

104. It has been already stated that the bands H were distinctly seen on common white paper, the substance usually employed as a screen in experiments on the spectrum, but that this was due to a change of refrangibility produced in the extreme violet rays. These same bands have been seen on paper in the experiments of others, though of course their visibility was not attributed to its true cause. By the method of observation described in Art. 100, or still better, by a method not yet explained, it may be seen that the change of refrangibility produced by white paper is by no means confined to the extreme violet rays, and those still more refrangible, but extends from about the middle of the spectrum to a good distance beyond the extreme violet. The distance to which the illumination can be traced by means of light merely scattered in the ordinary way, may be seen by examining the primitive spectrum. In the primitive spectrum formed on white paper and other white substances, I have not been able to trace the illumination beyond the edge of the broad band H, which accords very well with the illuminating power of the extreme violet when received directly into the eye.

Illuminating Power of the Rays of high Refrangibility.

105. The prolongation of the spectrum seen on turmeric paper was brought forward by Sir JOHN HERSCHEL as a proof of the visibility of the ultra-violet rays, or rather as a confirmation of other experiments which had led him to the same conclusion. Of course, the experiment with turmeric must now be regarded as having no bearing on the question; but from the way in which Sir JOHN speaks of it, it would appear that he thought the other experiments not so conclusive as to be independent of the confirmation which they received from this. The experiment with the distorted spectrum, indeed, must now be put out of account, because in this experiment, as I have been informed by Sir JOHN HERSCHEL, the light was only thrown on a screen. Accordingly, the question of the visibility of these rays may be regarded as open to further investigation.

While engaged in some of the experiments described in Art. 89, I had occasion to form a pure spectrum in air in a well-darkened room, the slit itself by which the sun's rays entered being covered by a deep blue glass, so that no great quantity of light entered even at this quarter. Now, if ever, it would appear that the ultra-violet rays ought to be seen by receiving them directly into the eye; for the blue glass was so transparent with regard to these rays that the fixed lines far beyond H were seen with facility, even on substances, such as white paper, which stand low in the scale of sensibility; and the length of the spectrum from B to H was about an inch and a quarter, so that when the extreme violet rays entered the pupil, supposed to be held near the pure spectrum, not only the extreme red rays transmitted by the blue glass, but even the brighter part of the transmitted blue and violet rays fell altogether outside it. However, on holding the eye a few inches in front of the pure spectrum, so as to see the fixed lines distinctly, the bands H were indeed seen with

great facility; but I was not able to make out fixed lines beyond the end of the group *I*, that is, about the end of FRAUNHOFER'S map. However, the eyes of different individuals may differ much in their power of being affected by the highly refrangible rays. It must be confessed, that on looking in the direction of the prisms, a good deal of blue light was seen, consisting of light which had been scattered at the surfaces of the prisms and lens. This light, though far from dazzling, was sufficient to prevent the eye from seeing excessively faint objects, even though they might be well defined. For want of a heliostat, I did not attempt an experiment I was meditating for securing a more perfect isolation of the ultra-violet rays*.

However, it seems to me to be a point of small importance, so far as regards its bearing on other physical questions, whether the illuminating power of these rays is absolutely null or only excessively feeble. It is quite certain, that if not absolutely null, their illuminating power is at least utterly disproportionate to the effect which they produce in the phenomena to which the present paper relates, and indeed that is true even of the violet rays. By *illuminating power*, I mean of course, power of producing the sensation of light when received directly into the eye; for by giving rise to light of lower refrangibility, they are able to illuminate strongly an object on which they fall.

Mode of Observation specially applicable to Opaque Bodies.

106. In some of the experiments already described, the change of refrangibility was exhibited, which was produced by washed papers and solid bodies. There exists, however, a mode of observation far preferable to those which have already been explained as applicable to such cases, and which may even in some instances be employed with advantage in the examination of transparent bodies. In the experiment described in Art. 100, the primitive spectrum is pure, but the derived spectrum impure, on account of the finite length of the slit. Were the slit reduced to a point, it is true that the derived spectrum would become pure like the primitive, but then the quantity of light would be so small that the primary spectrum would hardly bear prismatic analysis. It is well, once for all, to examine a few sensitive opaque substances in a very pure spectrum, because then the exhibition of fixed lines running across the colours in the derived spectrum removes even the shadow of a doubt as to the reality of the change of refrangibility of the incident light. Besides this, the only theoretical advantage in having the primitive spectrum very pure is, that it might be expected to enable us to detect any very rapid fluctuations in the colour or intensity of the dispersed light. Of course, I am now speaking only with reference to experiments in which the observer is employing the spectrum to examine some substance, not employing the substance to examine the spectrum. But practically, I have not found any advantage on this account; for abrupt, or almost abrupt changes in the colour or intensity of the dispersed light hardly ever, if ever, occur,

* See note B.

except when the active and the dispersed light have very nearly the same refrangibility. But such changes could not be observed even with a pure primitive spectrum, because in the place where they occur the primitive and derived spectra overlap; and independently of this, the brilliancy of the primitive spectrum would prevent all exact observation of the derived. It is true, that in the case of chlorophyll, or some of its modifications, changes of intensity having apparently somewhat the same nature were observed when the active and the dispersed light were widely separated in refrangibility. But the sensibility of this substance is difficult, if not impossible, to observe in the case of a washed paper or a green leaf, except by one of the methods not yet described, so that it is not to be expected that such fluctuations could be made out. Besides, it is to be remembered that the fluctuations observed in the case of solutions of chlorophyll, were fluctuations in the rate at which dispersed light was produced, not fluctuations in the sum total of the dispersed light produced by the time the active light was exhausted. Fluctuations of the former kind by no means imply fluctuations of the latter; and indeed, the circumstance, that maxima of activity in the solution correspond to minima of transparency, would seem to show that the total quantity of light dispersed, considered as a function of the refrangibility of the active light, is not subject to these fluctuations, or at least not to anything like the same extent. Now the total quantity of red light dispersed by a green leaf, or by a paper washed with a solution of chlorophyll, must depend upon the sensibility of this substance and upon its transparency conjointly, and therefore it is likely enough that such maxima and minima would not be observed, even were the dispersed light much stronger than it is.

