# OPTICKS:

OR, A

# TREATISE

OF THE

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

OF

# LIGHT.

*The Second Edition, with Additions.*

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*LONDON*:

Printed for W. and J. INNYS, Printers to the Royal Society, at the *Prince's-Arms* in St. *Paul's* Church-Yard. 1718.

# 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 Observation in the last Part 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*

*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* 1676, *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.*

April 1.
1704.

I. N.

# ADVERTISEMENT II.

*IN this Second Edition of these Opticks I have omitted the Mathematical Tracts publiſhed 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.

# CORRIGENDA.

PAGE 3. line 17. read *turned back*. p. 7. l. ult. for *Fig.* 3. r. *Much.* p. 40. l. 20. r. *de* and *fg*. p. 57. l. 3. r. *whole.* p. 95. l. 23. r. *PROP.* VIII. p. 111. l. 25. *Intervals, and you.* p. 112. l. 25. *that it emer-* p. 153. l. 11. r. *and the breadth.* p. 157. l. 24. r. *red homogeneal Light.* p. 160. l. 32. r. *the Vessel appeared of a red Colour like.* p. 165. l. 4. r. *they enter'd.* p. 196. l. 22. r. *ction of the Prism, on.* p. 204. l. 27. r. *will be* F λ, F μ. p. 212. l. 1. r. (*that is, in the Circumference on one side.* p. 237. l. 30. r. *more strongly reflecting.* p. 238. l. 3. r. *invented by* Otto Gueric, *and improved and made useful by Mr.* Boyle) p. 242. l. 19. r. *than.* p. 244. l. 19. r. *do. If* p. 266. l. 31. r. *Colours.* p. 322. l. 31. r. *continue to arise and be propagated, when* p. 336. l. 21. r. *to the Power.* p. 334. l. 6. r. *Ray.* p. 336. l. 22. r. *to the distance of.*

# THE FIRST BOOK OF OPTICKS.

## 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.

# *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 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 ſtopt cannot be the ſame with that which is let paſs. The leaſt Light or part of Light, which may be ſtopt alone without the reſt of the Light, or propogated 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

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.

## 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 returned back more or leſs eaſily.* As if Light paſs out of 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 Reflection 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.*

## DEFIN. VII.

*The Light whose Rays are all alike Refrangible, I call Simple, Homogeneal and Similiar; and that whose Rays are some more Refrangible than others, I call compound, Heterogenal 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.

## *AXIOMS.*

### 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 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.

Snppoſe 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 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 Parallel to the Perpendicular CPQ, the Line HE cutting the

Circum-

Circumference in E, and joyning 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 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.

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.

## 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

be found by finding the Refraction of any two Rays, as above; or more readily thus.

*Caſ.* 1. Let A C B [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 Q C, 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 Q C and in Proportion to Q C as the Sine of Incidence to the Sine of Refraction, the point *q* ſhall be the Focus of the refracted Rays.

*Caſ.* 2. Let A C B [in *Fig.* 5.] be the reflecting Surface of any Sphere whoſe Center is E. Biſect any Radius thereof (ſuppoſe E C) in T, and if in that *Radius on the ſame ſide the point T you take the Points Q and *q*, ſo that T Q, T E, 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.

*Caſ.* 3. Let A C B [in *Fig.* 6.] be the refracting Surface of any Sphere whoſe Center is E. In any Radius thereof E C produced both ways take E T 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 T Q be to E T as E *t* to *t q*, taking *t q* the contrary way from *t* which T Q 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.

And

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

*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 Centers 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 *t q* in ſuch Proportion to *t* E as *t* E or TE hath to TQ. Let *t q* lye 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.

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.

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

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 that Surface.

## 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 Reflexion 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

lours. 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 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 *m k*) as to converge and meet again at 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 imperfect-

ly

ly. If the Eye be tinged with any colour (as in the Disease of the *Jaundise*) 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 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 encreasing 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.

## 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.*

If the Object A [in *Fig.* 9.] be ſeen by Reflexion of a Looking-glaſs *m n*, 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.

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 F G drawn backward from F to *d*.

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

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 and 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 summ 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.

*PROPO-*

# PROPOSITIONS.

## PROP. I. THEOR. I.

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

### The Proof by Experiments.

*Exper.* I. 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 blew. 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 viewed it, I held it and the Prism before a Window in such manner that 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 it self 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 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 be turned downward, the Image of the Paper will be refracted downward, ſuppoſe to $\delta\varepsilon$, and the blue half will be refracted lower to $\delta\gamma$ than the red half is to $\phi\varepsilon$.

*Exper.* 2. About the aforeſaid Paper, whoſe two halfs were painted over with red and blue, and which was ſtiff like thin Paſtboard, 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 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 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 an half, and therefore is more refrangible.

*Illuſtration.* In the twelfth Figure, DE ſignifies the coloured Paper, DG theblue 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 rendred 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.

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 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 an 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.

*Exper.* 3. 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 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. 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

gure 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 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-mentioned 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 ſenſible effect in encreaſing 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 62½ Degrees, I found the length of the Image 9¾ or 10 Inches at the diſtance of 18½ Feet from the Priſm, the breadth of the hole in the Window-ſhut being ¼ of an Inch, as before. And becauſe it is eaſie 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 63½ Degrees, the length of this Image at the ſame diſtance of 18½ Feet was alſo about 10 Inches, or 10⅛. Beyond theſe Meaſures for about ¼ or ⅓ 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

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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 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. For let EG [in *Fig.* 13.] repreſent the Window-ſhut, F the hole made therein through which a beam of the Sun's Light was tranſmitted into the darkned Chamber, and ABC a Triangular Imaginary Plane whereby the Priſm is feigned to be cut tranſverſly 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

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 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

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 P T 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.

*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

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 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

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 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 [in *Fig.* 14.] 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

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 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 *π q k p*, and the Light KQRL into the long Image *k q r l*, and the Lights LRSM, MSVN, NVT, into ſo many other long Images *l r s m*, *m s v n*, *n v t τ*; and all theſe long Images would compoſe the four ſquare Image *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 *p t*, its upper end P being by the

the Refraction tranflated to a greater diftance 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 fecond Prifm 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 fame Light was by the Refraction of the firft Prifm tranflated farther from the place Y to which it tended before Refraction; and therefore fuffered as well in the firft Prifm as in the fecond a greater Refraction than the reft of the Light, and by confequence was more refrangible than the reft, even before its incidence on the firft Prifm.

Sometimes I placed a third Prifm after the fecond, and fometimes alfo a fourth after the third, by all which the Image might be often refracted fideways: but the Rays which were more refracted than the reft in the firft Prifm were alfo more refracted in all the reft, and that without any Dilatation of the Image fideways: and therefore thofe Rays for their conftancy of a greater Refraction are defervedly reputed more refrangible.

But that the meaning of this Experiment may more clearly appear, it is to be confidered that the Rays which are equally refrangible do fall upon a circle anfwering to the Sun's Difque. For this was proved in the third Experiment. By a Circle I underftand not here a perfect geometrical Circle, but any orbicular Figure whofe length is equal to its breadth, and which, as to fenfe, may feem circular. Let therefore A G [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 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.* 14, 15.] which is made by an unrefracted beam of Light was by any Dilatation 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 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 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, P T and *p t* 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 A E and G L which all the Circles in the Spectrum P T do touch, could not by that Refraction be tranſlated into the Lines *a e* and *g l* 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 *a e* and *g l* which touch thoſe Circles. And therefore ſince there is no ſuch Penumbra or Perturbation in thoſe right Lines there muſt be none in the Circles. Since the diſtance between

thoſe

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 D H [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 P T 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 *p t* upon the Wall. And you will find as before, that this Spectrum *p t* is inclined to that Spectrum P T, 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 $\pi$ of the Image $\pi\tau$ and which therefore ſuffer the greateſt Refraction in the firſt Priſm, are again in the ſecond Priſm more refracted than the reſt.

The ſame thing I try'd alſo by letting the Sun's Light into a dark Room through two little round holes F and $\phi$ [in *Fig.* 17.] made in the Window, and with two parallel Priſms ABC and $\alpha\beta\gamma$ 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

first Prisms be either white and circular, or coloured and oblong when it falls on the third.

*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, 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 of that Board. Let this trajected part of the 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 *d e*, 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 *a b c* 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 *d e* 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.

*Exper.* 7. At two holes made near one another in my Window-ſhut I placed two Priſms, one at each, 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 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.

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 continued 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

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.

I cauſed alſo the coloured Spectrums P T [in *Fig.* 17.] and M N made in a dark Chamber by the Refractions of two Priſms to lye 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 *p t* and *m n*, the violet end *m* of the Spectrum *m n* being by a greater Refraction tranſlated farther from its former place M T than the red end *t* of the other Spectrum *p t*.

I farther cauſed thoſe two Spectrums P T [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 P T M N; and then viewing them through a Priſm D H held parallel to their length, they appeared not co-incident as when viewed with the naked Eye, but in the form of two diſtinct Spectrums *p t* and *m n* croſſing one another in the middle after the manner of the letter X. Which ſhews that the red of the one Spectrum and violet of the other, which were co-incident at P N and M T, being parted from one another by a greater Refraction of the violet to *p* and *m*

than

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 viewed. 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, green, yellow, orange, red, fall ſucceſſively on the Paper from that Priſm, the violet Image changed Colour accordingly, turning ſucceſſively to indigo, blue, green, yel-

low

low and red, and in changing Colour came nearer and nearer to the red Image made by the other Prifm, until when it was alfo red both Images became fully co-incident.

I placed alfo two Paper Circles very near one another, the one in the red Light of one Prifm, 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 difturbed by any Light coming from thence. Thefe Circles thus illuminated, I viewed through a Prifm fo 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 ftill 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 ufes to be ftrongeft, I placed a Prifm at the hole of the Window-fhut, as in the third Experiment, yet fo that its Axis might be parallel to the Axis of the World, and at the oppofite Wall in the Sun's refracted Light, I placed an open Book. Then going fix Feet and two Inches from the Book, I placed there the abovementioned Lens, by which the Light reflected from the Book might be made to converge and meet again at the diftance of fix Feet and two Inches behind the Lens, and there paint the Species of the Book upon a fheet of white Paper much after the manner of the fecond Experiment. The Book and Lens being made faft,

I no-

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 would be conſiderably greater. For the coloured Light of the Priſm, by the interfering of the Circles deſcribed in the ſecond Figure

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 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

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when thoſe Rays which in this Priſm had ſuffered the greateſt Refraction and appeared of a 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 Sun's incident Light being of the ſame Temper and Conſtitution with his emergent Light, and the laſt being compounded of Rays differently refrangible, the firſt muſt be in like manner compounded.

*Illuſtration.* In the twenty firſt Figure, ABC is the firſt Priſm, BC its Baſe, B and C its equal

equal Angles at the Base, each of 45 Degrees, A its rectangular Vertex, F M a beam of the Sun's Light let into a dark Room through a hole F one third part of an Inch broad, M its Incidence on the Base of the Prism, M G a less refracted Ray, M H a more refracted Ray, MN the beam of Light reflected from the Base, V X Y the second Prism by which this beam in passing through it is refracted, N *t* the less refracted Light of this beam, and N *p* the more refracted part thereof. When the first Prism A B C is turned about its Axis according to the order of the Letters A B C, the Rays M H emerge more and more obliquely out of that Prism, and at length after their most oblique Emergence are reflected towards N, and going on to *p* do increase the number of the Rays N *p*. Afterwards by continuing the Motion of the first Prism, the Rays M G are also reflected to N and increase the number of the Rays N *t*. And therefore the Light M N admits into its Composition, first the more refrangible Rays, and then the less refrangible Rays, and yet after this Composition is of the same nature with the Sun's immediate Light F M, the Reflexion of the specular Base B C causing no alteration therein.

*Exper.* 10. Two Prisms, which were alike in shape, I tied so together, that their Axes and opposite Sides being parallel, they composed a Parallelopiped. And, the Sun shining into my dark Chamber through a little hole in the Window-shut, I placed that Parallelopiped in his beam at some distance from the hole, in such a posture that the Axes of the Prisms might be perpendicular to the incident Rays, and that those Rays being incident upon the first Side of one Prism, might go on through the two contiguous Sides of both Prisms, and emerge out of the last Side of the second Prism. This Side being parallel to the first Side of the first Prism, caused the emerging Light to be parallel to the incident. Then, beyond these two Prisms I placed a third, which might refract that emergent Light, and by that Refraction cast the usual Colours of the Prism upon the opposite Wall, or upon a sheet of white Paper held at a convenient distance behind the Prism for that refracted Light to fall upon it. After this I turned the Parallelopiped about its Axis, and found that when the contiguous Sides of the two Prisms became so oblique to the incident Rays that those Rays began all of them to be reflected, those Rays which in the third Prism had suffered the greatest Refraction and painted the Paper with violet and blue, were first of all by a total Reflexion taken out of the transmitted Light, the rest remaining and on the Paper painting their Colours of green, yellow, orange, and red as before; and afterwards by continuing the Motion of the two Prisms, the rest of the Rays also by a total Reflexion vanished in order, according to their degrees of Refrangibility. The Light therefore which emerged out of the two Prisms is compounded of Rays differently refrangible, seeing the more refrangible Rays may be taken out of it while the less refrangible remain. But this

Light

Light being trajected only through the parallel Superficies of the two Prisms, if it suffer'd any change by the Refraction of one Superficies it lost that impression by the contrary Refraction of the other Superficies, and so being restored to its pristine Constitution became of the same nature and condition as at first before its Incidence on those Prisms; and therefore, before its Incidence, was as much compounded of Rays differently refrangible, as afterwards.

*Illustration.* In the twenty second Figure ABC and BCD are the two Prisms tied together in the form of a Parallelopiped, their Sides BC and CB being contiguous, and their Sides AB and CD parallel. And HJK is the third Prism, by which the Sun's Light propagated through the hole F into the dark Chamber, and there passing through those sides of the Prisms AB, BC, CB and CD, is refracted at O to the white Paper PT, falling there partly upon P by a greater Refraction, partly upon T by a less Refraction, and partly upon R and other intermediate places by intermediate Refractions. By turning the Parallelopiped ACBD about its Axis, according to the order of the Letters A, C, D, B, at length when the contiguous Planes BC and CB become sufficiently oblique to the Rays FM, which are incident upon them at M, there will vanish totally out of the refracted Light OPT, first of all the most refracted Rays OP, (the rest OR and OT remaining as before) then the Rays OR and other intermediate ones, and lastly, the least refracted Rays OT. For when the Plane BC becomes sufficiently

 oblique

oblique to the Rays incident upon it, thoſe Rays will begin to be totally reflected by it towards N; and firſt the moſt refrangible Rays will be totally reflected (as was explained in the preceding Experiment) and by conſequence muſt firſt diſappear at P, and afterwards the reſt as they are in order totally reflected to N, they muſt diſappear in the ſame order at R and T. So then the Rays which at O ſuffer the greateſt Refraction, may be taken out of the Light MO whilſt the reſt of the Rays remain in it, and therefore that Light MO is compounded of Rays differently refrangible. And becauſe the Planes AB and CD are parallel, and therefore by equal and contrary Refractions deſtroy one anothers Effects, the incident Light FM muſt be of the ſame kind and nature with the emergent Light MO, and therefore doth alſo conſiſt of Rays differently refrangible. Theſe two Lights FM and MO, before the moſt refrangible Rays are ſeparated out of the emergent Light MO, agree in colour, and in all other properties ſo far as my obſervation reaches, and therefore are deſervedly reputed of the ſame nature and conſtitution, and by conſequence the one is compounded as well as the other. But after the moſt refrangible Rays begin to be totally reflected, and thereby ſeparated out of the emergent Light MO, that Light changes its colour from white to a dilute and faint yellow, a pretty good orange, a very full red ſucceſſively and then totally vaniſhes. For after the moſt refrangible Rays which paint the Paper at P with

P with a purple Colour, are by a total Reflexion taken out of the beam of Light MO, the reſt of the Colours which appear on the Paper at R and T being mixed in the Light MO compound there a faint yellow; and after the blue and part of the green which appear on the Paper between P and R are taken away, the reſt which appear between R and T (that is the yellow, orange, red and a little green) being mixed in the beam MO compound there an orange; and when all the Rays are by Reflexion taken out of the beam MO, except the leaſt refrangible, which at T appear of a full red, their Colour is the ſame in that beam MO as afterwards at T, the Refraction of the Priſm HJK ſerving only to ſeparate the differently refrangible Rays, without making any alteration in their Colours, as ſhall be more fully proved hereafter. All which confirms as well the firſt Propoſition as the ſecond.

