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# OPTICKS:

**OR, A**

## TREATISE

**OF THE**

***Reflections*, *Refractions*,**
***Inflections* and *Colours***

**OF**

## LIGHT.

***The* Fourth Edition, *corrected*.**

**By Sir *ISAAC NEWTON*, Knt.**

LONDON:
Printed for WILLIAM INNYS at the West-End of St. *Paul's*. MDCCXXX.
TITLE PAGE OF THE 1730 EDITION

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# SIR ISAAC NEWTON'S ADVERTISEMENTS

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## Advertisement I

*Part of the ensuing Discourse about Light was written at the Desire of some Gentlemen of the* Royal-Society, *in the Year 1675, and then sent to their Secretary, and read at their Meetings, and the rest was added about twelve Years after to complete the Theory; except the third Book, and the last Proposition of the Second, which were since put together out of scatter'd Papers. To avoid being engaged in Disputes about these Matters, I have hitherto delayed the printing, and should still have delayed it, had not the Importunity of Friends prevailed upon me. If any other Papers writ on this Subject are got out of my Hands they are imperfect, and were perhaps written before I had tried all the Experiments here set down, and fully satisfied my self about the Laws of Refractions and Composition of Colours. I have here publish'd what I think proper to come abroad, wishing that it may not be translated into another Language without my Consent.*

*The Crowns of Colours, which sometimes appear about the Sun and Moon, I have endeavoured to give an Account of; but for want of sufficient Observations leave that Matter to be farther examined. The Subject of the Third Book I have also left imperfect, not having tried all the Experiments which I intended when I was about these Matters, nor repeated some of those which I did try, until I had satisfied my self about all their Circumstances. To communicate what I have tried, and leave the rest to others for farther Enquiry, is all my Design in publishing these Papers.*

*In a Letter written to Mr.* Leibnitz *in the year 1679, and published by Dr.* Wallis, *I mention'd a Method by which I had found some general Theorems about squaring Curvilinear Figures, or comparing them with the Conic Sections, or other the simplest Figures with which they may be compared. And some Years ago I lent out a Manuscript containing such Theorems, and having since met with some Things copied out of it, I have on this Occasion made it publick, prefixing to it an* Introduction, *and subjoining a* Scholium *concerning that Method. And I have joined with it another small Tract concerning the Curvilinear Figures of the Second Kind, which was also written many Years ago, and made known to some Friends, who have solicited the making it publick.*

*I. N.*

April 1, 1704.

### Advertisement II

*In this Second Edition of these Opticks I have omitted the Mathematical Tracts publish'd at the End of the former Edition, as not belonging to the Subject. And at the End of the Third Book I have added some Questions. And to shew that I do not take Gravity for an essential Property of*

*Bodies, I have added one Question concerning its Cause, chusing to propose it by way of a Question, because I am not yet satisfied about it for want of Experiments.*

*I. N.*

July 16, 1717.

### Advertisement to this Fourth Edition

*This new Edition of Sir* Isaac Newton's Opticks *is carefully printed from the Third Edition, as it was corrected by the Author's own Hand, and left before his Death with the Bookseller. Since Sir* Isaac's Lectiones Opticæ, *which he publickly read in the University of* Cambridge *in the Years 1669, 1670, and 1671, are lately printed, it has been thought proper to make at the bottom of the Pages several Citations from thence, where may be found the Demonstrations, which the Author omitted in these* Opticks.

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# THE FIRST BOOK OF OPTICKS [Pg 1]

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# *PART I.*

My Design in this Book is not to explain the Properties of Light by Hypotheses, but to propose and prove them by Reason and Experiments: In order to which I shall premise the following Definitions and Axioms.

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## *DEFINITIONS*

### DEFIN. I.

*By the Rays of Light I understand its least Parts, and those as well Successive in the same Lines, as Contemporary in several Lines.* For it is manifest that Light consists of Parts, both Successive and Contemporary; because in the same place you may stop that which comes one moment, and let [Pg 2] pass that which comes presently after; and in the same time you may stop it in any one place, and let it pass in any other. For that part of Light which is stopp'd cannot be the same with that which is let pass. The least Light or part of Light, which may be stopp'd alone without the rest of the Light, or propagated alone, or do or suffer any thing alone, which the rest of the Light doth not or suffers not, I call a Ray of Light.

### DEFIN. II.

*Refrangibility of the Rays of Light, is their Disposition to be refracted or turned out of their Way in passing out of one transparent Body or Medium into another. And a greater or less Refrangibility of Rays, is their Disposition to be turned more or less out of their Way in like Incidences on the same Medium.* Mathematicians usually consider the Rays of Light to be Lines reaching from the luminous Body to the Body illuminated, and the refraction of those Rays to be the bending or breaking of those lines in their passing out of one Medium into another. And thus may Rays and Refractions be considered, if Light be propagated in an instant. But by an Argument taken from the Æquations of the times of the Eclipses of *Jupiter's Satellites*, it seems that Light is propagated in time, spending in its passage from the Sun to us about seven Minutes of time: And therefore I have chosen to define Rays and Refractions in such general terms as may agree to Light in both cases. [Pg 3]

## DEFIN. III.

*Reflexibility of Rays, is their Disposition to be reflected or turned back into the same Medium from any other Medium upon whose Surface they fall. And Rays are more or less reflexible, which are turned back more or less easily.* As if Light pass out of a Glass into Air, and by being inclined more and more to the common Surface of the Glass and Air, begins at length to be totally reflected by that Surface; those sorts of Rays which at like Incidences are reflected most copiously, or by inclining the Rays begin soonest to be totally reflected, are most reflexible.

## DEFIN. IV.

*The Angle of Incidence is that Angle, which the Line described by the incident Ray contains with the Perpendicular to the reflecting or refracting Surface at the Point of Incidence.*

## DEFIN. V.

*The Angle of Reflexion or Refraction, is the Angle which the line described by the reflected or refracted Ray containeth with the Perpendicular to the reflecting or refracting Surface at the Point of Incidence.*

## DEFIN. VI.

*The Sines of Incidence, Reflexion, and Refraction, are the Sines of the Angles of Incidence, Reflexion, and Refraction.* [Pg 4]

## DEFIN. VII

*The Light whose Rays are all alike Refrangible, I call Simple, Homogeneal and Similar; and that whose Rays are some more Refrangible than others, I call Compound, Heterogeneal and Dissimilar.* The former Light I call Homogeneal, not because I would affirm it so in all respects, but because the Rays which agree in Refrangibility, agree at least in all those their other Properties which I consider in the following Discourse.

## DEFIN. VIII.

*The Colours of Homogeneal Lights, I call Primary, Homogeneal and Simple; and those of Heterogeneal Lights, Heterogeneal and Compound.* For these are always compounded of the colours of Homogeneal Lights; as will appear in the following Discourse.

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# *AXIOMS.* [Pg 5]

## AX. I.

*The Angles of Reflexion and Refraction, lie in one and the same Plane with the Angle of Incidence.*

## AX. II.

*The Angle of Reflexion is equal to the Angle of Incidence.*

## AX. III.

*If the refracted Ray be returned directly back to the Point of Incidence, it shall be refracted into the Line before described by the incident Ray.*

## AX. IV.

*Refraction out of the rarer Medium into the denser, is made towards the Perpendicular; that is, so that the Angle of Refraction be less than the Angle of Incidence.*

## AX. V.

*The Sine of Incidence is either accurately or very nearly in a given Ratio to the Sine of Refraction.*

Whence if that Proportion be known in any one Inclination of the incident Ray, 'tis known in all the Inclinations, and thereby the Refraction in all cases of Incidence on the same refracting Body may be [Pg 6] determined. Thus if the Refraction be made out of Air into Water, the Sine of Incidence of the red Light is to the Sine of its Refraction as 4 to 3. If out of Air into Glass, the Sines are as 17 to 11. In Light of other Colours the Sines have other Proportions: but the difference is so little that it need seldom be considered.

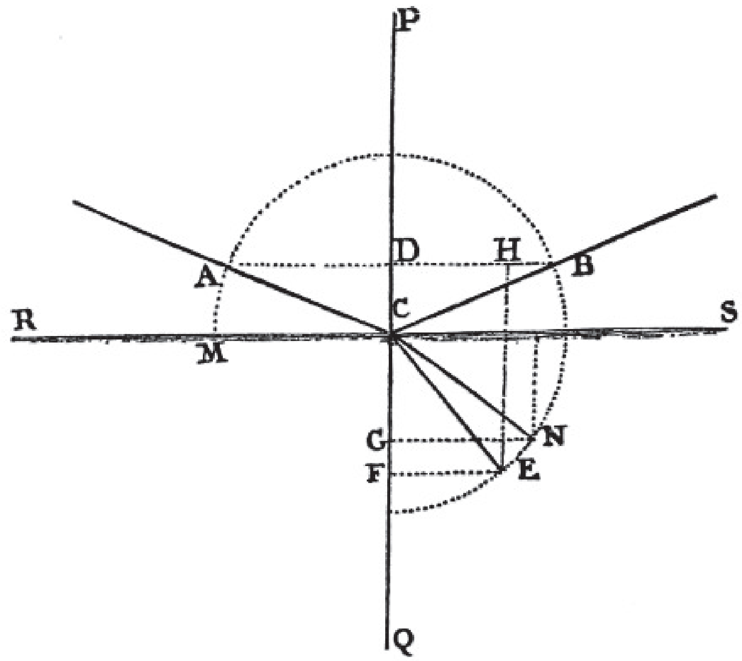


**Fig. 1**

Suppose therefore, that RS [in *Fig.* 1.] represents the Surface of stagnating Water, and that C is the point of Incidence in which any Ray coming in the Air from A in the Line AC is reflected or refracted, and I would know whither this Ray shall go after Reflexion or Refraction: I erect upon the Surface of the Water from the point of Incidence the Perpendicular CP and produce it downwards to Q, and conclude by the first Axiom, that the Ray after Reflexion and Refraction, shall be found somewhere in [Pg 7] the Plane of the Angle of Incidence ACP produced. I let fall therefore upon the Perpendicular CP the Sine of Incidence AD; and if the reflected Ray be desired, I produce AD to B so that DB be equal to AD, and draw CB. For this Line CB shall be the reflected Ray; the Angle of Reflexion BCP and its Sine BD being equal to the Angle and Sine of Incidence, as they ought to be by the second Axiom, But if the refracted Ray be desired, I produce AD to H, so that DH may be to AD as the Sine of Refraction to the Sine of Incidence, that is, (if the Light be red) as 3 to 4; and about the Center C and in the Plane ACP with the Radius CA describing a Circle ABE, I draw a parallel to the Perpendicular CPQ, the Line HE cutting the Circumference in E, and joining CE, this Line CE shall be the Line of the refracted Ray. For if EF be let fall perpendicularly on the Line PQ, this Line EF shall be the Sine of Refraction of the Ray CE, the Angle of Refraction being ECQ; and this Sine EF is equal to DH, and consequently in Proportion to the Sine of Incidence AD as 3 to 4.

