XII. *Experiments and Observations upon the Properties of Light.*

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Received November 6, 1849,—Read January 10, 1850.

THE optical inquiries of which I am about to give an account, were conducted at this place in the months of November and December 1848, and continued in autumn 1849 at Brougham, where the sun proved of course much less favourable than in Provence: they were further prosecuted in October. I had thus an opportunity of carefully reconsidering the conclusions at which I had originally arrived; of subjecting them first to analytical investigation, and afterwards to repetition and variation of the experiments; and of conferring with my brethren of the Royal Society and of the National Institute. The climate of Provence is singularly adapted to such studies. I find, by my journal of 1848, that during forty-six days which I spent in those experiments, from 8 A.M. to 3 P.M., I scarcely ever was interrupted by a cloud, although it was November and December*. I have since had the great benefit of a most excellent set of instruments made by M. Soleil of Paris, whose great ingenuity and profound knowledge of optical subjects can only be exceeded by his admirable workmanship. I ought however to observe, that although his heliostate is of great convenience in some experiments, it yet is subject (as all heliostates must be) to the imperfection of losing light by reflexion, and consequently I have generally been obliged to encounter the inconvenience of the motion of the sun's image, especially when I had to work with small pencils of light. This inconvenience is materially lessened by using horizontal prisms and plates.

Although I have made mention of the apparatus of great delicacy which I employed, it must be observed that this is only required for experiments of a kind to depend upon nice measurements. All the principles which I have to state as the result of my experiments in this paper, can be made with the most simple apparatus, and without any difficulty or expense, as will presently appear.

It is perhaps unnecessary to make an apology for the form of definitions and propositions into which my statement is thrown. This is adopted for the purpose of making the narrative shorter and more distinct, and of subjecting my doctrines to a fuller scrutiny. I must further premise that I purposely avoid all arguments and

* Of seventy-eight days of winter in 1849, I had here only five of cloudy weather. Of sixty-one days of summer at Brougham, I had but three or four of clear weather; one of these fortunately happened whilst Sir D. Brewster was with me, and he saw the more important experiments.

suggestions upon the two rival theories—the Newtonian or Atomic, and the Undulatory. The conclusions at which I have arrived are wholly independent, as it appears to me, of that controversy. I cautiously avoid giving any opinion upon it; and instead of belonging to the sect of undulationists or anti-undulationists, I incline to agree with my learned and eminent colleague M. Biot, who considers himself as a "*Rieniste,*" and neither "ondulationiste" nor "anti-ondulationiste."

Chateau Eleanor-Louise (*Provence*)*,
1*st November* 1849.

Definitions.

1. *Flexion* is the bending of the rays of light out of their course in passing near bodies. This has been sometimes termed *diffraction*, but *flexion* is the better word.

2. Flexion is of two kinds—*inflexion*, or the bending towards the body; *deflexion*, or the bending from the body.

3. *Flexibility*, *deflexibility*, *inflexibility*, express the disposition of the homogeneous or colour-making rays to be bent, deflected, inflected by bodies near which they pass.

Although there is always presumed to be a flexion and a separation of the most flexible rays from the least flexible (the red from the violet for example) when they pass by bodies, yet the compound rays are not so presumed to be decomposed when reflected by bodies. This is probably owing to the successive inflexions and deflexions before and after reflexion, correcting each other and making the whole beam continue parallel and undecomposed instead of becoming divergent and being decomposed.

Proposition I.

The flexion of any pencil or beam, whether of white or of homogeneous light, is in some constant proportion to the breadth of the coloured fringes formed by the rays after passing by the bending body. Those fringes are not three, but a very great number, continually decreasing as they recede from the bending body, in deflexion, where only one body is acting; and they are real images of the luminous body by whose light they are formed.

Exp. 1. If an edge be placed in a beam or in a pencil of white light, fringes are formed outside the shadow of the edge and parallel to it, by deflexion. They are seen distinctly to be coloured, the red being furthest from the shadow, the violet nearest, the green in the middle between the red and the violet. The best way to observe this is to receive the light on an instrument composed of two vertical and two horizontal plates, each moving by a screw so as to increase or lessen the distance

* In experiments at this place, in winter, I found one great advantage, namely, the more horizontal direction of the rays. In summer they are so nearly vertical, that a mirror must be used to obtain a long beam or pencil, which is often required in these experiments, and so the loss of light countervails the greater strength of the summer sun's light.

Fig. 1.

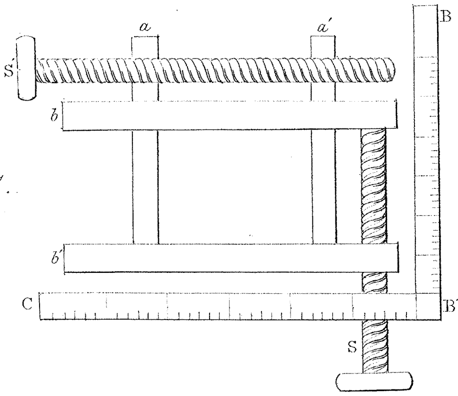


Fig. 2.

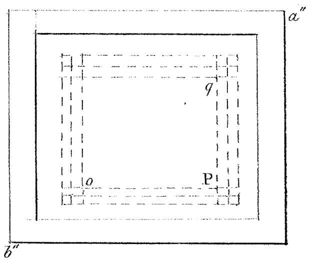


Fig. 3.

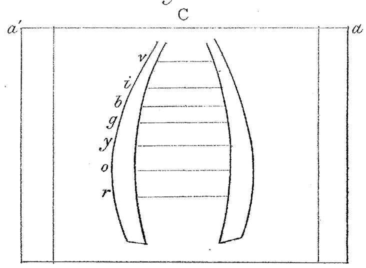


Fig. 4.

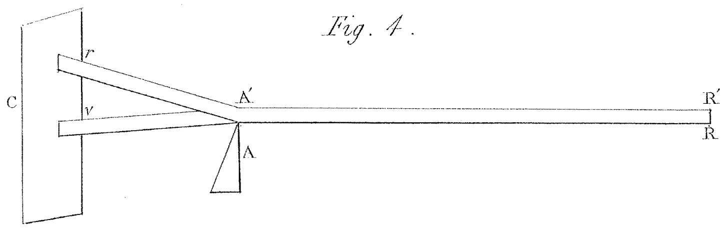


Fig. 5.

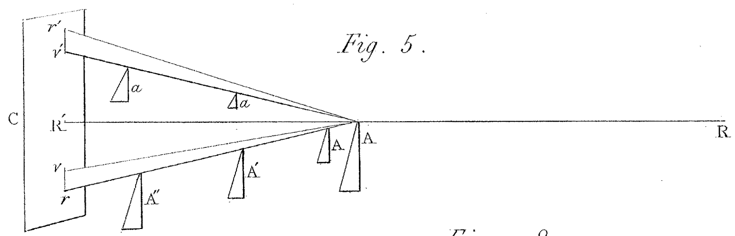


Fig. 6.

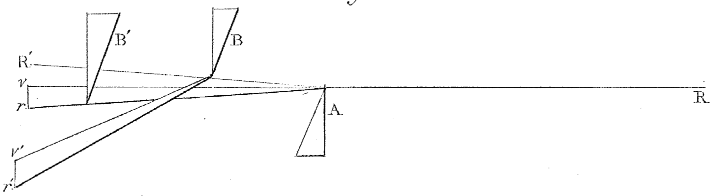


Fig. 7.

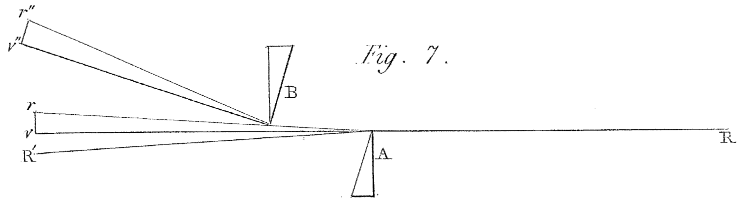


Fig. 8.

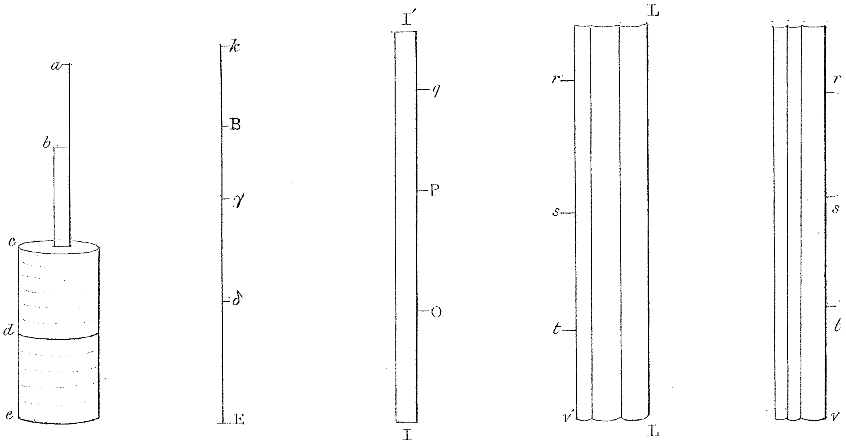


Fig. 9.

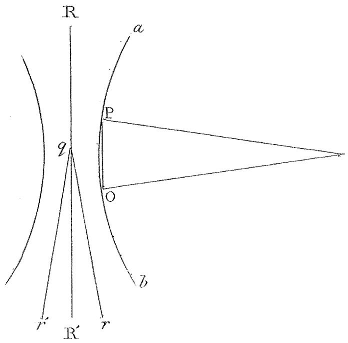


Fig. 10.

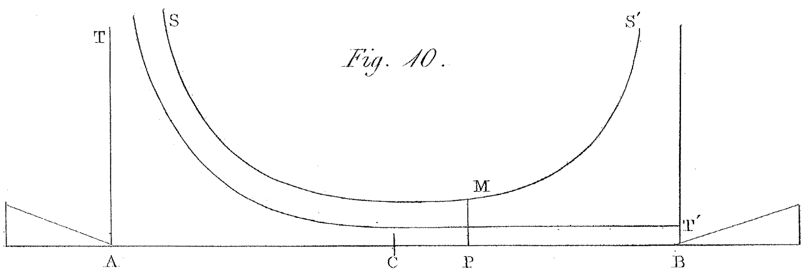
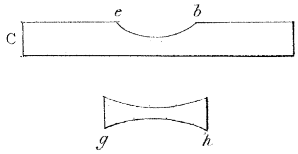


Fig. 12.



between the opposite edges. a, a' are (Plate X. fig. 1) the vertical, b, b' the horizontal edges, s, s' are the screws; and these may be fitted with micrometers, so as to measure very minute distances of the edges by graduated scales B B$'$, B$'$ C. For the purpose of the present proposition the aperture only needs be considered, of about a quarter of an inch square. The light passing through this aperture is received on a chart placed first one foot, and then several feet from the instrument. The fringes are increased in breadth by inclining the chart till it is horizontal, or nearly so, when the fringes parallel to b, b' are to be examined, and holding it inclined laterally when the fringes parallel to a, a' are to be examined. It is also convenient to let the white light beyond the fringes pass through; and for this purpose, a'', b'' being the figure of the instrument (fig. 2), and the light received on the chart, a hole may be made in its centre $o\,p\,q$, through which the greater portion of the white light may be suffered to pass. The fringes are plainly seen to run parallel to the edges forming them; as $o\,p$ parallel to b'' and $p\,q$ parallel to a''. The reddish is furthest from the shadow, the bluish nearest that shadow; also the fringe nearest the shadow is the broadest, the rest decrease as they recede from the shadow into the white light of the disc. Sometimes it is convenient to receive the fringes on a ground glass plate, and to place the eye behind it. They are thus rendered more perceptible.

When the edges are placed in homogeneous light, they are all of the colour which passes by any edge; and two diversities are here to be noted carefully. *First,* the fringes made by the red light are broader than those made by any of the other rays, and the violet are the narrowest, the intermediate fringes being of intermediate breadths. *Second,* the fringes made by the red are furthest from the direct rays, the violet nearest those rays, the intermediate at intermediate distances. This is plainly shown in the following experiment.