*Scholium.* If this Experiment and the former be conjoined and made one by applying a fourth Priſm VXY [in *Fig.* 22.] to refract the reflected beam MN towards *tp*, the concluſion will be clearer. For then the Light N*p* which in the fourth Priſm is more refracted, will become fuller and ſtronger when the Light OP, which in the third Priſm HJK is more refracted, vaniſhes at P; and afterwards when the leſs refracted Light OT vaniſhes at T, the leſs refracted Light N*t* will become encreaſed whilſt the more refracted Light at *p* receives no farther encreaſe. And as the trajected beam MO in vaniſhing is always of ſuch a Colour as ought to reſult from the mixture of the Colours which fall upon the Paper PT, ſo is the reflected beam MN always of ſuch a Colour as ought to reſult from the mixture of the Colours which fall upon the Paper *pt*. For when the moſt refrangible Rays are by a total Reflexion taken out of the beam MO, and leave that beam of an orange Colour, the Exceſs of thoſe Rays in the reflected Light, does not only make the violet, indigo and blue at *p* more full, but alſo makes the beam MN change from the yellowiſh Colour of the Sun's Light, to a pale white inclining to blue, and afterward recover its yellowiſh Colour again, ſo ſoon as all the reſt of the tranſmitted Light MOT is reflected.

Now ſeeing that in all this variety of Experiments, whether the Trial be made in Light reflected, and that either from natural Bodies, as in the firſt and ſecond Experiment, or ſpecular, as in the ninth; or in Light refracted, and that either before the unequally refracted Rays are by diverging ſeparated frome one another, and loſing their whiteneſs which they have altogether, appear ſeverally of ſeveral Colours, as in the fifth Experiment; or after they are ſeparated from one another, and appear colour'd as in the ſixth, ſeventh, and eighth Experiments; or in Light trajected through parallel Superficies, deſtroying each others Effects, as in the tenth Experiment; there are always found Rays, which at equal Incidences on the ſame Medium ſuffer unequal Refractions, and that without any ſplitting or dilating of ſingle Rays, or contingence in the inequality of the Refra-

Refractions, as is proved in the fifth and sixth Experiments. And seeing the Rays which differ in Refrangibility may be parted and sorted from one another, and that either by Refraction as in the third Experiment, or by Reflexion as in the tenth, and then the several sorts apart at equal Incidences suffer unequal Refractions, and those sorts are more refracted than others after separation, which were more refracted before it, as in the sixth and following Experiments, and if the Sun's Light be trajected through three or more cross Prisms successively, those Rays which in the first Prism are refracted more than others, are in all the following Prisms refracted more than others in the same rate and proportion, as appears by the fifth Experiment; it's manifest that the Sun's Light is an heterogeneous mixture of Rays, some of which are constantly more refrangible than others, as was proposed.

### *PROP.* III. Theor. III.

*The Sun's Light consists of Rays differing in Reflexibility, and those Rays are more reflexible than others which are more refrangible.*

THIS is manifest by the ninth and tenth Experiments: For in the ninth Experiment, by turning the Prism about its Axis, until the Rays within it which in going out into the Air were refracted by its Base, became so oblique to that Base, as to begin to be totally reflected thereby; thoſe Rays became firſt of all totally reflected, which before at equal Incidences with the reſt had ſuffered the greateſt Refraction. And the ſame thing happens in the Reflexion made by the common Baſe of the two Priſms in the tenth Experiment.

## *PROP.* IV. PROB. I.

*To ſeparate from one another the heterogeneous Rays of compound Light.*

THE heterogeneous Rays are in ſome meaſure ſeparated from one another by the Refraction of the Priſm in the third Experiment, and in the fifth Experiment by taking away the Penumbra from the rectilinear ſides of the coloured Image, that ſeparation in thoſe very rectilinear ſides or ſtraight edges of the Image becomes perfect. But in all places between thoſe rectilinear edges, thoſe innumerable Circles there deſcribed, which are ſeverally illuminated by homogeneal Rays, by interfering with one another, and being every where commix'd, do render the Light ſufficiently compound. But if theſe Circles, whilſt their centers keep their diſtances and poſitions, could be made leſs in diameter, their interfering one with another and by conſequence the mixture of the heterogeneous Rays would be proportionally diminiſhed. In the twenty third Figure let AG, BH, CJ, DK, EL, FM be the Circles which ſo many ſorts of Rays flowing from the

the ſame diſque of the Sun, do in the third Experiment illuminate; of all which and innumerable other intermediate ones lying in a continual Series between the two rectilinear and parallel edges of the Sun's oblong Image P T, that Image is compoſed as was explained in the fifth Experiment. And let *ag*, *bh*, *ci*, *dk*, *el*, *fm* be ſo many leſs Circles lying in a like continual Series between two parallel right Lines *af* and *gm* with the ſame diſtances between their centers, and illuminated by the ſame ſorts of Rays, that is the Circle *ag* with the ſame ſort by which the correſponding Circle AG was illuminated, and the Circle *bh* with the ſame ſort by which the correſponding Circle BH was illuminated, and the reſt of the Circles *ci*, *dk*, *el*, *fm* reſpectively, with the ſame ſorts of Rays by which the ſeveral correſponding Circles CJ, DK, EL, FM were illuminated. In the Figure PT compoſed of the greater Circles, three of thoſe Circles AG, BH, CJ, are ſo expanded into one another, that the three ſorts of Rays by which thoſe Circles are illuminated, together with other innumerable ſorts of intermediate Rays, are mixed at QR in the middle of the Circle BH. And the like mixture happens throughout almoſt the whole length of the Figure PT. But in the Figure *pt* compoſed of the leſs Circles, the three leſs Circles *ag*, *bh*, *ci*, which anſwer to thoſe three greater, do not extend into one another; nor are there any where mingled ſo much as any two of the three ſorts of Rays by which thoſe

Circles are illuminated, and which in the Figure PT are all of them intermingled at BH.

Now he that ſhall thus conſider it, will eaſily underſtand that the mixture is diminiſhed in the ſame proportion with the Diameters of the Circles. If the Diameters of the Circles whilſt their Centers remain the ſame, be made three times leſs than before, the mixture will be alſo three times leſs; if ten times leſs, the mixture will be ten times leſs, and ſo of other proportions. That is, the mixture of the Rays in the greater Figure PT will be to their mixture in the leſs *pt*, as the Latitude of the greater Figure is to the Latitude of the leſs. For the Latitudes of theſe Figures are equal to the Diameters of their Circles. And hence it eaſily follows, that the mixture of the Rays in the refracted Spectrum *pt* is to the mixture of the Rays in the direct and immediate Light of the Sun, as the breadth of that Spectrum is to the difference between the length and breadth of the ſame Spectrum.

So then, if we would diminiſh the mixture of the Rays, we are to diminiſh the Diameters of the Circles. Now theſe would be diminiſhed if the Sun's Diameter to which they anſwer could be made leſs than it is, or (which comes to the ſame purpoſe) if without doors, at a great diſtance from the Priſm towards the Sun, ſome opake Body were placed, with a round hole in the middle of it, to intercept all the Sun's Light, excepting ſo much as coming from the middle of his Body could paſs through

that

that hole to the Prism. For so the Circles AG, BH and the rest, would not any longer answer to the whose Disque of the Sun, but only to that part of it which could be seen from the Prism through that hole, that is to the apparent magnitude of that hole viewed from the Prism. But that these Circles may answer more distinctly to that hole, a Lens is to be placed by the Prism to cast the Image of the hole, (that is, every one of the Circles AG, BH, &c.) distinctly upon the Paper at PT, after such a manner as by a Lens placed at a Window the Species of Objects abroad are cast distinctly upon a Paper within the Room, and the rectilinear Sides of the oblong solar Image in the fifth Experiment became distinct without any Penumbra. If this be done it will not be necessary to place that hole very far off, no not beyond the Window. And therefore instead of that hole, I used the hole in the Window-shut as follows.

*Exper.* 11. In the Sun's Light let into my darkned Chamber through a small round hole in my Window-shut, at about ten or twelve Feet from the Window, I placed a Lens, by which the Image of the hole might be distinctly cast upon a Sheet of white Paper, placed at the distance of six, eight, ten or twelve Feet from the Lens. For according to the difference of the Lenses I used various distances, which I think not worth the while to describe. Then immediately after the Lens I placed a Prism, by which the trajected Light might be refracted either upwards or sideways, and thereby by the round Image which the Lens alone did caſt upon the Paper might be drawn out into a long one with parallel Sides, as in the third Experiment. This oblong Image I let fall upon another Paper at about the ſame diſtance from the Priſm as before, moving the Paper either towards the Priſm or from it, until I found the juſt diſtance where the rectilinear Sides of the Image became moſt diſtinct. For in this caſe the circular Images of the hole which compoſe that Image after the ſame manner that the Circles *ag*, *bh*, *ci*, &c. do the Figure *pt* [in *Fig.* 23.] were terminated moſt diſtinctly without any Penumbra, and therefore extended into one another the leaſt that they could, and by conſequence the mixture of the heterogeneous Rays was now the leaſt of all. By this means I uſed to form an oblong Image (ſuch as is *pt*) [in *Fig.* 23, and 24.] of circular Images of the hole (ſuch as are *ag*, *bh*, *ci*, &c.) and by uſing a greater or leſs hole in the Window-ſhut, I made the circular Images *ag*, *bh*, *ci*, &c. of which it was formed, to become greater or leſs at pleaſure, and thereby the mixture of the Rays in the Image *pt* to be as much or as little as I deſired.

*Illuſtration.* In the twenty fourth Figure, F repreſents the circular hole in the Window-ſhut, MN the Lens whereby the Image or Species of that hole is caſt diſtinctly upon a Paper at J, ABC the Priſm whereby the Rays are at their emerging out of the Lens refracted from J towards another Paper at *pt*, and the round Image at J is turned into an oblong Image *pt* falling

falling on that other Paper. This Image *p t* consists of Circles placed one after another in a rectilinear order, as was sufficiently explained in the fifth Experiment; and these Circles are equal to the Circle J, and consequently answer in magnitude to the hole F; and therefore by diminishing that hole they may be at pleasure diminished, whilst their Centers remain in their places. By this means I made the breadth of the Image *p t* to be forty times, and sometimes sixty or seventy times less than its length. As for instance, if the breadth of the hole F be one tenth of an Inch, and MF the distance of the Lens from the hole be 12 Feet; and if *p* B or *p* M the distance of the Image *p t* from the Prism or Lens be 10 Feet, and the refracting Angle of the Prism be 62 Degrees, the breadth of the Image *p t* will be one twelfth of an Inch and the length about six Inches, and therefore the length to the breadth as 72 to 1, and by consequence the Light of this Image 71 times less compound than the Sun's direct Light. And Light thus far simple and homogeneal, is sufficient for trying all the Experiments in this Book about simple Light. For the composition of heterogeneal Rays is in this Light so little that it is scarce to be discovered and perceived by Sense, except perhaps in the indigo and violet. For these being dark Colours, do easily suffer a sensible allay by that little scattering Light which uses to be refracted irregularly by the inequalities of the Prism.

Yet instead of the circular hole F, 'tis better to substitute an oblong hole shaped like a long

Paral-

Parallelogram with its length parallel to the Priſm A B C. For if this hole be an Inch or two long, and but a tenth or twentieth part of an Inch broad, or narrower: the Light of the Image *pt* will be as ſimple as before, or ſimpler, and the Image will become much broader, and therefore more fit to have Experiments tried in its Light than before.

Inſtead of this parallelogram hole may be ſubſtituted a triangular one of equal Sides, whoſe Baſe for inſtance is about the tenth part of an Inch, and its height an Inch or more. For by this means, if the Axis of the Priſm be parallel to the Perpendicular of the Triangle, the Image *pt* [in *Fig.* 25.] will now be formed of equicrural Triangles *ag*, *bh*, *ci*, *dk*, *el*, *fm*, &c. and innumerable other intermediate ones anſwering to the triangular hole in ſhape and bigneſs, and lying one after another in a continual Series between two parallel Lines *af* and *gm*. Theſe Triangles are a little intermingled at their Baſes but not at their Vertices, and therefore the Light on the brighter ſide *af* of the Image where the Baſes of the Triangles are, is a little compounded, but on the darker ſide *gm* is altogether uncompounded, and in all places between the ſides the Compoſition is proportional to the diſtances of the places from that obſcurer ſide *gm*. And having a Spectrum *pt* of ſuch a Compoſition, we may try Experiments either in its ſtronger and leſs ſimple Light near the ſide *af*, or in its weaker and ſimpler Light near the other ſide *gm*, as it ſhall ſeem moſt convenient.

But in making Experiments of this kind the Chamber ought to be made as dark as can be, lest any foreign Light mingle it self with the Light of the Spectrum *p t*, and render it compound; especially if we would try Experiments in the more simple Light next the side *g m* of the Spectrum; which being fainter, will have a less proportion to the foreign Light, and so by the mixture of that Light be more troubled and made more compound. The Lens also ought to be good, such as may serve for optical uses, and the Prism ought to have a large Angle, suppose of 65 or 70 Degrees, and to be well wrought, being made of Glass free from bubbles and veins, with its Sides not a little convex or concave, as usually happens, but truly plane, and its Polish elaborate, as in working Optick-glasses, and not such as is usually wrought with Putty, whereby the edges of the Sand-holes being worn away, there are left all over the Glass a numberless company of very little convex polite Risings like Waves. The edges also of the Prism and Lens so far as they may make any irregular Refraction, must be covered with a black Paper glewed on. And all the Light of the Sun's beam let into the Chamber which is useless and unprofitable to the Experiment, ought to be intercepted with black Paper or other black Obstacles. For otherwise the useless Light being reflected every way in the Chamber, will mix with the oblong Spectrum and help to disturb it. In trying these things so much diligence is not altogether necessary, but it will promote the success of the

Experiments, and by a very ſcrupulous Examiner of things deſerves to be applied. It's difficult to get Glaſs Priſms fit for this purpoſe, and therefore I uſed ſometimes priſmatick Veſſels made with pieces of broken Looking-glaſſes, and filled with Rain Water. And to increaſe the Refraction, I ſometimes impregnated the Water ſtrongly with *Saccharum Saturni*.

## *PROP.* V. Theor. IV.

*Homogeneal Light is refracted regularly without any Dilatation ſplitting or ſhattering of the Rays, and the confuſed Viſion of Objects ſeen through refracting Bodies by heterogeneal Light ariſes from the different Refrangibility of ſeveral ſorts of Rays.*

THE firſt part of this Propoſition has been already ſufficiently proved in the fifth Experiment, and will farther appear by the Experiments which follow.

*Exper.* 12. In the middle of a black Paper I made a round hole about a fifth or ſixth part of an Inch in diameter. Upon this Paper I cauſed the Spectrum of homogeneal Light deſcribed in the former Propoſition, ſo to fall, that ſome part of the Light might paſs through the hole of the Paper. This tranſmitted part of the Light I refracted with a Priſm placed behind the Paper, and letting this refracted Light fall perpendicularly upon a white Paper two or three Feet diſtant from the Priſm, I found that the

the Spectrum formed on the Paper by this Light was not oblong, as when 'tis made (in the third Experiment) by refracting the Sun's compound Light, but was (so far as I could judge by my Eye) perfectly circular, the length being no greater than the breadth. Which shews that this Light is refracted regularly without any Dilatation of the Rays.

