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XIII. *On the Theory of the dark Bands formed in the Spectrum from partial Interception by transparent Plates. By the Rev. BADEN POWELL, M.A., F.R.S., F.G.S., F.R.Ast.S., Savilian Professor of Geometry in the University of Oxford*.*

(1.) **T**HE phænomenon of peculiar dark bands crossing the prismatic spectrum, when half the pupil of the eye (looking through the prism) is covered by a thin plate of any transparent substance, the edge being turned *from the violet towards the red* end of the spectrum, was first described by Mr. Fox Talbot in 1837 (Lond. and Edinb. Phil. Mag. and Journal of Science, vol. x. p. 364.), who showed that these bands are due to the interference of the two halves of each primary pencil, one of which is retarded by the plate.

(2.) Sir David Brewster has given various new modifications of these experiments (British Association Reports, vol. vii. Trans. of Sections, p. 13.), the most material of which tend to show that the effect is fully produced *only* when the plate is in the position just described, and diminishes and disappears as it revolves in its own plane; the same observation being also extended to the case of the spectra formed by interference from grooved surfaces, or gratings.

(3.) The explanation given by Mr. F. Talbot accounts for *the production of the bands simply*, but assigns no reason why the interception must take place *on one side* more than the other. That it does so, is considered by Sir David Brewster as indicating an entirely *new property of light*; having reference to the different sides of the pencil related to their position of greater or less refrangibility, and which he has not inexpressively termed a peculiar "polarity."

* Communicated by the Author.

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(4.) My attention was drawn to the subject in the course of last summer, when I repeated the experiments, and devised several new modifications with reference to an explanation which it appeared to me was supplied by the undulatory theory; to these investigations I referred briefly at the Birmingham meeting of the British Association, 1839. For several reasons (on which I need not here enter) I have delayed publishing any details; nor should I do so now, but that having learned that Mr. Airy has recently pursued the research to many entirely new conclusions*, I am anxious to put on record the few points I have been able to establish, and to vindicate my views from misconceptions to which they have been exposed.

(5.) The following distinctions are important to be borne in mind with reference to the explanation of the phænomena.

In these experiments we have to consider the different elementary pencils of which the spectrum, as presented to the eye, is formed; and with respect to each of these, in the case of the *prismatic* spectrum it is easily seen that the edge of the plate intercepts *that half which lies towards the edge of the prism.*

In the *interference*-spectrum (according to Fraunhofer's method), the spectra are formed one on each side of the axis, with their violet ends towards it. The edge of the plate in this case must always intercept *that half of each primary pencil, which after passing the focus lies NEAREST to the axis.*

(6.) I have found that with the same prism the intercepting plate must be within limits of thickness, which differ according to the substance of the plate, and with the same plate the character of the bands differs with the medium of which the prism is formed. These differences appear to depend on the refractive and dispersive powers of the substances.

(7.) With a prism of flint glass and a plate of mica, the greatest thickness which can be used may be about the $\frac{1}{100}$ th of an inch. In this case the bands appear fine and numerous, and it seems only in consequence of their increase in number that they cease to be distinguishable when the thickness is increased beyond this.

If we use less thicknesses (such as those into which mica is easily split) the bands become broader and fewer, and at length faint and ill-defined. It is perhaps not possible to distinguish them if fewer than four or five are formed throughout the spectrum. The bands are never very dark; showing that only a portion of the rays is concerned in their formation.

[* A notice of Mr. Airy's paper on this subject will be found in our report of the proceedings of the Royal Society for June 18, 1840.—EDIT.]

(8.) When the plate is very thin, another set of appearances presents itself.

On splitting a piece of mica to such a tenuity that only a few indistinct broad bands were barely visible with a flint-glass prism, I observed at the same time *another set of very fine but extremely faint bands*, evidently independent of the former.

(9.) When the film of mica was still thinner, the *broad* bands ceased to appear altogether, and *only the fine* set were visible. To show *these* bands the films must be so thin as to be nearly iridescent: it is difficult to succeed in tearing them off sufficiently fine. I have sometimes used drops of water between glass plates pressed hard together. These bands are always very faint; but they are somewhat more conspicuous with prisms of the more dispersive oils, and always require a strong light to be seen.

(10.) There is, however, a more remarkable circumstance connected with *this set of bands*; *they continue to be formed when the edge of the thin film is towards the thicker side of the prism.*

(11.) In pursuing the *theoretical* explanation, we have to consider the conditions which may affect the rays situated towards the opposite sides of those primary homogeneous pencils, into which the incident beam of light is separated, and which converge in the eye to form the several points in the spectrum, both in the case of the prism, and of interference from grooves or gratings.