Exp. 2. In fig. 3, C represents the image of the aperture when the rays of the prismatic spectrum are made to pass through it. But instead of making the fringes by a single edge deflecting, and so casting them in the spectrum, I approach the opposite edges, so that both acting together on the light, the fringes are seen in the shadow and surrounding the spectrum. These fringes are no longer parallel to the shadows of the edges as they were in the white light, but incline towards the most refrangible and least flexible rays, and away from the least refrangible and most flexible. Thus the red part r of the fringes is nearest the shadow of the edge a'; the orange, o, next; then yellow, y; green, g; blue, b; indigo, i; and violet, v. Moreover, the fringe $r\,v$ is both inclined in this manner, so that its axis is inclined, and also its breadth increases gradually from v to r. This is a complete refutation of the notion entertained by some that Sir I. Newton's experiment of measuring the breadths in different coloured lights and finding the red broadest, the violet narrowest, explains the colours of the fringes made in white light as if these were only owing to the different breadths of the fringes formed by the different rays. The present experiment clearly proves, that not only the fringes are broadest in the least refrangible rays, but those rays are bent most out of their course, because both the axis of the fringes is inclined, and also their breadths are various.

Exp. 3. Though called by GRIMALDI, the discoverer, the three fringes, as well as by NEWTON and others who followed him, they are seen to be almost innumerable, if viewed through a prism to refract away the scattered light that obscures them. I stated this fact many years ago*.

Exp. 4. That the fringes are images may be at once perceived, not when formed in the light disc as in some of the foregoing experiments, but when formed in the shadow. Thus when the opposite edges are moved so near one another as to form fringes bordering the luminous body's image, they are formed like the disc they surround. When you view a candle through the interval of the opposite edges, you perceive that the fringes are images of its flame, with the wick, and that they move as the flame moves to and fro. When you observe the half-moon in like manner, you perceive that the side of the fringes answering to the rectilinear side of the moon, are rectilinear, and the other side circular; and when the full moon is thus viewed, the fringes on both sides are circular. The circular disc of the moon is, indeed, drawn or elongated as well as coloured. It is, that is to say, the fringe or image is exactly a spectrum by flexion. Like the prismatic spectrum, it is oblong, not circular, and it is coloured; only that its colours are much less vivid than those of the prismatic spectrum.

PROPOSITION II.

The rays of light, when inflected by bodies near which they pass, are thrown into a condition or state which disposes them to be on one of their sides more easily deflected than they were before the first flexion; and disposes them on the other side to be less easily deflected: and when deflected by bodies, they are thrown into a condition or state which disposes them on one side to be more easily inflected, and on the other side to be less easily inflected than they were before the first flexion.

Let RA (fig. 4) be a ray of light whose opposite sides are R A, R′ A′, and let A be a bending edge near which the ray passes, the side R′ A′ acquires by A's inflexion, a disposition to be more easily deflected by another body placed between A and the chart C, and the side R A acquires a disposition to be less easily deflected than before its first flexion; and in like manner R′ A′ acquires a disposition to be more easily inflected, and R A a disposition to be less easily inflected by a body placed between A and C.

Exp. 1. Place A′ (fig. 5) in any position between A and $v r$, the image made on C by A's influence, as at A′ or A″, or close to A at A‴. If it is placed on the same side of the ray with A, no difference whatever can be perceived to be made on the breadth of $r v$, or on its distance v R′ from the direct ray R R′. In like manner the image by deflexion $r' v'$ is not affected at all, either in its breadth, or in its removal from R R′ by any object, a, a', placed on the same side with A of the deflected ray A v'.

* Philosophical Transactions, 1797, Part II.

But (fig. 6) place B anywhere between A and *v r* on the side of the ray opposite to A, and the breadth of *r v* is increased, and also its distance from the direct ray R R′, as *v′ r′*; and in like manner (fig. 7) the deflected rays A *v*, A *r* are both more separated, making a broader image at *r″ v″*, and are further removed from RR′ by B's inflexion.

Exp. 2. If you bend the rays either by a single edge, or by the joint action of two edges, it makes not the least difference either in the breadth or in the distance from the direct rays of the images, or in the distension or elongation of the luminous body's disc, whether the bending body is a perfectly sharp edge (which in regard to the rays of light is a surface, though a narrow one), or is a plane (that is, a broader surface), or is a curve surface of a very small, or of a very large radius of curvature.

In fig. 8, *a e* is an instrument composed of four pieces of different forms, but all in a perfectly straight line; *a b* is an extremely sharp edge; *b c* a flat surface; *c d* a cylindrical or circular surface of a great radius of curvature; *d e* one of a small radius of curvature. But all these pieces are so placed that E $\delta\gamma$ is a tangent to *e d*, *d c*, and is a continuation of $\gamma\beta$ K, that is, of *c b*, *b a*. So the light passing by the whole *a b c d e*, passes by one straight line E K, uniting or joining the four surfaces. It is found that the image or fringe I I′, made by *a b c d e* (or E $\delta\gamma\beta$ K), is of the same breadth and in the same position throughout its whole length. So if directly opposite to this edge another straight edge is placed, and acts together with *a b c d e* on the light passing, the breadth of the fringe I is increased, and its distance is increased from the direct rays, but it has the exact same breadth from I to I′; its portion I′ *q* answering to *a b*, *q* P answering to *b c*, P O answering to *c d*, and O I answering to *d e*, are of the same breadth, provided care be taken that the second edge is exactly parallel to the edge E K. And this experiment may be made with the second edge behind *a b c d e*, as in Exp. 1 of this proposition; also it may be usefully varied by having the second edge composed of four surfaces like the first, only it becomes the more necessary to see that this compound edge is accurately made and kept quite parallel to the first, any deviation, however minute, greatly affecting the result. When care is thus used the fringes are as in *r v*, *v′ r′*, quite the same in breadth and in position through their whole length; and not the least difference is to be discerned in them, whether made by a second edge, which is one sharp edge, or by a compound second edge, similar to *a b c d e*.

Hence I conclude that the beam passing by the compound edge, or compound edges, is exactly as much distended by the different flexibility of the rays, and is exactly as much bent from its direct course when the flexion is performed by a sharp edge, by a plane surface, by a very flat cylinder, or by a very convex cylinder; and therefore that all the action of the body on the rays is exercised by one line, or one particle, and not first by one and then by others in succession; and this clearly proves that after a first flexion takes place, no other flexion is made by the body on the same side of the rays. This is easily shown.

For a plane surface is a series or succession of edges infinitely near each other;

and a curve surface in like manner is a succession of infinitely small and near plane surfaces or edges. Let *a b* (fig. 9) be the section of such a curve surface. The particle P coming first near enough the ray R R′ to bend it, then the next particle O is only further distant from R R′, the unbent ray, than the particle P by the versed sine of the infinitely small arch O P. But O is not at all further distant than P from the ray bent by P into *q r*, and yet we see that O produces no effect whatever on the ray after P has once bent it. No more do any of the other particles within whose spheres of flexion the ray bent by P passes. The deflected ray *q r′* no doubt is somewhat more distant from O than the incident ray was from P, but not so far as to be beyond O's sphere of deflexion; for O acts so as to make the other fringes at greater distances than the first. Consequently O could act on the first fringe made by P as much as P can in making the second, third, and other fringes; and if this be true of a curve surface, it is still more so of a plane surface; all whose particles are clearly equidistant from the ray's original path, and the particles after the first are in consequence of that first particle's flexion nearer the bent ray, at least in the case of inflexion. But it is to be observed, moreover, that in the experiment with two opposite edges, inflexion enters as well as deflexion, and consequently this demonstration, founded on the exact equality of the fringes made by compound double edges, appears to be conclusive. For it must be observed that this experiment of the different edges and surfaces, plane and curve, having precisely the same action, is identical with the former experiment of two edges being placed one behind the other, and the second producing no effect if placed on the same side of the ray with the first edge. These two edges are exactly like two successive particles of the same surface near to which the rays pass. Consequently the two experiments are not similar but identical; and thus the known fact of the edge and the back of a razor making the same fringes, proves the polarization of the rays on one side. Thus the proposition is proved as to polarization.

Exp. 3. The proposition is further demonstrated, as regards disposition, in the clearest manner by observing the effect of two bodies, as edges, whether placed directly opposite to each other while the rays pass between them so near as to be bent, or placed one behind the other but on opposite sides of the rays. Suppose the edges directly opposite one to the other, and suppose there is no disposition of the rays to be more easily bent by the one edge in consequence of the other edge's action. Then the breadth and distension and removal of the fringes caused by the two edges acting jointly, would be in proportion to the sum of the two separate actions. Suppose that one edge deflects and the other inflects, and suppose that inflexion and deflexion are equal at equal distances, following the same law; then the force exerted by each edge being equal to *d*, that exerted by both must be equal to 2 *d*. But instead of this we find it equal to 5*d*, or 6*d*, which must be owing to the action of the two introducing a new power, or inducing a new disposition on the rays beyond what the action of one did.

If, however, we would take the forces more correctly (fig. 10), let A and B be the two edges, and let their spheres of flexion be equal, AC($=a$) being A's sphere of inflexion and B's sphere of deflexion; BC ($=a$) being A's sphere of deflexion and B's sphere of inflexion; and let the flexion in each case be inversely as the mth power of the distance. Let CP$=x$, PM$=y$, the force acting on a ray at the distance $a+x$ from A and $a-x$ from B. Then if B is removed and only A acts, $y=\frac{1}{(a+x)^m}$. If B also acts, $y'=\frac{1}{(a+x)^m}+\frac{1}{(a-x)^m}$.

Now the loci of y and y' are different curves, one similar to a conic hyperbola, the other similar to a cubic; but of some such form when $m=1$, as S S$'$ and T T$'$. It is evident that the proportion of $y:y'$ can never be the same at any two points, and consequently that the breadths of the fringes made by the action of one can never bear the same proportion to the breadths of those made by the action of both, unless we introduce some other power as an element in the equation, some power whereby from both values, y and y', x may disappear, else any given proportion of $y:y'$ can only exist at some one value of x. Thus suppose (which the fact is) $y:y'::1:5$ or $1:6$, say $::1:6$, this proportion could only hold when

$$x=\frac{\left(5^{\frac{1}{m}}-1\right)a}{5^{\frac{1}{m}}+1} \text{ or } =\frac{\left(4^{\frac{1}{m}}-1\right)a}{4^{\frac{1}{m}}+1}, \text{ if } y:y'::1:5.$$

When $m=2$, the force being inversely as the square of the distance, then $x=\frac{a}{3}$ and $x=\frac{(\sqrt{5}-1)}{\sqrt{5}+1}a$, are the values at which alone $y:y'::1:5$ and $1:6$ respectively.

But this is wholly inconsistent with all the experiments; for all of these give nearly the same proportion of $y:y'$ without regard to the distance, consequently the new element must be introduced to reconcile this fact. Thus we can easily suppose the conditions, *disposition* and *polarization* (I use the latter term merely because the effect of the first edge resembles polarization, and I use it without giving any opinion as to its identity), to satisfy the equation by introducing into the value of y some function of $a-x$. But that the joint action of the two edges never can account for the difference produced on the fringes, is manifest from hence, that whatever value we give to m, we find the proportion of $y':y$ when $x=0$ only that of double, whereas 5 or 6 times is the fact. The same reasoning holds in the case of the spheres of flexion being of different extent; and there are other arguments arising from the analysis on this head, which it would be superfluous to go through, because what is delivered above enables any one to pursue the subject. The demonstration also holds if we suppose the deflective force to act as $\frac{1}{n}$ of the distance, while that of inflexion acts as $\frac{1}{m}$. But I have taken $m=n$ as simpler, and also as more probably the fact.

I have said that the rays become less easily inflected and deflected; but it is plain that on the polarized side they are not inflected or deflected at all. Their disposition on the opposite side is a matter of degree; their polarization is absolute and their flexion null.

PROPOSITION III.

The rays disposed on one side by the first flexion are polarized on that side by the second flexion, and the rays polarized on the other side by the first flexion are depolarized and disposed on that side by the second flexion.