107. Suppose now the slit by which the light enters to be placed in a horizontal instead of a vertical position, so as to lie in the plane of refraction. Corresponding to light of any given refrangibility, the image of the slit formed after refraction through the prisms and lens will now be a narrow parallelogram, which may be regarded as a horizontal line. The series of these lines, succeeding one another in a horizontal direction, and consequently overlapping, forms the spectrum incident on the body examined. This spectrum is now no longer pure, but only approximately so, a point, however, which, as we have seen, is not of much consequence. But by this trifling sacrifice two very great advantages are gained. The first is increase of illumination. When the slit is vertical, the spectrum received on the body occupies a rectangle having for breadth the length of the image of the slit; but when it is horizontal, the same, or very nearly the same quantity of light is concentrated into a rectangle having the same length as before (the length of the image of the slit being disregarded compared with that of the spectrum), but having for its breadth only the length of the image of a line drawn across the slit. Hence the intensity of the incident light is increased in the ratio of the breadth to the length of the slit. The second advantage is purity in the derived spectrum, a point of much consequence, because sometimes the composition of this spectrum presents very remarkable

peculiarities. If the slit be not too long, the spectrum formed in air is still sufficiently pure to allow us to make out in a general way what are the refrangibilities of those portions of the incident light which are most efficient in producing dispersed light; and this is nearly all that can be done even when the spectrum is very pure.

108. The method of observation which has just been described is that which latterly I have almost exclusively employed in examining opaque substances. As it will be convenient to have a name for it, I shall speak of examining a substance in a *linear spectrum*. In examining substances which are only slightly sensitive, it is often highly advantageous to cover the slit with a blue glass.

109. Fig. 5 is intended to represent the usual appearance of the primary linear spectrum, and of the primitive and derived spectra. XY is the primary spectrum, as seen by the naked eye, RV, ST are the primitive and derived spectra into which it is separated by the prism held to the eye. The direction of the shading in RV is intended to represent the composition of this spectrum, which may be regarded as consisting of an infinite number of images of the slit arranged obliquely in the order of their refrangibility. The direction of the shading in ST is that of the lines of the same colour and same refrangibility. Of course the figure does not represent the amount of vertical displacement of the primary spectrum when viewed through the prism held to the eye.

110. There is another mode of observation which I have occasionally found convenient when the object was to determine whether a substance exhibited so much as a low degree of sensibility. In this method the sun's light was reflected horizontally through a large lens, and then transmitted through a small lens placed in the condensed beam. The small lens was covered by a small vessel with parallel sides of glass, containing a blue ammoniacal solution of copper, or else by a deep blue glass combined with a weak solution of nitrate or sulphate of copper. The object of the latter solution was to absorb the extreme red which is transmitted by a blue glass. The light coming through the lens was then analysed by a prism, being received directly into the eye, or else allowed to fall on a white object which had been previously ascertained not to change the refrangibility of the light incident upon it. I found clean white earthenware to serve very well for such an object, but each observer ought to test for himself the substance he employs. When a test object, such as white earthenware, is used, it is placed at the focus of the lens, and the spot of blue light formed upon it is analysed by a prism to see if the absorption is sufficient. When the visible rays are considered to have been sufficiently absorbed, the object to be observed is placed at the focus of the lens, and the spot of light formed upon it is viewed through a prism. The spectrum then seen is compared with that given by the test object. This method of observation is rather easier than that of a linear spectrum, and is at least as delicate if the object be merely to determine whether a substance is sensitive or not, but on the whole it is not near so useful. It may sometimes be used with advantage in the case of translucent bodies.

111. An extremely pale solution of nitrate or sulphate of copper is sufficient to absorb the extreme red transmitted by a deep blue glass. This is not the case with the ammoniacal solution, which does not absorb the extreme red till it is of a pretty deep blue. Its absorbing power is greatest, not at the extreme red, but about the orange, as may be seen by using candle-light, which is richer in red rays than daylight.

112. Another method of observation which is sometimes useful, consists in employing a large lens and absorbing medium, as described in Art. 110, but leaving out the additional small lens. The substance to be examined is placed in the condensed beam, and viewed through an absorbing medium which is approximately complementary to the former. This method is chiefly useful in examining a confused mass of various substances. The most minute fragments of sensitive substances show themselves in this manner.

Results obtained with a Linear Spectrum.

113. When this method is applied to the examination of common objects, it is found that the property of producing a change of refrangibility in the incident light is extremely common. Thus, wood of various kinds, cork, horn, bone, ivory, white shells, leather, quills, white feathers, white bristles, the skin of the hand, the nails, are all more or less sensitive. To make a list of sensitive substances would be endless work; for it is very rare to meet with a white or light-coloured organic substance which is not more or less sensitive. I am not now speaking of organic substances obtained in a state of chemical isolation, of which some are sensitive and others insensible. That substances of a dark colour should frequently prove insensible is only what might have been expected, because the dispersed light is not reflected from the surface, but emanates from all points of a stratum of finite thickness; and in order that dispersed light should be forthcoming, it is necessary that the active light entering, and the dispersed light of a different refrangibility returning, should both escape absorption on the part of the colouring matter. Such substances usually consist of a mixture of various chemical ingredients, of which one or more may very likely be sensitive, in which case the substance may be compared to a solution of sulphate of quinine mixed with ink. Frequently however the colouring matter is itself sensitive.

114. Among sensitive substances I have mentioned the skin of the hand, which stands rather low in the scale. I have found the back of the hand a convenient test object. When the sunlight is not strong enough to show with ease the derived spectrum in the case of the hand, there is little use in attempting to observe.

115. It is needless to say that papers washed with tincture of turmeric, or with a solution of sulphate of quinine, display their sensibility in a remarkable manner when examined in a linear spectrum. The sensibility of turmeric paper is rather impaired by exposing the paper to the light, but on the other hand is materially increased by washing it with a solution of tartaric acid.