In like manner, if there be a Prism of Glass (that is, a Glass bounded with two Equal and Parallel Triangular ends, and three plain and well polished Sides, which meet in three Parallel Lines running from the three Angles of one end to the three Angles of the other end) and if the Refraction of the Light in passing cross this Prism be desired: Let ACB [in *Fig.* 2.] represent a Plane cutting this Prism transversly to its three Parallel lines or edges there where the Light passeth through it, and let DE be [Pg 8] the Ray incident upon the first side of the Prism AC where the Light goes into the Glass; and by putting the Proportion of the Sine of Incidence to the Sine of Refraction as 17 to 11 find EF the first refracted Ray. Then taking this Ray for the Incident Ray upon the second side of the Glass BC where the Light goes out, find the next refracted Ray FG by putting the Proportion of the Sine of Incidence to the Sine of Refraction as 11 to 17. For if the Sine of Incidence out of Air into Glass be to the Sine of Refraction as 17 to 11, the Sine of Incidence out of Glass into Air must on the contrary be to the Sine of Refraction as 11 to 17, by the third Axiom.

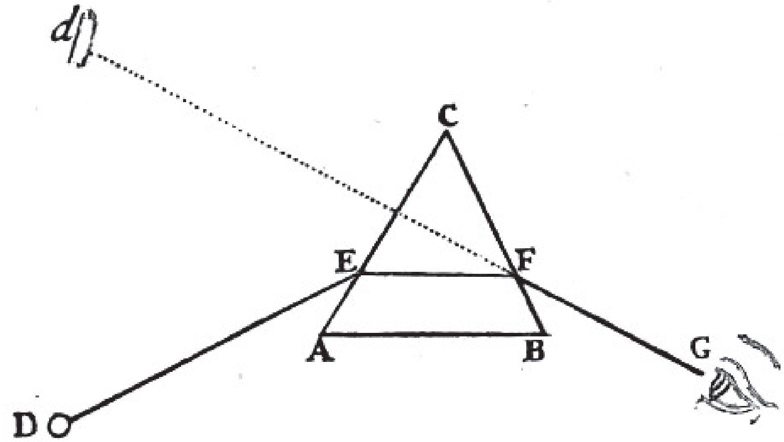


**Fig. 2.**

Much after the same manner, if ACBD [in *Fig.* 3.] represent a Glass spherically convex on both sides (usually called a *Lens*, such as is a Burning-glass, or Spectacle-glass, or an Object-glass of a Telescope) and it be required to know how Light falling upon it from any lucid point Q shall be refracted, let QM represent a Ray falling upon any point M of its first spherical Surface ACB, and by erecting a Perpendicular to the Glass at the point M, find the first refracted Ray MN by the Proportion of the Sines 17 to 11. Let that Ray in going out of the Glass be incident upon N, and then find the second refracted Ray N*q* by the Proportion of the Sines 11 to 17. And after the same manner may the Refraction be found when the Lens is convex on one side and plane or concave on the other, or concave on both sides. [Pg 9]

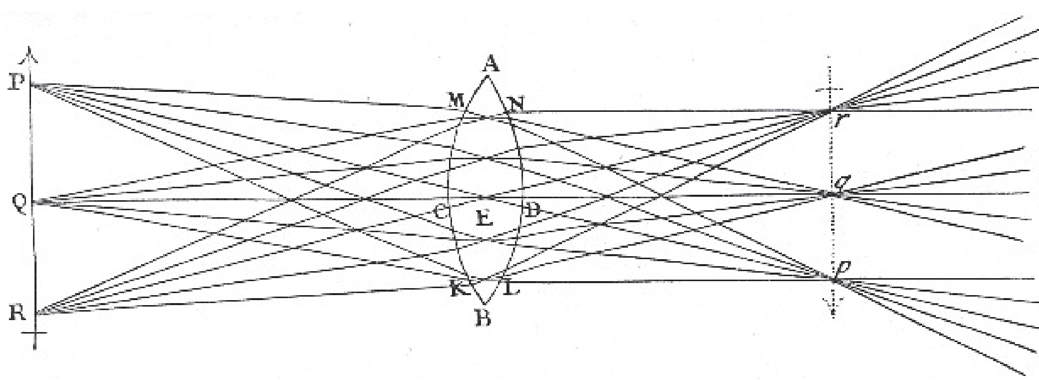


**Fig. 3.**

[Pg 10]

## AX. VI.

*Homogeneal Rays which flow from several Points of any Object, and fall perpendicularly or almost perpendicularly on any reflecting or refracting Plane or spherical Surface, shall afterwards diverge from so many other Points, or be parallel to so many other Lines, or converge to so many other Points, either accurately or without any sensible Error. And the same thing will happen, if the Rays be reflected or refracted successively by two or three or more Plane or Spherical Surfaces.*

The Point from which Rays diverge or to which they converge may be called their *Focus*. And the Focus of the incident Rays being given, that of the reflected or refracted ones may be found by finding the Refraction of any two Rays, as above; or more readily thus.

*Cas.* 1. Let ACB [in *Fig.* 4.] be a reflecting or refracting Plane, and Q the Focus of the incident Rays, and Q*q*C a Perpendicular to that Plane. And if this Perpendicular be produced to *q*, so that *q*C be equal to QC, the Point *q* shall be the Focus of the reflected Rays: Or if *q*C be taken on the same side of the Plane with QC, and in proportion to QC as the Sine of Incidence to the Sine of Refraction, the Point *q* shall be the Focus of the refracted Rays. [Pg 11]

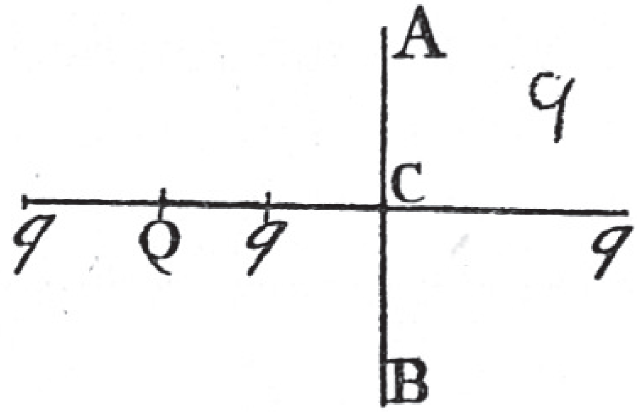


**Fig. 4.**

*Cas.* 2. Let ACB [in *Fig.* 5.] be the reflecting Surface of any Sphere whose Centre is E. Bisect any Radius thereof, (suppose EC) in T, and if in that Radius on the same side the Point T you take the Points Q and *q*, so that TQ, TE, and T*q*, be continual Proportionals, and the Point Q be the Focus of the incident Rays, the Point *q* shall be the Focus of the reflected ones.

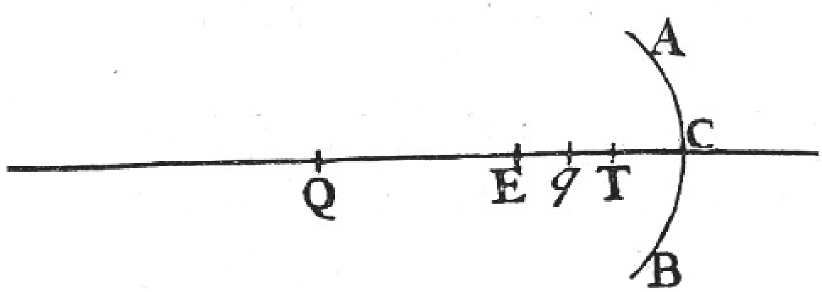


**Fig. 5.**

*Cas.* 3. Let ACB [in *Fig.* 6.] be the refracting Surface of any Sphere whose Centre is E. In any Radius thereof EC produced both ways take ET and C*t* equal to one another and severally in such Proportion to that Radius as the lesser of the Sines of Incidence and Refraction hath to the difference of those Sines. And then if in the same Line you find any two Points Q and *q*, so that TQ be to ET as E*t* to *tq*, taking *tq* the contrary way from *t* which TQ lieth from T, and if the Point Q be the Focus of any incident Rays, the Point *q* shall be the Focus of the refracted ones. [Pg 12]

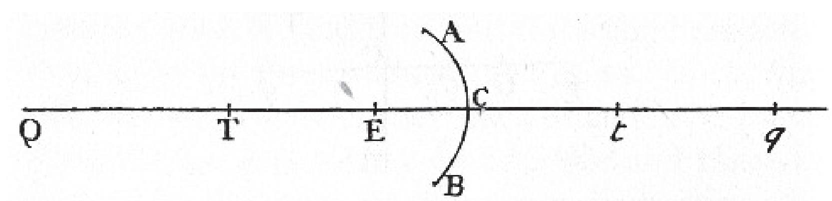


**Fig. 6.**

And by the same means the Focus of the Rays after two or more Reflexions or Refractions may be found.