This proposition is proved by carefully applying the first experiment of Prop. II.; but great care is required in this experiment, because when three edges are used consecutively, the third edge often appears to act on rays previously acted on by both the other two, when it is only acting on those previously acted on by one or other of those two. Thus when edge A has inflected and edge B afterwards deflects the rays disposed by A, a third edge C may, when applied on the side opposite to B, seem to increase the flexion, and yet on removing A altogether we may find the same effect continue, which proves that the only action exercised had been by B and C, and that C had not acted on rays previously bent by both A and B, which the experiment of course requires to prove the proposition. I was for a long while kept in great uncertainty by this circumstance, whether the third edge ever acted at all. That it never acted on the side of the ray on which the second edge acted, I plainly saw; but I frequently changed my opinion whether or not it acted on the opposite side, that is, on the same side with the first edge. Nor could I confidently determine this important point until I had the benefit of an instrument which I contrived for the purpose, and which, executed by M. SOLEIL, enabled me satisfactorily to perform the *experimentum crucis* as follows:—

In fig. X. AB is a beam, on a groove (of which the sides are graduated) three uprights are placed, the one, B, fixed, the other two, C and D, moving in the groove

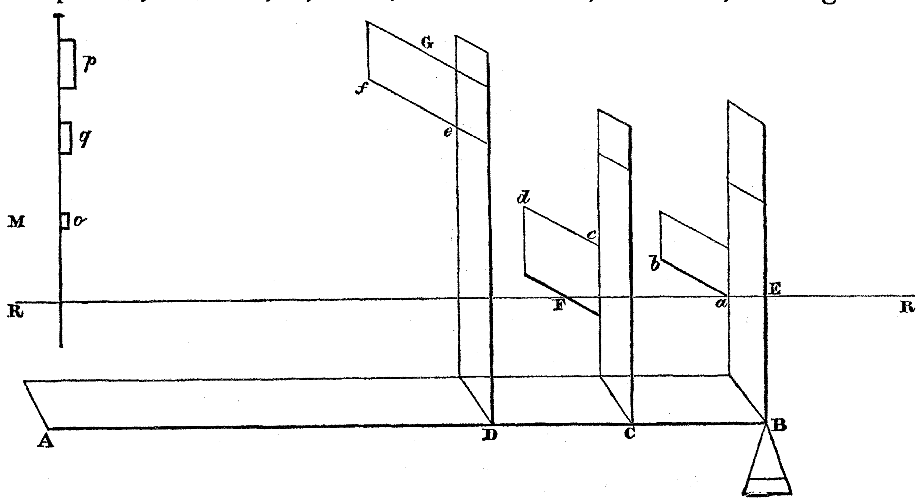


fig. X.

of AB. On each of the uprights is a broad sharp-edged plate, moving up and down the upright by a rack and pinion, so that both the plates F, G could be approached as near as possible to each other, and so could F be approached to the plate E on the fixed upright B; while also each of the three plates could be brought as near the rays that passed as was required; and so could each be brought as near the opposite edge of the neighbouring plate. It is quite necessary that this instrument should be heavy in order to give it solidity; it is equally necessary that the rack and pinion movement should be just and also easy; for the object is to fix the plates at will, so that their position in respect of the rays may be easily changed, and when once adjusted may be immovable until the observer desires to change their position.

The light was passed under the plate E and acted upon by *a b,* its lower edge. The second plate E was then raised on C so as to act on the side of the rays opposite to *a b*, by its upper edge *c d.* The fringes inflected by *a b* were thus deflected by *c d,* in virtue of the disposition given to the side next *c d.* Then the third plate G, on its stand D, was moved so that it could be brought to act by its lower edge *e f*, which was approached to the rays deflected by *c d,* and placed on their opposite side. The action was observed by examining the fringes on the chart M. Those which had been as *o,* made by the joint action of the two first edges E, F, were seen to move upwards to *p* as the third edge G came near the rays; and *p* was both broader than *o*, and further removed from the direct rays R R′. In order to make quite sure that this change in the size and position of *o* had not been occasioned by the mere action of two plates, as E and G or F and G, it was quite necessary to remove first E, by drawing it up the stand B. If the fringe *p* then vanished, complete proof was afforded that E had acted as well as G. Then F was removed, and if *p* vanished, proof was afforded that F acted as well as E and G. A very convenient variation of the experiment was also continued and was found satisfactory. When the joint action of F and G gave a fringe, as at *q*, E being removed up the stand B, then E was gently moved down that stand, and as it approached the pencil, which was on its way to F and G, you plainly perceived the fringe enlarged and removed from *q* to *p*. These experiments were therefore quite crucial, and demonstrated that all the edges had concurred to form the fringe at *p*, the first and third inflecting, the second de flecting.

The same experiments were made on the fringes formed by the deflexion of the first edge and the inflexion of the second, and the deflexion of the third.

It is thus perfectly clear that the rays bent by the first edge and disposed on their side opposite to that edge, are bent in the other direction by the second edge acting on that opposite side, and are afterwards again bent in the direction of the first bending by the action of the third edge upon the side which was opposite the second edge and nearest the first edge. But this side is the one polarized by the first edge, and therefore that side is depolarized by the action of the second edge. Hence it is proved that the rays polarized by one flexion are depolarized by a second; and as it is proved by repeated experiments that no body placed on the same side of the rays with any of the bending bodies, whether the first or the second or the third, exercises any action on those rays, it is thus manifest that any one flexion having disposed, a second polarizes the disposed side; and that any one flexion having polarized, a second flexion depolarizes and disposes the polarized side.

Exp. 3. Another test may be applied to this subject. Instead of a rectilinear edge, I made use of edges formed into a curve, as in fig. 12, where C is such an edge, and then the figure made is *g h*, corresponding to the curve *e b*. The first edge in the last experiment being formed like C, instead of a straight-lined edge, we can at once perceive that it has acted on the rays as well as the second and third edges, because these being straight-lined, never could give the comb-like shape *g h* to the fringes. This completely confirmed the other observations, and made the inference irresistible.

Proposition IV.

The disposition communicated by the flexion to the rays is alternative; and after inflexion they cannot be again inflected on either side; nor after deflexion can they be deflected. But they may be deflected after inflexion and inflected after deflexion, by another body acting upon the sides disposed, and not by its acting upon the sides polarized.

This is gathered from the experiments in proof of the second and third propositions.

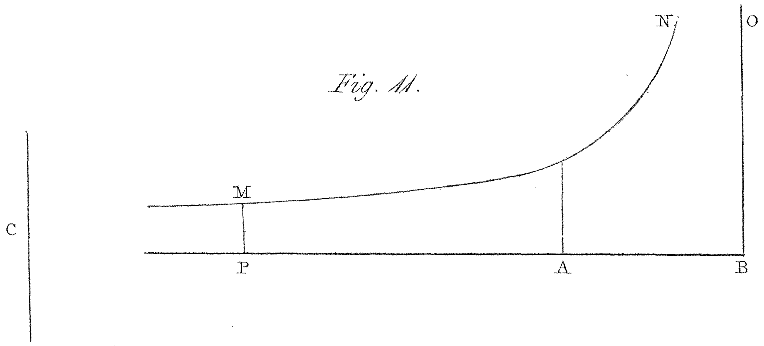
Proposition V.

The disposition impressed upon the rays, whether to be easily deflected or easily inflected by a second bending body, is strongest nearest the first bending body, and decreases as the distance between the two bodies increases.

Plate XI. fig. 11. Let $AB=a$ be the distance between the first bending body and a given point, more or less arbitrarily assumed; P the second body; $AP=x$; $PM=y$, the force exerted by the second body at P; C= the chart; $PM=y$ is in some inverse proportion to A P, but not as $\frac{1}{AP^m}$ or $\frac{1}{x^m}$, because it is not infinite at A, but of an assignable value there; therefore $y=\frac{1}{(a+x)^m}$; and the curve which is the locus of P has an asymptote at B, when $x=-a$. The fringes being received on the chart at C, it might be supposed that the difference in their breadth, by which I measure the force, or y, is owing to P approaching the chart C, in proportion as it recedes from A, and thus making the divergence less in the same proportion; but the experiments are wholly at variance with this supposition.

Exp. 1. The following table is the result of one such experiment. The first column contains the distances horizontally of P from A, being the sines of the angle made by the rays with the vertical edges; the second column contains the real distance of the second from the first edge, the secant of that angle; the third column gives the breadths of the fringes at the distances given in the preceding columns; the fourth gives the values of y, supposing M N were a conic hyperbola.

Fig. 11.



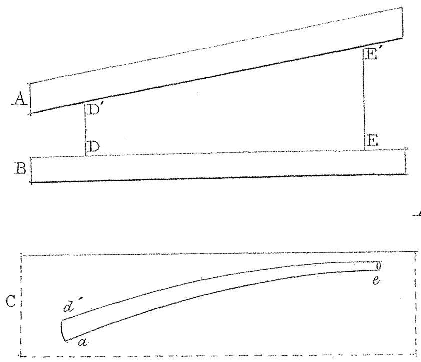
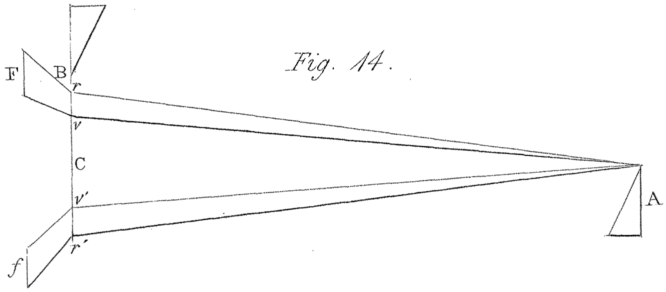


Fig. 13.

Fig. 14.



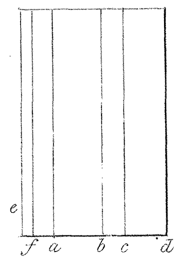


Fig. 16.

Fig. 15

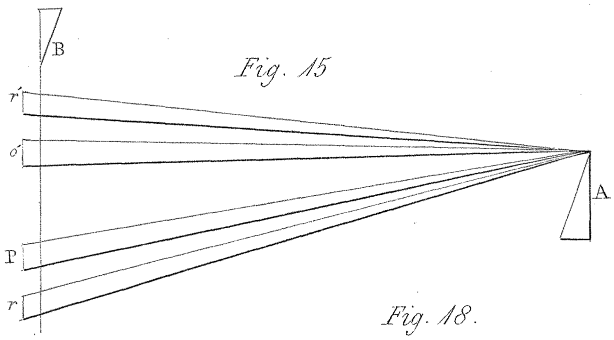


Fig. 17.

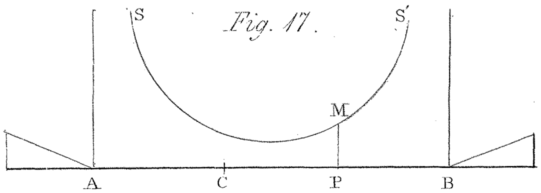
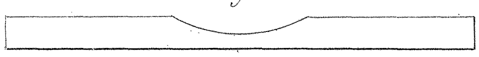
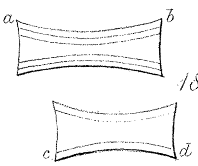


Fig. 18.





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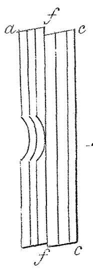


Fig. 21.

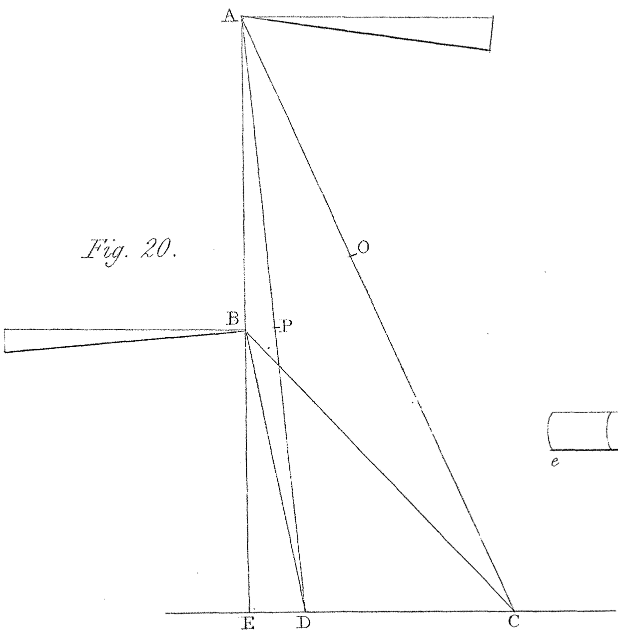


Fig. 20.

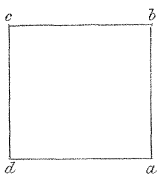


Fig. 19.

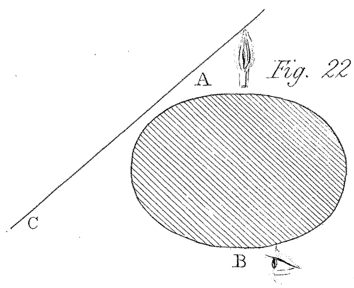


Fig. 22.

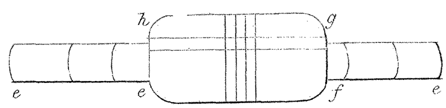


Fig. 19.

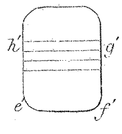


Fig. 19.

Sines.	Secants.	Real value of y.	Hyperbolic value.
20	35	$3\frac{1}{2}$	$3\frac{1}{2}$
65	85	$1\frac{2}{3}$	$1\frac{11}{17}$
85	$107\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{3}$
195	240	$0\frac{1}{2}$	$0\frac{7}{12}$

The unit here is $\frac{1}{20}$th of an inch.

