

LXV. On a new species of coloured fringes produced by the reflection of light between two plates of parallel glass of equal thickness

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while smoothness, compactness, and solidity were given to her walls, by filling the intervals of all the timbers with short wood—an expedient attended with many advantages, which I shall not dwell on, as he could not comprehend them. He goes on to say that the “decks are not loose as in the old system.” Now, really, when a Doctor, who is besides F.R.S. L. & E., has sailed to the Baltic in a ship, for the purpose of giving colour to a quarto volume which might as well have been written in Grub-street, we cannot help either suspecting his capacity for observation, or doubting his assertion respecting the voyage, as the Leith traders (of which I have built two or three) are not in the slovenly practice of carrying their decks about them “loose.”

But I have dwelt longer on his review than it merits, and shall conclude by advising him to pursue a Pythagorean system—Seven years of silence and seclusion to his chamber, with a diet of oatmeal, may perhaps increase his knowledge, and neutralize his superacetic disposition.

I am, &c.

Glasgow, Sept. 14, 1815.

A. STEWART.

LXV. *On a new Species of coloured Fringes produced by the Reflection of Light between two Plates of parallel Glass of equal Thickness.* By DAVID BREWSTER, LL.D. F.R.S. Edin. & F.A.S. E.*

DURING a series of experiments in which I was lately engaged, for the purpose of determining the law of the polarization of light, by successive reflections from plates of parallel glass, I observed that all the images of the luminous body which were formed by more than one reflection, were crossed by parallel fringes of coloured light, when the two plates had a small inclination to each other; and that these fringes suffered considerable changes, by varying the position of the plate with regard to the incident ray.

These coloured fringes seemed at first to have the same origin as those of thick plates, which were discovered by Newton, and afterwards examined by the Duke de Chaulnes, Mr. Brougham, and Mr. Jordan; and I considered the second plate of glass as performing the part of the quicksilver in Newton's glass mirror, or of the metallic speculum in the experiments of the Duke de Chaulnes and Mr. Brougham. A more attentive examination, however, convinced me that this was a mistake, and that the coloured fringes constituted a new class of phænomena, having

* From the Transactions of the Royal Society of Edinburgh for 1815.
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a different origin from those of thick plates, though explicable by the beautiful theory of fits of easy reflection and transmission by which Newton was enabled to explain all the phænomena of the colours of thick and thin plates.

In order to observe the phenomenon to the greatest advantage, let the light of a circular image subtending an angle of 1° or 2° be incident perpendicularly, or nearly so, upon two plates of parallel glass placed at the distance of one-tenth of an inch, and let one of the plates be gently inclined to the other, till one or more of the reflected images be distinctly separated from the bright image formed by transmitted light, and received upon the eye placed behind the plates. Under these circumstances the reflected image will be crossed with about fifteen or sixteen beautiful parallel fringes: the three central fringes consist of blackish and whitish stripes, and the exterior ones of brilliant stripes of red and green light; and the central fringes have the same appearance in relation to the external fringes, as the internal have to the external rings, formed either by thin plates, or by the action of topaz upon polarized light. If the two plates of glass are turned round in a plane at right angles to the incident ray, the reflected images will move round the bright image, and the parallel fringes will always preserve a direction at right angles to a line joining the centres of the bright and reflected images. Hence it follows, *that the direction of the fringes is always parallel to the common section of the four reflecting surfaces, which exercise an action upon the incident light.*

The position of the plates remaining as before, let the inclination of the plates, or, what is the same thing, the distance of the bright and the reflected image, be varied by a gentle motion of one of the plates, the coloured fringes will be found to increase in breadth as the inclination of the plates is diminished, and to diminish as the inclination of the plates is increased.

In order to determine the law according to which the magnitude of the fringes varies, I employed two plates of parallel glass $\frac{1}{1000}$ ths of an inch thick, and obtained the following measures for the fringes which crossed the image that had suffered two reflections between the plates. The pencil of light was incident nearly in a vertical direction upon the first plate.

Inclination of the Plates.	Angular breadth of each Fringe.
$1^\circ 11'$	$26' 50''$
$2^\circ 20'$	$13 \quad 3$
$5^\circ 36'$	$5 \quad 41$

Now since $5^\circ 36' : 26' 50'' :: 1^\circ 11' : 5' 40''$, and since $5^\circ 36' : 13 \quad 3 :: 2^\circ 20' : 5 \quad 27$, it follows, that *the breadth of the fringes is inversely as the inclination of the plates.*

Owing

Owing to the rapid diminution of the fringes, by increasing the angle formed by the plates, I could not with any degree of accuracy determine their breadth at greater angles of inclination; and therefore it still remains to be ascertained whether it varies with the sine, tangent, or secant of the angles.