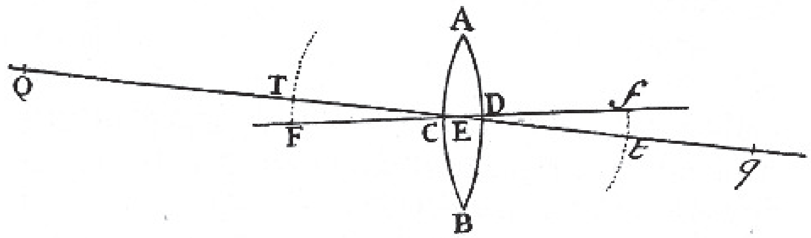


**Fig. 7.**

*Cas.* 4. Let ACBD [in *Fig.* 7.] be any refracting Lens, spherically Convex or Concave or Plane on either side, and let CD be its Axis (that is, the Line which cuts both its Surfaces perpendicularly, and passes through the Centres of the Spheres,) and in this Axis produced let F and *f* be the Foci of the refracted Rays found as above, when the incident Rays on both sides the Lens are parallel to the same Axis; and upon the Diameter F*f* bisected in E, describe a Circle. Suppose now that any Point Q be the Focus of any incident Rays. Draw QE cutting the said Circle in T and *t*, and therein take *tq* in such proportion to *t*E as *t*E or TE hath to TQ. Let *tq* lie the contrary way from *t* which TQ doth from T, and *q* shall be the Focus of the refracted Rays without any sensible Error, provided the Point Q be not so remote from the Axis, nor the Lens so broad as to make any of the Rays fall too obliquely on the refracting Surfaces.[A] [Pg 13]

And by the like Operations may the reflecting or refracting Surfaces be found when the two Foci are given, and thereby a Lens be formed, which shall make the Rays flow towards or from what Place you please.[B]

So then the Meaning of this Axiom is, that if Rays fall upon any Plane or Spherical Surface or Lens, and before their Incidence flow from or towards any Point Q, they shall after Reflexion or Refraction flow from or towards the Point *q* found by the foregoing Rules. And if the incident Rays flow from or towards several points Q, the reflected or refracted Rays shall flow from or towards so many other Points *q* found by the same Rules. Whether the reflected and refracted Rays flow from or towards the Point *q* is easily known by the situation of that Point. For if that Point be on the same side of the reflecting or refracting Surface or Lens with the Point Q, and the incident Rays flow from the Point Q, the reflected flow towards the Point *q* and the refracted from it; and if the incident Rays flow towards Q, the reflected flow from *q*, and the refracted towards it. And the contrary happens when *q* is on the other side of the Surface. [Pg 14]

## AX. VII.

*Wherever the Rays which come from all the Points of any Object meet again in so many Points after they have been made to converge by Reflection or Refraction, there they will make a Picture of the Object upon any white Body on which they fall.*

So if PR [in *Fig.* 3.] represent any Object without Doors, and AB be a Lens placed at a hole in the Window-shut of a dark Chamber, whereby the Rays that come from any Point Q of that Object are made to converge and meet again in the Point *q*; and if a Sheet of white Paper be held at *q* for the Light there to fall upon it, the Picture of that Object PR will appear upon the Paper in its proper shape and Colours. For as the Light which comes from the Point Q goes to the Point *q*, so the Light which comes from other Points P and R of the Object, will go to so many other correspondent Points *p* and *r* (as is manifest by the sixth Axiom;) so that every Point of the Object shall illuminate a correspondent Point of the Picture, and thereby make a Picture like the Object in Shape and Colour, this only excepted, that the Picture shall be inverted. And this is the Reason of that vulgar Experiment of casting [Pg 15] the Species of Objects from abroad upon a Wall or Sheet of white Paper in a dark Room.

In like manner, when a Man views any Object PQR, [in *Fig.* 8.] the Light which comes from the several Points of the Object is so refracted by the transparent skins and humours of the Eye, (that is, by the outward coat EFG, called the *Tunica Cornea*, and by the crystalline humour AB which is beyond the Pupil *mk*) as to converge and meet again in so many Points in the bottom of the Eye, and there to paint the Picture of the Object upon that skin (called the *Tunica Retina*) with which the bottom of the Eye is covered. For Anatomists, when they have taken off from the bottom of the Eye that outward and most thick Coat called the *Dura Mater*, can then see through the thinner Coats, the Pictures of Objects lively painted thereon. And these Pictures, propagated by Motion along the Fibres of the Optick Nerves into the Brain, are the cause of Vision. For accordingly as these Pictures are perfect or imperfect, the Object is seen perfectly or imperfectly. If the Eye be tinged with any colour (as in the Disease of the *Jaundice*) so as to tinge the Pictures in the bottom of the Eye with that Colour, then all Objects appear tinged with the same Colour. If the Humours of the Eye by old Age decay, so as by shrinking to make the *Cornea* and Coat of the *Crystalline Humour* grow flatter than [Pg 16] before, the Light will not be refracted enough, and for want of a sufficient Refraction will not converge to the bottom of the Eye but to some place beyond it, and by consequence paint in the bottom of the Eye a confused Picture, and according to the Indistinctness of this Picture the Object will appear confused. This is the reason of the decay of sight in old Men, and shews why their Sight is mended by Spectacles. For those Convex glasses supply the defect of plumpness in the Eye, and by increasing the Refraction make the Rays converge sooner, so as to convene distinctly at the bottom of the Eye if the Glass have a due degree of convexity. And the contrary happens in short-sighted Men whose Eyes are too plump. For the Refraction being now too great, the Rays converge and convene in the Eyes before they come at the bottom; and therefore the Picture made in the bottom and the Vision caused thereby will not be distinct, unless the Object be brought so near the Eye as that the place where the converging Rays convene may be removed to the bottom, or that the plumpness of the Eye be taken off and the Refractions diminished by a Concave-glass of a due degree of Concavity, or lastly that by Age the Eye grow flatter till it come to a due Figure: For short-sighted Men see remote Objects best in Old Age, and therefore they are accounted to have the most lasting Eyes. [Pg 17]

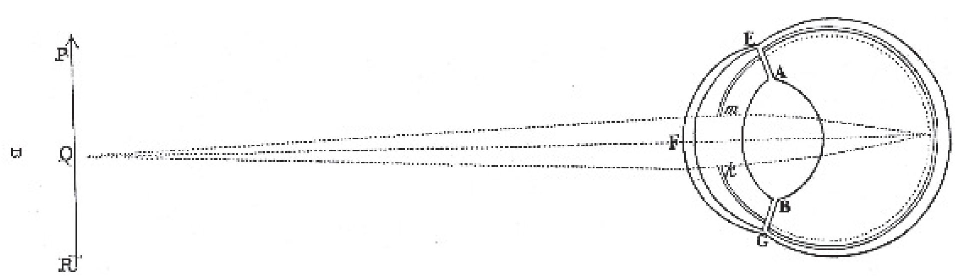


**Fig. 8.**

[Pg 18]

## AX. VIII.

*An Object seen by Reflexion or Refraction, appears in that place from whence the Rays after their last Reflexion or Refraction diverge in falling on the Spectator's Eye.*

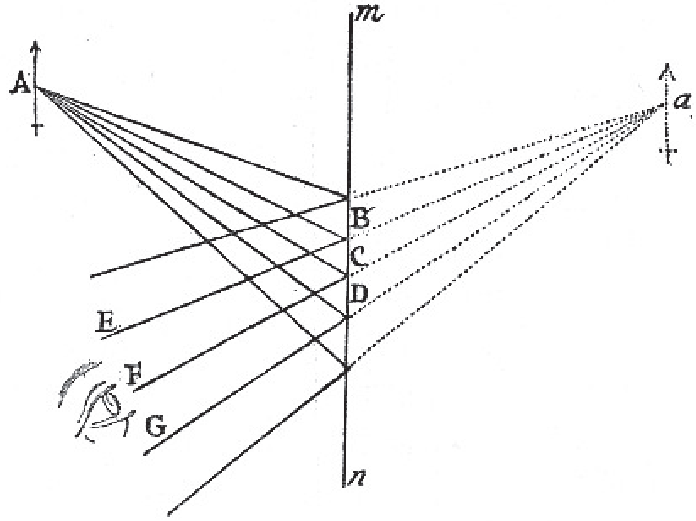


**Fig. 9.**

If the Object A [in Fig. 9.] be seen by Reflexion of a Looking-glass *mn*, it shall appear, not in its proper place A, but behind the Glass at *a*, from whence any Rays AB, AC, AD, which flow from one and the same Point of the Object, do after their Reflexion made in the Points B, C, D, diverge in going from the Glass to E, F, G, where they are incident on the Spectator's Eyes. For these Rays do make the same Picture in the bottom of the Eyes as if they had come from the Object really placed at *a* without the Interposition of the Looking-glass; and all Vision is made according to the place and shape of that Picture. [Pg 19]

In like manner the Object D [in Fig. 2.] seen through a Prism, appears not in its proper place D, but is thence translated to some other place *d* situated in the last refracted Ray FG drawn backward from F to *d*.

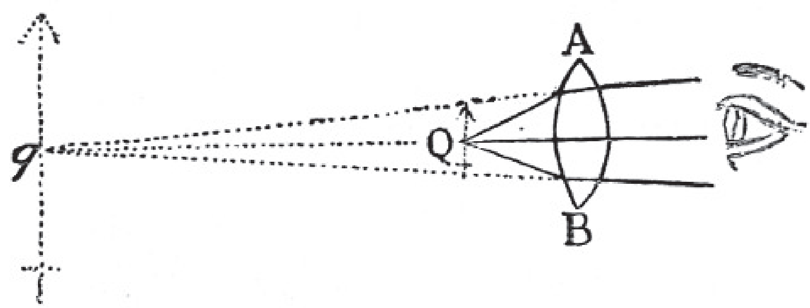


**Fig. 10.**

And so the Object Q [in Fig. 10.] seen through the Lens AB, appears at the place *q* from whence the Rays diverge in passing from the Lens to the Eye. Now it is to be noted, that the Image of the Object at *q* is so much bigger or lesser than the Object it self at Q, as the distance of the Image at *q* from the Lens AB is bigger or less than the distance of the Object at Q from the same Lens. And if the Object be seen through two or more such Convex or Concave-glasses, every Glass shall make a new Image, and the Object shall appear in the place of the bigness of the last Image. Which consideration unfolds the Theory of Microscopes and Telescopes. For that Theory consists in almost nothing else than the describing such Glasses as shall make the last Image of any Object as distinct and large and luminous as it can conveniently be made.

I have now given in Axioms and their Explications the sum of what hath hitherto been treated of in Opticks. For what hath been generally agreed on I content my self to assume under the notion of Principles, in order to what I have farther to write. And this may suffice for an Introduction to Readers of quick Wit and good Understanding not yet versed in Opticks: Although those who are already acquainted with this Science, and have handled Glasses, will more readily apprehend what followeth. [Pg 20]

## FOOTNOTES:

[A] In our Author's *Lectiones Opticæ*, Part I. Sect. IV. Prop 29, 30, there is an elegant Method of determining these *Foci*; not only in spherical Surfaces, but likewise in any other curved Figure whatever: And in Prop. 32, 33, the same thing is done for any Ray lying out of the Axis.

[B] *Ibid.* Prop. 34.

# *PROPOSITIONS.*

## *PROP.* I. Theor. I.

*Lights which differ in Colour, differ also in Degrees of Refrangibility.*

The Proof by Experiments.