It is plain that this agrees nearly with the conic hyperbola, but in no respect with a straight line; and upon calculating what effect the approach of P to C would have had, nothing could be more at variance with these numbers. But

Exp. 2. All doubt on this head is removed by making P the fixed point, and moving the first edge A nearer or further from it. In this experiment, the disturbing cause, arising from the varying distance from the chart, is entirely removed; and it is uniformly found that the decrease in the force varies notwithstanding with the increase of the distance. I have here only given the measures by way of illustration, and not in order to prove what the locus of y (or P) is, or, in other words, what the value of m is.

Exp. 3. When one plate with a rectilinear edge is placed in the rays, and a second such plate is placed at any distance between it and the chart, the fringes are of equal breadth throughout their length, and all equally removed from the direct rays, each point of the second edge being at the same distance from the corresponding point of the first. But let the second plate be placed at an angle with the first, and the fringes are very different. It is better to let the second be parallel to the chart, and to incline the first; for thus the different points of the fringes are at the same distance from the edge which bends the disposed rays. In fig. 13, B is the second plate, parallel to the chart C; A is the first plate; all the points of B, from D to E, are equidistant from C; therefore nothing can be ascribed to the divergence of the bent rays. B bends the rays disposed by A at different distances D D′ and E E′ from the point of disposition. The fringe is now of various breadths from $d\,d'$ to e, the broadest part being that answering to the smallest distance of D, the point of flexion, from D′ the point of disposition; the narrowest part, e, answering to E E′, or the greatest distance of the point of flexion from the point of disposition. Moreover, the whole fringe is now inclined; it is in the form of a curve from $d\,d'$ to e, and the broad part $d\,d'$, formed by the flexion nearest the disposition, is furthest removed from the direct rays; the narrowest part, e, is nearest these direct rays. It is thus quite clear that the flexion by B is in some inverse proportion to the distance at which the rays are bent by B from the point where they were disposed by A. I repeatedly examined the curve $d\,e$, and found it certainly to be the conic hyperbola. Therefore $m=1$, and the equation to the force of disposition is $y=\frac{1}{x}$.

In order to ascertain the value of m, I was not satisfied with ordinary admeasurements, but had an instrument made of great accuracy and even delicacy. It consisted of two plates, A and B (Plate VI.), with sharp rectilinear edges, one, A, horizontal, the other, B, moving vertically on a pivot, and both nicely graduated. The angle at which the second plate was vertically inclined to the first, was likewise ascertained by a vertical graduated quadrant E. Moreover the edges moved also horizontally, and their angle with each other was measured by a horizontal graduated quadrant K. There was a fine micrometer F to ascertain the distances of the two edges from each other, and another to measure the breadth of the fringes on the chart. The observations made with this instrument gave me undoubted assurance that the equation to the curve M N in fig. 11 is $yx=a$, a conic hyperbola, and that the disposing force is inversely as the distance at which the flexion of the rays bent and disposed takes place.

Scholium.—It is clear that the extraordinary property we have now been examining, has no connexion with the different breadths of the pencils at different distances from the point of the first flexion, owing to the divergence caused by that flexion.

By the same kind of analysis, which we shall use in demonstrating the 6th Proposition, it may be shown,—*first*, that the divergence of the rays alone would give a different result, the fringes made by an inflexion following a deflexion and those made by a deflexion following an inflexion; *secondly*, that in no case would the equation to the disposing force be the conic hyperbola, even where that fringe decreased with the increase of the distance; *thirdly*, even where the effect of increasing the distance is such as the dispersion would lead to expect, the rate of decrease of the fringes is very much greater in fact than that calculation would lead to, five or six times as great in many cases; and *lastly*, that instead of the law of decrease being uniform, it would, if caused by the dispersion, vary at different distances from the two edges*. Nothing therefore can be more manifest than that the phenomena in question depend upon a peculiar property of the rays, which makes them change in their disposition with the length of the space through which they have travelled.

It should seem that light may be compared, when bent and thereby disposed, to a body in its nascent state, which, as we find by constant experience, has properties different from those which it has afterwards; and I have therefore contrived some experiments for the purpose of ascertaining whether or not light at the moment of its production (by artificial means) has properties other than those which it possesses after it has been some time produced. This will form the subject of a future inquiry. I would suggest, however, at present that the electric fluid ought to be examined with a view to find whether or not it has any property analogous to disposition, that is, whether it becomes more difficultly attracted at some distance from its evolution, as light is more difficultly bent at a distance from the point of its being disposed. On heat a like experiment may be made. The thermometer would no doubt stand at a different height at different distances from the source of the heat; but the question

* I have given demonstrations of these propositions in a memoir presented to the National Institute, but I am reluctant to load the present paper with them.

is if it will not reach its full height, whatever that may be, more quickly near its source than far from it. This experiment ought above all to be made on radiant heat, in which I confidently expect a property will be found similar to the disposition of light. It is also plain that we may expect strong analogies in magnetism and electro-magnetism.—I throw out these things because my time for such investigations may not be sufficiently extended to let me undertake them with success.

Proposition VI.

The figures made by the inflexion of the second body acting upon the rays deflected by the first, must, according to the calculus applied to the case, be broader than those made by the second body deflecting those rays inflected by the first.

In fig. 14, let A v' be the violet rays and A r' the red, inflected by A and deflected by B. Let A r be the red and A v the violet deflected by A and inflected by B. The action of B must inflect A r, A v into a broader fringe F, than the action of B deflects A v', A r' into the fringe f.

Let B $r=a$ be the distance at which B acts on A r; $rv=d$ be the divergence of the red and violet; c be the distance of the two bent pencils, and $v'r'$ the divergence of the inflected pencil, equal also to d, because we may take the different inflexibility to be as the different deflexibility. B acts on the red of A rv as $\frac{r}{a^m}$; on the violet as $\frac{v}{(a+d)^m}$; and so on A v' as $\frac{v}{(a+d+c)^m}$; on A r' as $\frac{r}{(a+2d+c)^m}$. It is evident that the action in bending A r, A v, or the fringe made by that action, is to the fringe made by the action on A r', A v', as $\frac{r}{a^m}-\frac{v}{(a+d)^m} : \frac{r}{(a+2d+c)^m}-\frac{v}{(a+d+c)^m}$; and ultimately the two actions (or sets of fringes) are (supposing $a=1$ and d also $=1$, for simplifying the expression) as

$$2^m \times r\ (3+c)^m\ (2+c)^m - v\ (3+c)^m\ (2+c)^m \text{ to } 2^m r\ (2+c)^m - 2^m v\ (3+c)^m.$$

Now the former of these expressions must always be greater than the latter, because $(3+c)^m>1$, and also $(3+c)^m-1>(2+c)^m-1$; and this whatever be the value of m and of c, and whatever proportion we allow of r to v, the flexibilities. But it is also manifest that the excess of the first expression above the second will be greater if the flexibility of the red exceed that of the violet, or if r is greater than v, as $2v$. Hence we conclude; *first*, that in mixed or white light the fringes inflected by B after deflexion by A are greater than those deflected by B after inflexion by A; *secondly*, that they are also greater in homogeneous light; *thirdly*, that the excess of the inflected fringes over the deflected is greater in mixed than in homogeneous light.

The action of flexion after disposition is so much greater than that of simple flexion, that I have only taken into the calculation the compound flexion. But the most accurate analysis is that which makes the two fringes as

$$D+\frac{r}{a^m}-\frac{v}{(a+d)^m} \text{ to } D+\frac{r}{(a+2d+c)^m}-\frac{v}{(a+d+c)^m},$$

D being the breadth of the fringes on the chart by simple flexion in case the rays had passed on without disposition and without a second flexion. If it be carefully kept in mind that D is much less than $\frac{r}{a^m}$, or even $\frac{r}{(a+2d+c)^m}$, and that d is still less than D, then it will always be certain that the first quantity is larger than the second.

Cor.—It is a corollary to this proposition that the difference of the two sets of fringes is increased by the disposition communicated by the rays in passing by the first body. For the excess of the value of r over that of v being increased, the difference between the two expressions is increased.

Proposition VII.

When one body only acts upon the rays, it must, by deflexion, form them into fringes or images decreasing as the distance from the bending body increases. But when the rays deflected and disposed by one body are afterwards inflected by a second body, the fringes will increase as they recede from the direct rays. Also when the fringes made by the inflexion of one body, and which increase with the distance from the direct rays, are deflected by a second body, the effect of the disposition and of the distances is such as to correct the effect of the first flexion, and the fringes by deflexion of the second body are made to decrease as they recede from the direct rays.

In fig. 15, A P is the pencil inflected by A and forming the first and narrower fringe p; A r is the pencil inflected nearer to A and forming the broader fringe r. Such are the relative breadths, because they are inversely as some power of the distance at which A acts on them. But if B afterwards acts, it is shown by the same reasoning which was applied to the last proposition that r will be less than p; and so in like manner will r' be made less than o', though o' was greater than r', until B's action, and the effects of disposition with the greater proximity of the smaller fringe, altered the proportions.

Proposition VIII.

It is proved by experiment that the inflexion of the second body makes broader fringes or images than its deflexion after the inflexion of the first body; and also that the inflecto-deflexion fringes decrease, and the deflecto-inflexion fringes increase with the distance from the direct rays.

Exp. 1. It must be observed that when we examine the fringes (or images) made by the second edge deflecting the rays which the first had inflected, we can see the effects of the disposition communicated to the rays at a much greater distance of the second edge from the first, than we can perceive the effects of that disposition upon the inflexion by the second edge of the rays deflected by the first. Indeed we only lose the fringes thus made by deflexion, in consequence of their becoming so minute as to be imperceptible to our senses. But it is otherwise with the fringes or images made by the second edge inflecting the rays which the first had deflected. These can only be seen when the second edge is near the first, because the rays cannot pass on so as to form the images on the chart, if the second is distant from the first. The pencils diverge both by the deflexion and by the inflexion of the first edge. But we can always, when the inflected rays pass too far from the second edge, bring this so near them as to act on them, whereas we in so doing intercept the deflected rays. However, after this is explained, we find no difficulty in examining the effects of the inflexion by the second edge, only we must place it near the first, and thus we have two sets of fringes, one extending into the shadow of the first edge at an inch distance between the two edges; but at three-fourths of an inch, nay, at two inches, or even more, this experiment can well be made.

Exp. 2. At these distances I examined repeatedly the comparative breadths of the two sets. In fig. 16, *a b* is the white disc, on each side of which are fringes; those on the one side, *b c*, *c d*, are by the inflexion of the second edge; those on the opposite side, *a f*, *f e*, are by the deflexion of that second edge. I repeatedly measured these sets of fringes, and at various distances from the second edge; and I always found them much broader on the side of the second edge than on the opposite side. Thus *a b* being the breadth of 5, *b c* was 3, and *c d* $4\frac{1}{2}$, while, on the opposite side, *a f* was $=1$ and *f e* only $\frac{3}{4}$ or $\frac{1}{2}$. The fringes by inflexion of the second edge also uniformly increased as they receded from *a b*, the direct rays, whereas the opposite fringes as constantly decreased.

Exp. 3. If however the distance between the two edges be reduced, it is observed that the disparity between the two sets of fringes decreases, and they become gradually nearly equal; and when the edges are quite opposite each other there is no difference observable in the two sets. Each ray is disposed and polarized alike and affected alike by the two edges, and no difference can be perceived between the two sets.

Exp. 4. The experiments also agree entirely with the calculus in respect of the relative values of r and v affecting the result. It appears that the fringes by the second edge's inflexion are broader than those by that edge's deflexion, whether we use white or homogeneous light. In the latter, however, the difference is not so considerable. This I have repeatedly tried and made others try, whose sight was better than my own. I may take the liberty of mentioning my friend Lord Douro, who has, I believe, hereditarily, great acuteness of vision.

Proposition IX.

The joint action of two bodies situated similarly with respect to the rays which pass between them so near as to be affected by both bodies, must, whatever be the law of their action, provided it be inversely as some power of the distance, produce fringes or images which increase with the distance from the direct rays.

Let (fig. 17) A and B be the two bodies, and $AC=CB=a$ be their spheres of flexion, so that A inflects and B deflects through A C, and A deflects and B inflects through C B. Let C P$=x$, P M$=y$. The force y, exerted by the joint action of A and B on any ray passing between them at P, is equal to $\frac{1}{(a+x)^m}+\frac{1}{(a-x)^n}$, supposing deflexion and inflexion to follow different laws. To find the minimum value of y, take its differential $dy=0$; therefore we have

$$-m(a+x)^{-m-1}dx+n(a-x)^{-n-1}dx=0, \text{ or } m(a-x)^{n+1}=n(a+x)^{m+1}.$$

If $m=n$ (as there is every reason for supposing), then $a-x=a+x$, or $x=0$; and therefore, whatever be the value of m (that is whatever be the law of the force), the minimum value of y is at the point C where A's deflexion begins. The curve S S′, which is the locus of M, comes nearest the axis at C, and recedes from that axis constantly between C and B. Hence it is plain that the fringes must increase (they being in proportion to the united action of A and B) from C to B; and in like manner must those made by B's deflexion and A's inflexion increase constantly from C to A; and this is true whatever be the law of the bending force, provided it is in some inverse ratio to the distance.

