements are made with a little care, a group of six lines is seen much further on. Of these, the first two are only moderately dark, and the first is rather diffuse; they stand off a little from the others, and are a little closer together than the other four. Of the latter, the first, marked *o*, is very strong, considering the faintness of the light which it interrupts; the second and third are faint, and difficult to see; the fourth, marked *p*, is black like the first, and a good deal broader. The line *p* was situated, by measurement, as far beyond H as H beyond *b*. Once or twice in the height of summer, and under the most favourable circumstances, I have observed two broad dusky bands still further on. The first of these had the appearance of being resolvable into two. The excessively faint light seen beyond the second seemed to end rather abruptly at the distance represented by the border of the accompanying plate, as if there were there the edge of another dark band beyond which nothing could be seen. In order to see the dusky bands last mentioned, and even to see the group *p* to most advantage, it was necessary to allow the central part of the beam incident on the prisms to pass through them close to their edges, so that evidently a great deal of light was lost by passing by the prisms altogether. This circumstance, combined with others which I have observed, convinces me that the great obstacle to seeing the fixed lines in this part of the spectrum consists in the opacity of glass. Were glass as transparent with respect to the invisible rays of very high refrangibility as it is with respect to the rays belonging to the visible spectrum, I know not how much further I might have been able to see.

I have endeavoured to identify the fixed lines in my map with the fixed lines represented in M. SILBERMANN'S map of the chemical spectrum, with a copy of which my friend Professor THOMSON has kindly furnished me. I am still uncertain respecting the identification. M. SILBERMANN'S map is so very much more detailed than my own, and must have been made with so much purer a spectrum, that the two systems of lines are not directly comparable.

23. From the difficulty of identification some persons might be disposed to imagine that the chemical rays, and those which produced the blue light in a solution of quinine, were of a different nature, and had each a system of fixed lines of its own. For my own part, I was too well acquainted with the Protean character of fixed lines to regard the difficulty of identification as any valid argument in support of such a view. And that this difficulty arose from nothing more than the different degrees of purity of the spectra is now put past dispute, for my friend Mr. KINGSLEY of Sidney Sussex College, to whom I recently showed some of the experiments mentioned in this paper, has kindly taken for me some photographs of spectra having nearly the same degree of extent and purity as those with which I worked, and these show the fixed lines just as they appeared in a solution of sulphate of quinine and in other media\*.

24. The position of a point in the spectrum which does not coincide with one of the principal fixed lines, will be denoted by referring it to two of those lines, in a manner which will be most easily explained by an example. Thus  $\frac{1}{2}GH$ ,  $G\frac{1}{2}H$ ,  $GH\frac{1}{2}$  will be used to denote respectively a point situated at a distance below G equal to half the interval from G to H, a point midway between G and H, and a point situated at the same distance above H. In using this notation, the letters denoting fixed lines will be written in the order of refrangibility, and the fraction expressing the part of the interval between these lines, which must be conceived to be measured off in order to reach the point whose position it is required to express, will be written before, between, or after the letters, according as the measurement is to be taken from the first line in the negative direction, from the first line in the positive direction, or from the second line in the positive direction, the positive direction being that of increasing refrangibility.

25. From the experiments already described, it appears that the beam of dispersed light which was observed in the experiments of Sir DAVID BREWSTER consisted of two very distinct portions, one arising merely from light reflected from motes, and the other having a far more remarkable origin. It will be convenient to have names for these two kinds of dispersion, and I shall accordingly call them respectively *false internal dispersion* and *true internal dispersion*, or simply *false dispersion* and *true dispersion* when the context sufficiently shows that internal dispersion is spoken of. When dispersion is mentioned without qualification, it is to be understood of true dispersion. Now that it appears that the mere reflexion of light from solid particles held in mechanical suspension has nothing to do with that remarkable kind of internal

\* See note A at the end.



dispersion which is characterized by the “*quaquaversus* polarization,” the phenomenon of false dispersion ceases to be of much interest in an optical point of view; while on the other hand the phenomenon of true dispersion, which had always been very remarkable, is now calculated to excite a great additional interest. It will be convenient to mention here the principal characters by which true and false dispersion may be distinguished, although it will be anticipating in some measure the results of observations yet to be described.