*Exper.* 1. I took a black oblong stiff Paper terminated by Parallel Sides, and with a Perpendicular right Line drawn cross from one Side to the other, distinguished it into two equal Parts. One of these parts I painted with a red colour and the other with a blue. The Paper was very black, and the Colours intense and thickly laid on, that the Phænomenon might be more conspicuous. This Paper I view'd through a Prism of solid Glass, whose two Sides through which the Light passed to the Eye were plane and well polished, and contained an Angle of about sixty degrees; which Angle I call the refracting Angle of the Prism. And whilst I view'd it, I held it and the Prism before a Window in such manner that [Pg 21] the Sides of the Paper were parallel to the Prism, and both those Sides and the Prism were parallel to the Horizon, and the cross Line was also parallel to it: and that the Light which fell from the Window upon the Paper made an Angle with the Paper, equal to that Angle which was made with the same Paper by the Light reflected from it to the Eye. Beyond the Prism was the Wall of the Chamber under the Window covered over with black Cloth, and the Cloth was involved in Darkness that no Light might be reflected from thence, which in passing by the Edges of the Paper to the Eye, might mingle itself with the Light of the Paper, and obscure the Phænomenon thereof. These things being thus ordered, I found that if the refracting Angle of the Prism be turned upwards, so that the Paper may seem to be lifted upwards by the Refraction, its blue half will be lifted higher by the Refraction than its red half. But if the refracting Angle of the Prism be turned downward, so that the Paper may seem to be carried lower by the Refraction, its blue half will be carried something lower thereby than its red half. Wherefore in both Cases the Light which comes from the blue half of the Paper through the Prism to the Eye, does in like Circumstances suffer a greater Refraction than the Light which comes from the red half, and by consequence is more refrangible.

*Illustration.* In the eleventh Figure, MN represents the Window, and DE the Paper terminated with parallel Sides DJ and HE, and by the transverse Line FG distinguished into two halfs, the one DG of [Pg 22] an intensely blue Colour, the other FE of an intensely red. And BAC*cab* represents the Prism whose refracting Planes AB*ba* and AC*ca* meet in the Edge of the refracting Angle A*a*. This Edge A*a* being upward, is parallel both to the Horizon, and to the Parallel-Edges of the Paper DJ and HE, and the transverse Line FG is perpendicular to the Plane of the Window. And *de* represents the Image of the Paper seen by Refraction upwards in such manner, that the blue half DG is carried higher to *dg* than the red half FE is to *fe*, and therefore suffers a greater Refraction. If the Edge of the refracting Angle [Pg 23] be turned downward, the Image of the Paper will be refracted downward; suppose to δε, and the blue half will be refracted lower to δγ than the red half is to πε.

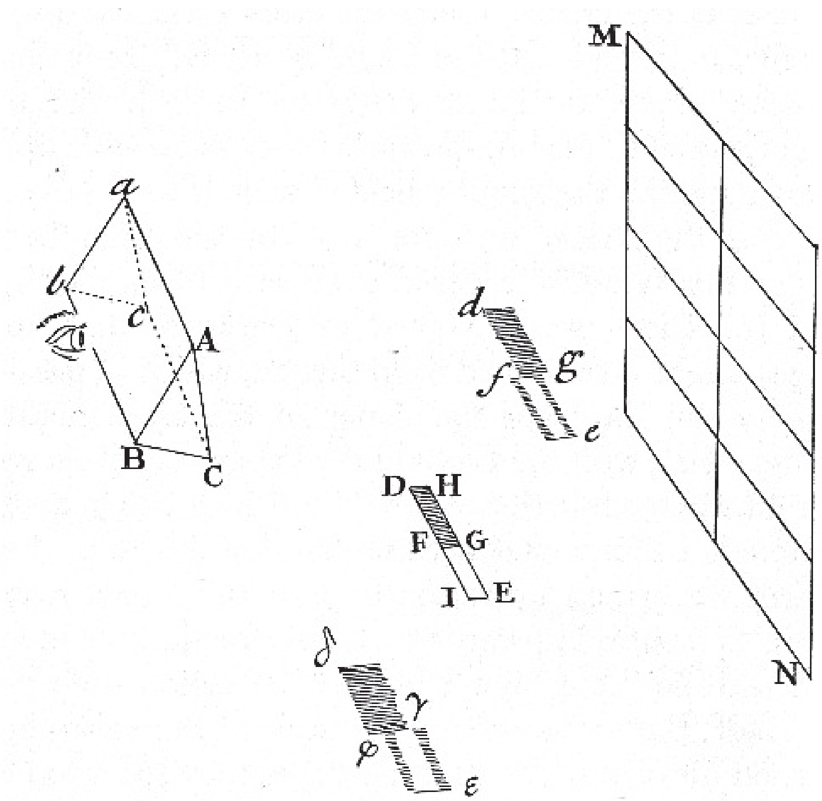


**Fig. 11.**

*Exper.* 2. About the aforesaid Paper, whose two halfs were painted over with red and blue, and which was stiff like thin Pasteboard, I lapped several times a slender Thred of very black Silk, in such manner that the several parts of the Thred might appear upon the Colours like so many black Lines drawn over them, or like long and slender dark Shadows cast upon them. I might have drawn black Lines with a Pen, but the Threds were smaller and better defined. This Paper thus coloured and lined I set against a Wall perpendicularly to the Horizon, so that one of the Colours might stand to the Right Hand, and the other to the Left. Close before the Paper, at the Confine of the Colours below, I placed a Candle to illuminate the Paper strongly: For the Experiment was tried in the Night. The Flame of the Candle reached up to the lower edge of the Paper, or a very little higher. Then at the distance of six Feet, and one or two Inches from the Paper upon the Floor I erected a Glass Lens four Inches and a quarter broad, which might collect the Rays coming from the several Points of the Paper, and make them converge towards so many other Points at the same distance of six Feet, and one or two Inches on the other side of the Lens, and so form the Image of the coloured Paper upon a white Paper placed [Pg 24] there, after the same manner that a Lens at a Hole in a Window casts the Images of Objects abroad upon a Sheet of white Paper in a dark Room. The aforesaid white Paper, erected perpendicular to the Horizon, and to the Rays which fell upon it from the Lens, I moved sometimes towards the Lens, sometimes from it, to find the Places where the Images of the blue and red Parts of the coloured Paper appeared most distinct. Those Places I easily knew by the Images of the black Lines which I had made by winding the Silk about the Paper. For the Images of those fine and slender Lines (which by reason of their Blackness were like Shadows on the Colours) were confused and scarce visible, unless when the Colours on either side of each Line were terminated most distinctly, Noting therefore, as diligently as I could, the Places where the Images of the red and blue halfs of the coloured Paper appeared most distinct, I found that where the red half of the Paper appeared distinct, the blue half appeared confused, so that the black Lines drawn upon it could scarce be seen; and on the contrary, where the blue half appeared most distinct, the red half appeared confused, so that the black Lines upon it were scarce visible. And between the two Places where these Images appeared distinct there was the distance of an Inch and a half; the distance of the white Paper from the Lens, when the Image of the red half of the coloured Paper appeared most distinct, being greater by an Inch and an half than the distance of the same white Paper from the Lens, when the Image of the blue half appeared most [Pg 25] distinct. In like Incidences therefore of the blue and red upon the Lens, the blue was refracted more by the Lens than the red, so as to converge sooner by an Inch and a half, and therefore is more refrangible.

*Illustration.* In the twelfth Figure (p. 27), DE signifies the coloured Paper, DG the blue half, FE the red half, MN the Lens, HJ the white Paper in that Place where the red half with its black Lines appeared distinct, and *hi* the same Paper in that Place where the blue half appeared distinct. The Place *hi* was nearer to the Lens MN than the Place HJ by an Inch and an half.

*Scholium.* The same Things succeed, notwithstanding that some of the Circumstances be varied; as in the first Experiment when the Prism and Paper are any ways inclined to the Horizon, and in both when coloured Lines are drawn upon very black Paper. But in the Description of these Experiments, I have set down such Circumstances, by which either the Phænomenon might be render'd more conspicuous, or a Novice might more easily try them, or by which I did try them only. The same Thing, I have often done in the following Experiments: Concerning all which, this one Admonition may suffice. Now from these Experiments it follows not, that all the Light of the blue is more refrangible than all the Light of the red: For both Lights are mixed of Rays differently refrangible, so that in the red there are some Rays not less refrangible than those of the blue, and in the blue there are some Rays not more refrangible [Pg 26] than those of the red: But these Rays, in proportion to the whole Light, are but few, and serve to diminish the Event of the Experiment, but are not able to destroy it. For, if the red and blue Colours were more dilute and weak, the distance of the Images would be less than an Inch and a half; and if they were more intense and full, that distance would be greater, as will appear hereafter. These Experiments may suffice for the Colours of Natural Bodies. For in the Colours made by the Refraction of Prisms, this Proposition will appear by the Experiments which are now to follow in the next Proposition.

## *PROP.* II. Theor. II.

*The Light of the Sun consists of Rays differently Refrangible.*

The Proof by Experiments. [Pg 27]

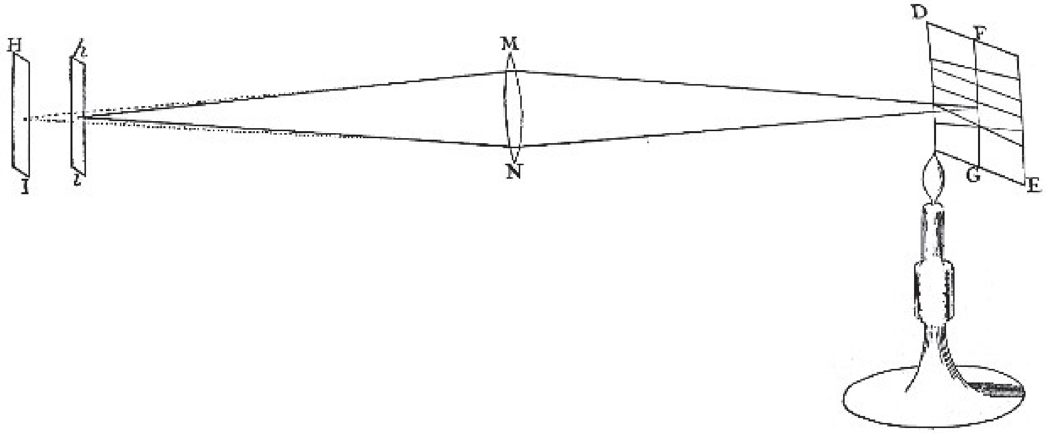


**Fig. 12.**

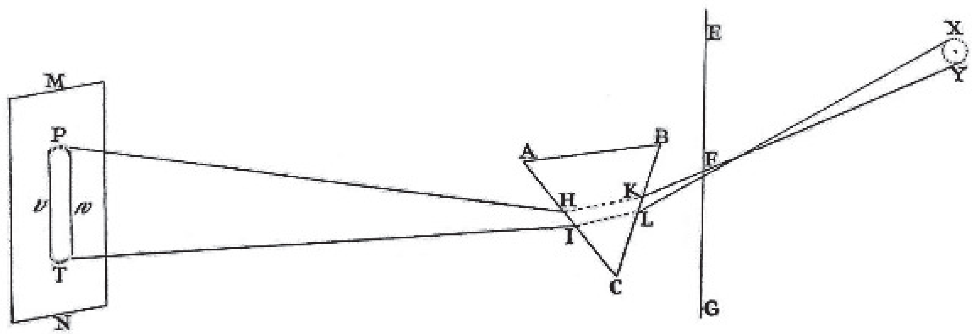


**Fig. 13.**

*Exper.* 3. [Pg 28]