116. Paper washed with an ethereal solution from dried archil exhibited very well the sensibility of that substance. The derived spectrum consisted chiefly of two distinct portions, one containing orange and a little red, the other consisting chiefly of green, just as in the beam of dispersed light, produced by white light taken as a whole, which the solution itself exhibited. Indeed, I have found that the prismatic composition of dispersed light could be determined even more conveniently by means of a linear spectrum than by means of the beam dispersed by a solution.

117. The inside of the capsules of the *Datura stramonium* is nearly white, and apparently uniform. But when the capsules are examined in a linear spectrum, certain patches shine out like bright clouds in the invisible rays. The whole of the inside is sensitive, as such substances almost always are, but these patches, which are probably spots against which the seeds have pressed, are remarkably so. The capsules were examined after they had begun to burst.

118. By means of a linear spectrum the sensibility of chlorophyll may be detected in a green leaf. It is exhibited by the appearance in the derived spectrum of a narrow pure red band of remarkably low refrangibility. The refrangibility is so low that I have always found this band separated from the derived spectrum due to other sensitive substances with which chlorophyll or one of its modifications might have been mixed.

119. The petals of flowers, so far as I have examined, are as a class rather remarkable for their insensibility, some appearing quite insensible, and others only slightly sensitive. The bright yellow chaffy involucre of a species of everlasting, proved, however, highly sensitive, and its sensibility was also displayed in an alcoholic solution. This medium was sensitive enough to exhibit a pretty copious dispersive reflexion of a pale greenish yellow light. Its sensibility was more confined than usual to the rays of very high refrangibility.

120. Among petals, the most remarkable which I have observed are those of the purple groundsel (*Senecio elegans*). These petals disperse a red light, more copious than is usual among petals. If a petal be placed behind a slit, and the transmitted light be analysed, it is found to exhibit three remarkable bands of absorption, much resembling those of blue glass, but closer together, and beginning later in the spectrum, the first appearing about the place of the orange. These bands are still better seen in a solution of the colouring matter in weak alcohol. On examining this medium by the third method, with a lens of shorter focus than usual, and looking down from above, the places of the absorption bands were indicated by tooth-shaped interruptions in the beam of light reflected from motes. The points of these teeth were occupied by red dispersed light, which did not appear in the intervening beams of light reflected from motes, from whence it appears that there is the same sort of connexion between the absorption and dispersion of this medium as was noticed in Art. 59, in the case of solutions of chlorophyll and its modifications.

121. A collection of sea-weeds appeared all more or less sensitive, most of them highly so. All, or almost all, except the white ones, exhibited in the derived spectrum the peculiar red band indicative of chlorophyll and its modifications. The transmitted light also exhibited more or less the absorption bands due to this substance, which was likewise, in the specimens tried, extracted by alcohol. But the most remarkable example of sensibility found in sea-weeds occurs in the case of the red colouring matter contained in orangy red, red, pink, and purple sea-weeds. To judge by its optical properties, this colouring matter appears to be the same in all cases, but to be mixed in different proportions with chlorophyll, or some modification of it, and probably other colouring matters, thus giving rise to the various tints seen in such sea-weeds. The derived spectrum exhibited by sea-weeds of this kind consists mainly of a band of unusual brightness, containing some red, followed by orange and yellow. This band fades away gradually at its less refrangible limit, where it is separated by a dark interval from the narrow well-defined red band of still lower refrangibility due to chlorophyll. At its more refrangible limit, however, it breaks off with unusual abruptness.

122. When the light transmitted through such a sea-weed is subjected to prismatic analysis, in addition to one at least of the absorption bands due to chlorophyll, there is seen a band obliterating the yellow, another dividing the green from the blue, and a third, far less conspicuous, dividing the green into two. The whole of the green is absorbed more rapidly than the blue beyond, and not merely than the red, which last is the final tint.

123. The red colouring matter is easily extracted by cold water from certain kinds of red sea-weed, if fresh gathered; but when once the plant has been dried, the colouring matter cannot be extracted in any way that I know of. It is apparently insoluble in alcohol and ether, and is decomposed by boiling. Cold water extracts only a trace of it after a long time.

124. A piece of recently gathered red sea-weed, on being mashed with cold water, readily gave out its red colouring matter. When the residue was treated with alcohol, the fluid was almost immediately coloured green by chlorophyll, whereas this substance is only very slowly and sparingly extracted by alcohol from dried sea-weeds. A dried sea-weed may apparently be assimilated to an intimate mixture of gum and resin, which it would be very difficult to dissolve, whether it were attacked by water or alcohol.

125. The solution of the red colouring matter was highly sensitive, exhibiting a copious dispersive reflexion of a yellowish orange light. The transmitted light was pink or red, according to the thickness through which the light passed. When this light was analysed, the same three absorption bands which have been already mentioned were perceived. The analysis of the light transmitted by the fronds of various red sea-weeds had rendered it extremely probable that the faint division in the

green did belong to the red colouring matter; but till I had obtained this matter in solution I did not feel certain that it might not have been due to chlorophyll, the spectrum of which exhibits a division in the green.

126. When this fluid was examined in Sir DAVID BREWSTER'S manner, and the dispersed beam was analysed, the spectrum was found to consist of a broad band like that which has been already described as seen in the derived spectrum given by a frond of red sea-weed. When the solution, which happened to be very weak, was examined by the third method, the dispersion was found to be produced chiefly by a portion of the incident spectrum, having a breadth about equal to that of the interval between the two principal bands of absorption. To each of these bands corresponded a maximum of activity. The tint of the dispersed light was nearly uniform; but by the fourth method of observation some faint dispersed red could be made out, which appeared before the main part of the dispersion had come on. This medium affords a very good example of an intimate connexion between absorption and internal dispersion.

127. The colouring matters of birds' feathers appeared to be insensible, white feathers being most sensitive, pale ones next, and dark ones not at all: however, I have not examined a large collection.

128. Of coloured fruits, such as currants, &c., the colouring matter appeared, in the very few cases which I have examined, to be quite insensible.