*Exper.* 13. In the homogeneal Light I placed a Paper Circle of a quarter of an Inch in diameter, and in the Sun's unrefracted heterogeneal white Light I placed another Paper Circle of the same bigness. And going from the Papers to the distance of some Feet, I viewed both Circles through a Prism. The Circle illuminated by the Sun's heterogeneal Light appeared very oblong as in the fourth Experiment, the length being many times greater than the breadth: but the other Circle illuminated with homogeneal Light appeared circular and distinctly defined as when 'tis viewed with the naked Eye. Which proves the whole Proposition.

*Exper.* 14. In the homogeneal Light I placed Flies and such like minute Objects, and viewing them through a Prism, I saw their parts as distinctly defined as if I had viewed them with the naked Eye. The same Objects placed in the Sun's unrefracted heterogeneal Light which was white I viewed also through a Prism, and saw them most confusedly defined, so that I could not distinguish their smaller parts from one another. I placed also the Letters of a small print one while in the homogeneal Light and then in the heterogeneal, and viewing them through a Prism, they appeared in the latter case so confused and indistinct that I could not read them; but in the former they appeared so distinct that I could read readily, and thought I saw them as distinct as when I viewed them with my naked Eye. In both cases I viewed the same Objects through the same Prism at the same distance from me and in the same situation. There was no difference but in the Light by which the Objects were illuminated, and which in one case was simple and in the other compound, and therefore the distinct Vision in the former case and confused in the latter could arise from nothing else than from that difference of the Lights. Which proves the whole Proposition.

And in these three Experiments it is farther very remarkable, that the Colour of homogeneal Light was never changed by the Refraction.

## *PROP.* VI. THEOR. V.

*The Sine of Incidence of every Ray considered apart, is to its Sine of Refraction in a given Ratio.*

THAT every Ray considered apart is constant to it self in some degree of Refrangibility, is sufficiently manifest out of what has been said. Those Rays which in the first Refraction are at equal Incidences most refracted, are also in the following Refractions at equal Inci-

Incidences moſt refracted; and ſo of the leaſt refrangible, and the reſt which have any mean degree of Refrangibility, as is manifeſt by the fifth, ſixth, ſeventh, and eighth, and ninth Experiments. And thoſe which the firſt time at like Incidences are equally refracted, are again at like Incidences equally and uniformly refracted, and that whether they be refracted before they be ſeparated from one another as in the fifth Experiment, or whether they be refracted apart, as in the twelfth, thirteenth and fourteenth Experiments. The Refraction therefore of every Ray apart is regular, and what Rule that Refraction obſerves we are now to ſhew.

The late Writers in Opticks teach, that the Sines of Incidence are in a given Proportion to the Sines of Refraction, as was explained in the fifth Axiom; and ſome by Inſtruments fitted for meaſuring of Refractions, or otherwiſe experimentally examining this Proportion, do acquaint us that they have found it accurate. But whilſt they, not underſtanding the different Refrangibility of ſeveral Rays, conceived them all to be refracted according to one and the ſame Proportion, 'tis to be preſumed that they adapted their meaſures only to the middle of the refracted Light; ſo that from their meaſures we may conclude only that the Rays which have a mean degree of Refrangibility, that is thoſe which when ſeparated from the reſt appear green, are refracted according to a given Proportion of their Sines. And therefore we are now to ſhew that the like given

Proportions obtain in all the reſt. That it ſhould be ſo is very reaſonable, Nature being ever conformable to her ſelf: but an experimental Proof is deſired. And ſuch a Proof will be had if we can ſhew that the Sines of Refraction of Rays differently refrangible are one to another in a given Proportion when their Sines of Incidence are equal. For if the Sines of Refraction of all the Rays are in given Proportions to the Sine of Refraction of a Ray which has a mean degree of Refrangibility, and this Sine is in a given Proportion to the equal Sines of Incidence, thoſe other Sines of Refraction will alſo be in given Proportions to the equal Sines of Incidence. Now when the Sines of Incidence are equal, it will appear by the following Experiment that the Sines of Refraction are in a given Proportion to one another.

*Exper*. 15. The Sun ſhining into a dark Chamber through a little round hole in the Window-ſhut, let S [in *Fig*. 26.] repreſent his round white Image painted on the oppoſite Wall by his direct Light, PT his oblong coloured Image made by refracting that Light with a Priſm placed at the Window; and *p t*, or 2 *p* 2 *t*, or 3 *p* 3 *t*, his oblong colour'd Image made by refracting again the ſame Light ſideways with a ſecond Priſm placed immediately after the firſt in a croſs poſition to it, as was explained in the fifth Experiment: that is to ſay, *p t* when the Refraction of the ſecond Priſm is ſmall, 2 *p* 2 *t* when its Refraction is greater, and 3 *p* 3 *t* when it is greateſt. For

2 ſuch

ſuch will be the diverſity of the Refractions if the refracting Angle of the ſecond Priſm be of various magnitudes; ſuppoſe of fifteen or twenty Degrees to make the Image *pt*, of thirty or forty to make the Image 2*p* 2*t*, and of ſixty to make the Image 3*p* 3*t*. But for want of ſolid Glaſs Priſms with Angles of convenient bigneſſes, there may be Veſſels made of poliſhed Plates of Glaſs cemented together in the form of Priſms and filled with Water. Theſe things being thus ordered, I obſerved that all the ſolar Images or coloured Spectrums PT, *pt*, 2*p* 2 *t*, 3 *p* 3 *t* did very nearly converge to the place S on which the direct Light of the Sun fell and painted his white round Image when the Priſms were taken away. The Axis of the Spectrum PT, that is the Line drawn through the middle of it parallel to its rectilinear Sides, did when produced paſs exactly through the middle of that white round Image S. And when the Refraction of the ſecond Priſm was equal to the Refraction of the firſt, the refracting Angles of them both being about 60 Degrees, the Axis of the Spectrum 3 *p* 3 *t* made by that Refraction, did when produced paſs alſo through the middle of the ſame white round Image S. But when the Refraction of the ſecond Priſm was leſs than that of the firſt, the produced Axes of the Spectrums *t p* or 2*t* 2 *p* made by that Refraction did cut the produced Axis of the Spectrum TP in the points *m* and *n*, a little beyond the center of that white round Image S. Whence the proportion of the Line 3*t* T to the Line 3*p* P was a little greater than the Proportion of $2tT$ to $2pP$, and this Proportion a little greater than that of $tT$ to $pP$. Now when the Light of the Spectrum PT falls perpendicularly upon the Wall, those Lines $3tT$, $3pP$, and $2tT$, $2pP$ and $tT$, $pP$, are the Tangents of the Refractions, and therefore by this Experiment the Proportions of the Tangents of the Refractions are obtained, from whence the Proportions of the Sines being derived, they come out equal, ſo far as by viewing the Spectrums and uſing ſome mathematical Reaſoning I could eſtimate. For I did not make an accurate Computation. So then the Propoſition holds true in every Ray apart, ſo far as appears by Experiment. And that it is accurately true, may be demonſtrated upon this Suppoſition, *That Bodies refract Light by acting upon its Rays in Lines perpendicular to their Surfaces.* But in order to this Demonſtration, I muſt diſtinguiſh the Motion of every Ray into two Motions, the one perpendicular to the refracting Surface, the other parallel to it, and concerning the perpendicular Motion lay down the following Propoſition.

If any Motion or moving thing whatſoever be incident with any velocity on any broad and thin ſpace terminated on both ſides by two parallel Planes, and in its paſſage through that ſpace be urged perpendicularly towards the farther Plane by any force which at given diſtances from the Plane is of given quantities; the perpendicular velocity of that Motion or Thing, at its emerging out of that ſpace, ſhall be always equal to the ſquare Root of the ſum of the

the ſquare of the perpendicular velocity of that Motion or Thing at its Incidence on that ſpace; and of the ſquare of the perpendicular velocity which that Motion or Thing would have at its Emergence, if at its Incidence its perpendicular velocity was infinitely little.

And the ſame Propoſition holds true of any Motion or Thing perpendicularly retarded in its paſſage through that ſpace, if inſtead of the ſum of the two Squares you take their difference. The demonſtration Mathematicians will eaſily find out, and therefore I ſhall not trouble the Reader with it.

Suppoſe now that a Ray coming moſt obliquely in the Line MC [in *Fig.* 1.] be refracted at C by the Plane RS into the Line CN, and if it be required to find the Line CE into which any other Ray AC ſhall be refracted; let MC, AD, be the Sines of Incidence of the two Rays, and NG, EF, their Sines of Refraction, and let the equal Motions of the incident Rays be repreſented by the equal Lines MC and AC, and the Motion MC being conſidered as parallel to the refracting Plane, let the other Motion AC be diſtinguiſhed into two Motions AD and DC, one of which AD is parallel, and the other DC perpendicular to the refracting Surface. In like manner, let the Motions of the emerging Rays be diſtinguiſh'd into two, whereof the perpendicular ones are $\frac{MC}{MG}CG$ and $\frac{AD}{EF}CF$. And if the force of the refracting Plane begins to act upon the Rays either in that Plane or at a certain diſtance from it on the one ſide, and ends at a certain diſtance from it on the other

 ſide,

ſide, and in all places between thoſe two limits acts upon the Rays in Lines perpendicular to that refracting Plane, and the Actions upon the Rays at equal diſtances from the refracting Plane be equal, and at unequal ones either equal or unequal according to any rate whatever; that Motion of the Ray which is parallel to the refracting Plane will ſuffer no alteration by that force; and that Motion which is perpendicular to it will be altered according to the rule of the foregoing Propoſition. If therefore for the perpendicular velocity of the emerging Ray CN you write $\frac{MC}{NG}$ CG as above, then the perpendicular velocity of any other emerging Ray CE which was $\frac{AD}{EF}$CF, will be equal to the ſquare Root of $CDq + \frac{MCq}{NGq} CGq$. And by ſquaring theſe Equals, and adding to them the Equals $ADq$ and $MCq - CDq$, and dividing the Sums by the Equals $CFq + EFq$ and $CGq + NGq$, you will have $\frac{MCq}{NGq}$ equal to $\frac{MCq}{NGq}$. Whence AD, the Sine of Incidence, is to EF the Sine of Refraction, as MC to NG, that is, in a given *ratio*. And this Demonſtration being general, without determining what Light is, or by what kind of force it is refracted, or aſſuming any thing farther than that the refracting Body acts upon the Rays in Lines perpendicular to its Surface; I take it to be a very convincing Argument of the full truth of this Propoſition.

So then, if the *ratio* of the Sines of Incidence and Refraction of any ſort of Rays be found

found in any one case, 'tis given in all cases; and this may be readily found by the method in the following Proposition.

## *PROP.* VII. THEOR. VI.

*The Perfection of Telescopes is impeded by the different Refrangibility of the Rays of Light.*

THE Imperfection of Telescopes is vulgarly attributed to the spherical Figures of the Glasses, and therefore Mathematicians have propounded to figure them by the conical Sections. To shew that they are mistaken, I have inserted this Proposition; the truth of which will appear by the measures of the Refractions of the several sorts of Rays; and these measures I thus determine.

In the third Experiment of the first Book, where the refracting Angle of the Prism was $62\frac{1}{2}$ Degrees, the half of that Angle 31 deg. 15 min. is the Angle of Incidence of the Rays at their going out of the Glass into the Air; and the Sine of this Angle is 5188, the Radius being 10000. When the Axis of this Prism was parallel to the Horizon, and the Refraction of the Rays at their Incidence on this Prism equal to that at their Emergence out of it, I observed with a Quadrant the Angle which the mean refrangible Rays (that is, those which went to the middle of the Sun's coloured Image) made with the Horizon and by this Angle and the Sun's altitude observed at the same time, I found the Angle which the emergent Rays contained with the incident to be 44 deg. and 40 min. and the half of this Angle added to the Angle of Incidence 31 deg. 15 min. makes the Angle of Refraction, which is therefore 53 deg. 35 min. and its Sine 8047. Theſe are the Sines of Incidence and Refraction of the mean refrangible Rays, and their proportion in round numbers is 20 to 31. This Glaſs was of a colour inclining to green. The laſt of the Priſms mentioned in the third Experiment was of clear white Glaſs. Its refracting Angle $63\frac{1}{2}$ Degrees. The Angle which the emergent Rays contained, with the incident 45 deg. 50 min. The Sine of half the firſt Angle 5262. The Sine of half the ſum of the Angles 8157. And their proportion in round numbers 20 to 31, as before.

From the length of the Image, which was about $9\frac{3}{4}$ or 10 Inches, ſubduct its breadth, which was $2\frac{1}{8}$ Inches, and the remainder $7\frac{3}{4}$ Inches would be the length of the Image were the Sun but a point, and therefore ſubtends the Angle which the moſt and leaſt refrangible Rays, when incident on the Priſm in the ſame Lines, do contain with one another after their Emergence. Whence this Angle is 2 deg. 0′. 7″. For the diſtance between the Image and the Priſm where this Angle is made, was $18\frac{1}{2}$ Feet, and at that diſtance the Chord $7\frac{3}{4}$ Inches ſubtends an Angle of 2 deg. 0′. 7″. Now half this Angle is the Angle which theſe emergent Rays contain with the emergent mean refrangible Rays, and a quarter thereof, that is 30′. 2″. may be accounted the Angle which they would contain with the ſame emergent mean refrangible Rays, were

were they co-incident to them within the Glaſs and ſuffered no other Refraction than that at their Emergence. For if two equal Refractions, the one at the Incidence of the Rays on the Priſm, the other at their Emergence, make half the Angle 2 deg. 0′. 7″. then one of thoſe Refractions will make about a quarter of that Angle, and this quarter added to and ſubducted from the Angle of Refraction of the mean refrangible Rays, which was 53 deg. 35′, gives the Angles of Refraction of the moſt and leaſt refrangible Rays 54 deg. 5′ 2″, and 53 deg. 4′ 58″, whoſe Sines are 8099 and 7995, the common Angle of Incidence being 31 deg. 15′ and its Sine 5188; and theſe Sines in the leaſt round numbers are in proportion to one another, as 78 and 77 to 50.

Now if you ſubduct the common Sine of Incidence 50 from the Sines of Refraction 77 and 78, the remainders 27 and 28 ſhew that in ſmall Refractions the Refraction of the leaſt refrangible Rays is to the Refraction of the moſt refrangible ones as 27 to 28 very nearly, and that the difference of the Refractions of the leaſt refrangible and moſt refrangible Rays is about the $27\frac{1}{2}$th part of the whole Refraction of the mean refrangible Rays.

Whence they that are skilled in Opticks will eaſily underſtand, that the breadth of the leaſt circular ſpace into which Object-glaſſes of Teleſcopes can collect all ſorts of parallel Rays, is about the $27\frac{1}{2}$th part of half the Aperture of the Glaſs, or 55th part of the whole Aperture; and that the Focus of the moſt refrangible Rays is nearer

nearer to the Object-glaſs than the Focus of the leaſt refrangible ones, by about the $27\frac{1}{2}$th part of the diſtance between the Object-glaſs and the Focus of the mean refrangible ones.

And if Rays of all ſorts, flowing from any one lucid point in the Axis of any convex Lens, be made by the Refraction of the Lens to converge to points not too remote from the Lens, the Focus of the moſt refrangible Rays ſhall be nearer to the Lens than the Focus of the leaſt refrangible ones, by a diſtance which is to the $27\frac{1}{2}$th part of the diſtance of the Focus of the mean refrangible Rays from the Lens as the diſtance between that Focus and the lucid point from whence the Rays flow is to the diſtance between that lucid point and the Lens very nearly.