In a very dark Chamber, at a round Hole, about one third Part of an Inch broad, made in the Shut of a Window, I placed a Glass Prism, whereby the Beam of the Sun's Light, which came in at that Hole, might be refracted upwards toward the opposite Wall of the Chamber, and there form a colour'd Image of the Sun. The Axis of the Prism (that is, the Line passing through the middle of the Prism from one end of it to the other end parallel to the edge of the Refracting Angle) was in this and the following Experiments perpendicular to the incident Rays. About this Axis I turned the Prism slowly, and saw the refracted Light on the Wall, or coloured Image of the Sun, first to descend, and then to ascend. Between the Descent and Ascent, when the Image seemed Stationary, I stopp'd the Prism, and fix'd it in that Posture, that it should be moved no more. For in that Posture the Refractions of the Light at the two Sides of the refracting Angle, that is, at the Entrance of the Rays into the Prism, and at their going out of it, were equal to one another.[C] So also in other Experiments, as often as I would have the Refractions on both sides the Prism to be equal to one another, I noted the Place where the Image of the Sun formed by the refracted Light stood still between its two contrary Motions, in the common Period of its Progress and Regress; and when the Image fell upon that Place, I made fast the Prism. And in this Posture, as the most convenient, it is to be understood that all the Prisms are placed in the following Experiments, unless where some other Posture is described. The Prism therefore being placed in this Posture, I let the refracted Light fall perpendicularly upon a Sheet of white Paper at the opposite Wall of the Chamber, and observed the Figure and Dimensions of the Solar Image formed on the Paper by that Light. This Image was Oblong and not Oval, but terminated with two Rectilinear and Parallel Sides, and two Semicircular Ends. On its Sides it was bounded pretty distinctly, but on its [Pg 29] Ends very confusedly and indistinctly, the Light there decaying and vanishing by degrees. The Breadth of this Image answered to the Sun's Diameter, and was about two Inches and the eighth Part of an

Inch, including the Penumbra. For the Image was eighteen Feet and an half distant from the Prism, and at this distance that Breadth, if diminished by the Diameter of the Hole in the Window-shut, that is by a quarter of an Inch, subtended an Angle at the Prism of about half a Degree, which is the Sun's apparent Diameter. But the Length of the Image was about ten Inches and a quarter, and the Length of the Rectilinear Sides about eight Inches; and the refracting Angle of the Prism, whereby so great a Length was made, was 64 degrees. With a less Angle the Length of the Image was less, the Breadth remaining the same. If the Prism was turned about its Axis that way which made the Rays emerge more obliquely out of the second refracting Surface of the Prism, the Image soon became an Inch or two longer, or more; and if the Prism was turned about the contrary way, so as to make the Rays fall more obliquely on the first refracting Surface, the Image soon became an Inch or two shorter. And therefore in trying this Experiment, I was as curious as I could be in placing the Prism by the above-mention'd Rule exactly in such a Posture, that the Refractions of the Rays at their Emergence out of the Prism might be equal to that at their Incidence on it. This Prism had some Veins running along within the Glass from one end to the other, which scattered some of the Sun's Light irregularly, but had no [Pg 30] sensible Effect in increasing the Length of the coloured Spectrum. For I tried the same Experiment with other Prisms with the same Success. And particularly with a Prism which seemed free from such Veins, and whose refracting Angle was 62-1/2 Degrees, I found the Length of the Image 9-3/4 or 10 Inches at the distance of 18-1/2 Feet from the Prism, the Breadth of the Hole in the Window-shut being 1/4 of an Inch, as before. And because it is easy to commit a Mistake in placing the Prism in its due Posture, I repeated the Experiment four or five Times, and always found the Length of the Image that which is set down above. With another Prism of clearer Glass and better Polish, which seemed free from Veins, and whose refracting Angle was 63-1/2 Degrees, the Length of this Image at the same distance of 18-1/2 Feet was also about 10 Inches, or 10-1/8. Beyond these Measures for about a 1/4 or 1/3 of an Inch at either end of the Spectrum the Light of the Clouds seemed to be a little tinged with red and violet, but so very faintly, that I suspected that Tincture might either wholly, or in great Measure arise from some Rays of the Spectrum scattered irregularly by some Inequalities in the Substance and Polish of the Glass, and therefore I did not include it in these Measures. Now the different Magnitude of the hole in the Window-shut, and different thickness of the Prism where the Rays passed through it, and different inclinations of the Prism to the Horizon, made no sensible changes in the length of the Image. Neither did the different matter of the Prisms make any: for in a [Pg 31] Vessel made of polished Plates of Glass cemented together in the shape of a Prism and filled with Water, there is the like Success of the Experiment according to the quantity of the Refraction. It is farther to be observed, that the Rays went on in right Lines from the Prism to the Image, and therefore at their very going out of the Prism had all that Inclination to one another from which the length of the Image proceeded, that is, the Inclination of more than two degrees and an half. And yet according to the Laws of Opticks vulgarly received, they could not possibly be so much inclined to one another.[D] For let EG [*Fig.* 13. (p. 27)] represent the Window-shut, F the hole made therein through which a beam of the Sun's Light was transmitted into the darkened Chamber, and ABC a Triangular Imaginary Plane whereby the Prism is feigned to be cut transversely through the middle of the Light. Or if you please, let ABC represent the Prism it self, looking directly towards the Spectator's Eye with its nearer end: And let XY be the Sun, MN the Paper upon which the Solar Image or Spectrum is cast, and PT the Image it self whose sides towards *v* and *w* are Rectilinear and Parallel, and ends towards P and T Semicircular. YKHP and XLJT are two Rays, the first of which comes from the lower part of the Sun to the higher part of the Image, and is refracted in the Prism at K and H, and the latter comes from the higher part of the Sun to the lower part of the Image, and is refracted at L and J. Since the Refractions [Pg 32] on both sides the Prism are equal to one another, that is, the Refraction at K equal to the Refraction at J, and the Refraction at L equal to the Refraction at H, so that the Refractions of the incident Rays at K and L taken together, are equal to the Refractions of the emergent Rays at H and J taken together: it follows by adding equal things to equal things, that the Refractions at K and H taken together, are equal to the Refractions at J and L taken together, and therefore the two Rays being equally refracted, have the same Inclination to one another after Refraction which they had before; that is, the Inclination of half a Degree answering to the Sun's Diameter. For so great was the inclination of the Rays to one another before Refraction. So then, the length of the Image PT would by the Rules of Vulgar Opticks subtend an Angle of half a Degree at the Prism, and by Consequence be equal to the breadth *vw*; and therefore the Image would be round. Thus it would be were the two Rays XLJT and YKHP, and all the rest which form the Image P*w*T*v*, alike refrangible. And therefore seeing by Experience it is found that the Image is not round, but about five times longer than broad, the Rays which going to the upper end P of the Image suffer the greatest Refraction, must be more refrangible than those which go to the lower end T, unless the Inequality of Refraction be casual.

This Image or Spectrum PT was coloured, being red at its least refracted end T, and violet at its most refracted end P, and yellow green and blue in the intermediate Spaces. Which agrees with the first Proposition, that Lights which differ in Colour, do also differ in Refrangibility. The length of the Image in the foregoing Experiments, I measured from the faintest and outmost red at one end, to the faintest and outmost blue at the other end, excepting only a little Penumbra, whose breadth scarce exceeded a quarter of an Inch, as was said above. [Pg 33]

*Exper.* 4. In the Sun's Beam which was propagated into the Room through the hole in the Window-shut, at the distance of some Feet from the hole, I held the Prism in such a Posture, that its Axis might be perpendicular to that Beam. Then I looked through the Prism upon the hole, and turning the Prism to and fro about its Axis, to make the Image of the Hole ascend and descend, when between its two contrary Motions it seemed Stationary, I stopp'd the Prism, that the Refractions of both sides of the refracting Angle might be equal to each other, as in the former Experiment. In this situation of the Prism viewing through it the said Hole, I observed the length of its refracted Image to be many times greater than its breadth, and that the most refracted part thereof appeared violet, the least refracted red, the middle parts blue, green and yellow in order. The same thing happen'd when I removed the Prism out of the Sun's Light, and looked through it upon the hole shining by the Light of the Clouds beyond it. And yet if the Refraction were done regularly according to one certain Proportion of the Sines of [Pg 34] Incidence and Refraction as is vulgarly supposed, the refracted Image ought to have appeared round.

So then, by these two Experiments it appears, that in Equal Incidences there is a considerable inequality of Refractions. But whence this inequality arises, whether it be that some of the incident Rays are refracted more, and others less, constantly, or by chance, or that one and the same Ray is by Refraction disturbed, shatter'd, dilated, and as it were split and spread into many diverging Rays, as *Grimaldo* supposes, does not yet appear by these Experiments, but will appear by those that follow.

*Exper.* 5. Considering therefore, that if in the third Experiment the Image of the Sun should be drawn out into an oblong Form, either by a Dilatation of every Ray, or by any other casual inequality of the Refractions, the same oblong Image would by a second Refraction made sideways be drawn out as much in breadth by the like Dilatation of the Rays, or other casual inequality of the Refractions sideways, I tried what would be the Effects of such a second Refraction. For this end I ordered all things as in the third Experiment, and then placed a second Prism immediately after the first in a cross Position to it, that it might again refract the beam of the Sun's Light which came to it through the first Prism. In the first Prism this beam was refracted upwards, and in the second sideways. And I found that by the Refraction of the second Prism, the breadth of the Image was not increased, but its superior part, which in the first Prism suffered the greater Refraction, and appeared violet and blue, did [Pg 35] again in the second Prism suffer a greater Refraction than its inferior part, which appeared red and yellow, and this without any Dilatation of the Image in breadth.