129. A set of water colours were by no means remarkable for sensibility, but rather the contrary. The inorganic colours appeared quite insensible, except white lead, the sensibility of which was perhaps due to size, and offered nothing striking, either as to its character or as to its amount. Some lakes and other organic colours proved moderately sensitive. But I found one water colour, called Indian yellow, which stands pretty high among sensitive substances. In its mode of dispersion it much resembles turmeric, but it does not come up to that substance in the amount of sensibility. It is said to be composed of urate of lime, but I do not know how far it may be regarded as chemically pure.

130. Many of the substances used in dyeing, and dyed articles in common use, furnish very remarkable examples of sensibility. Archil, litmus and turmeric have been already mentioned; and I have been recently informed by a friend that the *Mercurialis perennis*, in which a striking instance of sensibility was observed, was formerly employed in dyeing. A piece of scarlet cloth, examined in a linear spectrum, gave a copious derived spectrum which was very narrow, consisting chiefly of the more refrangible red. With a vertical slit the bands H and fixed lines beyond were seen on a red ground. Paper washed with a solution of cochineal and afterwards with a solution of alum, when examined in a linear spectrum, displayed a pretty high degree of sensibility, the derived spectrum consisting in this case of a red band. If tartaric acid be used instead of alum, the dispersion is a good deal more copious.

Common red tape is another example in which the derived spectrum is very copious,

consisting mainly of a red band. Some red wool, dyed I suppose with madder, proved extremely sensitive. The derived spectrum in this case was pretty broad, but red was the predominant colour. Green wool, dyed I do not know with what, was also very sensitive, giving a pretty broad derived spectrum, in which green was the predominant colour. These examples may suffice, but the reader must not suppose that they form the only instances in which dispersion was observed among dyed substances. On the contrary, it is extremely common in this class.

131. Brazil wood, safflower, red sandal wood, fustic and madder, all gave rise to solutions having a pretty high degree of sensibility. The solutions here referred to were such as were obtained directly by water, &c., in which the colours which these substances are capable of producing were not brought out. The beautiful red colouring matters of logwood and camwood appear to be insensible; for a fresh-made solution of logwood in water exhibited no perceptible sensibility, and the slight sensibility exhibited by a similar solution of camwood seemed to have no relation to the red colouring matter.

132. Paper washed with a solution of madder in alcohol was sensitive in a pretty high degree, but the sensibility was greatly increased by afterwards washing with a solution of alum. Accordingly I found that a decoction of madder in a solution of alum exhibited a very high degree of sensibility, displaying a copious dispersive reflexion of a yellow light. In this medium the dispersion commenced about the fixed line D, and continued from thence onwards far beyond the extreme violet, so that the group of fixed lines n was seen with great ease.

133. Safflower red, examined in the shape in which it is sold on what is called a *pink saucer*, proved highly sensitive, giving a bright and narrow derived spectrum, which consisted chiefly of the more refrangible red. This substance possesses some other remarkable optical properties, which however do not belong to the immediate subject of this paper.

134. Metals proved totally insensible. I have examined gold, platinum, silver, mercury, copper, iron, lead, zinc and tin. Brass is like simple metals in this respect; but if the surface be lackered the lacker displays its own sensibility.

135. The non-metallic elements, carbon, sulphur, iodine and bromine, are insensible.

136. Among common stones I have found dark flint, limestone, chalk and some others which were sensitive, though only in a low degree compared with organic substances. To guard against any impurity of the surface, the stones were broken across, and the fresh surface examined. In the cases mentioned, the sensibility observed is not to be attributed to the chief ingredient of the stone, for quartz, chalcidony, Iceland spar and Carrara marble were insensible.

Compounds of Uranium.

137. Towards the end of last autumn, when the lateness of the season afforded but few opportunities for observation, I learned from different sources that the kind of yellow glass which has been already mentioned as possessing in so high a degree the property of internal dispersion was coloured with oxide of uranium. This rendered it interesting to examine other compounds of uranium; and I accordingly procured some crystallized nitrate of the peroxide, which, with a few other compounds formed from it, and some of the natural minerals which contain uranium, were examined by methods which have been already explained.

138. The crystals of the nitrate were not sufficiently large and perfect to admit of observation by the methods applicable to fluids and clear solids, but they could be readily observed by means of a linear spectrum. They proved to be sensitive in a very high degree, dispersing a green light which had the same very remarkable composition that has been already described in the case of the yellow glass. On placing a crystal in the continuation of the same linear spectrum with the glass, and viewing the whole through a prism, the five bright bands of which the derived spectrum given by each of the two media usually consisted, appeared to correspond to one another as regards their position in the spectrum. With great concentration of light I have seen an additional band of greater refrangibility in the spectrum of the crystals.

139. Some crystals of nitrate of uranium were gently heated so as to expel a good part at least of the water of crystallization. The residue after some time became opaque and nearly white. In this state it was still more sensitive than the crystals. The dispersed light was not exactly of the same tint, but more nearly white; and the derived spectrum was found on being analysed to contain, in addition to the bright bands usually seen in the derived spectrum of the crystals, another blue band still more refrangible. The fused mass gradually attracted moisture from the air, its colour changed to that of the crystals, and the most refrangible of the bright bands disappeared from the derived spectrum. Although when the incident light was very much concentrated I have seen this band even in the crystals, it was faint compared with the preceding bands, whereas in the case of the whitish mass its intensity was not very different from that of the others. It appears therefore that the quality as well as the quantity of the dispersed light was altered by depriving the crystals of a part of their water.

140. A solution of nitrate of uranium in water is decidedly sensitive, though not sufficiently so to exhibit much dispersive reflexion. When the dispersed beam is analysed it is resolved into bright bands. When the solution is examined in a pure spectrum, the mode of dispersion is found to agree with that of canary glass. The dispersion commences abruptly at the same part of the spectrum as in the case of the glass, and after a rather narrow band in which light is copiously dispersed, there follows a remarkable minimum of sensibility, just as in the glass (see Art. 76.), where the dispersed light is almost imperceptible. After this the dispersion is resumed,

and offers nothing remarkable. The minimum of sensibility occurs at the very same place in the spectrum, whether the sensitive medium be a solution of nitrate of uranium or glass coloured yellow by uranium.