If the light of the circular object, instead of falling perpendicularly upon the plates, is incident at different obliquities, so that the plane of incidence is *at right angles to the common section of the plates*, no fringes are visible across any of the images. But if the plane of incidence is *parallel to the common section of the plates*, the reflected images increase in brightness with the obliquity of incidence, and the coloured fringes become more vivid. When the angle of incidence increases from 0° to 90°, the images that have suffered the greatest number of reflections are crossed by other fringes inclined to them at a small angle. At an angle of about 44°, the image formed by four reflections is covered with interfering fringes; but it is not till the angle of incidence is greater, that this irregularity is distinctly seen on the image formed by two reflections.

Hitherto I had observed no fringes upon the first or bright image, which is obviously composed of light that has not suffered reflection from the second plate of glass. By concealing, however, the bright light of the first image, so as to perceive the image formed by a second reflection, within the first plate, and by viewing this image through a small aperture, which I found of the greatest service in giving distinctness to all the phenomena, I observed fringes across the first image, far surpassing in precision of outline, and in richness of colouring, every analogous phenomenon which I had seen. When these fringes were concealed, I also observed other fringes on the image immediately behind them, and formed by a third reflection, from the interior of the first plate. I now concealed the second image, upon which the fringes were extremely bright, and very faint stripes were seen upon the one immediately behind it.

On examining these phenomena a little more attentively, I observed that the size of the fringes in the first image varied with the distance of the eye from the plates, while those on the second and fourth image diminished with that distance.

The magnitude of this change will be understood from the following experiments:

Angles of Incidence.	Number of Fringes across the first Image.		Number of Fringes across second Image.	
	Eye near.	Eye a few Inches distant.	Eye near.	Eye a few Inches distant.
0°			6	6 $\frac{1}{3}$
47	4 $\frac{1}{3}$	3 $\frac{1}{2}$	5	5 $\frac{1}{3}$
61	3 $\frac{1}{2}$	3	4	4 $\frac{1}{3}$
73	2 $\frac{2}{3}$	2 $\frac{1}{2}$	3	3 $\frac{1}{2}$

When the fringes on the second image were inclined to the right, those on the first image were inclined to the left; so that, both in point of position and magnitude, the two sets of fringes follow a different law.

The preceding measures of the magnitude of the fringes at different obliquities, were not taken with that accuracy which is necessary for determining the law of their variation. I have made numerous experiments for this purpose; but when the angle of incidence is considerable, there is always such a degree of distortion in the fringes, and such a perceptible variation in their magnitude, from the slightest change in the position of the eye, that I found it quite impracticable to take measures in which any confidence could be placed. This difficulty no doubt arises from the imperfect flatness of the surfaces of the plates of glass; and I fear that even our best artists are not capable of producing better plates than those which I used in the preceding experiments. The following measures may be considered as tolerably correct.

The inclination of the plates was not the same as in the preceding experiments:

Angles of Incidence.	Number of Fringes across the first Image.	Number of Fringes across the second Image.
0° 0'		6 $\frac{1}{3}$
36 56	5	5 $\frac{1}{4}$
58 48	3 $\frac{1}{5}$	4 $\frac{1}{6}$
62 52	4 $\frac{1}{6}$	3 $\frac{2}{3}$
71 30	2 $\frac{1}{4}$	2 $\frac{1}{2}$

If the two parallel plates are placed at *any distance whatever*, and the preceding experiments repeated, the fringes will be found to suffer no change either in their magnitude or direction.

I now took three plates of parallel glass, that gave the coloured fringes when any two of them were put into the proper position. When the third plate was placed either before the other two, or between them, or behind them, it did not in the least degree affect the fringes which they produced. When it was placed, however, in such a position as to form a new reflected image, this image was also crossed by the coloured fringes.

When the *third* piece of parallel glass was cemented with Canada balsam upon the face of the *first* plate, or upon the back of the *second* plate, the fringes disappeared. When the interval between the two plates was filled with water, or with Canada balsam, the fringes were very faint, though distinctly perceptible. Hence it follows, that the production of the fringes depends

depends upon the action of all the four surfaces of the two plates of parallel glass.

All the preceding experiments were made with plates which were cut out of the same piece of glass, and had therefore the same thickness. I now tried plates of different thicknesses, both when ground parallel, and when cut from common plate glass; but I could never render the coloured fringes visible, unless when the glass was parallel, and exactly of the same thickness in both plates. I also tried plates of topaz, of equal thicknesses, and plates of sulphate of lime; but though I used pieces of various thicknesses, I have never succeeded in making them exhibit the coloured fringes, owing, perhaps, to the imperfect flatness of their surfaces.