Now in either case a distinction of this kind is deducible from the wave-theory, on comparing the length of undulatory route of the two extreme rays of any primary pencil; from which it appears that *one of these rays is always more retarded than the other*, as well in the prismatic as in the interference spectrum: that side of the pencil which is *previously the least retarded, being that to which the plate is applied* in the original form of the experiment. This distinction, combined with the general principles of explanation at first referred to, appear to me not only sufficiently to account for the *ordinary* phenomena, but in *my modification* of the experiment to assign a reason why a similar effect should be produced on the *opposite* side.

(12.) With regard to the mathematical investigation, in the case of the prism, without going into a formal discussion, it is sufficient to observe, that on the principles of mathematical optics, when a diverging pencil of homogeneous light is refracted through a prism in the position of minimum deviation,

the emergent pencil will originate from a geometrical focus, which is *not a single point*, but a *caustic*, whose *convexity* is towards the edge of the prism. Hence, on the principles of the wave-theory, it follows that the side of the pencil which lies *towards the edge* of the prism is that which undergoes less *retardation*, or has the *shorter* undulatory route; this difference varies slightly for the different primary rays.

I had arrived at this conclusion by a different approximate method, when in some correspondence the Astronomer Royal pointed out to me the above view of the problem, as connected with his investigations "on the light in the neighbourhood of a caustic." (Camb. Trans., vol. vi. part 3*.)

(13.) With respect to the interference-spectrum, we have only to follow out the investigation given in Mr. Airy's tract (Arts. 80, 83.) (as that gentleman has suggested to me) in the following manner.

Taking the focus as the origin and the axis of the object-glass as the axis of x , let xy be the coordinates of any point in the wave, ab those of a point in the focal image on the same side of the axis, then the radius of the wave being c , we have

$$c^2 = x^2 + y^2;$$

and expanding and neglecting powers of y above the third, we find

$$x = c - \frac{y^2}{2c}.$$

The distance g from xy to ab will be

$$g = \sqrt{(x-a)^2 + (y-b)^2};$$

here performing the various expansions, and for brevity writing $e^2 = (c-a)^2 + b^2$, we at length obtain (going to the third power of y)

$$\rho = e \times \left\{ \begin{aligned} &1 + \frac{1}{2} \left\{ \frac{2b}{e^2} y + \frac{a}{c e^3} y^2 \right\} \\ &- \frac{1}{8} \left\{ \frac{-2b}{e^2} y + \frac{a}{c e^3} y^2 \right\}^2 \\ &+ \frac{1}{16} \left\{ \frac{-2b}{e^2} y \right\}^3 \end{aligned} \right\}.$$

The terms involving the second power of y have the same value on each side of the axis, and those depending on the third power are found to be

[* See Lond. and Edin. Phil. Mag. vol. xii. p. 452.—EDIT.]

$$\left. \begin{aligned} & -\frac{1}{8} \left\{ \frac{-4ba}{ce^4} y^3 \right\} \\ & + \frac{1}{16} \left\{ \frac{-8b^3}{e^6} y^3 \right\} \end{aligned} \right\} = \frac{by^3}{2e^4} \left\{ \frac{a}{c} - \frac{b^2}{e^2} \right\}.$$

Here, if $\frac{a}{c} < \frac{b^2}{e^2}$, (which is the case, the image being formed in the focus, so that in fact we might assume $a = 0$,) it follows that when b and y have the same sign, this expression will be negative; that is, for the ray which has b and y on the same side, or is *nearest the axis after passing the focus*, the route will be the *shortest*. The difference will be very small, and will vary slightly for the different rays of the spectrum.

(14.) This difference of retardation in the several rays of each primary pencil, combined with the obvious principle laid down by Mr. F. Talbot, appears to me to supply an explanation of the phænomena.

The whole effect in these experiments is made up of two parts, the original retardation, and that superinduced by the plate. If the previously *least* retarded ray be intercepted, we take the *difference*, if the *most* retarded, the *sum* of the two effects.

When we apply the plate, the whole resulting retardation may fall within the limits, (before mentioned, § 6.) or not, according to the magnitude of the two retardations, and according as we take their sum or difference. If it be beyond the limits for one portion of the pencil, it may be within them for another.

In general, in the original form of the experiment, that is, for plates of ordinary thickness, the *difference* falls *within* the limits, though the *sum* is *beyond* them, for all portions of the pencil. But with a very thin plate, the *sum* may also be *within* the limits for *those parts* of the pencil whose difference of retardation is small: Or, in other words, with plates of a *certain thickness*, the retardation is too great to give bands with any portion of the pencils, when the plate is applied to the previously *most* retarded side: but it will give bands with some portion when applied to the previously *least* retarded side.

On the other hand, if an *extremely thin* plate be applied to the *most* retarded side, it will still give bands with one portion of the pencils, as well as when applied to the least retarded side with other portions.

Oxford, July 5, 1840.