Proposition X.

It is proved by experiment that the fringes or images increase as the distance increases from the direct rays.

Exp. 1. Repeated observations and measurements satisfy us of this fact. We may either receive the images on a chart at various distances from the double edge instrument, approaching the edges until the fringes appear, or we may receive them on a plate of ground glass held between the sun and the eye. We may thus measure them with a micrometer; but no such nicety is required, because their increase in breadth is manifest. The only doubt is with respect to their relative breadth when the edges are not very near and just when they begin to form fringes. Sometimes it should seem that these very narrow fringes decrease instead of increasing. However, it is not probable that this should be found true, at least when care is taken to place the two edges exactly opposite each other; because if it were true that at this greater distance of A from B (fig. 17) they decreased, then there must be a minimum value of P M between C and B, and between C and A; and consequently the law of flexion must vary in the different distances of A and B from the rays P, a supposition at variance it should seem with the law of continuity.

Exp. 2. The truth of this proposition is rendered more apparent by exposing the two edges to the rays forming the prismatic spectrum. The increase is thus rendered manifest. If the fringes are received on a ground glass plate, you can perceive twelve or thirteen on each side of the image by the direct rays. It is also worth while to make similar observations on artificial lights, and on the moon's light. The proposition receives additional support from these. But care must always be taken in such observations, which require the eye to be placed near the edges, that we are not misled by the effect of the small aperture in reversing the action of the edges. Thus when viewing the moon or a candle through the interval of two edges, one being in advance of the other, we have the coloured images (or fringes) cast on the wrong side. But if we are only making the experiment required to illustrate this proposition, the edges being to be kept directly opposite, no confusion can arise.

It is to be noted that the increase of breadth in the fringes is not very rapid in any of these experiments; nor are we led by the calculus to expect it. Thus suppose $m=1$, we find $\left(\text{because } y=\frac{2a}{a^2-x^2}\right)$ at the point C, when $x=0$, the breadth should be proportional to $\frac{2}{a}$. Take $x=\frac{a}{10}$, and the breadth is as $\frac{200}{99}$, or the breadth of the one fringe is to the other only as 200 to 198 or 100 : 99. We need not wonder therefore if there is only a gradual increase of breadth from C to B and from C to A. The increase is more rapid between $x=\frac{a}{2}$ and B than between C and $\frac{a}{2}$. Thus between the value of $x=\frac{a}{4}$ and $\frac{a}{2}$ the increase is as 4 : 5. But from $\frac{a}{2}$ to $\frac{3a}{4}$ the increase is as 7 : 12; and this too agrees exactly with the experiments; for as the edges are approached the increase of the fringes becomes more apparent.

Proposition XI.

The phenomena described in the foregoing propositions are wholly unconnected with interference, and incapable of being referred to it.

1. When the fringes in the shadow are formed by what is supposed to be interference, there are also formed other fringes outside the shadow and in the white light. If the rays passing on one side the bending body (as a pin or needle) are stopped, the internal fringes on the opposite side of the shadow are no longer seen. But no effect whatever is produced on the external fringes. These continue as long as the rays passing on the same side of the body on which they are formed, continue to pass. The external fringes have many other properties which wholly distinguish them from the internal or interference fringes.

2. Interference is said to be in proportion to the different lengths of the interfering rays, and not to operate unless those lengths are somewhat near an equality. In my experiments the second body may be placed a foot and a half away from the first, and the fringes by disposition are still found, though much narrower than when the bending bodies are more near to one another.

3. The breadth of the interference fringes is said to be in some inverse proportion to the difference in length of the interfering rays. It is commonly said to be inversely as that difference.

In fig. 20, A is the first and B the second edge. By interference the fringe at C should be broadest and at D narrowest, because A C—B C=A O is less than A D —B D=A P; and so as you recede from D, the fringes should become broader and broader, because the two rays become more nearly equal. But the very reverse is notoriously the case, the breadth of the fringes decreasing with their distance from the direct rays.

4. In the case of the fringes formed by the second body inflecting and the first deflecting, there can be no interference at all; for the whole action is on one and the same pencil or beam. A deflects and then B inflects the same ray; and when a third edge is placed on the opposite side to B, it only deflects the same ray, which is thus twice bent further from the direct rays, the last bending increasing that distance.

5. Let A be the first and B the second edge as before (fig. 20). Suppose B to be moveable, and find the equation to the disposing force at different distances of the two edges, we shall find this to be $y=\frac{1}{\sqrt{a^2+b^2}-\sqrt{(a-x)^2+b^2}}$, a being $=$A E, $b=$E D, and AB$=x$. But all the experiments show it to be $y=\frac{a}{x}$, a wholly different curve.

Again, let B be fixed, or the distance of the two edges be constant, we shall get the equation (a being $=$A E, $b=$B E, $b=$D E and E C$=x$) $y=\frac{1}{\sqrt{a^2+(x-b)^2}-\sqrt{c^2+x^2}}$, also a wholly different curve from the conic hyperbola, which all experiments give. Therefore the conclusion from the whole is that the phenomena have no reference to interference.

Having delivered the doctrines resulting from these experiments, I have some few particulars to add, both as illustrating and confirming the foregoing propositions, as removing one or two difficulties which have occurred to others until they were met by facts, and also as showing the tendency of the results at which we have arrived.

1. It may have been observed that in all these propositions I have taken for granted the inflexion of the rays by the body first acting upon them as well as their deflexion by that body, and have reasoned on that supposition. It is, however, not to be denied that we cannot easily perceive the fringes made by the single inflexion, as we can without any difficulty perceive those made by the single deflexion, and fully described in Proposition I. Sir I. NEWTON even assumes that no fringes are made within the shadow. I here purposely keep out of view the fringes made in the shadow of a hair or other small body, because the principle of interference there comes into play. However, I will now state the grounds of my assuming inflexion and separation of the rays by their different flexibility, when only a single body acts on them. In the *first* place, the first body does act in some way; for the second only acts after the first, and if the first be removed the fringes made in its shadow by the second at once vanish. *Secondly*, these fringes made by the second depend upon its proximity to the first. *Thirdly*, the following experiment seems decisive. Place instead of a straight edge one of the form in fig. 18, and then apply at some distance from it, the second edge, as in the former experiments. You find that the fringes assume the form, somewhat like a small tooth-comb, of $a\,b$. If the second edge is

furnished with a similar curve surface the form is more complete, as in *c d*. But the straight edge being used after the first flexion of the curved one, clearly shows that the first edge bends as well as the second, indeed more than the second, for the side of the figure answering to that curved edge is most curved. *Fourthly*, the whole experiments with two edges directly opposite each other negative the idea of there being no inflexion; indeed they seem to prove the inflexion equal to the deflexion. The phenomena under Proposition X. can in no way be reconciled to the supposition of the first edge not inflecting the rays*.

2. We must ever keep in view the difference between the fringes or images described by Sir I. NEWTON and measured by him, as made by the rays passing on each side of a hair, and the fringes or images which are made without the interference of rays passing on both sides. It is clear that the rays which form those fringes with their dark intervals do not proceed after passing the hair in straight lines. Sir I. NEWTON's measures† prove this; for at half a foot from the hair he found the first fringe $\frac{1}{170}$th of an inch broad, and the second fringe $\frac{1}{290}$; and at nine feet distance the former were $\frac{1}{32}$, the latter $\frac{1}{55}$, instead of being $\frac{1}{9}$ and $\frac{1}{10}$, and the latter less than $\frac{1}{16}$, and so of all the other measures in the table, each being invariably about one-third what it ought to be if the rays moved in straight lines; and this also explains why the fringes do not run into one another, or encroach on the dark intervals in the case of the hair, as they must do if the rays moved in straight lines.

But the case of the fringes or images which we have been examining and reasoning upon is wholly different. I have measured the breadths of those formed by disposition and polarization, and found that they are broad in proportion to the distance from the bending edge of the chart on which they are received; and vary from the results given by similar triangles in so trifling a degree, that it can arise only from error in measurement. Thus in an average of five trials, at the relative distances of 41 and 73 inches, the disc was $6\frac{3}{5}$ at the shorter, and $10\frac{1}{5}$ at the longer distance; the fringe next it $3\frac{7}{10}$ at the shorter, and $5\frac{7}{10}$ at the longer distance, whereas the proportions by similar triangles would have been $9\frac{1}{8}$ and $5\frac{1}{8}$, so that the difference is small, and is by excess, and not, as in the hair experiment, by defect. Had the difference been as in Sir I. NEWTON's experiment, instead of $10\frac{1}{5}$ and $5\frac{7}{10}$, it would have been $3\frac{1}{24}$ and $1\frac{17}{24}$. In another measurement at 101 and 158 inches respectively, the disc was $15\frac{1}{3}$, the fringe $8\frac{1}{3}$ instead of $14\frac{3}{5}$ and $9\frac{1}{8}$ respectively. But by Sir I. NEWTON's proportions these should have been $4\frac{3}{5}$ and $3\frac{1}{24}$. It is plain that if the measures had been taken with the micrometer instruments, which had not been then furnished, there would have been no deviation. I have since tried the experiment, not as above, on the fringes formed by the double-edged instrument, but on those formed by one edge at a distance behind the other, and have found no reason to doubt that the rays follow a rectilinear course.

* If you hold a body between the eye and a light, as that of a candle, and approach it to the rays, you see the flame drawn towards the body; and a beginning of images or fringes is perceived on that side.

† Optics, B. iii. obs. 3.

It may further be observed, that in the fringes or images by disposition and polarization, the dark intervals disappear at short distances from the point of flexion, and that the fringes run into one another, so that we find the red mixed with the blue and violet. This is one reason why I often experimented with the prismatic rays.

3. It follows from the property of light, which I have termed disposition, on one side the ray, and polarization on the opposite side, superinduced by flexion, that those two sides only being affected, the other two at right angles to these are not at all affected by the flexion which has disposed and polarized the two former. Consequently, although an edge placed parallel to the disposing edge and opposite to it acts powerfully on the disposed light, yet an edge placed at right angles to the former edge or across the rays, does not affect them any more than it would rays which had not been subjected to the previous action of a first edge. Thus (fig. 19) if *a b c d* be the section of the ray, an edge parallel to *a b*, after the ray has been disposed, will affect the ray greatly, provided it had been disposed by an edge also parallel to *a b*. The sides *a b* and *c d*, however, are alone affected; and therefore the second edge, if placed parallel to *a d* or *b c*, will not at all bend the ray more or make images (or fringes) more powerfully than it would do if no previous flexion and disposition had taken place. Let us see how this is in fact: *e f g h* is the distended disc after flexion, by passing through the aperture of the two-edged instrument (Plate XI.). It is slightly tinged with red at the two ends *f g* and *e h*, beyond which, and in the shadow of the edges, are the usual fringes or coloured images by flexion and disposition, *e*, *c*, the edges being parallel to *e h*, *f g*. Place another edge at some distance from the two, as 3 or 4 inches, and parallel to these two, but in the light, and you will see in the disc a succession of narrow fringes parallel to the edges, and in front of the third edge's shadow. These fringes are on the white disc, and their colours are very bright, much more so than the colours of those fringes described in Proposition I., and which are fringes made by deflexion without any disposition. But whether this superior brightness is owing to the glare of the disc's light being diminished by the flexion of the first two edges, or not, for the present I stop not to inquire. This is certain, that if the third edge be placed across the beam, and at right angles to the two first edges, you no longer have the small fringes. They are not formed in the direction *h g*, parallel to the edges as now placed. If the double edges are changed, and are placed in the direction $h' g'$, you again have the bright fringes; but then, if the third edge is now placed parallel to $h' e'$, you cease to have them. Care must, however, be taken in this experiment not to mistake for these bright fringes the ordinary deflexion fringes made by one flexion without disposition, as described in Proposition I. For these may be perceived, and even somewhat more distinctly in the disc than in the full light of the white pencil or beam.

Now are these bright fringes only the flexion fringes, that is fringes by simple flexion without disposition? To ascertain this I made these experiments.

Exp. 1. If they are the common fringes, and only enlarged by the greater divergence of the rays after flexion, and more bright by the dimness of the distended disc, then it will follow that the greater the distension, and the greater the divergence of the rays, the broader will be the bright fringes in question. I repeatedly have tried the thing by this test, and I uniformly find that increasing the divergence, by approaching the edges of the instrument, has no effect whatever in increasing the breadth of the fringes in question.