Now to examine whether the difference between the Refractions which the moſt refrangible and the leaſt refrangible Rays flowing from the ſame point ſuffer in the Object-glaſſes of Teleſcopes and ſuch like Glaſſes, be ſo great as is here deſcribed, I contrived the following Experiment.

*Exper.* 16. The Lens which I uſed in the ſecond and eighth Experiments, being placed ſix Feet and an Inch diſtant from any Object, collected the Species of that Object by the mean refrangible Rays at the diſtance of ſix Feet and an Inch from the Lens on the other ſide. And therefore by the foregoing Rule it ought to collect the Species of that Object by the leaſt refrangible Rays at the diſtance of ſix Feet and $3\frac{2}{3}$ Inches from the Lens, and by the moſt refrangible

frangible ones at the distance of five Feet and $10\frac{1}{3}$ Inches from it: So that between the two places where these least and most refrangible Rays collect the Species, there may be the distance of about $5\frac{1}{3}$ Inches. For by that Rule, as six Feet and an Inch (the distance of the Lens from the lucid Object) is to twelve Feet and two Inches (the distance of the lucid Object from the Focus of the mean refrangible Rays) that is, as one is to two, so is the $27\frac{1}{2}$th part of six Feet and an Inch (the distance between the Lens and the same Focus) to the distance between the Focus of the most refrangible Rays and the Focus of the least refrangible ones, which is therefore $5\frac{17}{32}$ Inches, that is very nearly $5\frac{1}{3}$ Inches. Now to know whether this measure was true, I repeated the second and eighth Experiment with coloured Light, which was less compounded than that I there made use of: For I now separated the heterogeneous Rays from one another by the method I described in the eleventh Experiment, so as to make a coloured Spectrum about twelve or fifteen times longer than broad. This Spectrum I cast on a printed Book, and placing the abovementioned Lens at the distance of six Feet and an Inch from this Spectrum to collect the Species of the illuminated Letters at the same distance on the other side, I found that the Species of the Letters illuminated with blue were nearer to the Lens than those illuminated with deep red by about three Inches or three and a quarter: but the Species of the Letters illuminated with indigo and violet appeared so confused

fuſed and indiſtinct, that I could not read them: Whereupon viewing the Priſm, I found it was full of Veins running from one end of the Glaſs to the other; ſo that the Refraction could not be regular. I took another Priſm therefore which was free from Veins, and inſtead of the Letters I uſed two or three parallel black Lines a little broader than the ſtroakes of the Letters, and caſting the Colours upon theſe Lines in ſuch manner that the Lines ran along the Colours from one end of the Spectrum to the other, I found that the Focus where the indigo, or confine of this Colour and violet caſt the Species of the black Lines moſt diſtinctly, to be about four Inches or $4\frac{1}{4}$ nearer to the Lens than the Focus where the deepeſt red caſt the Species of the ſame black Lines moſt diſtinctly. The violet was ſo faint and dark, that I could not diſcern the Species of the Lines diſtinctly by that Colour; and therefore conſidering that the Priſm was made of a dark coloured Glaſs inclining to green, I took another Priſm of clear white Glaſs; but the Spectrum of Colours which this Priſm made had long white ſtreams of faint Light ſhooting out from both ends of the Colours, which made me conclude that ſomething was amiſs; and viewing the Priſm, I found two or three little bubbles in the Glaſs which refracted the Light irregularly. Wherefore I covered that part of the Glaſs with black Paper, and letting the Light paſs through another part of it which was free from ſuch bubbles, the Spectrum of Colours became free from thoſe irregular Streams of Light, and was

was now ſuch as I deſired. But ſtill I found the violet ſo dark and faint, that I could ſcarce ſee the Species of the Lines by the violet, and not at all by the deepeſt part of it, which was next the end of the Spectrum. I ſuſpected therefore that this faint and dark Colour might be allayed by that ſcattering Light which was refracted, and reflected irregularly, partly by ſome very ſmall bubbles in the Glaſſes, and partly by the inequalities of their Poliſh: which Light, tho' it was but little, yet it being of a white Colour, might ſuffice to affect the Senſe ſo ſtrongly as to diſturb the Phænomena of that weak and dark Colour the violet, and therefore I tried, as in the 12th, 13th and 14th Experiments, whether the Light of this Colour did not conſiſt of a ſenſible mixture of heterogeneous Rays, but found it did not. Nor did the Refractions cauſe any other ſenſible Colour than violet to emerge out of this Light, as they would have done out of white Light, and by conſequence out of this violet Light had it been ſenſibly compounded with white Light. And therefore I concluded, that the reaſon why I could not ſee the Species of the Lines diſtinctly by this Colour, was only the darkneſs of this Colour and thinneſs of its Light, and its diſtance from the Axis of the Lens; I divided therefore thoſe parallel black Lines into equal parts, by which I might readily know the diſtances of the Colours in the Spectrum from one another, and noted the diſtances of the Lens from the Foci of ſuch Colours as caſt the Species of the Lines diſtinctly, and then conſidered

dered whether the difference of thoſe diſtances bear ſuch proportion to 5$\frac{1}{3}$ Inches, the greateſt difference of the diſtances which the Foci of the deepeſt red and violet ought to have from the Lens, as the diſtance of the obſerved Colours from one another in the Spectrum bear to the greateſt diſtance of the deepeſt red and violet meaſured in the rectilinear ſides of the Spectrum, that is, to the length of thoſe Sides or Exceſs of the length of the Spectrum above its breadth. And my Obſervations were as follows.

When I obſerved and compared the deepeſt ſenſible red, and the Colour in the Confine of green and blue, which at the rectilinear Sides of the Spectrum was diſtant from it half the length of thoſe Sides, the Focus where the Confine of green and blue caſt the Species of the Lines diſtinctly on the Paper, was nearer to the Lens than the Focus where the red caſt thoſe Lines diſtinctly on it by about 2$\frac{1}{2}$ or 2$\frac{3}{4}$ Inches. For ſometimes the Meaſures were a little greater, ſometimes a little leſs, but ſeldom varied from one another above $\frac{1}{3}$ of an Inch. For it was very difficult to define the places of the Foci, without ſome little Errors. Now if the Colours diſtant half the length of the Image, (meaſured at its rectilinear Sides) give 2$\frac{1}{2}$ or 2$\frac{3}{4}$ difference of the diſtances of their Foci from the Lens, then the Colours diſtant the whole length ought to give 5 or 5$\frac{1}{2}$ Inches difference of thoſe diſtances.

But here it's to be noted, that I could not ſee the red to the full end of the Spectrum, but

but only to the center of the Semicircle which bounded that end, or a little farther; and therefore I compared this red not with that Colour which was exactly in the middle of the Spectrum, or Confine of green and blue, but with that which verged a little more to the blue than to the green: And as I reckoned the whole length of the Colours not to be the whole length of the Spectrum, but the length of its rectilinear Sides, so completing the semicircular Ends into Circles, when either of the observed Colours fell within those Circles, I measured the distance of that Colour from the semicircular end of the Spectrum, and subducting half this distance from the measured distance of the two Colours, I took the remainder for their corrected distance; and in these Observations set down this corrected distance for the difference of the distances of their Foci from the Lens. For as the length of the rectilinear Sides of the Spectrum would be the whole length of all the Colours, were the Circles of which (as we shewed) that Spectrum consists contracted and reduced to physical Points, so in that case this corrected distance would be the real distance of the two observed Colours.

When therefore I farther observed the deepest sensible red, and that blue whose corrected distance from it was $\frac{7}{12}$ parts of the length of the rectilinear Sides of the Spectrum, the difference of the distances of their Foci from the Lens was about $3\frac{1}{4}$ Inches, and as 7 to 12 so is $3\frac{1}{4}$ to $5\frac{4}{7}$.

When

When I obſerved the deepeſt ſenſible red, and that indigo whoſe corrected diſtance was $\frac{8}{12}$ or $\frac{2}{3}$ of the length of the rectilinear Sides of the Spectrum, the difference of the diſtances of their Foci from the Lens, was about $3\frac{2}{3}$ Inches, and as 2 to 3 ſo is $3\frac{2}{3}$ to $5\frac{1}{2}$.

When I obſerved the deepeſt ſenſible red, and that deep indigo whoſe corrected diſtance from one another was $\frac{9}{12}$ or $\frac{3}{4}$ of the length of the rectilinear Sides of the Spectrum, the difference of the diſtances of their Foci from the Lens was about 4 Inches; and as 3 to 4 ſo is 4 to $5\frac{1}{3}$.

When I obſerved the deepeſt ſenſible red, and that part of the violet next the indigo, whoſe corrected diſtance from the red was $\frac{10}{12}$ or $\frac{5}{6}$ of the length of the rectilinear Sides of the Spectrum, the difference of the diſtances of their Foci from the Lens was about $4\frac{1}{2}$ Inches, and as 5 to 6, ſo is $4\frac{1}{2}$ to $5\frac{2}{5}$. For ſometimes when the Lens was advantagiouſly placed, ſo that its Axis reſpected the blue, and all things elſe were well ordered, and the Sun ſhone clear, and I held my Eye very near to the Paper on which the Lens caſt the Species of the Lines, I could ſee pretty diſtinctly the Species of thoſe Lines by that part of the violet which was next the indigo; and ſometimes I could ſee them by above half the violet. For in making theſe Experiments I had obſerved, that the Species of thoſe Colours only appear diſtinct which were in or near the Axis of the Lens: So that if the blue or indigo were in the Axis, I could ſee their Species diſtinctly; and then the red appeared

peared much leſs diſtinct than before. Wherefore I contrived to make the Spectrum of Colours ſhorter than before, ſo that both its ends might be nearer to the Axis of the Lens. And now its length was about $2\frac{1}{2}$ Inches and breadth about $\frac{1}{5}$ or $\frac{1}{6}$ of an Inch. Alſo inſtead of the black Lines on which the Spectrum was caſt, I made one black Line broader than thoſe, that I might ſee its Species more eaſily; and this Line I divided by ſhort croſs Lines into equal parts, for meaſuring the diſtances of the obſerved Colours. And now I could ſometimes ſee the Species of this Line with its diviſions almoſt as far as the center of the ſemicircular violet end of the Spectrum, and made theſe farther Obſervations.

When I obſerved the deepeſt ſenſible red, and that part of the violet whoſe corrected diſtance from it was about $\frac{8}{9}$ parts of the rectilinear Sides of the Spectrum the difference of the diſtances of the Foci of thoſe Colours from the Lens, was one time $4\frac{2}{3}$, another time $4\frac{3}{4}$, another time $4\frac{7}{8}$ Inches, and as 8 to 9, ſo are $4\frac{2}{3}$, $4\frac{3}{4}$, $4\frac{7}{8}$, to $5\frac{1}{4}$, $5\frac{11}{32}$ $5\frac{31}{64}$ reſpectively.

When I obſerved the deepeſt ſenſible red, and deepeſt ſenſible violet, (the corrected diſtance of which Colours when all things were ordered to the beſt advantage, and the Sun ſhone very clear, was about $\frac{11}{12}$ or $\frac{15}{16}$ parts of the length of the rectilinear Sides of the coloured Spectrum) I found the difference of the diſtances of their Foci from the Lens ſometimes $4\frac{3}{4}$ ſometimes $5\frac{1}{4}$, and for the moſt part 5 Inches

ches or thereabouts: and as 11 to 12 or 15 to 16, so is five Inches to $5\frac{1}{2}$ or $5\frac{1}{3}$ Inches.

And by this progression of Experiments I satisfied my self, that had the Light at the very ends of the Spectrum been strong enough to make the Species of the black Lines appear plainly on the Paper, the Focus of the deepest violet would have been found nearer to the Lens, than the Focus of the deepest red, by about $5\frac{1}{3}$ Inches at least. And this is a farther evidence, that the Sines of Incidence and Refraction of the several sorts of Rays, hold the same proportion to one another in the smallest Refractions which they do in the greatest.

My progress in making this nice and troublesome Experiment I have set down more at large, that they that shall try it after me may be aware of the circumspection requisite to make it succeed well. And if they cannot make it succeed so well as I did, they may notwithstanding collect by the proportion of the distance of the Colours of the Spectrum, to the difference of the distances of their Foci from the Lens, what would be the success in the more distant Colours by a better trial. And yet if they use a broader Lens than I did, and fix it to a long straight Staff by means of which it may be readily and truly directed to the Colour whose Focus is desired, I question not but the Experiment will succeed better with them than it did with me. For I directed the Axis as nearly as I could to the middle of the Colours, and then the faint ends of the Spectrum being remote from the Axis, cast their Species less distinctly

on

on the Paper than they would have done had the Axis been successively directed to them.

Now by what has been said, it's certain that the Rays which differ in Refrangibility do not converge to the same Focus, but if they flow from a lucid point, as far from the Lens on one side as their Foci are on the other, the Focus of the most refrangible Rays shall be nearer to the Lens than that of the least refrangible, by above the fourteenth part of the whole distance: and if they flow from a lucid point, so very remote from the Lens that before their Incidence they may be accounted parallel, the Focus of the most refrangible Rays shall be nearer to the Lens than the Focus of the least refrangible, by about the 27th or 28th part of their whole distance from it. And the diameter of the Circle in the middle space between those two Foci which they illuminate when they fall there on any Plane, perpendicular to the Axis (which Circle is the least into which they can all be gathered) is about the 55th part of the diameter of the Aperture of the Glass. So that 'tis a wonder that Telescopes represent Objects so distinct as they do. But were all the Rays of Light equally refrangible, the Error arising only from the sphericalness of the Figures of Glasses would be many hundred times less. For if the Object-glass of a Telescope be Plano-convex, and the Plane side be turned towards the Object, and the diameter of the Sphere whereof this Glass is a segment, be called D, and the semidiameter of the Aperture of the Glass be called S, and the Sine of Incidence out of Glass into Air, be to the Sine of Refraction as I to R: the Rays which come parallel to the Axis of the Glaſs, ſhall in the place where the Image of the Object is moſt diſtinctly made, be ſcattered all over a little Circle whoſe diameter is $\frac{Rq}{Iq} \times \frac{S\ cub.}{D\ quad.}$ very nearly, as I gather by computing the Errors of the Rays by the method of infinite Series, and rejecting the Terms whoſe Quantities are inconſiderable. As for inſtance, if the Sine of Incidence I, be to the Sine of Refraction R, as 20 to 31, and if D the diameter of the Sphere to which the convex ſide of the Glaſs is ground, be 100 Feet or 1200 Inches, and S the ſemidiameter of the Aperture be two Inches, the diameter of the little Circle (that is $\frac{Rq \times S\ cub.}{Iq \times D\ quad.}$) will be $\frac{31 \times 31 \times 8}{20 \times 20 \times 1200 \times 1200}$ (or $\frac{961}{72000000}$) parts of an Inch. But the diameter of the little Circle through which theſe Rays are ſcattered by unequal Refrangibility, will be about the 55th part of the Aperture of the Object-glaſs which here is four Inches. And therefore the Error ariſing from the ſpherical Figure of the Glaſs, is to the Error ariſing from the different Refrangibility of the Rays, as $\frac{961}{72000000}$ to $\frac{4}{55}$ that is as 1 to 5449: and therefore being in compariſon ſo very little, deſerves not to be conſidered.