141. *Yellow Uranite*.—This mineral, when examined in a linear spectrum, proved to be sensitive in an extremely high degree. The derived spectrum consisted, as in the case of the glass, of bright bands arranged at regular intervals, but in this case six were seen, a band being visible in the faint red at the extremity of the spectrum which could not be made out in the case of the glass.

142. *Green Uranite, or Chalcolite*.—According to M. PELIGOT the formula of the yellow uranite of Autun is PhO^5 , CaO , $2(\text{U}^2\text{O}^2\text{O})$, 8HO , and the green uranite differs from the yellow only in having the lime replaced by oxide of copper*. Yet a specimen of green uranite on being examined in a linear spectrum proved totally insensible. The primitive spectrum showed however a very remarkable system of dark bands depending on the absorption of light by the mineral. In examining these bands, the previous prismatic decomposition of the light, so far from being necessary, is decidedly inconvenient. It is better to dispense with the prisms altogether, using only the lens, and placing the mineral so that the image of the slit is formed upon it. The bright line thus formed is viewed from a convenient distance through a prism, the eye being held out of the direction of regular reflexion. The position of any bands which may appear in the spectrum can then be determined by means of the fixed lines, which are seen at the same time; or, if it be desired to see the latter more distinctly, it will be sufficient to attach a fragment of paper to the mineral or other substance, placing it so that the image of the slit is formed partly on the paper and partly on the substance to be examined. I have frequently found this mode of observation convenient in examining the absorption of light by opaque substances. The manner in which the absorption of the medium comes into play in this case will be considered in greater detail further on (see Art. 176.).

143. When green uranite was examined in this manner, it showed a very remarkable system of dark bands of absorption. These bands were seven in number, or at any rate six, and were arranged with all the regularity of bands of interference. The first was situated at about $b\frac{4}{7}\text{F}$, the second at F ; the middle of the sixth fell a very little short of G ; the third, fourth and fifth were arranged at regular intervals between the second and sixth; the seventh was situated about as far beyond the sixth as the sixth beyond the fifth. The spectrum was so faint in the region of the seventh band as to leave some slight doubts respecting its existence. There would not have been light enough to see bands further on.

144. Uranite is highly lamellar in its structure, from whence it is otherwise called uran-mica. The reader may perhaps suppose that the dark bands described in the last paragraph were bands of interference, which I had mistaken for bands of absorption, and that they were really of the nature of NEWTON'S rings, or more exactly of

* Annales de Chimie, tom. v. (1842) p. 46.

the bands seen in an experiment due to the Baron von WREDE. There may, it will perhaps be said, have been a fissure parallel to the first surface, so as to separate a thin plate; and the interference of the two streams of light reflected respectively on the upper and under surface of this plate may have produced the bands observed. But various phenomena attending these bands are irreconcilable with such a supposition. Towards the edges of the crystal, where flaws did in fact exist, bands of the same nature as Von WREDE's were actually observed. But these had an appearance totally different from that of the others. The dark bands of the interference system were more intensely black and better defined than those of the other system, and were very variable, depending as they did upon the thickness of the plate by which they were formed, whereas the bands belonging to the first system were always the same. Besides, were these bands due to interference, there is no reason why they should be confined to one region of the spectrum, and that by no means the brightest. However, to take away all possible doubts respecting the nature of the bands, I detached a small scale from the crystal, and having placed it behind a slit in a beam of sunlight condensed by a lens, I analysed the transmitted light by a prism. Were the bands really due to absorption, they ought to be more distinct in the transmitted light, whereas, were they of the nature of Von WREDE's bands, they ought to be faint, and almost imperceptible. The spectrum of the transmitted light contained however four dark bands, which were well defined and intensely black. The whole of the spectrum beyond the place of the next band was absorbed, which is the reason why four bands only were visible.

145. The absorption bands of green uranite, though they showed great regularity with respect to their positions, did not appear very regular with regard to their intensities. The second, fifth and sixth seemed to me to be more conspicuous than the first, third and fourth. I cannot say for certain whether this ought to be attributed to fluctuations in the absorbing power of the medium, or fluctuations in the original intensity of the solar spectrum, but I am strongly inclined to prefer the former view.

146. The intervals between the absorption bands of green uranite were nearly equal to the intervals between the bright bands of which the derived spectrum consisted in the case of yellow uranite. After having seen both systems, I could not fail to be impressed with the conviction of a most intimate connexion between the causes of the two phenomena, unconnected as at first sight they might appear. The more I examined the compounds of uranium, the more this conviction was strengthened in my mind.

147. Yellow uranite exhibits a system of absorption bands similar to those of green uranite. Nitrate of uranium also shows a similar system. In a solution I have observed seven of these bands arranged at regular intervals. The first absorption band coincided with F, the fifth with G nearly. The absorption bands may also be seen by analysing the light transmitted through the crystals. The following arrangement exhibited at one view the absorption bands and those due to the light which had changed its refrangibility.

148. The sun's light was reflected horizontally by a mirror, and condensed by passing through a large lens. It was then transmitted through a vessel with parallel sides containing a moderately strong ammoniacal solution of a salt of copper. The strength of the solution, and the length of the path of the light within it, were such as to allow of the transmission of a little green besides the blue and violet. A crystal of nitrate of uranium was then attached to a narrow slit, and placed in the blue beam which had been transmitted through the solution, the crystal being turned towards the incident light. The light coming from the crystal through the slit was then viewed from behind, and analysed by a prism. A most remarkable spectrum was thus exhibited, consisting from end to end of nothing but bands arranged at regular intervals. The interval between consecutive bands appeared to increase gradually from the red to the violet, just as is the case with bands of interference. Although this interval appeared to alter continuously from one end of the spectrum to the other, the entire system of bands was made up of two distinct systems, different in appearance, and very different in nature. The less refrangible part of the spectrum, where only for the crystal there would have been nothing but darkness, was filled with narrow bright bands, due to the light which had changed its refrangibility. These bands were much narrower than the dark intervals between them, but they were not mere lines containing light of definite refrangibility. The more refrangible part of the spectrum was occupied by the system of bands of absorption. The interval between the most refrangible bright band and the least refrangible dark band of absorption appeared to be a very little greater than one band-interval, so that had there been one band more of either kind the least refrangible absorption band would have been situated immediately above the most refrangible bright band. With strong light I think I have seen an additional band of this nature.