*Illustration.* Let S [*Fig.* 14, 15.] represent the Sun, F the hole in the Window, ABC the first Prism, DH the second Prism, Y the round Image of the Sun made by a direct beam of Light when the Prisms are taken away, PT the oblong Image of the Sun made by that beam passing through the first Prism alone, when the second Prism is taken away, and *pt* the Image made by the cross Refractions of both Prisms together. Now if the Rays which tend towards the several Points of the round Image Y were dilated and spread by the Refraction of the first Prism, so that they should not any longer go in single Lines to single Points, but that every Ray being split, shattered, and changed from a Linear Ray to a Superficies of Rays diverging from the Point of Refraction, and lying in the Plane of the Angles of Incidence and Refraction, they should go in those Planes to so many Lines reaching almost from one end of the Image PT to the other, and if that Image should thence become oblong: those Rays and their several parts tending towards the several Points of the Image PT ought to be again dilated and spread sideways by the transverse Refraction of the second Prism, so as to compose a four square Image, such as is represented at πτ. For the better understanding of which, let the Image PT be distinguished into five [Pg 36]

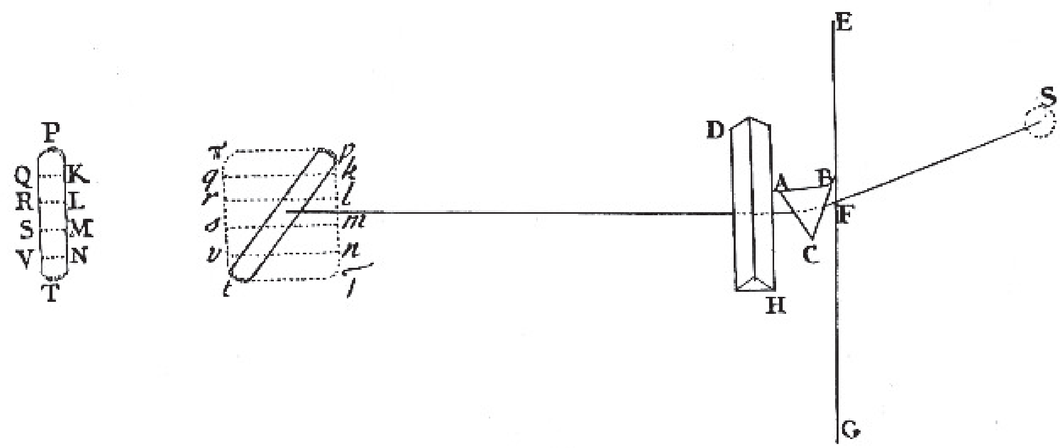


**Fig. 14**

equal parts PQK, KQRL, LRSM, MSVN, NVT. And by the same irregularity that the orbicular Light Y is by the Refraction of the first Prism dilated and drawn out into a long Image PT, the Light PQK which takes up a space of the same length and breadth with the Light Y ought to be by the Refraction of the second Prism dilated and drawn out into the long Image *πqkp*, and the Light KQRL into the long Image *kqrl*, and the Lights LRSM, MSVN, NVT, into so many other long Images *lrsm*, *msvn*, *nvtτ*; and all these long Images would compose the four square Images *πτ*. Thus it ought to be were every Ray dilated by Refraction, and spread into a triangular Superficies of Rays diverging from the Point of Refraction. For the second Refraction would spread the Rays one way as much as the first doth another, and so dilate the Image in breadth as much as the first doth in length. And the same thing ought to happen, were some rays casually refracted more than others. But the Event is otherwise. The Image PT was not made broader by the Refraction of the second Prism, but only became oblique, as 'tis represented at *pt*, its upper end P being by the Refraction translated to a greater distance than its lower end T. So then the Light which went towards the upper end P of the Image, was (at equal Incidences) more refracted in the second Prism, than the Light which tended towards the lower end T, that is the blue and violet, than the red and yellow; and therefore was more refrangible. The same Light was by the Refraction of the first Prism translated farther from the place Y to which it tended before Refraction; and therefore suffered as well in the first Prism as in the second a greater Refraction than the rest of the Light, and by consequence was more refrangible than the rest, even before its incidence on the first Prism. [Pg 37] [Pg 38]

Sometimes I placed a third Prism after the second, and sometimes also a fourth after the third, by all which the Image might be often refracted sideways: but the Rays which were more refracted than the rest in the first Prism were also more refracted in all the rest, and that without any Dilatation of the

Image sideways: and therefore those Rays for their constancy of a greater Refraction are deservedly reputed more refrangible.

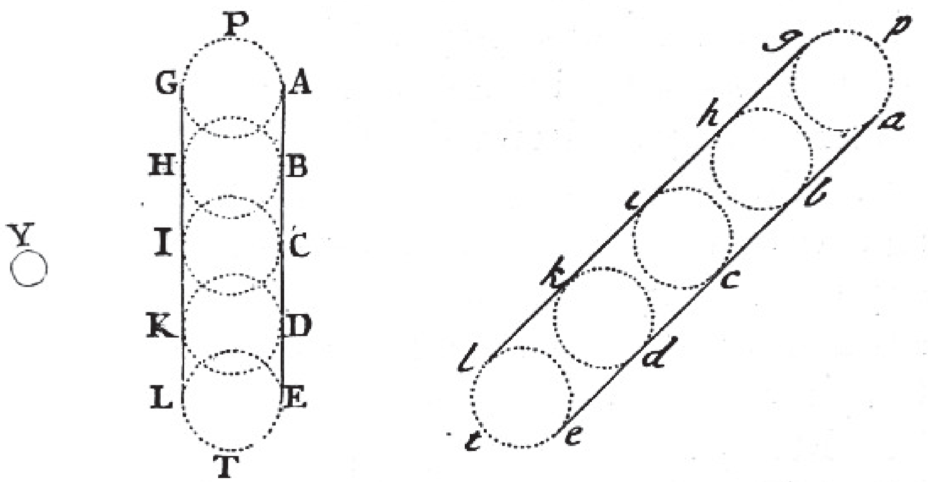


**Fig. 15**

But that the meaning of this Experiment may more clearly appear, it is to be considered that the Rays which are equally refrangible do fall upon a Circle answering to the Sun's Disque. For this was proved in the third Experiment. By a Circle I understand not here a perfect geometrical Circle, but any orbicular Figure whose length is equal to its breadth, and which, as to Sense, may seem circular. Let therefore AG [in *Fig.* 15.] represent the Circle which all the most refrangible Rays propagated from the whole Disque of the Sun, would illuminate and paint upon the opposite Wall if they were alone; EL the Circle which all the least refrangible Rays would in like manner illuminate and paint if they were alone; BH, CJ, DK, the Circles which so many intermediate sorts of Rays would successively paint upon the Wall, if they were singly propagated from the Sun in successive order, the rest being always [Pg 39] intercepted; and conceive that there are other intermediate Circles without Number, which innumerable other intermediate sorts of Rays would successively paint upon the Wall if the Sun should successively emit every sort apart. And seeing the Sun emits all these sorts at once, they must all together illuminate and paint innumerable equal Circles, of all which, being according to their degrees of Refrangibility placed in order in a continual Series, that oblong Spectrum PT is composed which I described in the third Experiment. Now if the Sun's circular Image Y [in *Fig.* 15.] which is made by an unrefracted beam of Light was by any Dilation of the single Rays, or by any other irregularity in the Refraction of the first Prism, converted into the oblong Spectrum, PT: then ought every Circle AG, BH, CJ, &c. in that Spectrum, by the cross Refraction of the second Prism again dilating or otherwise [Pg 40] scattering the Rays as before, to be in like manner drawn out and transformed into an oblong Figure, and thereby the breadth of the Image PT would be now as much augmented as the length of the Image Y was before by the Refraction of the first Prism; and thus by the Refractions of both Prisms together would be formed a four square Figure *pπtτ*, as I described above. Wherefore since the breadth of the Spectrum PT is not increased by the Refraction sideways, it is certain that the Rays are not split or dilated, or otherways irregularly scatter'd by that Refraction, but that every Circle is by a regular and uniform Refraction translated entire into another Place, as the Circle AG by the greatest Refraction into the place *ag*, the Circle BH by a less Refraction into the place *bh*, the Circle CJ by a Refraction still less into the place *ci*, and so of the rest; by which means a new Spectrum *pt* inclined to the former PT is in like manner composed of Circles lying in a right Line; and these Circles must be of the same bigness with the former, because the breadths of all the Spectrums Y, PT and *pt* at equal distances from the Prisms are equal.

I considered farther, that by the breadth of the hole F through which the Light enters into the dark Chamber, there is a Penumbra made in the Circuit of the Spectrum Y, and that Penumbra remains in the rectilinear Sides of the Spectrums PT and *pt*. I placed therefore at that hole a Lens or Object-glass of a Telescope which might cast the Image of the Sun distinctly on Y without any Penumbra at all, and [Pg 41] found that the Penumbra of the rectilinear Sides of the oblong Spectrums PT and *pt* was also thereby taken away, so that those Sides appeared as distinctly defined as did the Circumference of the first Image Y. Thus it happens if the Glass of the Prisms be free from Veins, and their sides be accurately plane and well polished without those numberless Waves or Curles which usually arise from Sand-holes a little smoothed in polishing with Putty. If the Glass be only well polished and free from Veins, and the Sides not accurately plane, but a little Convex or Concave, as it frequently happens; yet may the three Spectrums Y, PT and *pt* want Penumbras, but not in equal distances from the Prisms. Now from this want of Penumbras, I knew more certainly that every one of the Circles was refracted according to some most regular, uniform and constant Law. For if there were any irregularity in the Refraction, the right Lines AE and GL, which all the Circles in the Spectrum PT do touch, could not by that Refraction be translated into the Lines *ae* and *gl* as distinct and straight as they were before, but there would arise in those translated Lines some Penumbra or Crookedness or Undulation, or other sensible Perturbation contrary to what is found by Experience. Whatsoever Penumbra or Perturbation should be made in the Circles by the cross Refraction of the second Prism, all that Penumbra or Perturbation would be conspicuous in the right Lines *ae* and *gl* which touch those Circles. And therefore since there is no such Penumbra or Perturbation in those right Lines, there must [Pg 42] be none in the Circles. Since the distance between those Tangents or breadth of the Spectrum is not increased by the Refractions, the Diameters of the Circles are not increased thereby. Since those Tangents continue to be right Lines, every Circle which in the first Prism is more or less refracted, is exactly in the same proportion more or less refracted in the second. And seeing all these things continue to succeed after the same manner when the Rays are again in a third Prism, and again in a fourth refracted sideways, it is evident that the Rays of one and the same Circle, as to their degree of Refrangibility, continue always uniform and homogeneal to one another, and that those of several Circles do differ in degree of Refrangibility, and that in some certain and constant Proportion. Which is the thing I was to prove.