But you will ſay, if the Errors cauſed by the different Refrangibility be ſo very great, how comes it to paſs that Objects appear through Teleſcopes ſo diſtinct as they do? I anſwer, 'tis becauſe

becauſe the erring Rays are not ſcattered uniformly over all that circular ſpace, but collected infinitely more denſely in the center than in any other part of the Circle, and in the way from the center to the circumference grow continually rarer and rarer, ſo as at the circumference to become infinitely rare; and by reaſon of their rarity are not ſtrong enough to be viſible, unleſs in the center and very near it. Let ADE [in *Fig.* 27.] repreſent one of thoſe Circles deſcribed with the Center C and Semidiameter AC, and let BFG be a ſmaller Circle concentrick to the former, cutting with its circumference the Diameter AC in B, and biſect AC in N, and by my reckoning the Denſity of the Light in any place B will be to its Denſity in N, as AB to BC; and the whole Light within the leſſer Circle BFG, will be to the whole Light within the greater AED, as the Exceſs of the Square of AC above the Square of AB, is to the Square of AC. As if BC be the fifth part of AC, the Light will be four times denſer in B than in N, and the whole Light within the leſs Circle, will be to the whole Light within the greater, as nine to twenty five. Whence it's evident that the Light within the leſs Circle, muſt ſtrike the Senſe much more ſtrongly, than that faint and dilated Light round about between it and the circumference of the greater.

But it's farther to be noted, that the moſt luminous of the priſmatick Colours are the yellow and orange. Theſe affect the Senſes more ſtrongly than all the reſt together, and next to theſe in ſtrength are the red and green. The blue compared with theſe is a faint and dark Colour, and the indigo and violet are much darker and fainter, ſo that theſe compared with the ſtronger Colours are little to be regarded. The Images of Objects are therefore to be placed, not in the Focus of the mean refrangible Rays which are in the confine of green and blue, but in the Focus of thoſe Rays which are in the middle of the orange and yellow; there where the Colour is moſt luminous and fulgent, that is in the brighteſt yellow, that yellow which inclines more to orange than to green. And by the Refraction of theſe Rays (whoſe Sines of Incidence and Refraction in Glaſs are as 17 and 11) the Refraction of Glaſs and Cryſtal for optical Uſes is to be meaſured. Let us therefore place the Image of the Object in the Focus of theſe Rays, and all the yellow and orange will fall within a Circle, whoſe diameter is about the 250th part of the diameter of the Aperture of the Glaſs. And if you add the brighter half of the red, (that half which is next the orange) and the brighter half of the green, (that half which is next the yellow) about three fifth parts of the Light of theſe two Colours will fall within the ſame Circle, and two fifth parts will fall without it round about; and that which falls without will be ſpread through almoſt as much more ſpace as that which falls within, and ſo in the groſs be almoſt three times rarer. Of the other half of the red and green, (that is of the deep dark red and willow green) about one quarter will fall within this Circle, and three quarters without, and that which falls without will be ſpread through about four or five times more ſpace than that which falls within; and ſo in the groſs be rarer, and if compared with the whole Light within it, will be about 25 times rarer than all that taken in the groſs; or rather more than 30 or 40 times rarer, becauſe the deep red in the end of the Spectrum of Colours made by a Priſm is very thin and rare, and the willow green is ſomething rarer than the orange and yellow. The Light of theſe Colours therefore being ſo very much rarer than that within the Circle, will ſcarce affect the Senſe, eſpecially ſince the deep red and willow green of this Light, are much darker Colours than the reſt. And for the ſame reaſon the blue and violet being much darker Colours than theſe, and much more rarified, may be neglected. For the denſe and bright Light of the Circle, will obſcure the rare and weak Light of theſe dark Colours round about it, and render them almoſt inſenſible. The ſenſible Image of a lucid point is therefore ſcarce broader than a Circle whoſe diameter is the 250th part of the diameter of the Aperture of the Object-glaſs of a good Teleſcope, or not much broader, if you except a faint and dark miſty Light round about it, which a Spectator will ſcarce regard. And therefore in a Teleſcope whoſe aperture is four Inches, and length an hundred Feet, it exceeds not 2″ 45‴, or 3″. And in a Teleſcope whoſe aperture is two Inches, and length 20 or 30 Feet, it may be 5″ or 6″ and ſcarce above. And this anſwers well to experience: For ſome Aſtronomers have found the Diameters of the fix'd Stars, in Teleſcopes of between 20 and 60 Feet in length, to be about 5″ or 6″, or at moſt 8″ or 10″ in diameter. But if the Eye-Glaſs be tincted faintly with the ſmoke of a Lamp or Torch, to obſcure the Light of the Star, the fainter Light in the circumference of the Star ceaſes to be viſible, and the Star (if the Glaſs be ſufficiently ſoiled with ſmoke) appears ſomething more like a mathematical Point. And for the ſame reaſon, the enormous part of the Light in the circumference of every lucid Point ought to be leſs diſcernible in ſhorter Teleſcopes than in longer, becauſe the ſhorter tranſmit leſs Light to the Eye.

Now that the fix'd Stars, by reaſon of their immenſe diſtance, appear like Points, unleſs ſo far as their Light is dilated by Refraction, may appear from hence; that when the Moon paſſes over them and eclipſes them, their Light vaniſhes, not gradually like that of the Planets, but all at once; and in the end of the Eclipſe it returns into Sight all at once, or certainly in leſs time than the ſecond of a Minute; the Refraction of the Moon's Atmoſphere a little protracting the time in which the Light of the Star firſt vaniſhes, and afterwards returns into Sight.

Now if we ſuppoſe the ſenſible Image of a lucid Point, to be even 250 times narrower than the aperture of the Glaſs: yet this Image would be ſtill much greater than if it were only from the ſpherical Figure of the Glaſs. For were it not for the different Refrangibility of the

Rays,

Rays, its breadth in an 100 Foot Teleſcope whoſe aperture is 4 Inches would be but $\frac{961}{72000000}$ parts of an Inch, as is manifeſt by the foregoing computation. And therefore in this caſe the greateſt Errors ariſing from the ſpherical Figure of the Glaſs, would be to the greateſt ſenſible Errors ariſing from the different Refrangibility of the Rays as $\frac{961}{72000000}$ to $\frac{4}{250}$ at moſt, that is only as 1 to 1200. And this ſufficiently ſhews that it is not the ſpherical Figures of Glaſſes but the different Refrangibility of the Rays which hinders the perfection of Teleſcopes.

There is another Argument by which it may appear that the different Refrangibility of Rays, is the true cauſe of the imperfection of Teleſcopes. For the Errors of the Rays ariſing from the ſpherical Figures of Object-glaſſes, are as the Cubes of the Apertures of the Object-glaſſes; and thence to make Teleſcopes of various lengths, magnify with equal diſtinctneſs, the Apertures of the Object-glaſſes, and the Charges or magnifying Powers, ought to be as the Cubes of the ſquare Roots of their lengths; which doth not anſwer to experience. But the Errors of the Rays ariſing from the different Refrangibility, are as the Apertures of the Object-glaſſes, and thence to make Teleſcopes of various lengths, magnify with equal diſtinctneſs, their Apertures and Charges ought to be as the ſquare Roots of their lengths; and this anſwers to experience, as is well known. For inſtance, a Teleſcope of 64 Feet in length, with an Aperture of $2\frac{2}{3}$ Inches, magnifies about 120 times, with as much diſtinctneſs as one of a Foot in length, with $\frac{1}{3}$ of an Inch aperture, magnifies 15 times.

Now were it not for this different Refrangibility of Rays, Teleſcopes might be brought to a greater perfection than we have yet deſcrib'd, by compoſing the Object-Glaſs of two Glaſſes with Water between them. Let ADFC [in *Fig.* 28.] repreſent the Object-glaſs compoſed of two Glaſſes ABED and BEFC, alike convex on the outſides AGD and CHF, and alike concave on the inſides BME, BNE, with Water in the concavity BMEN. Let the Sine of Incidence out of Glaſs into Air be as I to R, and out of Water into Air as K to R, and by conſequence out of Glaſs into Water, as I to K: and let the diameter of the Sphere to which the convex ſides AGD and CHF are ground be D, and the diameter of the Sphere to which the concave ſides BME and BNE are ground be to D, as the Cube Root of KK—KI to the Cube Root of RK—RI: and the Refractions on the concave ſides of the Glaſſes, will very much correct the Errors of the Refractions on the convex ſides, ſo far as they ariſe from the ſphericalneſs of the Figure. And by this means might Teleſcopes be brought to ſufficient perfection, were it not for the different Refrangibility of ſeveral ſorts of Rays. But by reaſon of this different Refrangibility, I do not yet ſee any other means of improving Teleſcopes by Refractions alone than that of increaſing their lengths, for which end the late Contrivance of

*Hugenius*

*Hugenius* ſeems well accommodated. For very long Tubes are cumberſome, and ſcarce to be readily managed, and by reaſon of their length are very apt to bend, and ſhake by bending ſo as to cauſe a continual trembling in the Objects, whereby it becomes difficult to ſee them diſtinctly: whereas by his contrivance the Glaſſes are readily manageable, and the Object-glaſs being fix'd upon a ſtrong upright Pole becomes more ſteady.

Seeing therefore the Improvement of Teleſcopes of given lengths by Refractions is deſperate; I contrived heretofore a Perſpective by Reflexion, uſing inſtead of an Object-glaſs a concave Metal. The diameter of the Sphere to which the Metal was ground concave was about 25 Engliſh Inches, and by conſequence the length of the Inſtrument about ſix Inches and a quarter. The Eye-glaſs was Plano-convex, and the diameter of the Sphere to which the convex ſide was ground was about $\frac{1}{5}$ of an Inch, or a little leſs, and by conſequence it magnified between 30 and 40 times. By another way of meaſuring I found that it magnified about 35 times. The concave Metal bore an Aperture of an Inch and a third part; but the Aperture was limited not by an opake Circle, covering the Limb of the Metal round about, but by an opake Circle placed between the Eye-glaſs and the Eye, and perforated in the middle with a little round hole for the Rays to paſs through to the Eye. For this Circle by being placed here, ſtopp'd much of the erroneous Light, which otherwiſe would have diſturbed the

the Viſion. By comparing it with a pretty good Perſpective of four Feet in length, made with a concave Eye-glaſs, I could read at a greater diſtance with my own Inſtrument than with the Glaſs. Yet Objects appeared much darker in it than in the Glaſs, and that partly becauſe more Light was loſt by Reflexion in the Metal, than by Refraction in the Glaſs, and partly becauſe my Inſtrument was overcharged. Had it magnified but 30 or 25 times it would have made the Object appear more briſk and pleaſant. Two of theſe I made about 16 Years ago, and have one of them ſtill by me by which I can prove the truth of what I write. Yet it is not ſo good as at the firſt. For the concave has been divers times tarniſhed and cleared again, by rubbing it with very ſoft Leather. When I made theſe, an Artiſt in *London* undertook to imitate it; but uſing another way of poliſhing them than I did, he fell much ſhort of what I had attained to, as I afterwards underſtood by diſcourſing the under Workman he had employed. The Poliſh I uſed was in this manner. I had two round Copper Plates each ſix Inches in diameter, the one convex the other concave, ground very true to one another. On the convex I ground the Object-Metal or Concave which was to be poliſh'd, till it had taken the Figure of the Convex and was ready for a Poliſh. Then I pitched over the convex very thinly, by dropping melted Pitch upon it and warming it to keep the Pitch ſoft, whilſt I ground it with the concave Copper wetted to make it ſpread eavenly all over the convex.

Thus

Thus by working it well I made it as thin as a Groat, and after the convex was cold I ground it again to give it as true a Figure as I could. Then I took Putty which I had made very fine by washing it from all its grosser Particles, and laying a little of this upon the Pitch, I ground it upon the Pitch with the concave Copper till it had done making a noise; and then upon the Pitch I ground the Object-Metal with a brisk motion, for about two or three Minutes of time, leaning hard upon it. Then I put fresh Putty upon the Pitch and ground it again till it had done making a noise, and afterwards ground the Object-Metal upon it as before. And this Work I repeated till the Metal was polished, grinding it the last time with all my strength for a good while together, and frequently breathing upon the Pitch to keep it moist without laying on any more fresh Putty. The Object-Metal was two Inches broad and about one third part of an Inch thick, to keep it from bending. I had two of these Metals, and when I had polished them both I tried which was best, and ground the other again to see if I could make it better than that which I kept. And thus by many Trials I learn'd the way of polishing, till I made those two reflecting Perspectives I spake of above. For this Art of polishing will be better learn'd by repeated Practice than by my Description. Before I ground the Object-Metal on the Pitch, I always ground the Putty on it with the concave Copper till it had done making a noise, because if the Particles of the Putty were not by this means made to ſtick faſt in the Pitch, they would by rolling up and down grate and fret the Object-Metal and fill it full of little holes.

But becauſe Metal is more difficult to poliſh than Glaſs, and is afterwards very apt to be ſpoiled by tarniſhing, and reflects not ſo much Light as Glaſs quick-ſilver'd over does: I would propound to uſe inſtead of the Metal, a Glaſs ground concave on the foreſide, and as much convex on the back-ſide, and quick-ſilver'd over on the convex ſide. The Glaſs muſt be every where of the ſame thickneſs exactly. Otherwiſe it will make Objects look colour'd and indiſtinct. By ſuch a Glaſs I tried about five or ſix Years ago to make a reflecting Teleſcope of four Feet in length to magnify about 150 times, and I ſatisfied my ſelf that there wants nothing but a good Artiſt to bring the Deſign to perfection. For the Glaſs being wrought by one of our *London* Artiſts after ſuch a manner as they grind Glaſſes for Teleſcopes, tho' it ſeemed as well wrought as the Object-glaſſes uſe to be, yet when it was quick-ſilver'd, the Reflexion diſcovered innumerable Inequalities all over the Glaſs. And by reaſon of theſe Inequalities, Objects appeared indiſtinct in this Inſtrument. For the Errors of reflected Rays cauſed by any Inequality of the Glaſs, are about ſix times greater than the Errors of refracted Rays cauſed by the like Inequalities. Yet by this Experiment I ſatisfied my ſelf that the Reflexion on the concave ſide of the Glaſs, which I feared would diſturb the Viſion, did no ſenſible prejudice to it, and by conſequence that nothing is wanting

to

to perfect these Telescopes, but good Workmen who can grind and polish Glasses truly spherical. An Object-glass of a fourteen Foot Telescope, made by an Artificer at *London*, I once mended considerably, by grinding it on Pitch with Putty, and leaning very easily on it in the grinding, lest the Putty should scratch it. Whether this way may not do well enough for polishing these reflecting Glasses, I have not yet tried. But he that shall try either this or any other way of polishing which he may think better, may do well to make his Glasses ready for polishing by grinding them without that violence, wherewith our *London* Workmen press their Glasses in grinding. For by such violent pressure, Glasses are apt to bend a little in the grinding, and such bending will certainly spoil their Figure. To recommend therefore the consideration of these reflecting Glasses, to such Artists as are curious in figuring Glasses, I shall describe this optical Instrument in the following Proposition.