In order to ascertain if the magnitude of the fringes depended on the thickness of the glass plates, I procured a piece of parallel crown glass $\frac{1.68}{1000}$ dths of an inch thick, and compared the fringes which it produced, at an inclination of $2^{\circ} 20'$, and at a vertical incidence, with those produced by another piece of glass $\frac{1.26}{1000}$ dths of an inch thick. In the first case, the circular image was crossed by *five* fringes, and in the second case with *seven* fringes: but

$$\frac{121}{1000} : \frac{168}{1000} :: 5 : 7 \text{ nearly.}$$

In another experiment, I found, from a mean of five measurements, that the thickest of these pairs of plates produced fringes each of which had a breadth of $11' 10''$, when the inclination of the plates was $1^{\circ} 58'$. Now the other pair of plates gave fringes $13' 3''$ broad, at an inclination of $2^{\circ} 20''$, which gives $15' 29''$ for their breadth at an angle of $1^{\circ} 58'$, and

$$\frac{121}{1000} : \frac{168}{1000} :: 11' 10'' : 15' 30''.$$

Hence *the magnitudes of the fringes are inversely as the thicknesses of the plates which produce them, at a given inclination; and in general the magnitudes of the fringes are in the compound inverse ratio of the thickness of the plates, and of their angle of inclination.*

Hitherto we have supposed the glass plates to be placed between the eye and the luminous object, so that only the 2d, 4th, and 6th reflected images were seen. When the eye is placed between the plates and the luminous object, so as to perceive the 1st, 3d, and 5th reflected images, the coloured fringes are also seen, having the same characters as those already noticed.

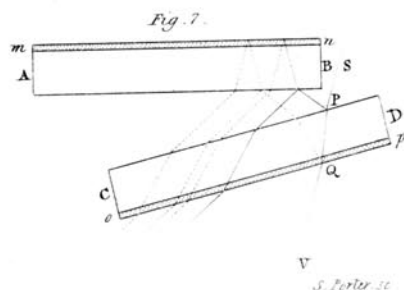
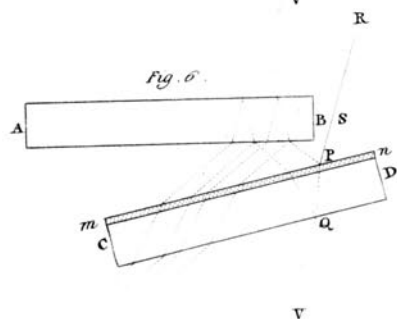
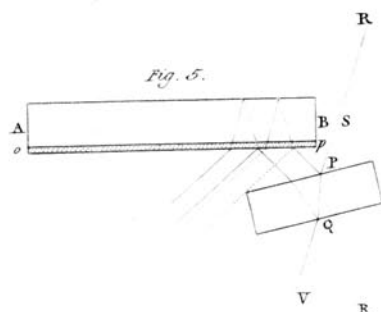
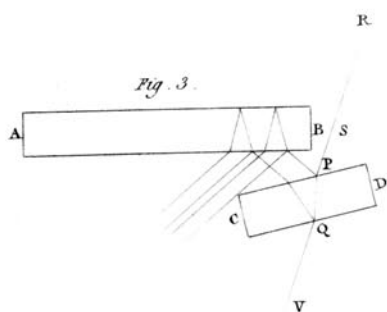
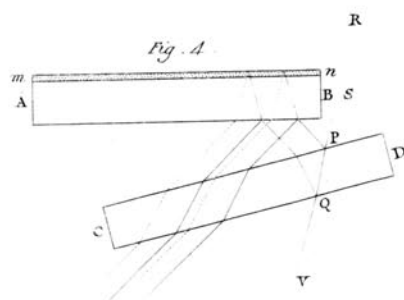
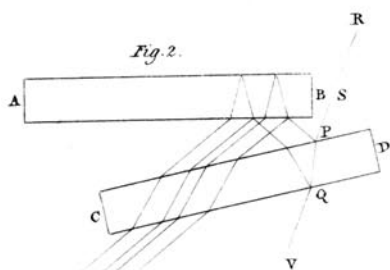
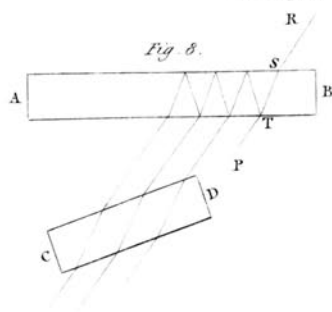
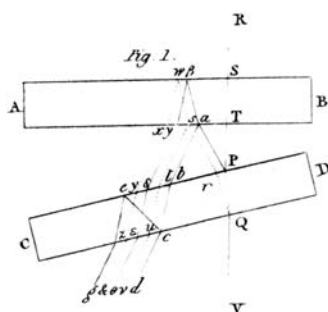
The phenomena which have been described are equally produced when the fringes are formed by polarized light, and they do not suffer the least change when examined by doubly refracting or doubly polarizing crystals.