Exp. 2. If these fringes are not connected with disposition, it will follow that the distance of the edge which forms them from the double-edged instrument cannot affect them. But I have distinctly ascertained that their breadth does depend on that distance, and in order to remove all doubt as to the distance between the chart and the third edge which forms them, I allowed that edge to remain fixed, and varied its distance from the other two by bringing the double-edge instrument nearer the third edge. The breadths of the bright fringes varied most remarkably, being in some inverse power of that distance. Thus, to take one measurement as an example of the rest, at 4 feet from the third edge the chart was fixed and the third edge kept constantly at that distance from it. Then the double-edge instrument was placed successively at $14\frac{1}{2}$, at 9 and at $4\frac{1}{2}$ eighths of an inch from the third edge. The breadths were respectively 2, $3\frac{3}{4}$ and $4\frac{1}{4}$ twentieths of an inch. In some experiments these measures approached more nearly the hyperbolic values of y, but I give the experiment now only for the important and indeed decisive evidence which it affords, that these fringes are caused by disposition, and are wholly different from those formed without previous flexion.

Exp. 3. If the greater breadth of these fringes is owing to dispersion, then they should be formed more in the rays of the prismatic spectrum than in white light, or even in light bent by flexion. Yet we find it more difficult to trace fringes across the prismatic spectrum than in white light, and more difficult across the spectrum when there is divergence, than when formed parallel to its sides when there is no divergence. There are fringes formed, but of the narrow kind, which are described in Prop. I.

Exp. 4. I have tried the effect on the fringes in question of the curvilinear edge described in the first article of these observations, and the effect of which is represented in fig. 18. It is certain that at a distance from the double-edge instrument the third edge seems only to form fringes rectilinear, or of its own form. But when placed very near, as half an inch from the instrument, plainly there is a curvilinear form given to the fringes in question; and this is most easily perceived, when, by moving the third edge towards the side of the pencil, you form the smaller fringes so as to be drawn across or along the greater ones made by the two first edges.

I think, without pursuing this subject further, it must be admitted that these fringes in light, which is bent and disposed, lend an important confirmation to the doctrine of disposition. It is clear that the rays are affected only on two of their four sides, or *a b* and *c d,* if these are parallel to the bending body's edge, and not at all on the sides *c b* and *d a*; that, on the other hand, *c b* and *d a* are affected when the edges are placed parallel to these two sides of the rays; and thus the connection of the fringes in question, with the preceding action of which disposed and polarized, is clearly proved.

4. It is an obvious extension and variation of this experiment both to apply edges parallel to the first and disposing edges, and also to apply edges at right angles to their direction; and important results follow from this experiment. But until a more minute examination of the phenomena with accurate admeasurements can be had, I prefer not entering on this subject further than to say, that the extreme difficulty of obtaining fringes or images at once from the edges parallel to the first two, and from edges at right angles to these, indicates an action not always at right angles to the bending body, but whether conical or not I have not hitherto been able to ascertain. That the first body only disposes and polarizes in one direction is certain. But it seems difficult to explain the effect of the first two edges in preventing the fringes or images from being made by the second at right angles to those formed by the first two edges, if no lateral action exists. One can suppose the approaching of those two first edges to make the fringes narrower and narrower than those which the second two edges form when placed at right angles to the first. But this is by no means all that happens. There is hardly any set of fringes at all formed at right angles to the first set (parallel to the first two edges) when the first two are approached so near each other as greatly to distend the disc.

5. I reserve for future inquiry also the opinion held by Sir I. NEWTON, that the different homogeneous rays are acted upon by bodies at different distances, this action extending furthest over the least refrangible rays. He inferred this from the greater breadth of the fringes in those rays.

It is in my apprehension, though I once held a different opinion*, not impossible to account for the difference of the breadth of the fringes by the different flexibility of the rays; and the reasoning in one of the foregoing propositions shows how this inquiry may be conducted. But one thing is certain, and probably Sir I. NEWTON had made the experiment and grounded his opinion upon the result. If you place a screen, with a narrow slit in the prismatic spectrum's rays, parallel to the rectilinear sides, and then place a second prism at right angles to the first and between the screen and the chart, you will see the image of the slit drawn on one side, the violet being furthest drawn, the red least drawn; but you will find no difference in the breadth of the image cast by the slit. Flexion, however, operates in a different manner, because it acts on rays, which, though of the same flexibility, are at different distances from the body.

6. The internal fringes in the shadow (said by interference) deserve to be examined much more minutely than they ever have been; and I have made many experiments on these, by which an action of the rays on one another is, I think, sufficiently proved. I shall here content myself with only stating such results as bear on

* Philosophical Transactions, 1797.

the question of interference affecting my own other experiments. *First.* I observe that when one side of a needle or pin is grooved so as to be partly curvilinear, the other side remaining straight, we have internal fringes of the form in fig. 21. *Secondly.* It is not at all necessary the pin or other body forming them should be of very small diameter, although it is certain that the breadth of the fringes is inversely as the diameter. I have obtained them easily from a body one-quarter or one-third of an inch in diameter, but they must be received at a considerable distance from the body. *Thirdly,* and this is very material as to interference at all affecting my experiments, although certainly the internal fringes vanish when the rays are stopped coming from the opposite side of the object, the external fringes are not in the smallest degree affected, unless you stop the light coming on their own side; stopping the opposite rays has no effect whatever. Thus, stopping the light on the side *a* (fig. 19), the fringes *ff* vanish, but not the external fringes *c*. This at once proves there is no interference in forming the external ones. *Lastly.* I may observe, that the law of disposition and polarization in some sort, though with modification, affects the internal fringes as well as the external.

It is a curious fact connected with polarization by inflexion, and which indeed is only to be accounted for by that affection of light, that nothing else prevents the rays from circulating round bodies exposed to them, at least bodies of moderate diameter. If the successive particles of the surface inflected, one particle acting after the other, the rays must necessarily come round to the very point of the first flexion. We should thus see a candle placed at A (fig. 22) when the eye was placed at B, because the rays would be inflected all round; and even in parts of the earth where the sea is smooth, nothing but the small curvature of the surface could prevent us from seeing the sun many hours after light had begun by placing the eye close to the ground. This, however, in bodies of a small diameter, must inevitably happen. The polarization of the rays alone prevents it, by making it impossible they should be more than once inflected on their side which was next the bending body, therefore they go on straight to C. But for polarity they must move round the body.

7. It must not be lightly supposed, that because such inquiries as we have been engaged in are on phenomena of a minute description and relate to very small distances, therefore they are unimportant. Their results lead to the constitution of light, and its motion, and its action, and the relations between light and all bodies. I purposely abstain from pursuing the principles which I have ventured to explain into their consequences, and reserve for another occasion some more general inquiries founded upon what goes before. This course is dictated by the manifest expediency of first expounding the fundamental principles, and I therefore begin by respectfully submitting these to the consideration of the learned in such matters.

In the meantime, however, I will mention one inference to be drawn from the foregoing propositions of some interest.

As it is clear that the disposition varies with the distance, and is inversely as that distance, and as this forms an inherent and essential property of the light itself, what is the result? Plainly this, that the motion of light is quite uniform after flexion, and apparently before also. The flexion produces acceleration but only for an instant. If *ss* is the space through which the ray moves after entering the sphere of flexion, and v the velocity before it enters that sphere; it moves after entering with a velocity $=\sqrt{v^2+Zdz}$, Z being the law of the bending force. Then this is greater than v; consequently there is an acceleration, though not very great; but because $y=\frac{a}{x}$, if s is the space, t the time, the force of acceleration is $\frac{s}{tds}\times\frac{tds-sdt}{t^2}$; but $y=\frac{a}{x}$ shows that s is as t, else $y=\frac{a}{x}$ would be impossible; therefore the accelerating force $\frac{s}{ds}\times\frac{tds-sdt}{t^3}=0$, and so it is shown there is no acceleration after the ray leaves the sphere of flexion.

Description of the Instruments.

PLATE XII.

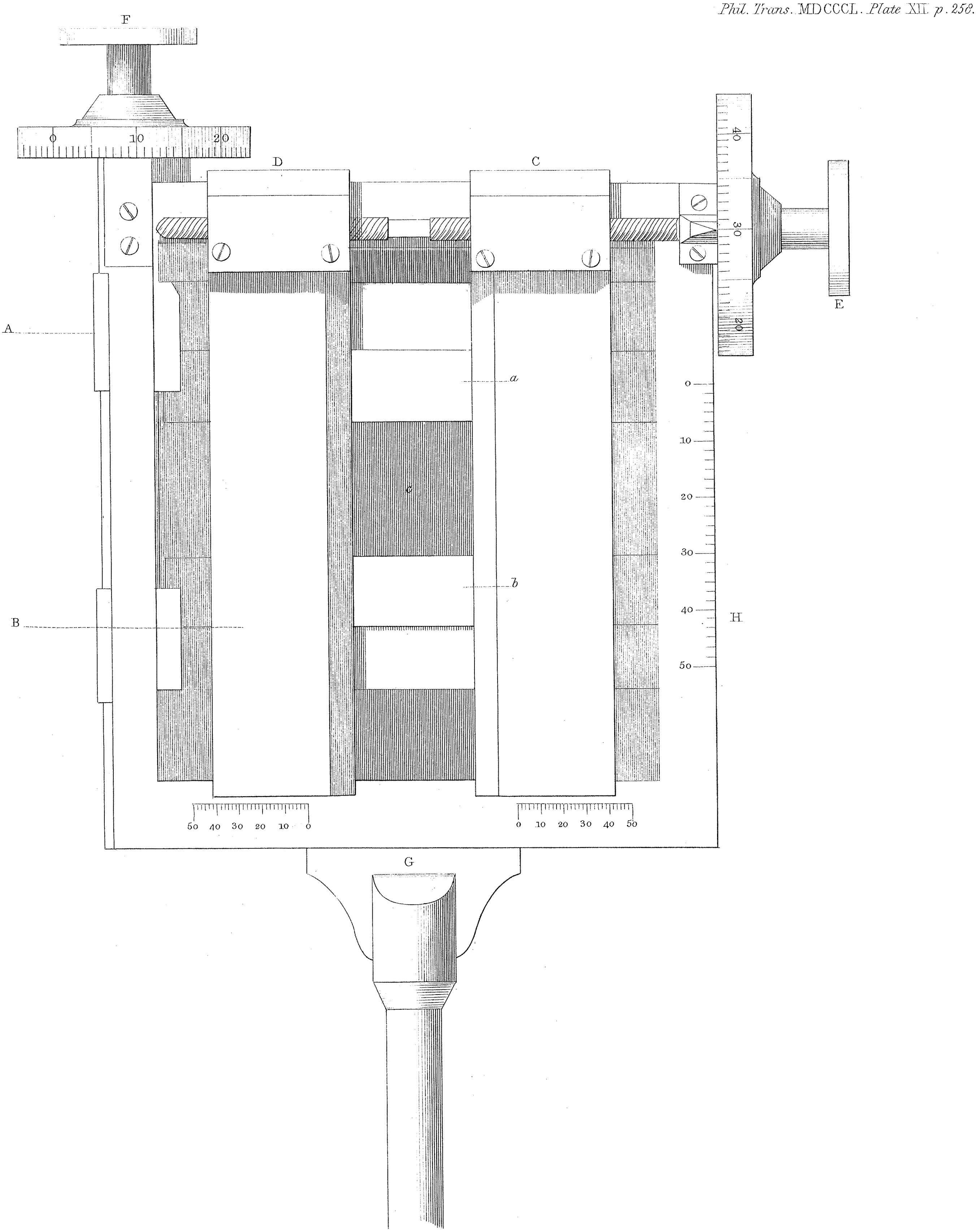
Is the instrument with two plates or edges. A, B, horizontal, D, C vertical; the former moved by the screw E, which has also a micrometer for the distances on the scale G; the latter, in like manner, moved by F, connected with micrometer and scale H.

PLATE XIII.

Is the instrument with four surfaces. A D, *a d* are two parallel plates, moving horizontally by a rack and pinion E. Each plate has an edge composed of four surfaces; A, *a*, a sharp edge or very narrow surface; B, *b*, a flat surface; C, *c*, a cylindrical surface of large radius of curvature, and so flat; D, *d*, one of small radius, and so very convex: this is represented on the figure by A' B' C' D' beside the other. Care is to be taken that A B C D and *a b c d* be a perfectly straight line, made up of the sharp edge, the plane surface and the tangents to the two cylinders. H is a plate with a sharp and straight edge, *o p*, which can be brought by its handle F to come opposite to the compound edge *a b c d*, when it is desired to try the flexion by the latter, without another flexion by an opposite compound edge, but only with a flexion by a rectilinear simple edge.

PLATE XIV.