## *PROP.* VII. PROB. II.

*To shorten Telescopes.*

LET ABDC [in *Fig.* 29.] represent a Glass spherically concave on the foreside AB, and as much convex on the backside CD, so that it be every where of an equal thickness. Let it not be thicker on one side than on the other, lest it make Objects appear colour'd and indi-

indiſtinct, and let it be very truly wrought and quick-ſilver'd over on the backſide; and ſet in the Tube V X Y Z which muſt be very black within. Let E F G repreſent a Priſm of Glaſs or Cryſtal placed near the other end of the Tube, in the middle of it, by means of a handle of Braſs or Iron F G K, to the end of which made flat it is cemented. Let this Priſm be rectangular at E, and let the other two Angles at F and G be accurately equal to each other, and by conſequence equal to half right ones, and let the plane ſides F E and G E be ſquare, and by conſequence the third ſide F G a rectangular Parallelogram, whoſe length is to its breadth in a ſubduplicate proportion of two to one. Let it be ſo placed in the Tube, that the Axis of the Speculum may paſs through the middle of the ſquare ſide E F perpendicularly, and by conſequence through the middle of the ſide F G at an Angle of 45 Degrees, and let the ſide E F be turned towards the Speculum, and the diſtance of this Priſm from the Speculum be ſuch that the Rays of the Light PQ, RS, &c. which are incident upon the Speculum in Lines parallel to the Axis thereof, may enter the Priſm at the ſide E F, and be reflected by the ſide F G, and thence go out of it through the ſide G E, to the point T which muſt be the common Focus of the Speculum A B D C, and of a Plano-convex Eye-glaſs H, through which thoſe Rays muſt paſs to the Eye. And let the Rays at their coming out of the Glaſs paſs through a ſmall round hole, or aperture made in a little plate of Lead, Braſs, or Silver, wherewith the

the Glaſs is to be covered, which hole muſt be no bigger than is neceſſary for Light enough to paſs through. For ſo it will render the Object diſtinct, the Plate in which 'tis made intercepting all the erroneous part of the Light which comes from the verges of the Speculum A B. Such an Inſtrument well made, if it be ſix Foot long, (reckoning the length from the Speculum to the Priſm, and thence to the Focus T) will bear an aperture of ſix Inches at the Speculum, and magnify between two and three hundred times. But the hole H here limits the aperture with more advantage, than if the aperture was placed at the Speculum. If the Inſtrument be made longer or ſhorter, the aperture muſt be in proportion as the Cube of the ſquare-ſquare Root of the length, and the magnifying as the aperture. But it's convenient that the Speculum be an Inch or two broader than the aperture at the leaſt, and that the Glaſs of the Speculum be thick, that it bend not in the working. The Priſm E F G muſt be no bigger than is neceſſary, and its back ſide F G muſt not be quick-ſilver'd over. For without quick-ſilver it will reflect all the Light incident on it from the Speculum.

In this Inſtrument the Object will be inverted, but may be erected by making the ſquare ſides E F and E G of the Priſm E F G not plane but ſpherically convex, that the Rays may croſs as well before they come at it as afterwards between it and the Eye-glaſs. If it be deſired that the Inſtrument bear a larger aperture, that may be alſo done by compoſing the Speculum of two Glaſſes with Water between them.

If the Theory of making Teleſcopes could at length be fully brought into practice, yet there would be certain Bounds beyond which Teleſcopes could not perform. For the Air through which we look upon the Stars, is in a perpetual Tremor; as may be ſeen by the tremulous Motion of Shadows caſt from high Towers, and by the twinkling of the fix'd Stars. But theſe Stars do not twinkle when viewed through Teleſcopes which have large apertures. For the Rays of Light which paſs through divers parts of the aperture, tremble each of them apart, and by means of their various and ſometimes contrary Tremors, fall at one and the ſame time upon different points in the bottom of the Eye, and their trembling Motions are too quick and confuſed to be perceived ſeverally. And all theſe illuminated Points conſtitute one broad lucid Point, compoſed of thoſe many trembling Points confuſedly and inſenſibly mixed with one another by very ſhort and ſwift Tremors, and thereby cauſe the Star to appear broader than it is, and without any trembling of the whole. Long Teleſcopes may cauſe Objects to appear brighter and larger than ſhort ones can do, but they cannot be ſo formed as to take away that confuſion of the Rays which ariſes from the Tremors of the Atmoſphere. The only remedy is a moſt ſerene and quiet Air, ſuch as may perhaps be found on the tops of the higheſt Mountains above the groſſer Clouds.

Fig: 1.

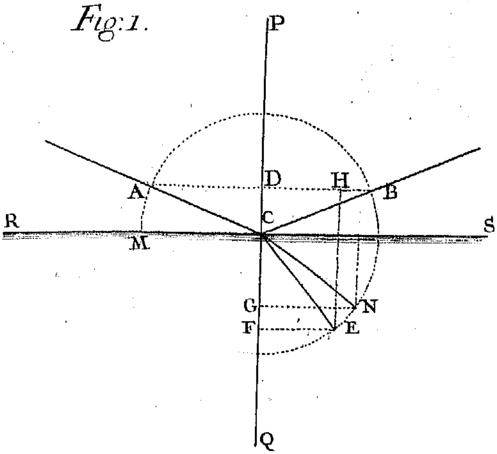



Fig. 2

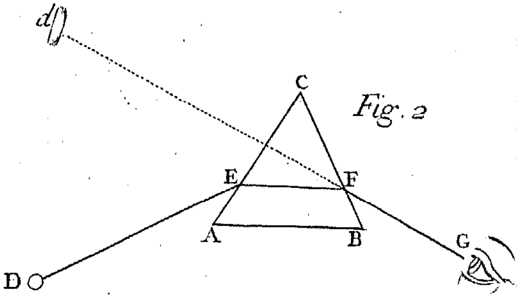



Fig: 3.

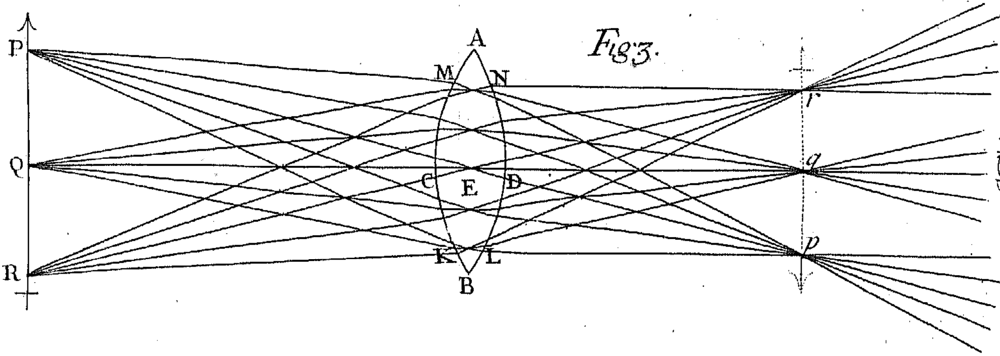



Fig: 4.

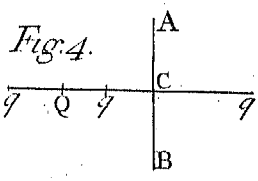



Fig: 5.

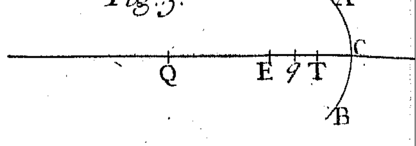



Fig: 7.

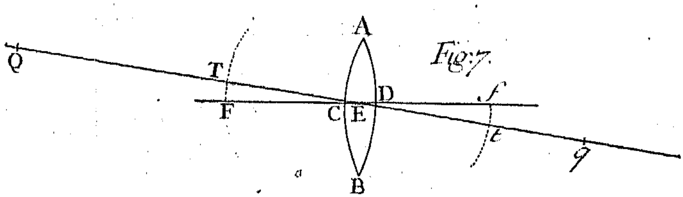



Fig: 6.

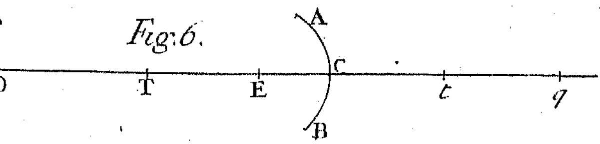


Fig: 8

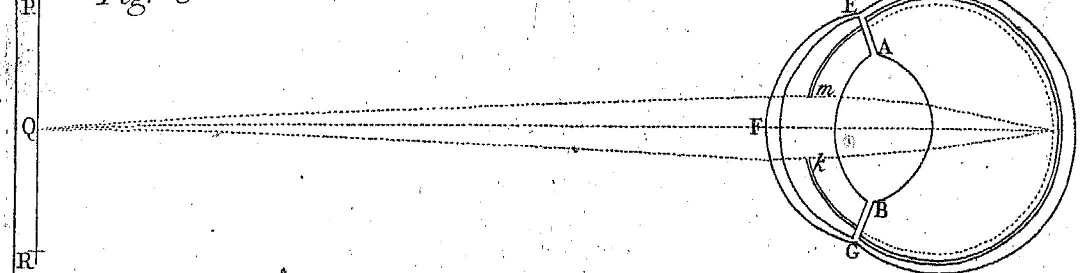



Fig. 9

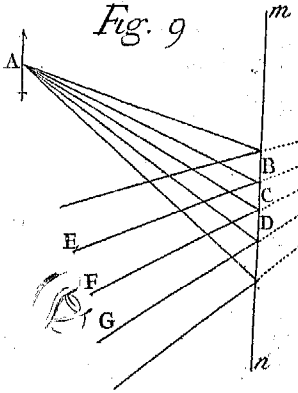



Fig. 11

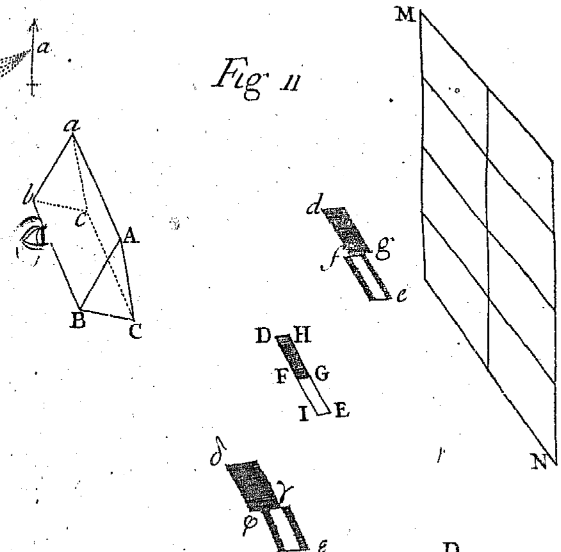
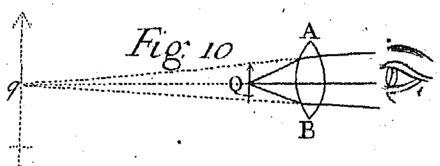