26. In true dispersion the dispersed light has a perfectly continuous appearance. In false dispersion, on the other hand, it has generally more or less of a sparkling appearance, and on close inspection is either wholly resolved into bright specks, or so far resolved as to leave on the mind the impression that if the resolution be not complete it is only for want of a sufficient magnifying power.

In true dispersion the dispersed light is perfectly unpolarized. In false dispersion, on the contrary, at a proper inclination the light is almost perfectly polarized in the plane of reflexion.

In false dispersion, which is merely a phenomenon of reflexion, the dispersed light has of course the same refrangibility as the incident light. In true dispersion heterogeneous dispersed light arises from a homogeneous beam incident on the body by which the dispersion is produced.

27. In those bodies, whether solid or liquid, which possess in a high degree the power of internal dispersion, the colour thence arising may be seen by exposing the body to ordinary daylight, looking at it in such a direction that the regularly reflected light does not enter the eye, and excluding transmitted light by placing a piece of black cloth or velvet behind, or by some similar contrivance. It has been usual to speak of the colour so exhibited as displayed by reflexion. As however the cause now appears to be so very different from ordinary reflexion, it seems objectionable to continue to use that term without qualification, and I shall accordingly speak of the phenomenon as *dispersive reflexion*\*. Thus dispersive reflexion is nothing more than internal dispersion considered as viewed in a particular way.

28. The tint exhibited by dispersive reflexion is modified in a peculiar manner by the absorbing power of the medium. In the first place, the light which enters the eye in a given direction is made up of portions which have been dispersed by particles situated at different distances from the surface at which the light emerges. The word *particle* is here used as synonymous, not with *molecule*, but with *differential element*. If we consider any particular particle, the light which it sends into the eye has had to traverse the medium, first in reaching the particle, and then in proceeding towards the eye. On account of the change of refrangibility which takes place in dispersion, the effect of the absorption of the medium is different for the two portions of the whole path within the medium, so that this effect may be regarded as a function of

\* I confess I do not like this term. I am almost inclined to coin a word, and call the appearance *fluorescence*, from fluor-spar, as the analogous term *opalescence* is derived from the name of a mineral.

two independent variables, namely, the lengths of the path before and after dispersion; whereas, had the light been merely reflected from coloured particles held in suspension, the effect of absorption would have been a function of only one independent variable, namely, the length of the entire path within the medium.

29. When false dispersion abounds in a fluid, it may be detected at once by the eye, without having recourse to any of the characters already mentioned whereby it may be distinguished from true dispersion. When a fluid is free from false dispersion it appears perfectly clear, when viewed by transmitted light, although it may be highly coloured, and may even possess to such an extent the property of exhibiting true internal dispersion as to display, when properly viewed, a copious dispersive reflexion. On the contrary, when false dispersion abounds, the fluid, if not plainly muddy, has at least a sort of opalescent appearance when viewed by transmitted light, which, after a little experience, the eye in most cases readily recognises. In viewing the phenomenon of dispersive reflexion, as exhibited in a fluid, it might be supposed that the fluid was water, or else some clear though coloured liquid, holding in suspension a water colour in a state of extreme subdivision. But on holding the fluid before the eye, so as to view it by transmitted light, or rather view a bright well-defined object through it, the illusion is instantly dispelled. The reason of this difference appears to admit of easy explanation, and will be noticed further on.

30. Light will be spoken of in this paper as *active* when it is considered in its capacity of producing other light by internal dispersion. A medium will be said to be *sensitive* when it is capable of exhibiting dispersed light under the influence of light (visible or invisible) incident upon it. In the contrary case it will be called *insensible*.

I shall now return to the description of the appearances exhibited by some of the media most remarkable for their sensibility.

*Decoction of the Bark of the Horse-Chestnut (Æsculus hippocastanum).*

31. In Sir JOHN HERSCHEL'S second paper it is stated that esculine possesses in perfection the peculiar properties which had been found to belong to quinine. Having tried without success to procure the former alkaloid, I was content to let this substance pass, till I found how admirably a mere decoction or infusion of the bark of the tree answered for all purposes of observation.