There is yet another Circumstance or two of this Experiment by which it becomes still more plain and convincing. Let the second Prism DH [in *Fig.* 16.] be placed not immediately after the first, but at some distance from it; suppose in the mid-way between it and the Wall on which the oblong Spectrum PT is cast, so that the Light from the first Prism may fall upon it in the form of an oblong Spectrum πτ parallel to this second Prism, and be refracted sideways to form the oblong Spectrum *pt* upon the Wall. And you will find as before, that this Spectrum *pt* is inclined to that Spectrum PT, which the first Prism forms alone without the second; the blue ends P and *p* being farther distant from one another than the red ones T and *t*, and by consequence that the Rays which go to the blue end π of the Image πτ, and which therefore suffer the greatest Refraction in the first Prism, are again in the second Prism more refracted than the rest. [Pg 43]

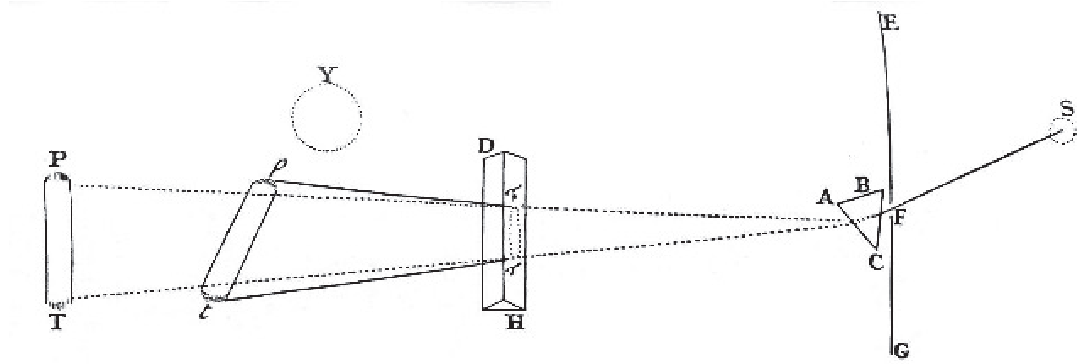


**Fig. 16.**

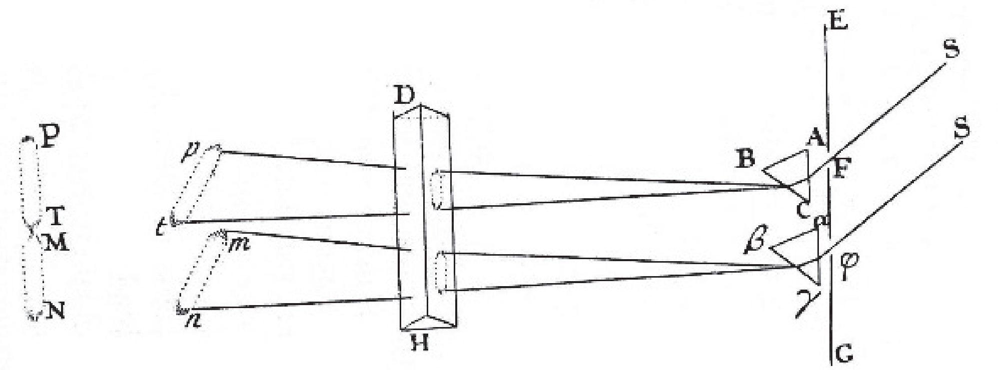


**Fig. 17.**

The same thing I try'd also by letting the Sun's Light into a dark Room through two little round holes F and φ [in *Fig.* 17.] made in the Window, and with two parallel Prisms ABC and αβγ placed at those holes (one at each) refracting those two beams of Light to the opposite Wall of the Chamber, in such manner that the two colour'd Images PT and MN which they there painted were joined end to end and lay in one straight Line, the red end T of the one touching the blue end M of the other. For if these two refracted Beams were again by a third Prism DH placed cross to the two first, refracted sideways, and the Spectrums thereby translated to some other part of the Wall of the Chamber, suppose the Spectrum PT to *pt* and the Spectrum MN to *mn*, these translated Spectrums *pt* and *mn* would not lie in one straight Line with their ends contiguous as before, but be broken off from one another and become parallel, the blue end *m* of the Image *mn* being by a greater Refraction translated farther from its former place MT, than the red end *t* of the other Image *pt* from the same place MT; which puts the Proposition past Dispute. And this happens whether the third Prism DH be placed immediately after the two first, or at a great distance from them, so that the Light refracted in the two first Prisms be either white and circular, or coloured and oblong when it falls on the third. [Pg 44] [Pg 45]

*Exper.* 6. In the middle of two thin Boards I made round holes a third part of an Inch in diameter, and in the Window-shut a much broader hole being made to let into my darkned Chamber a large Beam of the Sun's Light; I placed a Prism behind the Shut in that beam to refract it towards the opposite Wall, and close behind the Prism I fixed one of the Boards, in such manner that the middle of the refracted Light might pass through the hole made in it, and the rest be intercepted by the Board. Then at the distance of about twelve Feet from the first Board I fixed the other Board in such manner that the middle of the refracted Light which came through the hole in the first Board, and fell upon the opposite Wall, might pass through the hole in this other Board, and the rest being intercepted by the Board might paint upon it the coloured Spectrum of the Sun. And close behind this Board I fixed another Prism to refract the Light which came through the hole. Then I returned speedily to the first Prism, and by turning it slowly to and fro about its Axis, I caused the Image which fell upon the second Board to move up and down upon that Board, that all its parts might successively pass through the hole in that Board and fall upon the Prism behind it. And in the mean time, I noted the places on the opposite Wall to which that Light after its Refraction in the second Prism did pass; and by the difference of the places I found that the Light which being most refracted in the first Prism did go to the blue end of the Image, [Pg 46] was again more refracted in the second Prism than the Light which went to the red end of that Image, which proves as well the first Proposition as the second. And this happened whether the Axis of the two Prisms were parallel, or inclined to one another, and to the Horizon in any given Angles.

*Illustration.* Let F [in *Fig.* 18.] be the wide hole in the Window-shut, through which the Sun shines upon the first Prism ABC, and let the refracted Light fall upon the middle of the Board DE, and the middle part of that Light upon the hole G made in the middle part of that Board. Let this trajected part of that Light fall again upon the middle of the second Board *de*, and there paint such an oblong coloured Image of the Sun as was described in the third Experiment. By turning the Prism ABC slowly to and fro about its Axis, this Image will be made to move up and down the Board *de*, and by this means all its parts from one end to the other may be made to pass successively through the hole *g* which is made in the middle of that Board. In the mean while another Prism *abc* is to be fixed next after that hole *g*, to refract the trajected Light a second time. And these things being thus ordered, I marked the places M and N of the opposite Wall upon which the refracted Light fell, and found that whilst the two Boards and second Prism remained unmoved, those places by turning the first Prism about its Axis were changed perpetually. For when the lower part of the Light which fell upon the second Board *de* was cast through the hole *g*, it went to a lower place M on the Wall and when the higher part of that Light was cast through the same hole *g*, it went to a higher place N on the Wall, and when any intermediate part of the Light was cast through that hole, it went to some place on the Wall between M and N. The unchanged Position of the holes in the Boards, made the Incidence of the Rays upon the second Prism to be the same in all cases. And yet in that common Incidence some of the Rays were more refracted, and others less. And those were more refracted in this Prism, which by a greater Refraction in the first Prism were more turned out of the way, and therefore for their Constancy of being more refracted are deservedly called more refrangible. [Pg 47]

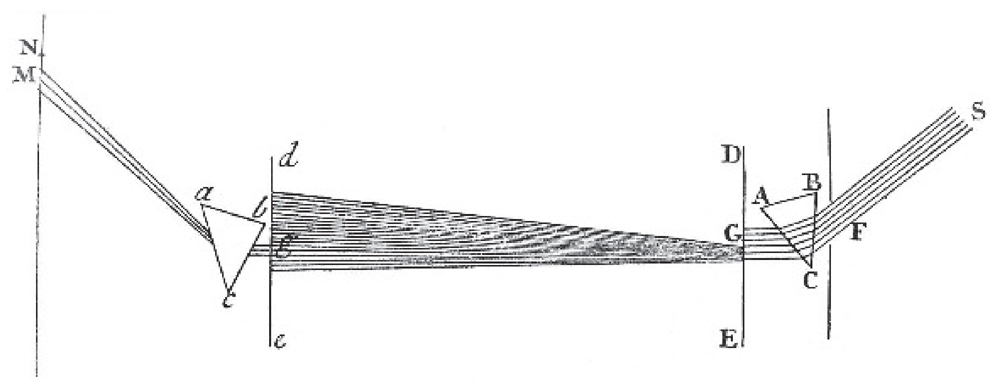


**Fig. 18.**

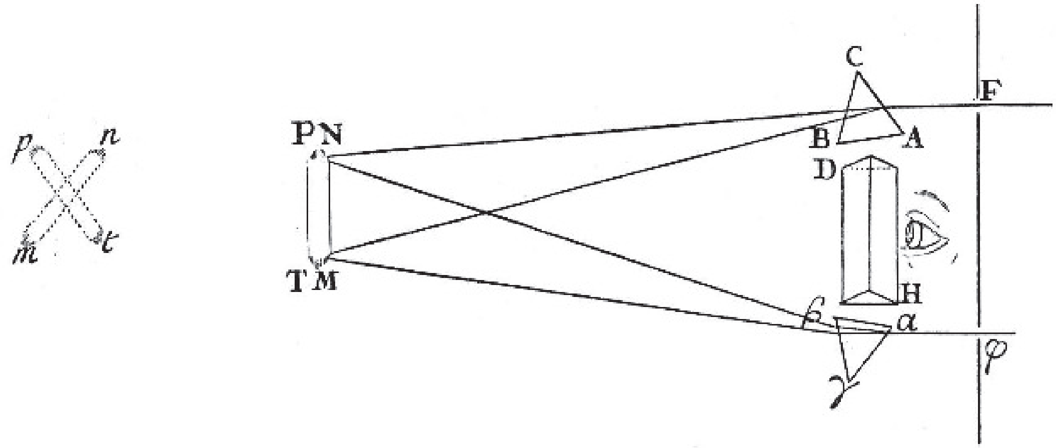


**Fig. 20.**

*Exper.* 7. At two holes made near one another in my Window-shut I placed two Prisms, one at each, [Pg 48]
which might cast upon the opposite Wall (after the manner of the third Experiment) two oblong coloured Images of the Sun. And at a little distance from the Wall I placed a long slender Paper with straight and parallel edges, and ordered the Prisms and Paper so, that the red Colour of one Image might fall directly upon one half of the Paper, and the violet Colour of the other Image upon the other half of the same Paper; so that the Paper appeared of two Colours, red and violet, much after the manner of the painted Paper in the first and second Experiments. Then with a black Cloth I covered the Wall behind the Paper, that no Light might be reflected from it to disturb the Experiment, and viewing the Paper through a third Prism held parallel to it, I saw that half of it which was illuminated by [Pg 49]
the violet Light to be divided from the other half by a greater Refraction, especially when I went a good way off from the Paper. For when I viewed it too near at hand, the two halfs of the Paper did not appear fully divided from one another, but seemed contiguous at one of their Angles like the painted Paper in the first Experiment. Which also happened when the Paper was too broad.