Fig: 10



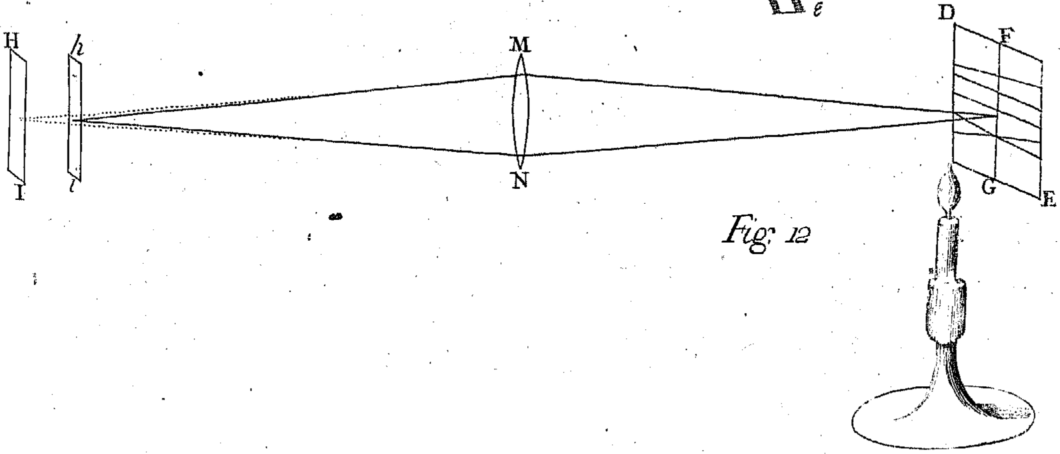




Fig: 12

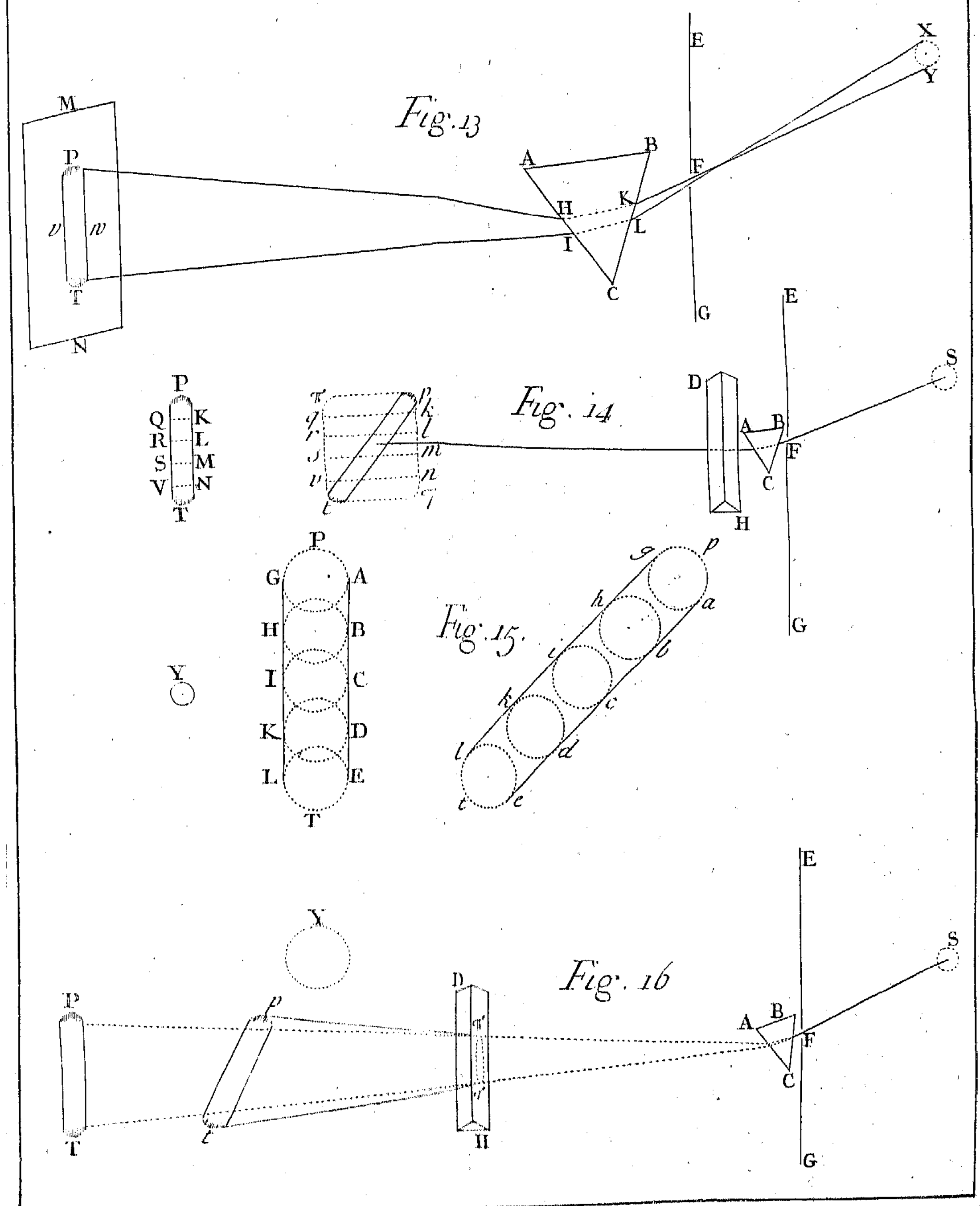


Fig. 13
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Fig. 14
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Fig. 16
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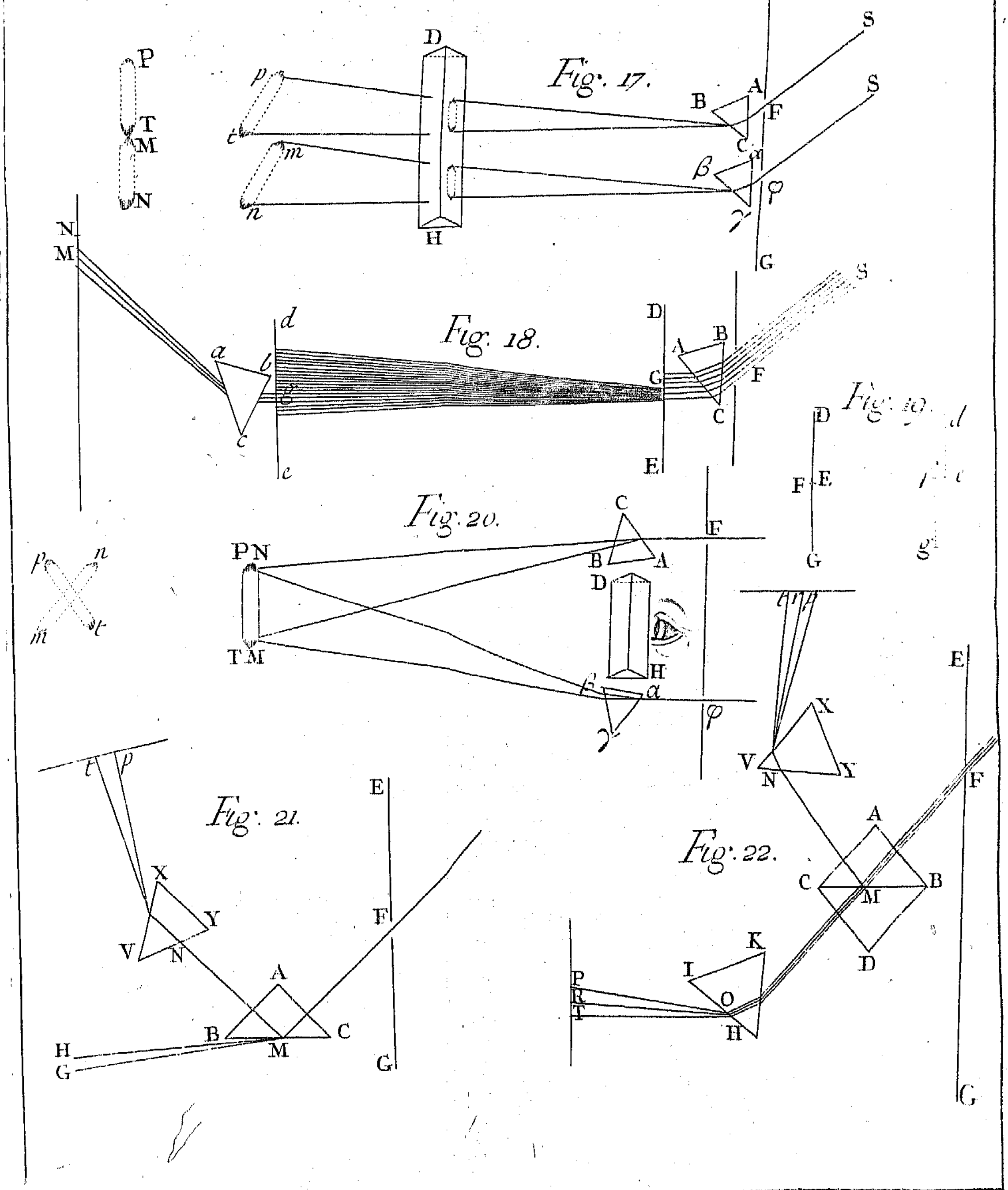
Book I. Part I. Plate IV.



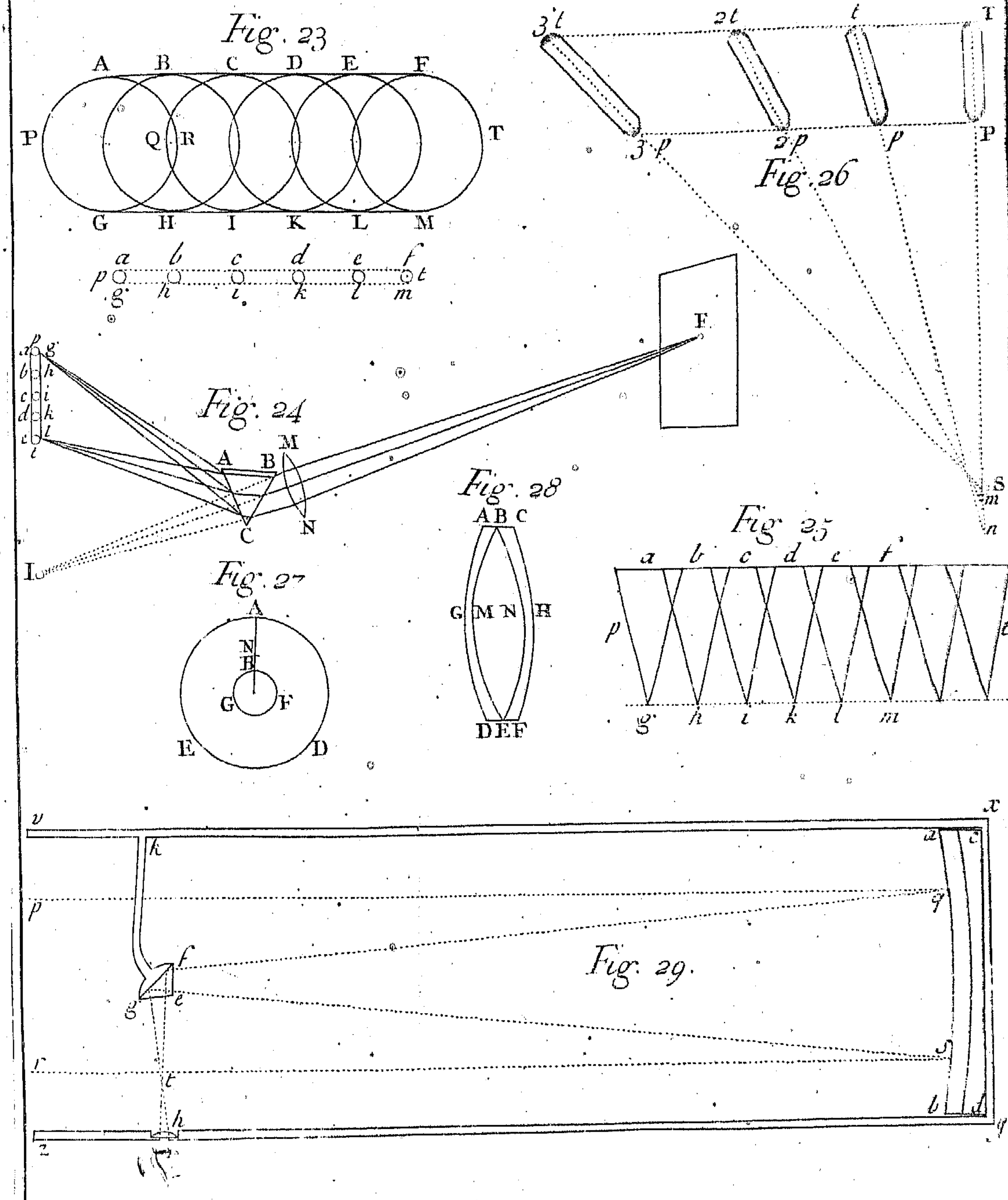


Fig. 23
Fig. 26
Fig. 24
Fig. 28
Fig. 25
Fig. 27
Fig. 29

# THE FIRST BOOK OF OPTICKS.

## PART II.

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

*The Phænomena of Colours in refracted or reflected Light are not caused by new Modifications of the Light variously impress'd, according to the various Terminations of the Light and Shadow.*

The Proof by Experiments.

*Exper.* 1. FOR if the Sun shine into a very dark Chamber through an oblong hole F, [in *Fig.* 1.] whose breadth is the sixth or eighth part of an Inch, or something less; and his beam F H do afterwards pass first through a very large Prifm ABC, diftant about 20 Feet from the hole, and parallel to it, and then (with its white part) through an oblong hole H, whofe breadth is about the fortieth or fixtieth part of an Inch, and which is made in a black opake Body GI, and placed at the diftance of two or three Feet from the Prifm, in a parallel Situation both to the Prifm and to the former hole, and if this white Light thus trafinitted through the hole H, fall afterwards upon a white Paper *p t*, placed after that hole H, at the diftance of three or four Feet from it, and there paint the ufual Colours of the Prifm, fuppofe red at *t*, yellow at *s*, green at *r*, blue at *q*, and violet at *p*; you may with an Iron Wire, or any fuch like flender opake Body, whofe breadth is about the tenth part of an Inch, by intercepting the Rays at *k*, *l*, *m*, *n* or *o*, take away any one of the Colours at *t*, *s*, *r*, *q* or *p*, whilft the other Colours remain upon the Paper as before; or with an Obftacle fomething bigger you may take away any two, or three, or four Colours together, the reft remaining: So that any one of the Colours as well as violet may become outmoft in the Confine of the Shadow towards *p*, and any one of them as well as red may become outmoft in the Confine of the Shadow towards *t*, and any one of them may alfo border upon the Shadow made within the Colours by the Obftacle R intercepting fome intermediate part of the Light; and, laftly, any one of them by being left alone may border upon the Shadow on either hand. All the Colours have themfelves indifferently to any Confines of Shadow,

dow, and therefore the differences of these Colours from one another, do not arise from the different Confines of Shadow, whereby Light is variously modified, as has hitherto been the Opinion of Philosophers. In trying these things 'tis to be observed, that by how much the holes F and H are narrower, and the Intervals between them, and the Prism greater, and the Chamber darker, by so much the better doth the Experiment succeed; provided the Light be not so far diminished, but that the Colours at *pt* be sufficiently visible. To procure a Prism of solid Glass large enough for this Experiment will be difficult, and therefore a prismatick Vessel must be made of polish'd Glass Plates cemented together, and filled with salt Water or clear Oil.

*Exper*. 2. The Sun's Light let into a dark Chamber through the round hole F, [in *Fig*.2.] half an Inch wide, passed first through the Prism ABC placed at the hole, and then through a Lens PT something more than four Inches broad, and about eight Feet distant from the Prism, and thence converged to O the Focus of the Lens distant from it about three Feet, and there fell upon a white Paper DE. If that Paper was perpendicular to that Light incident upon it, as 'tis represented in the posture DE, all the Colours upon it at O appeared white. But if the Paper being turned about an Axis parallel to the Prism, became very much inclined to the Light as 'tis represented in the Positions *de* and *δε*; the same Light in the one case appeared yellow and red, in the other blue.

 Here

Here one and the ſame part of the Light in one and the ſame place, according to the various Inclinations of the Paper, appeared in one caſe white, in another yellow or red, in a third blue, whilſt the Confine of Light and Shadow, and the Refractions of the Priſm in all theſe caſes remained the ſame.

*Exper.* 3. Such another Experiment may be more eaſily tried as follows. Let a broad beam of the Sun's Light coming into a dark Chamber through a hole in the Window-ſhut be refracted by a large Priſm ABC, [in *Fig.* 3.] whoſe refracting Angle C is more than 60 Degrees, and ſo ſoon as it comes out of the Priſm let it fall upon the white Paper DE glewed upon a ſtiff Plane; and this Light, when the Paper is perpendicular to it, as 'tis repreſented in DE, will appear perfectly white upon the Paper, but when the Paper is very much inclin'd to it in ſuch a manner as to keep always parallel to the Axis of the Priſm, the whiteneſs of the whole Light upon the Paper will according to the inclination of the Paper this way or that way, change either into yellow and red, as in the poſture *de*, or into blue and violet, as in the poſture *δε*. And if the Light before it fall upon the Paper be twice refracted the ſame way by two parallel Priſms, theſe Colours will become the more conſpicuous. Here all the middle parts of the broad beam of white Light which fell upon the Paper, did without any Confine of Shadow to modify it, become colour'd all over with one uniform Colour, the Colour being always the ſame in the middle of the

the Paper as at the edges, and this Colour changed according to the various Obliquity of the reflecting Paper, without any change in the Refractions or Shadow, or in the Light which fell upon the Paper. And therefore these Colours are to be derived from some other Cause than the new Modifications of Light by Refractions and Shadows.

If it be asked, What then is their Cause? I answer, That the Paper in the posture *de*, being more oblique to the more refrangible Rays than to the less refrangible ones, is more strongly illuminated by the latter than by the former, and therefore the less refrangible Rays are predominant in the reflected Light. And wherever they are predominant in any Light they tinge it with red or yellow, as may in some measure appear by the first Proposition of the first Book, and will more fully appear hereafter. And the contrary happens in the posture of the Paper *δε*, the more refrangible Rays being then predominant which always tinge Light with blues and violets.

*Exper.* 4. The Colours of Bubbles with which Children play are various, and change their Situation variously, without any respect to any Confine of Shadow. If such a Bubble be cover'd with a concave Glass, to keep it from being agitated by any Wind or Motion of the Air, the Colours will slowly and regularly change their Situation, even whilst the Eye, and the Bubble, and all Bodies which emit any Light, or cast any Shadow, remain unmoved. And therefore their Colours arise from some regular

Cauſe which depends not on any Confine of Shadow. What this Cauſe is will be ſhewed in the next Book.

To theſe Experiments may be added the tenth Experiment of the firſt Book, where the Sun's Light in a dark Room being trajected through the parallel Superficies of two Priſms tied together in the form of a Parallelopipede, became totally of one uniform yellow or red Colour, at its emerging out of the Priſms. Here, in the production of theſe Colours, the Confine of Shadow can have nothing to do. For the Light changes from white to yellow, orange and red ſucceſſively, without any alteration of the Confine of Shadow: And at both edges of the emerging Light where the contrary Confines of Shadow ought to produce different Effects, the Colour is one and the ſame, whether it be white, yellow, orange or red: And in the middle of the emerging Light, where there is no Confine of Shadow at all, the Colour is the very ſame as at the edges, the whole Light at its very firſt Emergence being of one uniform Colour, whether white, yellow, orange or red, and going on thence perpetually without any change of Colour, ſuch as the Confine of Shadow is vulgarly ſuppoſed to work in refracted Light after its Emergence. Neither can theſe Colours ariſe from any new Modifications of the Light by Refractions, becauſe they change ſucceſſively from white to yellow, orange and red, while the Refractions remain the ſame, and alſo becauſe the Refractions are made contrary ways by parallel Superficies which

deſtroy

destroy one anothers Effects. They arise not therefore from any Modifications of Light made by Refractions and Shadows, but have some other cause. What that Cause is we shewed above in this tenth Experiment, and need not here repeat it.

There is yet another material circumstance of this Experiment. For this emerging Light being by a third Prism HIK [in *Fig.* 22. *Part* 1.] refracted towards the Paper PT, and there painting the usual Colours of the Prism, red, yellow, green, blue, violet: If these Colours arose from the Refractions of that Prism modifying the Light, they would not be in the Light before its Incidence on that Prism. And yet in that Experiment we found that when by turning the two first Prisms about their common Axis all the Colours were made to vanish but the red; the Light which makes that red being left alone, appeared of the very same red Colour before its Incidence on the third Prism. And in general we find by other Experiments that when the Rays which differ in Refrangibility are separated from one another, and any one sort of them is considered apart, the Colour of the Light which they compose cannot be changed by any Refraction or Reflexion whatever, as it ought to be were Colours nothing else than Modifications of Light caused by Refractions, and Reflexions, and Shadows. This unchangeableness of Colour I am now to describe in the following Proposition.

*PROP.*

## PROP. II. THEOR. II.

*All homogeneal Light has its proper Colour answering to its Degree of Refrangibility, and that Colour cannot be changed by Reflexions and Refractions.*

IN the Experiments of the fourth Proposition of the first Book, when I had separated the heterogeneous Rays from one another, the Spectrum *pt* formed by the separated Rays, did in the progress from its end *p*, on which the most refrangible Rays fell, unto its other end *t*, on which the least refrangible Rays fell, appear tinged with this series of Colours, violet, indigo, blue, green, yellow, orange, red, together with all their intermediate degrees in a continual Succession perpetually varying. So that there appeared as many degrees of Colours, as there were sorts of Rays differing in Refrangibility.