149. *Pitchblende*.—This mineral proved to be quite insensible, and exhibited nothing remarkable.

150. *Hydrate of Peroxide of Uranium*.—Some crystallized nitrate of uranium was exposed to a heat a good deal short of redness, whereby most of the acid was expelled. The residue was of a deep brick-red colour, and consisted no doubt chiefly of anhydrous peroxide. It was quite insensible. In order to remove any undecomposed nitrate, it was boiled with water, whereby the undecomposed nitrate was dissolved, and the peroxide converted into a hydrate. This hydrate, after having been washed and dried at the temperature of the air, was of an extremely beautiful yellow colour, and was I suppose the hydrate $U^2O^3 + 2HO$ described in chemical treatises. It was tolerably sensitive, in fact for an inorganic substance extremely so, though the sensibility was much less than that of nitrate of uranium, yellow uranite, or canary glass. The derived spectrum consisted as before of separate bright bands. A small portion of the powder was attached by water to blotting-paper, and dried before a fire. The powder thus obtained on paper was duller than before, and inclined a little more to orange, though the colour was not much deeper than that of the former hydrate.

From its colour and the circumstances of its formation, it was probably the other hydrate $U^2O^3 + HO$. It proved on examination to be totally insensible.

151. *Acetate of Peroxide of Uranium*, prepared by dissolving the yellow hydrate of the peroxide in acetic acid, and evaporating to crystallize.—This salt is extremely sensitive, about as much so as the nitrate. The derived spectrum consisted of six bright bands arranged at regular intervals. It seemed to me that the last five of these were respectively a little more refrangible than the five bands given by the nitrate, and then a sixth band was visible in the faint red in the case of the acetate which was not ordinarily seen in the nitrate. However, this observation has need to be repeated under more favourable circumstances.

152. Nitrate and acetate of peroxide of uranium, yellow uranite, and canary glass, are all so highly sensitive as to allow the primary spectrum to be examined with a prism at some distance. In the first three media the bright bands are narrow, much narrower than the dark intervals between; in the glass they appear much broader than in the other media.

153. *Oxalate of Peroxide of Uranium*, prepared in the manner mentioned by M. PELIGOT, namely, by adding a saturated solution of oxalic acid to a solution of nitrate of uranium, washing and drying the precipitate.—This salt was sensitive, but only in a low degree. However, the derived spectrum bore prismatic examination sufficiently to show three or four bright bands. The absorption of the medium was examined by spreading some of the powder on glass along with water and allowing it to dry. The layer was then examined by different methods. The salt exhibits three very intense absorption bands in the highly refrangible part of the spectrum. The positions of these bands, by measurement, were F 0.31 G, F 0.58 G, F 0.85 G.

154. *Phosphate of Peroxide of Uranium*, prepared by precipitation from a solution of nitrate of uranium by adding a solution of common phosphate of soda.—This salt was sensitive, though not in a high degree. It was a good deal more sensitive than the oxalate, but I think not so much so as the hydrate of the peroxide. The derived spectrum consisted of bright bands as usual*.

155. *Uranate of Potassa*, prepared by dropping a solution of nitrate of uranium into a solution of caustic potash, stopping long before the alkali was neutralized.—This salt was found to be insensible, both in its original state as a gelatinous hydrate, and in various stages of drying.

156. *Uranate of Lime*, prepared in a similar manner with lime-water.—This salt, which after drying is of a fine orange colour, was like the preceding found to be insensible. It seemed interesting to examine these two salts, because the former contains two elements (not counting oxygen) in common with canary glass, and the latter two elements in common with yellow uranite. Yet the salts are insensible while the two other media are so remarkably sensitive.

157. *Solutions by means of alkaline carbonates*.—It is known to chemists that alka-

* See note C.

line carbonates, added in solution to a solution of nitrate of uranium, give yellow precipitates which are redissolved in an excess of the precipitant. The solutions thus obtained with the carbonates of potassa and soda, which were of a greenish yellow colour, were found to be totally insensible. They exhibited however four of those singular absorption bands so characteristic of salts of peroxide of uranium. Of these the third fell a little short of G, its more refrangible edge nearly coinciding with that fixed line; the first and second were situated between F and G, the distance of the first beyond F being somewhat greater than the interval between two consecutive bands. The fourth, which was situated beyond G, was fainter than the others. The second and third were the most conspicuous of the set.

158. The absorption bands due to peroxide of uranium afford an easy mode of detecting that substance in solution. For this purpose the solutions mentioned in the preceding paragraph are much preferable to the nitrate, for they produce much stronger bands when only a small quantity of uranium is present. The absorption bands of nitrate of uranium are visible, as might have been expected, in presence of a large quantity of nitrate of copper*.

Optical Tests of Uranium in Blowpipe Experiments.

159. When a bead of microcosmic salt is fused with oxide of uranium, and brought to its highest state of oxidation, it is yellow by transmitted light. Such a bead is sensitive in a very high degree, quite as much so as canary glass. When the light falls sideways on it, and it is held against black cloth or a dark object, it exhibits plainly the green colour due to internal dispersion. When properly examined by means of sunlight its sensibility is evident at once, and when the dispersed light is viewed through a prism it is resolved into bright bands. One of the most convenient modes of examining such minute objects consists in reflecting the sun's light horizontally through a large lens, intercepting by means of absorbing media all the rays except those of very high refrangibility, placing the object to be examined in the condensed beam, and viewing it through a prism. So delicate is this test when applied to uranium, that on one occasion, when engaged in examining a bead coloured green by chromium, which had been fused in the exterior flame, I observed the appearance given by uranium. This turned out to be actually due to uranium, of which a mere trace was accidentally present without my knowledge.