When the eye is placed at a considerable distance, either before or behind the glass plates, all the fringes have a very distorted appearance, arising probably from the imperfect figure of the reflecting surfaces.

In order to explain the changes which the light undergoes in its passage through the plates of glass, let AB , CD , Plate VII. fig. 1. be a section of two plates at right angles to the common section of their surfaces, and let RS be a ray of light incident nearly in a vertical direction. This ray, after passing through the first plate AB , will suffer a small refraction at P and Q , and emerge in the direction QV parallel to RS . At the point P , in the second plate CD , the ray TP will be reflected to a , again reflected to b , and after suffering a refraction at b and c , will emerge in the direction cd , forming with RV an angle equal to twice the inclination of the plates. A portion of the reflected ray Pa will enter the first plate at a , and having suffered reflection and refraction at β , the reflected portion $\beta\gamma$ will reach the eye at θ . The ray $Pabc$ will likewise suffer a reflection at c and at e , and will reach the eye at g . In like manner, a part of the ray PQ will be reflected at Q , and move in the direction $Qrstuv$, and another part of it in the direction $swxyz$, and these rays will suffer several other reflections; but the images which they form will be so faint, that the eye will not be capable of perceiving them. When the observer, therefore, looks at a luminous body, in the direction SR , through the glass plates, he will perceive two images, one of which is a bright image, seen by the transmitted light QV , and the other is a faint image, seen principally by the reflected light $Pabcd$, and composed of several images formed by the pencils cd , uv , θ , z , θ , and eg . The bright image is not crossed by coloured fringes, but the fringes appear distinctly upon the other image; and the light by which these fringes are formed, has suffered two reflections from the exterior surfaces, and two refractions at the interior surfaces of the plates.

When the ray RS is incident obliquely, so as to produce the coloured fringes, the plane of incidence is parallel to the common section of the plates. In this case, it is difficult to represent in a diagram the progress of the rays, as they are reflected in a plane at right angles to that in which they are refracted. The changes, however, which the light must undergo in the production of the fringes, may be understood from figs. 2, 3, 4, 5, 6, 7, and 8, where AB and CD are the two plates of glass inclined at a small angle, and RS a ray of light incident obliquely, in a plane at right angles to the common section of the plate.

In fig. 2. the plates are so arranged, that the incident ray
RS



RS does not pass through the first plate AB. In this case, the *fringes are produced* in the same manner as if the ray had passed through AB.

In fig. 3. the rays reflected from the plate AD do not pass through the second plate CD. In this case, the *fringes are produced* as formerly.

In fig. 4. the reflection from the external surface *mn* of the plate AB is destroyed by a layer of indurated Canada balsam. In this case *no fringes are produced*.

In fig. 5. the refraction and reflection at the interior surface *op* of the plate AB are destroyed by a layer of Canada balsam. In this case *no fringes are produced*.

In fig. 6. the refraction of the interior surface of the plate CD is destroyed by a layer of Canada balsam, and in this case *no fringes are produced*.

In fig. 7. the reflection from the external surfaces *mn, op*, of the two plates is destroyed, and *no fringes are produced*.

In all these cases, the fringes are obviously produced by a refraction and a reflection in each of the two plates, and the interfering fringes are produced by the secondary reflections within the glass plates.

The fringes, however, which appear upon the first or bright images, are produced in a different manner from those formed by the light that has been reflected from the plate CD; for the light of which they are composed has suffered two or more reflections within the plate AB, as shown in fig. 8. and two refractions by the plate CD. These refractions are absolutely necessary to the production of the fringes; for they disappear when the light reaches the eye, without passing through the second plate. Any variation in the distance of the plates, when their inclination and thickness remain the same, ought obviously to produce no change in the appearance of the fringes, as the fits will return in the same manner as before.

In order to compare the preceding phenomena with the Newtonian Theory of Fits, I propose to resume the investigation with plates of parallel glass, that differ very considerably in thickness, and that have their surfaces ground as flat and polished as highly as possible; and I have no doubt but that all the results may be calculated by means of that beautiful theory.

The fundamental experiment by which I ascertained the production of coloured fringes by two plates of glass of equal thickness, has been repeated and verified by my friend M. Biot of the Institute of France, and was exhibited at a public meeting of that distinguished body.