This medium is even more sensitive than a solution of sulphate of quinine, and disperses like it a blue light. The description of the mode of dispersion in the latter medium will apply in almost all points to the former: the principal difference consists in the circumstance that in the horse-chestnut solution the dispersion begins earlier in the spectrum than in the solution of quinine. In a solution of sulphate of quinine of convenient strength, we have seen that the dispersion came on at about  $G\frac{1}{2}H$ , the excessively faint dispersion which was exhibited earlier being left out of consideration, whereas in a decoction of the bark of the horse-chestnut, diluted so as to be

of a convenient strength, it came on a little before G. This explains the reason of an observation of Sir DAVID BREWSTER's, who has remarked that "a beam of light that has passed through the esculine solution disperses blue light, but not copiously, when transmitted through the quinine solution ; but the beam that has passed through quinine is copiously dispersed when transmitted through esculine\*."

*Green Fluor-Spar from Alston Moor.*

32. It is well known that some specimens of fluor-spar exhibit a sort of double colour. In particular, a variety found at Alston Moor, which is green when seen by transmitted light, appears when viewed in a certain manner of a beautiful deep blue. This blue colour seems to have been considered by Sir JOHN HERSCHEL as merely superficial. It has been shown however by Sir DAVID BREWSTER to arise from light dispersed in the interior of the crystal, and to have no particular relation to the surface.

The crystal with which the following observations were made was of a fine but not intense green when viewed by transmitted light. On viewing a pure spectrum through it, there was found to be a dark band of absorption in the red. This band was narrow, and by no means intense. The crystal exhibited a copious deep blue by dispersive reflexion.

33. On admitting into the crystal a cone of sunlight formed by a lens of short focus, and then analysing the dispersed beam, it was found to consist of a very little red followed by a dark interval, then green, faintly fringed below with less refrangible colours down perhaps to the orange, then blue, or bluish-green, followed by a great deal of indigo or violet. Independently of the gap in the red, the spectrum was not quite continuous, for a band of bluish-green, not very broad, was separated by dusky bands from the green below and the indigo above. The separate red band and the two dusky bands were all so faint as to be difficult to see.

The dispersed beam was readily proved to be truly dispersed, for it was unpolarized, and a pale brown glass cut it off when placed in the first position, although it transmitted it in a great measure when placed in the second.

34. When the crystal was examined by the third method, the general result closely resembled that produced by sulphate of quinine. The dispersion commenced about half-way between G and H, and continued from thence onwards far beyond H. It was strongest about H. The fixed lines were seen with beautiful distinctness as dark planes in the crystal. The groups H, *l*, *m* were quite evident, and *n* might be seen without difficulty. I have even seen some of the fixed lines of the group *p*. The tint of the dispersed light appeared as nearly as possible uniform throughout. The distance to which this light could be traced from the surface, did not at all diminish so rapidly in this crystal, with an increase in the refrangibility of the incident light,

\* Philosophical Magazine, vol. xxxii. (June 1848), p. 406.

as it had done in the case of a solution of sulphate of quinine. Indeed, it was difficult to say how far the decrease in the depth to which the incident rays could be traced, by means of the dispersed light which they produced, was due merely to the increasing faintness of the light, and how far it indicated a real increase in the absorbing energy of the crystal; whereas in the case of sulphate of quinine the appearance presented unequivocally indicated a very rapid increase of absorbing power.

35. On examining the crystal by the second method, the general appearance was the same as in the case of sulphate of quinine, but the beam of falsely dispersed light was absent. In addition to the copious beam of deep blue light dispersed by the most refrangible rays, there was however a faint beam of red or reddish light dispersed by rays of low refrangibility. This beam was too faint to be seen by the third method of examination. It will be remembered that the prismatic analysis of the transmitted light gave a band of absorption in the red. Another crystal of a pale colour, which did not give a similar band of absorption in the red, exhibited nothing but the blue beam of dispersed light when examined by the second method.