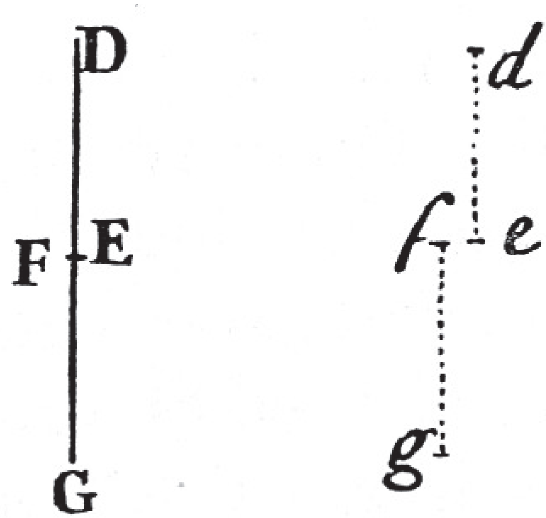


**Fig. 19.**

Sometimes instead of the Paper I used a white Thred, and this appeared through the Prism divided into two parallel Threds as is represented in the nineteenth Figure, where DG denotes the Thred illuminated with violet Light from D to E and with red Light from F to G, and *defg* are the parts of the Thred seen by Refraction. If one half of the Thred be constantly illuminated with red, and the other half be illuminated with all the Colours successively, (which may be done by causing one of the Prisms to be turned about its Axis whilst the other remains unmoved) this other half in viewing the Thred through the Prism, will appear in a continual right Line with the first half when illuminated with red, and begin to be a little divided from it when illuminated with Orange, and remove farther from it when illuminated with yellow, and still farther when with green, and farther when with blue, and go yet farther off when illuminated with Indigo, and farthest when with deep violet. Which plainly shews, that the Lights of several Colours are more and more refrangible one than another, in this Order of their Colours, red, orange, yellow, green, blue, indigo, deep violet; and so proves as well the first Proposition as the second. [Pg 50]

I caused also the coloured Spectrums PT [in *Fig.* 17.] and MN made in a dark Chamber by the Refractions of two Prisms to lie in a Right Line end to end, as was described above in the fifth Experiment, and viewing them through a third Prism held parallel to their Length, they appeared no longer in a Right Line, but became broken from one another, as they are represented at *pt* and *mn*, the violet end *m* of the Spectrum *mn* being by a greater Refraction translated farther from its former Place MT than the red end *t* of the other Spectrum *pt*.

I farther caused those two Spectrums PT [in *Fig.* 20.] and MN to become co-incident in an inverted Order of their Colours, the red end of each falling on the violet end of the other, as they are represented in the oblong Figure PTMN; and then viewing them through a Prism DH held parallel to their Length, they appeared not co-incident, as when view'd with the naked Eye, but in the form of two distinct Spectrums *pt* and *mn* crossing one another in the middle after the manner of the Letter X. [Pg 51] Which shews that the red of the one Spectrum and violet of the other, which were co-incident at PN and MT, being parted from one another by a greater Refraction of the violet to *p* and *m* than of the red to *n* and *t*, do differ in degrees of Refrangibility.

I illuminated also a little Circular Piece of white Paper all over with the Lights of both Prisms intermixed, and when it was illuminated with the red of one Spectrum, and deep violet of the other, so as by the Mixture of those Colours to appear all over purple, I viewed the Paper, first at a less distance, and then at a greater, through a third Prism; and as I went from the Paper, the refracted Image thereof became more and more divided by the unequal Refraction of the two mixed Colours, and at length parted into two distinct Images, a red one and a violet one, whereof the violet was farthest from the Paper, and therefore suffered the greatest Refraction. And when that Prism at the Window, which cast the violet on the Paper was taken away, the violet Image disappeared; but when the other Prism was taken away the red vanished; which shews, that these two Images were nothing else than the Lights of the two Prisms, which had been intermixed on the purple Paper, but were parted again by their unequal Refractions made in the third Prism, through which the Paper was view'd. This also was observable, that if one of the Prisms at the Window, suppose that which cast the violet on the Paper, was turned about its Axis to make all the Colours in this order, violet, indigo, blue, [Pg 52] green, yellow, orange, red, fall successively on the Paper from that Prism, the violet Image changed Colour accordingly, turning successively to indigo, blue, green, yellow and red, and in changing Colour came nearer and nearer to the red Image made by the other Prism, until when it was also red both Images became fully co-incident.

I placed also two Paper Circles very near one another, the one in the red Light of one Prism, and the other in the violet Light of the other. The Circles were each of them an Inch in diameter, and behind them the Wall was dark, that the Experiment might not be disturbed by any Light coming from thence. These Circles thus illuminated, I viewed through a Prism, so held, that the Refraction might be made towards the red Circle, and as I went from them they came nearer and nearer together, and at length became co-incident; and afterwards when I went still farther off, they parted again in a contrary Order, the violet by a greater Refraction being carried beyond the red.

*Exper.* 8. In Summer, when the Sun's Light uses to be strongest, I placed a Prism at the Hole of the Window-shut, as in the third Experiment, yet so that its Axis might be parallel to the Axis of the World, and at the opposite Wall in the Sun's refracted Light, I placed an open Book. Then going six Feet and two Inches from the Book, I placed there the above-mentioned Lens, by which the Light reflected from the Book might be made to converge and meet again at the distance of six Feet and two [Pg 53] Inches behind the Lens, and there paint the Species of the Book upon a Sheet of white Paper much after the manner of the second Experiment. The Book and Lens being made fast, I noted the Place where the Paper was, when the Letters of the Book, illuminated by the fullest red Light of the Solar Image falling upon it, did cast their Species on that Paper most distinctly: And then I stay'd till by the Motion of the Sun, and consequent Motion of his Image on the Book, all the Colours from that red to the middle of the blue pass'd over those Letters; and when those Letters were illuminated by that blue, I noted again the Place of the Paper when they cast their Species most distinctly upon it: And I found that this last Place of the Paper was nearer to the Lens than its former Place by about two Inches and an half, or two and three quarters. So much sooner therefore did the Light in the violet end of the Image by a greater Refraction converge and meet, than the Light in the red end. But in trying this, the Chamber was as dark as I could make it. For, if these Colours be diluted and weakned by the Mixture of any adventitious Light, the distance between the Places of the Paper will not be so great. This distance in the second Experiment, where the Colours of natural Bodies were made use of, was but an Inch and an half, by reason of the Imperfection of those Colours. Here in the Colours of the Prism, which are manifestly more full, intense, and lively than those of natural Bodies, the distance is two Inches and three quarters. And were the Colours still more full, I question not but that the distance [Pg 54] would be considerably greater. For the coloured Light of the Prism, by the interfering of the Circles described in the second Figure of the fifth Experiment, and also by the Light of the very bright Clouds next the Sun's Body intermixing with these Colours, and by the Light scattered by the Inequalities in the Polish of the Prism, was so very much compounded, that the Species which those faint and dark Colours, the indigo and violet, cast upon the Paper were not distinct enough to be well observed.

*Exper.* 9. A Prism, whose two Angles at its Base were equal to one another, and half right ones, and the third a right one, I placed in a Beam of the Sun's Light let into a dark Chamber through a Hole in the Window-shut, as in the third Experiment. And turning the Prism slowly about its Axis, until all the Light which went through one of its Angles, and was refracted by it began to be reflected by its Base, at which till then it went out of the Glass, I observed that those Rays which had suffered the greatest Refraction were sooner reflected than the rest. I conceived therefore, that those Rays of the reflected Light, which were most refrangible, did first of all by a total Reflexion become more copious in that Light than the rest, and that afterwards the rest also, by a total Reflexion, became as copious as these. To try this, I made the reflected Light pass through another Prism, and being refracted by it to fall afterwards upon a Sheet of white Paper placed at some distance behind it, and there by that [Pg 55] Refraction to paint the usual Colours of the Prism. And then causing the first Prism to be turned about its Axis as above, I observed that when those Rays, which in this Prism had suffered the greatest Refraction, and appeared of a blue and violet Colour began to be totally reflected, the blue and violet Light on the Paper, which was most refracted in the second Prism, received a sensible Increase above that of the red and yellow, which was least refracted; and afterwards, when the rest of the Light which was green, yellow, and red, began to be totally reflected in the first Prism, the Light of those Colours on the Paper received as great an Increase as the violet and blue had done before. Whence 'tis manifest, that the Beam of Light reflected by the Base of the Prism, being augmented first by the more refrangible Rays, and afterwards by the less refrangible ones, is compounded of Rays differently refrangible. And that all such reflected Light is of the same Nature with the Sun's Light before its Incidence on the Base of the Prism, no Man ever doubted; it being generally allowed, that Light by such Reflexions suffers no Alteration in its Modifications and Properties. I do not here take Notice of any Refractions made in the sides of the first Prism, because the Light enters it perpendicularly at the first side, and goes out perpendicularly at the second side, and therefore suffers none. So then, the