Is the instrument by which is tried the *experimentum crucis* on the action of the third edge, and also the experiments on the distances of the edges as affecting the disposing force. G is the groove in which the uprights H, I, K move. There is a scale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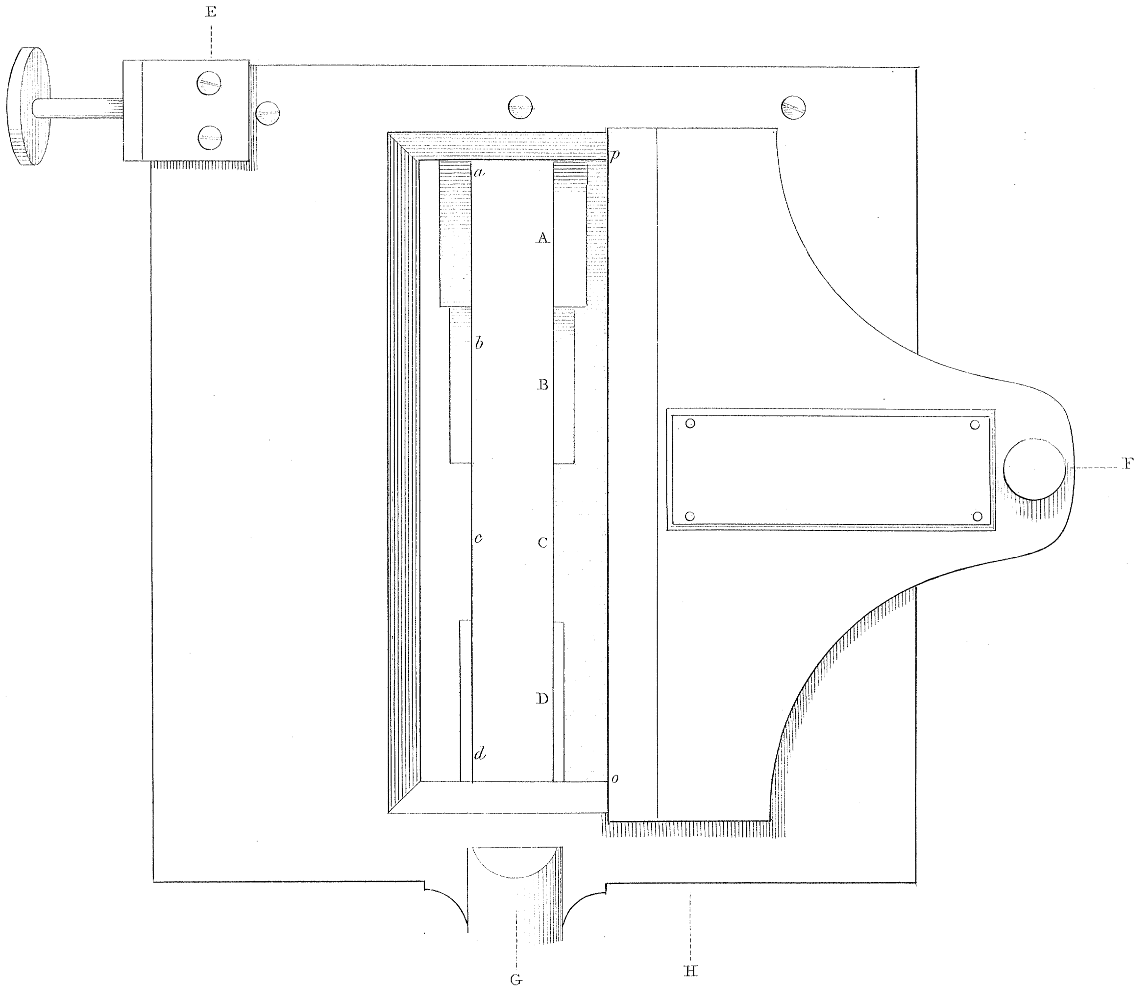
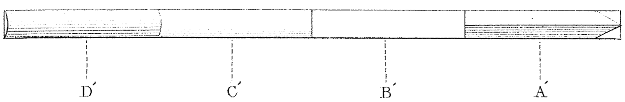
G

J. Basire sc.





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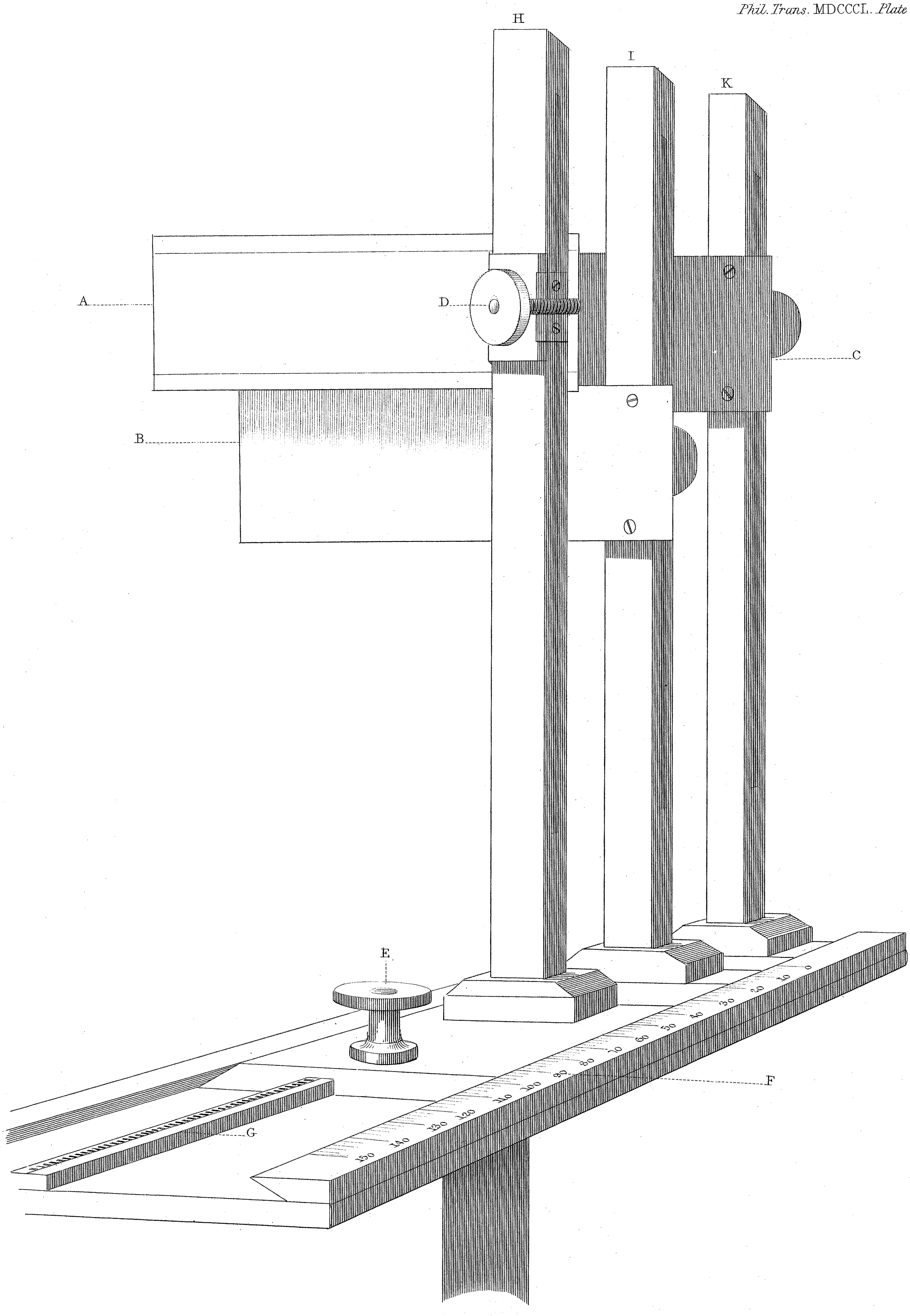

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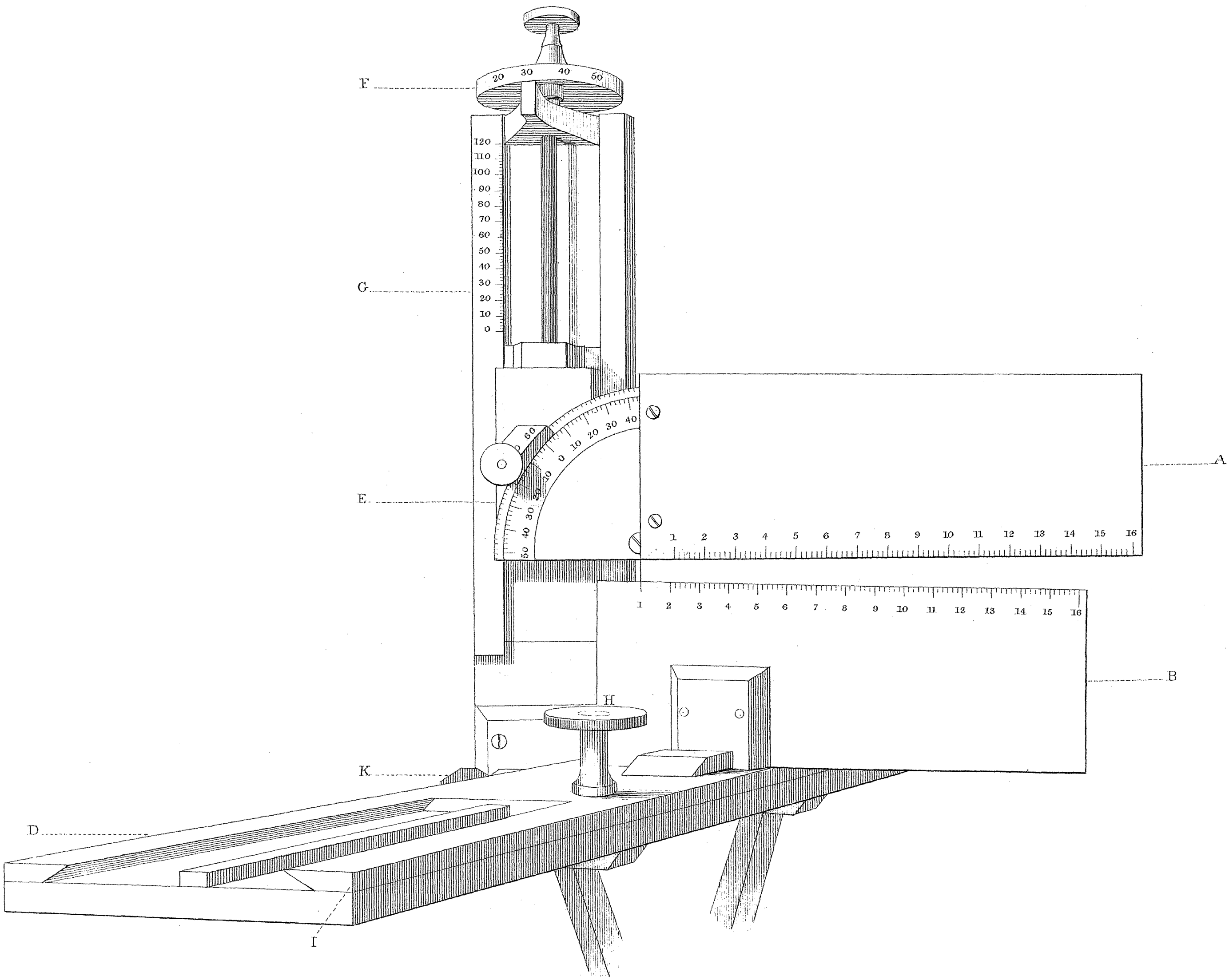