36. On examining the crystal by the fourth method, the extreme red proved inactive. The activity commenced about the most refrangible limit of the red transmitted by a deep blue glass, when the dispersed light was red, but extremely faint. On moving the lens onwards through the spectrum, the dispersed light rapidly became brighter, and then died away. When at its brightest, although even then it was almost too faint for prismatic examination, it appeared to consist of not quite homogeneous light a little lower in refrangibility than the active light. For a considerable distance further on there was no sensible dispersion produced. The dispersed light became again perceptible when the active light belonged to the greenish yellow, or not till the blue, according to the intensity of the incident light. As the lens moved on the dispersed light remained faint for a considerable time. It was first reddish and then brownish, with a refrangibility answering to its colour. When the active light was at  $G\frac{1}{2}$  H, or thereabouts, the dispersed light rapidly grew much brighter, and became of a fine blue. On analysis it was found to consist of rays the refrangibility of which ranged within wide limits. The red rays were, however, almost wholly wanting, while the rays belonging to the more refrangible part of the spectrum resulting from the analysis of the dispersed beam were particularly copious. The most refrangible limit of the dispersed light did not quite reach in refrangibility the active light. The dispersed light was most copious when the active light belonged to the neighbourhood of H. As the lens moved on the dispersed light grew less bright, and gradually died away.

*Solution of Guaiacum in Alcohol.*

37. This is one of the media mentioned by Sir DAVID BREWSTER, who remarks that it "disperses, by the stratum chiefly near its surface, a beautiful violet light."

When this fluid is examined by the third or fourth method, it is found to exhibit a copious internal dispersion, which begins to be conspicuous much lower down in the spectrum than in the cases already described. In observing by the third method, the true dispersion appeared to commence about the end of the green, the dispersed light being reddish-brown. By the fourth method the dispersion could be traced as low down as  $D\frac{1}{3}b$ , the dispersed light being reddish. As the lens moved onwards, in a direction from the red to the violet, the more refrangible colours entered in succession into the dispersed beam, and it became successively brownish, yellowish, greenish, and bluish. In whatever part of the spectrum the lens might be, it was found that the most refrangible part of the dispersed beam was of lower refrangibility than the active light. This could be easily determined by means of the beam of falsely dispersed light, which was always visible so long as the active light belonged to the visible part of the spectrum.

38. With the third arrangement the fixed lines were seen as before by means of the dispersed light, but in this fluid they could be seen much lower down in the spectrum than in the solution of sulphate of quinine. The group H was seen on a greenish ground. About the group *l* the ground was still greenish, but the dispersed light was not very copious. The beautiful violet light mentioned by Sir DAVID BREWSTER is produced only by rays of extremely high refrangibility, and is found to extend from the beginning of the group *m* to the end of the group *n*, and even further. This part of the dispersion is best seen with a rather dilute solution.

39. In a solution of guaiacum, just as in the solution of sulphate of quinine, the absorbing power of the medium increases very rapidly with the refrangibility of the light. This is shown by the rapid decrease in the distance from the surface to which the dispersed light can be traced. The reason why the violet dispersed light is confined to a very thin stratum adjacent to the surface by which the light enters, is simply that the medium is so nearly opaque with regard to the invisible rays beyond the extreme violet that all such rays are absorbed by the time the light has passed through a very thin stratum of the fluid.

40. If the solution be strong the colour is of considerable depth. In all such cases it is necessary to take the precaution, mentioned by Sir DAVID BREWSTER, of transmitting the incident beam as near as possible to the upper surface, so as just to graze it. The absorption of the medium would otherwise modify the tint of the dispersed beam.

41. The solutions of quinine and guaiacum present a striking contrast with respect to the change of tint of the dispersed beam. In the former solution the change is but slight, if we except that part of the dispersion which is very faint; whereas in the latter, the prismatic colour which makes the nearest match to the composite tint of the dispersed beam runs through nearly the entire spectrum, as the refrangibility of the active light changes from that of the green rays to that of invisible rays situated far beyond the extreme violet.