160. The green communicated to microcosmic salt by uranium after exposure to the reducing flame has a very peculiar composition, by means of which the presence of uranium may be instantly detected. For this purpose it is sufficient to view through a prism the inverted image of the flame of a candle formed by the bead, the latter being so held as to be seen projected on a dark object. The observation is perfectly simple, and occupies only a few seconds. The spectrum exhibits an isolated band at the red extremity, followed by a very intense dark band of absorption. A

* See note D.

similar dark band, but not quite so intense, occurs in the green: beyond the green there is usually but little light seen. As the absorption progresses the first dark band invades all the space from the red to the green, and the spectrum consists of an isolated red band and a green band divided into two. In its mode of absorption, the medium has a strong general resemblance to chlorophyll. The green due to copper or to chromium shows nothing remarkable when viewed through a prism, and could not possibly be confounded with the green due to protoxide of uranium. The absorption bands due to this oxide are not completely brought out till the bead is cold.

161. Uranium produces the same effects with borax as with microcosmic salt, but they are less distinct, or at least less easily produced.

162. When the uranium contained in a bead of microcosmic salt is thoroughly oxidized, and the bead is gently heated, so as just to be self-luminous, the light which it gives out is not red, like that of most substances at a low heat, but green, or rather greenish white.

163. Solutions of protoxide of uranium have a very remarkable effect on the spectrum, resembling more or less that of a bead of microcosmic salt coloured green by uranium. Of course the absorption can be observed much better by means of a solution than by a mere bead. I have observed several bands of absorption in such solutions, but the cases which I have hitherto examined are too few to justify me in entering into detail. Besides, the absorption bands due to protoxide of uranium do not belong properly to my subject, the compounds of this oxide, so far as I have examined, being insensible.

Appearance of highly Sensitive Media in a Beam from which the Visible Rays are nearly excluded.

164. When a large beam of sunlight is reflected horizontally into a darkened room, and transmitted through an absorbing medium, placed in the window, of such a nature as to let pass only the feebly illuminating rays of high refrangibility and the invisible rays beyond, various sensitive media have a very strange and unnatural appearance when placed in the beam, on account of the peculiar softness of the dispersed light with which the media appear as it were self-luminous, and the almost entire absence of strong light reflected from convexities. Among substances eminently proper for this experiment, may be mentioned a solution of the bark of the horse-chestnut, or of sulphate of quinine, or of stramonium seeds, a decoction of madder in a solution of alum, and above all, ornamental articles of canary glass. The appearance of a specimen of yellow uranite was curiously altered by this mode of examination. By daylight the mineral appeared much of the same colour as the stone in which it was imbedded, but when placed in a beam such as that above mentioned the uranite was strongly luminous, while the stone remained dark.

Natural Crystals.

165. Of natural crystals I have hitherto examined only a small number. For a long time I was occupied almost exclusively with vegetable products, the mineral kingdom not appearing promising. However, I have found internal dispersion in certain specimens of apatite, arragonite, chrysoberyl, cyanite, and topaz. In all these cases the dispersion appeared due, as in the case of fluor-spar, to some substance accidentally present in small quantity; so that yellow uranite is at present the only natural crystal to the essential constituents of which the property of internal dispersion has been found to belong.

166. Among the minerals just mentioned apatite was the most sensitive, though it fell very far short of yellow uranite. That the sensibility was not due to phosphate of lime, was plain from the circumstances that a colourless specimen was insensible, and that the amount of sensibility was found to be different in different parts of the same sensitive specimen. With the exception of the colourless crystal already mentioned, all the specimens of apatite examined were of a greenish colour, and all were sensitive. The dispersed light was something of an orange colour, but was not homogeneous orange. In one specimen it consisted of three distinct bright bands at regular intervals. The mode in which the sensibility of this crystal was connected with the refrangibility of the incident rays was very peculiar. In arragonite dispersion was found in the transparent specimens examined; the translucent specimens were found to be insensible. The dispersed light was of a brownish white colour. In the same crystal some parts were insensible and others more or less sensitive. The portions of equal sensibility were arranged in plane strata, just as in the case of fluor-spar, as has been noticed by Sir DAVID BREWSTER. In a specimen which had been cut for showing conical refraction, the strata were in some places perpendicular to the plane of the optic axes, and in other parts parallel to the line bisecting the axes, and inclined to their plane at such an angle that the two directions of the strata must have been parallel to two of the commonest lateral faces. Another specimen showed strata parallel to an oblique terminal face. The strata are plainly due, as Sir DAVID BREWSTER has remarked with reference to fluor-spar, to some substance taken up during crystallization. Accordingly, they preserve a sort of history of the growth of the crystal. In a twin crystal of fluor-spar, the direction of the strata in that part of the mass which was common to the geometrical forms of both crystals, showed to which crystal it really belonged. In fluor-spar the strata are parallel to the faces of the cube, at least in the specimens which I have examined, and the same has been observed by Sir DAVID BREWSTER.

In chrysoberyl, cyanite and topaz, the dispersed light was red or reddish, and was too variable to allow of its being attributed to the essential constituents of the crystals. In these cases the sensibility was but slight; indeed in cyanite there was only a trace of dispersion when the crystal was examined under great concentration of light.

Coloured Glasses.

167. Besides canary glass, I have examined the common coloured glasses, including that coloured by gold, but with one exception have not met with any example in which the sensibility observed appeared to have any connexion with the colouring matter. The paler glasses exhibited a little internal dispersion, because the colour was not sufficiently intense to mask the dispersion which a common colourless glass would exhibit.

168. The exception occurred in the case of the pale brown glass, which has been already mentioned in connexion with my first experiment. This glass dispersed a red light under the influence of the highly refrangible rays. The colour of the light was not pure prismatic red, but red was predominant. A similar dispersion, due apparently to the same cause, was observed in the case of one of the common reddish brown German wine bottles. The sensibility of these glasses appears to be due to an alkaline sulphuret. A bead purposely coloured in this manner was in fact found to disperse a red light like the glasses. Moreover, in the confused masses obtained by fusing sulphate of soda and sulphate of potash on charcoal before the blowpipe, certain portions were found which dispersed a red light, and that pretty copiously for an inorganic substance. A similar dispersion was observed among the products obtained by fusing together sulphur and carbonate of potash, while other parts of the confused mass exhibited dispersion of a different kind. It seems plain that among the combinations of sulphur with the alkalies sensitive compounds exist, but what they are I have not examined.