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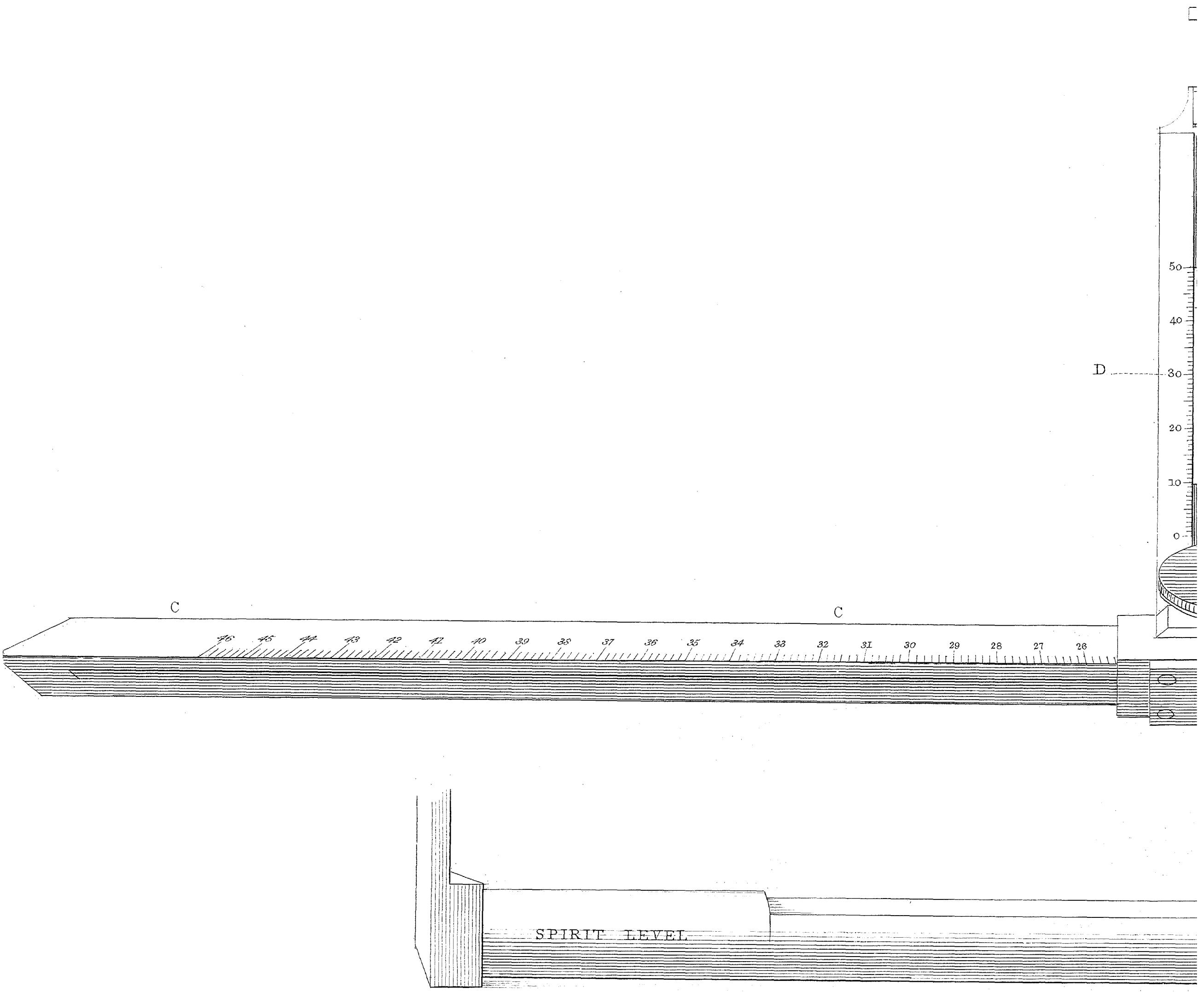

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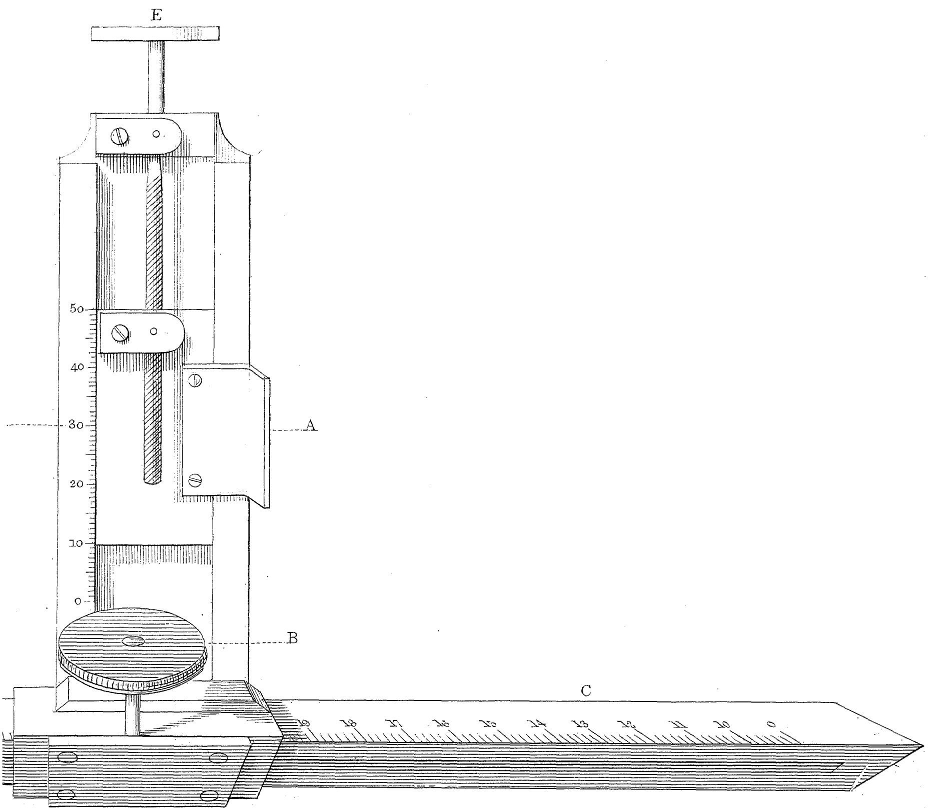
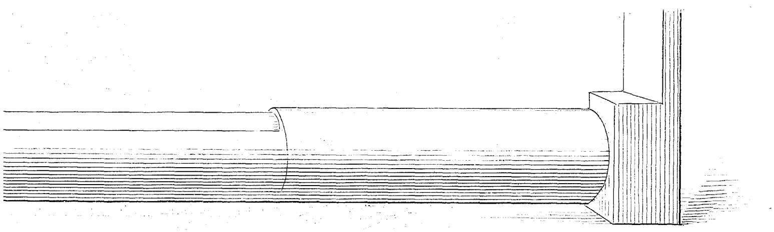
SPIRIT LEVEL





J. Basire sc.

graduated, F, by which the relative distances can always be determined of the plates A, C and B. A moves up and down upon H, B upon I, and C upon K; each plate is moved up and down by rack and pinion D. The uprights also move along the groove G by rack and pinion E.

PLATE XV.

Is the instrument for ascertaining more nicely the effects of distance on disposition. A is a plate with graduated edge; it moves vertically on a pivot, and its angle with the horizontal line is measured by the quadrant E. A also moves horizontally, and its horizontal angle is measured by the quadrant K. B is another plate with graduated edge, moving in a groove D, by rack and pinion H, and along a graduated beam I. F is a fine micrometer, by which the distance of A above B, when A is horizontal, can always be measured to the greatest nicety by the circle F and the scale G.

PLATE XVI.

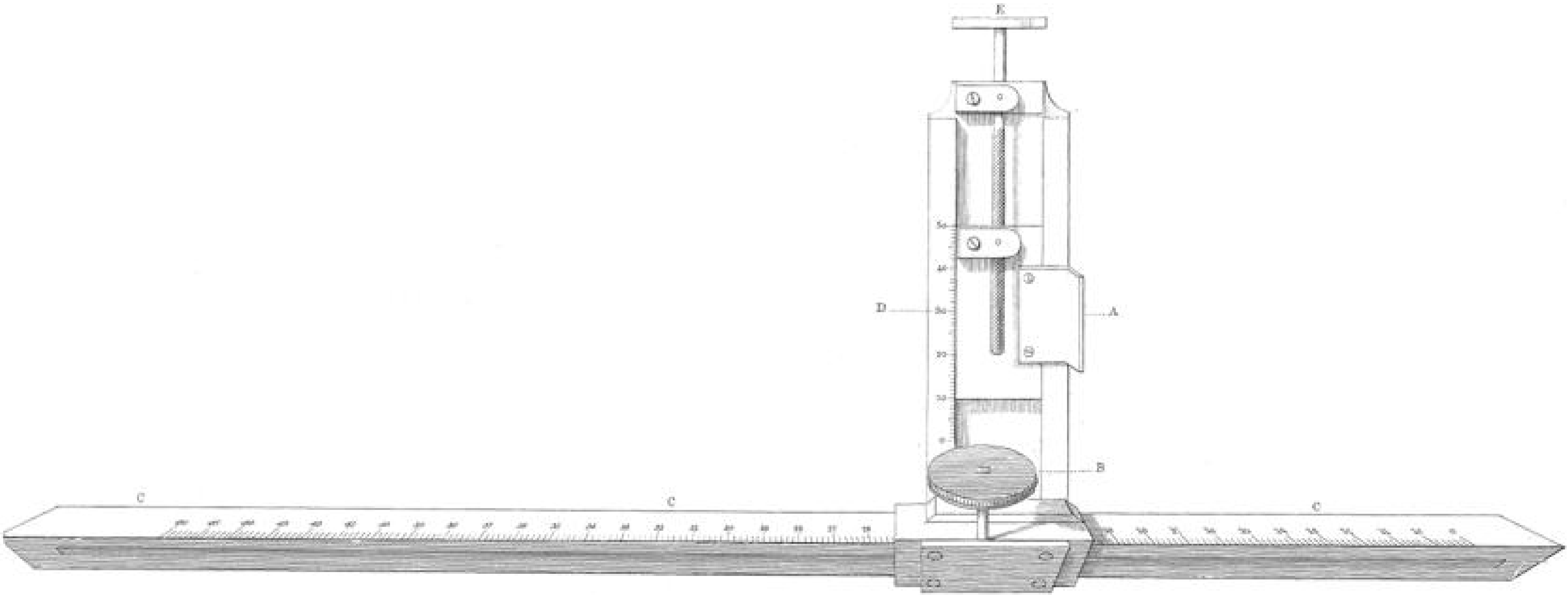
Is an instrument also for measuring the effect of the distance of the edges upon the disposing forces. C C C is a graduated beam, adjusted by the spirit-level, and on it moves the upright on which a plate A moves by micrometer screw E, so that the distance of A from the rays that pass along C C C after flexion by a plate fixed at one end of the beam, can be ascertained by the scale D. I have experimented with this, but I did not find it so easy to work by as the other apparatus. C C C is brought to an exact level by screws not noted in the drawing.

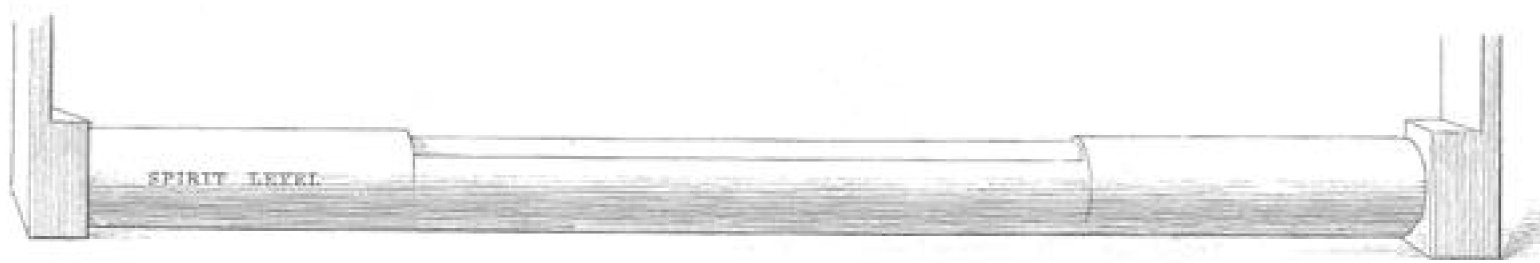
Appendix.

PHILOSOPHICAL TRANSACTIONS, PART I. 1850.

ERRATA.

Page 245, line 13, *after* placed *insert* parallel to it.
—— 246, line 1, *for* VI. *read* XV.
—— 246, line 1, *for* one, A, *read* one, B.
—— 246, line 2, *for* B *read* A.
—— 246, line 17, *after* result *insert* in.
—— 246, line 19, *for* fringe *read* force.
—— 252, line 13, *erase* b=DE, *and for* $\frac{1}{\sqrt{a^2+(x-b)^2}-\sqrt{c^2+x^2}}$ *read* $\frac{1}{\sqrt{a^2+x^2}-\sqrt{b^2+x^2}}$.
—— 253, line 16, *for* being *read* between.
—— 254, line 19, *for* XI. *read* XII.
—— 254, line 21, *for* e, c *read* c, c.
—— 257, line 13, *for* 19 *read* 21.
—— 257, line 25, *for* light *read* night.
—— 257, line 29, *for* polarity *read* polarization.
—— 258, line 4, for ss read z.
—— 258, line 6, *for* $\sqrt{v^2+Zdz}$ *read* $\sqrt{v^2+2\int Zdz}$.
In figs. 6 and 7, R R′ should be a straight line.
In fig. 9, P should be opposite to q.





J. Basire sc.