Cautions with respect to the discrimination between true and false internal dispersion.

169. In the early part of this paper certain tests were given for distinguishing between true and false internal dispersion in a fluid. But it requires some experience in observations of this kind to be able readily to decide, and a too rigid adherence to one of the tests to the exclusion of the others might lead to error.

The first test relates to the continuous appearance of a truly dispersed beam. But sometimes solid particles exist in mechanical suspension, which are so fine and so numerous, that this test alone might lead the observer to mistake a falsely for a truly dispersed beam. On the other hand, if a fluid which itself alone exhibits no internal dispersion, true or false, hold solid particles in what is obviously mere mechanical suspension, we must not immediately conclude that the medium, taken as a whole, is incapable of changing the refrangibility of any portion of the light incident upon it. For we have seen that the fluid state is not in the least degree essential to the exhibition of sensibility, and of course a fluid will serve as well as anything else for the mere mechanical support of a sensitive substance.

170. Thus lycopodium is very sensitive, as appears by examining the powder in a linear spectrum. Accordingly, I found that when a little lycopodium was mixed with water, and the whole medium was examined by the fourth method, it displayed

its sensibility, although the beam of light which had changed its refrangibility was plainly discontinuous. When Indian yellow was used instead of lycopodium, the whole medium exhibited its sensibility when it was examined by the fourth method. In this case the suspended particles were so fine that the beam of light which had changed its refrangibility appeared to be continuous, though of course it was not really so. In observing with muddy fluids like these, it is almost necessary to employ absorbing media, since otherwise the effect of the light scattered at the surfaces of the prisms and large lens might lead the observer to conclusions altogether erroneous.

171. The next test relates to the polarization of a falsely dispersed beam. Being engaged on one occasion in examining the effects of acids and alkalis on a weak solution of a sensitive substance, employing sunlight which had been merely reflected through a small lens, I met with a beam which had every appearance of having been only falsely dispersed, but on viewing it from above through a doubly refracting prism I was surprised at first by finding it unpolarized. It soon occurred to me that the beam must have been due, not to solid motes, but to excessively small bubbles of carbonic acid gas, the existence of which was thus revealed, though they were too small to be seen directly. The light being incident on these bubbles at an angle of about 45° , which is very little less than the angle of total reflexion, the reflected light would be almost perfectly unpolarized*.

172. Water which had been merely boiled in a test tube gave a similar result. The unpolarized beam of falsely dispersed light was of course due in this case to the air which had been held in solution. This shows why long-continued boiling should be necessary, in order to free water from air. It is not that the affinity of water for air is so great as to be only gradually overcome, but that the air, immediately expelled from solution when the temperature rises sufficiently, is still retained in a state of mechanical mixture, forming excessively minute bubbles, the terminal velocity of which is insensible. Accordingly it is not till larger bubbles are formed, by the casual meeting of a number of these small bubbles, that the air rises to the surface and escapes.

173. With respect to the test of true dispersion depending on the change of refrangibility, it has been already remarked that in some cases the change is so slight, that if this test alone were applied, the observer might mistake true dispersion for false. However, it is only in rare cases that there is any danger of being deceived in this manner in the application of the test; but on the other hand, in observing a muddy fluid or a translucent solid by the fourth method, the observer, if not on his guard, might easily be deceived by the effect of scattered light, and be led to mistake false dispersion for true. Thus suppose the medium to be water holding in suspension particles of an insensible water colour, and the small lens to be placed a little beyond the commencement of the violet. Two beams of light would enter the lens, namely, a regularly refracted beam of violet, and a scattered beam of white light.

* See note E.

Of these the latter would be insignificant compared with the former, were it not that the illuminating power of the colours belonging to the middle of the spectrum is so very much greater than that of the violet. When the dispersed beam was analysed by a prism, it would be decomposed into a violet beam of definite refrangibility, followed by a dark interval, and then a broad band containing the colours of the brighter part of the spectrum in their natural order. This is what is constantly seen in cases of true dispersion; but the polarization of the beam, and its behaviour under the action of absorbing media, would reveal the counterfeit character of the dispersion.

On the Colours of Natural Bodies.

174. By this expression I mean to include only the colours to which it is usually applied, namely, those of leaves, flowers, paints, dyed articles, &c., which form the great mass of the colours that fall under our observation. I do not refer to colours due to refraction, such as those of the rainbow, or to diffraction, such as those of the coronæ seen about the sun and moon, or to interference, such as those seen in the clear wings of small flies, or to the colours which accompany specular reflexion, which last are usually but slight, though sometimes pretty intense.

In some few instances, as for example in the case of fluor-spar, various salts of peroxide of uranium, acid solutions of disulphate of quinine, &c., colours are observed, sufficiently strong to arrest attention, which have a remarkable and hitherto unsuspected origin. But I am not now speaking of colours arising from a change of refrangibility in the incident light. In the vast majority of cases these colours are far too feeble to form any sensible portion of the whole colour observed. The colours which dyed articles give out under the influence of the highly refrangible rays usually agree more or less nearly with those of which such substances commonly appear, and it is possible that the colour arising from a change of refrangibility may contribute in some slight degree to the brilliancy of the tint observed. If, however, the effect be sensible I am persuaded that it is but slight; and very brilliant colours may be produced without a change of refrangibility, as for example in the case of biniodide of mercury. For the present I shall neglect the light which may have changed its refrangibility.

175. Few, I suppose, now attach much importance to the bold speculations in which NEWTON attributed the colours of natural bodies to the reflexion of light from thin plates. Sir DAVID BREWSTER has shown how extremely different the prismatic composition of the green of the vegetable world is, from what it ought to be, according to NEWTON'S theory, and what NEWTON supposed that it was. It is now admitted that the various colours of natural bodies are merely particular instances of one general phenomenon, namely, that of absorption. Absorption is most conveniently studied in a clear fluid or solid, but it does not the less exist in a body of irregular structure, such as a dyed cloth or a coloured powder.