*Exper.* 5. Now that these Colours could not be changed by Refraction, I knew by refracting with a Prism sometimes one very little part of this Light, sometimes another very little part, as is described in the twelfth Experiment of the first Book. For by this Refraction the Colour of the Light was never changed in the least. If any part of the red Light was refracted, it remained totally of the same red Colour as before. No orange, no yellow, no green or blue, no other new Colour was produced by that Refraction. Neither did the Colour any ways change by repeated Refractions, but continued always

always the ſame red entirely as at firſt. The like conſtancy and immutability I found alſo in the blue, green, and other Colours. So alſo if I looked through a Priſm upon any Body illuminated with any part of this homogeneal Light, as in the fourteenth Experiment of the firſt Book is deſcribed; I could not perceive any new Colour generated this way. All Bodies illuminated with compound Light appear through Priſms confuſed (as was ſaid above) and tinged with various new Colours, but thoſe illuminated with homogeneal Light appeared through Priſms neither leſs diſtinct, nor otherwiſe colour'd, than when viewed with the naked Eyes. Their Colours were not in the leaſt changed by the Refraction of the interpoſed Priſm. I ſpeak here of a ſenſible change of Colour: For the Light which I here call homogeneal, being not abſolutely homogeneal, there ought to ariſe ſome little change of Colour from its heterogeneity. But if that heterogeneity was ſo little as it might be made by the ſaid Experiments of the fourth Propoſition, that change was not ſenſible, and therefore in Experiments, where Senſe is Judge, ought to be accounted none at all.

*Exper.* 6. And as theſe Colours were not changeable by Refractions, ſo neither were they by Reflexions. For all white, grey, red, yellow, green, blue, violet Bodies, as Paper, Aſhes, red Lead, Orpiment, Indico, Biſe, Gold, Silver, Copper, Graſs, blue Flowers, Violets, Bubbles of Water tinged with various Colours, Peacock's Feathers, the Tincture of *Lignum*

*Nephri-*

*Nephriticum*, and ſuch like, in red homogeneal Light appeared totally red, in blue Light totally blue, in green Light totally green, and ſo of other Colours. In the homogeneal Light of any Colour they all appeared totally of that ſame Colour, with this only difference, that ſome of them reflected that Light more ſtrongly, others more faintly. I never yet found any Body which by reflecting homogeneal Light could ſenſibly change its Colour.

From all which it is manifeſt, that if the Sun's Light conſiſted of but one ſort of Rays, there would be but one Colour in the whole World, nor would it be poſſible to produce any new Colour by Reflexions and Refractions, and by conſequence that the variety of Colours depends upon the compoſition of Light.

## *DEFINITION.*

THE homogeneal Light and Rays which appear red, or rather make Objects appear ſo, I call Rubrific or Red-making; thoſe which make Objects appear yellow, green, blue and violet, I call Yellow-making, Green-making, Blue-making, Violet-making, and ſo of the reſt. And if at any time I ſpeak of Light and Rays as coloured or endued with Colours, I would be underſtood to ſpeak not philoſophically and properly, but groſſly, and accordingly to ſuch Conceptions as vulgar People in ſeeing all theſe Experiments would be apt to frame. For the Rays to ſpeak properly are not coloured. In them there is nothing elſe than a certain power and diſpoſition to ſtir up a Senſation of this or that Colour. For as Sound in a Bell or muſical String, or other ſounding Body, is nothing but a trembling Motion, and in the Air nothing but that Motion propagated from the Object, and in the Senſorium 'tis a Senſe of that Motion under the form of Sound; ſo Colours in the Object are nothing but a Diſpoſition to reflect this or that ſort of Rays more copiouſly than the reſt; in the Rays they are nothing but their Diſpoſitions to propagate this or that Motion into the Senſorium, and in the Senſorium they are Senſations of thoſe Motions under the forms of Colours.

## *PROP.* III. PROB. I.

*To define the Refrangibility of the ſeveral ſorts of homogeneal Light anſwering to the ſeveral Colours.*

FOR determining this Problem I made the following Experiment.

*Exper.* 7. When I had cauſed the rectilinear ſides AF, GM, [in *Fig.* 4.] of the Spectrum of Colours made by the Priſm to be diſtinctly defined, as in the fifth Experiment of the firſt Part is deſcribed, there were found in it all the homogeneal Colours in the ſame order and ſituation one among another as in the Spectrum of ſimple Light, deſcribed in the fourth Propoſition of that Part. For the Circles of which the Spectrum of compound Light

PT

PT is composed, and which in the middle parts of the Spectrum interfere and are intermix'd with one another, are not intermix'd in their outmost parts where they touch those rectilinear sides AF and GM. And therefore in those rectilinear sides when distinctly defined, there is no new Colour generated by Refraction. I observed also, that if any where between the two outmost Circles TMF and PGA a right Line, as $\gamma\delta$, was cross to the Spectrum, so as at both ends to fall perpendicularly upon its rectilinear sides, there appeared one and the same Colour and degree of Colour from one end of this Line to the other. I delineated therefore in a Paper the perimeter of the Spectrum FAPGMT, and in trying the third Experiment of the first Book, I held the Paper so that the Spectrum might fall upon this delineated Figure, and agree with it exactly, whilst an Assistant whose Eyes for distinguishing Colours were more critical than mine, did by right Lines $\alpha\beta$, $\gamma\delta$, $\varepsilon\zeta$, &c. drawn cross the Spectrum, note the Confines of the Colours, that is of the red M$\alpha\beta$F, of the orange $\alpha\gamma\delta\beta$, of the yellow $\gamma\varepsilon\zeta\delta$, of the green $\varepsilon\eta\theta\zeta$, of the blue $\eta\iota\kappa\theta$, of the indico $\iota\lambda\mu\kappa$, and of the violet $\lambda$GA$\mu$. And this Operation being divers times repeated both in the same and in several Papers, I found that the Observations agreed well enough with one another, and that the rectilinear sides MG and FA were by the said cross Lines divided after the manner of a musical Chord. Let GM be produced to X, that MX may be equal to GM, and conceive

GX,

GX, λX, ιX, ηX, εX, γX, αX, MX, to be in proportion to one another, as the numbers, 1, $\frac{8}{9}$, $\frac{5}{6}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{9}{16}$, $\frac{1}{2}$, and ſo to repreſent the Chords of the Key, and of a Tone, a third Minor, a fourth, a fifth, a ſixth Major, a ſeventh and an eighth above that Key: And the Intervals Mα, αγ, γε, εη, ηι, ιλ, and λG, will be the Spaces which the ſeveral Colours (red, orange, yellow, green, blue, indigo, violet) take up.

Now theſe Intervals or Spaces ſubtending the differences of the Refractions of the Rays going to the limits of thoſe Colours, thas is, to the Points M, α, γ, ε, η, ι, λ, G, may without any ſenſible Error be accounted proportional to the differences of the Sines of Refraction of thoſe Rays having one common Sine of Incidence, and therefore ſince the common Sine of Incidence of the moſt and leaſt refrangible Rays out of Glaſs into Air was (by a method deſcribed above) found in proportion to their Sines of Refraction, as 50 to 77 and 78, divide the difference between the Sines of Refraction 77 and 78, as the Line GM is divided by thoſe Intervals, you will have 77, $77\frac{1}{8}$, $77\frac{1}{5}$, $77\frac{1}{3}$, $77\frac{1}{2}$, $77\frac{2}{3}$, $77\frac{7}{9}$, 78, the Sines of Refraction of thoſe Rays out of Glaſs into Air, their common Sine of Incidence being 50. So then the Sines of the Incidences of all the red-making Rays out of Glaſs into Air, were to the Sines of their Refractions, not greater than 50 to 77, nor leſs than 50 to $77\frac{1}{8}$, but they varied from one another according to all intermediate proportions. And the Sines of the Incidences of the green-making Rays were to the Sines of their Refractions in all proportions from that of 50 to $77\frac{1}{3}$, unto that of 50 to $77\frac{1}{2}$. And by the like limits abovementioned were the Refractions of the Rays belonging to the reſt of the Colours defined, the Sines of the red-making Rays extending from 77 to $77\frac{1}{8}$, thoſe of the orange-making from $77\frac{1}{8}$ to $77\frac{1}{5}$, thoſe of the yellow-making from $77\frac{1}{5}$ to $77\frac{1}{3}$, thoſe of the green-making from $77\frac{1}{3}$ to $77\frac{1}{2}$, thoſe of the blue-making from $77\frac{1}{2}$ to $77\frac{2}{3}$, thoſe of the indigo-making from $77\frac{2}{3}$ to $77\frac{7}{9}$, and thoſe of the violet from $77\frac{7}{9}$ to 78.

Theſe are the Laws of the Refractions made out of Glaſs into Air, and thence by the third Axiom of the firſt part of this Book, the Laws of the Refractions made out of Air into Glaſs are eaſily derived.

*Exper.* 8. I found moreover that when Light goes out of Air through ſeveral contiguous refracting Mediums as through Water and Glaſs, and thence goes out again into Air, whether the refracting Superficies be parallel or inclin'd to one another, that Light as often as by contrary Refractions 'tis ſo corrected, that emergeth in Lines parallel to thoſe in which it was incident, continues ever after to be white. But if the emergent Rays be inclined to the incident, the whiteneſs of the emerging Light will by degrees in paſſing on from the place of Emergence, become tinged in its edges with Colours. This I tryed by refracting Light with Priſms of Glaſs placed within a priſmatick Veſſel of Water. Now thoſe Colours argue a diverging

verging and ſeparation of the heterogeneous Rays from one another by means of their unequal Refractions, as in what follows will more fully appear. And, on the contrary, the permanent whiteneſs argues, that in like Incidences of the Rays there is no ſuch ſeparation of the emerging Rays, and by conſequence no inequality of their whole Refractions. Whence I ſeem to gather the two following Theorems.

1. The Exceſſes of the Sines of Refraction of ſeveral ſorts of Rays above their common Sine of Incidence when the Refractions are made out of divers denſer Mediums immediately into one and the ſame rarer Medium, ſuppoſe of Air, are to one another in a given Proportion.

2. The Proportion of the Sine of Incidence to the Sine of Refraction of one and the ſame ſort of Rays out of one Medium into another, is compoſed of the Proportion of the Sine of Incidence to the Sine of Refraction out of the firſt Medium into any third Medium, and of the Proportion of the Sine of Incidence to the Sine of Refraction out of that third Medium into the ſecond Medium.

By the firſt Theorem the Refractions of the Rays of every ſort made out of any Medium into Air are known by having the Refraction of the Rays of any one ſort. As for inſtance, if the Refractions of the Rays of every ſort out of Rain-water into Air be deſired, let the common Sine of Incidence out of Glaſs into Air be ſubducted from the Sines of Refraction, and the Exceſſes will be $27$, $27\frac{1}{8}$, $27\frac{1}{5}$, $27\frac{1}{3}$, $27\frac{1}{2}$, $27\frac{2}{3}$, $27\frac{7}{9}$, $28$. Suppoſe now that the Sine of Incidence of the leaſt refrangible Rays be to their Sine of Refraction out of Rain-water into Air as 3 to 4, and ſay as 1 the difference of thoſe Sines is to 3 the Sine of Incidence, ſo is 27 the leaſt of the Exceſſes above-mentioned to a fourth number 81; and 81 will be the common Sine of Incidence out of Rain-water into Air, to which Sine if you add all the abovementioned Exceſſes you will have the deſired Sines of the Refractions $108$, $108\frac{1}{8}$, $108\frac{1}{5}$, $108\frac{1}{3}$, $108\frac{1}{2}$, $108\frac{2}{3}$, $108\frac{7}{9}$, $109$.

By the latter Theorem the Refraction out of one Medium into another is gathered as often as you have the Refractions out of them both into any third Medium. As if the Sine of Incidence of any Ray out of Glaſs into Air be to its Sine of Refraction, as 20 to 31, and the Sine of Incidence of the ſame Ray out of Air into Water, be to its Sine of Refraction as 4 to 3; the Sine of Incidence of that Ray out of Glaſs into Water will be to its Sine of Refraction as 20 to 31 and 4 to 3 jointly, that is, as the Factum of 20 and 4 to the Factum of 31 and 3, or as 80 to 93.

And theſe Theorems being admitted into Opticks, there would be ſcope enough of handling that Science voluminouſly after a new manner; not only by teaching thoſe things which tend to the perfection of Viſion, but alſo by determining mathematically all kinds of Phænomena of Colours which could be produced by Refractions. For to do this, there is nothing elſe requiſite than to find out the Separations of heterogeneous Rays, and their various Mixtures and Proportions in every Mixture. By this way of arguing I invented almoſt all the Phænomena deſcribed in theſe Books, beſide ſome others leſs neceſſary to the Argument; and by the ſucceſſes I met with in the Trials, I dare promiſe, that to him who ſhall argue truly, and then try all things with good Glaſſes and ſufficient Circumſpection, the expected Event will not be wanting. But he is firſt to know what Colours will ariſe from any others mix'd in any aſſigned Proportion.

## *PROP.* IV. Theor. III.

*Colours may be produced by Compoſition which ſhall be like to the Colours of homogeneal Light as to the Appearance of Colour, but not as to the Immutability of Colour and Conſtitution of Light. And thoſe Colours by how much they are more compounded by ſo much are they leſs full and intenſe, and by too much Compoſition they may be diluted and weaken'd till they ceaſe, and the Mixture becomes white or grey. There may be alſo Colours produced by Compoſition, which are not fully like any of the Colours of homogeneal Light.*

FOR a Mixture of homogeneal red and yellow compounds an orange, like in appearance of Colour to that orange which in the ſeries of unmixed priſmatick Colours lies between them; but the Light of one orange is homogeneal as to Refrangibility, that of the other is heterogeneal, and the Colour of the one, if viewed through a Priſm, remains unchanged, that of the other is changed and reſolved into its component Colours red and yellow. And after the ſame manner other neighbouring homogeneal Colours may compound new Colours, like the intermediate homogeneal ones, as yellow and green, the Colour between them both, and afterwards, if blue be added, there will be made a green the midde Colour of the three which enter the Compoſition. For the yellow and blue on either hand, if they are equal in quantity they draw the intermediate green equally towards themſelves in Compoſition, and ſo keep it as it were in *Æquilibrio*, that it verge not more to the yellow on the one hand, than to the blue on the other, but by their mix'd Actions remain ſtill a middſe Colour. To this mix'd green there may be farther added ſome red and violet, and yet the green will not preſently ceaſe but only grow leſs full and vivid, and by increaſing the red and violet it will grow more and more dilute, until by the prevalence of the added Colours it be overcome and turned into whiteneſs, or ſome other Colour. So if to the Colour of any homogeneal Light, the Sun's white Light compoſed of all ſorts of Rays be added, that Colour will not vaniſh or change its Species but be diluted, and by adding more and more white it will be diluted more and more perpetually. Laſtly, if

red

red and violet be mingled, there will be generated according to their various Proportions various Purples, ſuch as are not like in appearance to the Colour of any homogeneal Light, and of theſe Purples mix'd with yellow and blue may be made other new Colours.

## *PROP.* V. THEOR. IV.

*Whiteneſs and all grey Colours between white and black, may be compounded of Colours, and the whiteneſs of the Sun's Light is compounded of all the primary Colours mix'd in a due Proportion.*

### The Proof by Experiments.

*Exper.* 9. THE Sun ſhining into a dark Chamber through a little round hole in the Window-ſhut, and his Light being there refracted by a Priſm to caſt his coloured Image PT [in *Fig.* 5.] upon the oppoſite Wall: I held a white Paper V to that Image in ſuch manner that it might be illuminated by the colour'd Light reflected from thence, and yet not intercept any part of that Light in its paſſage from the Priſm to the Spectrum. And I found that when the Paper was held nearer to any Colour than to the reſt, it appeared of that Colour to which it approached neareſt; but when it was equally or almoſt equally diſtant from all the Colours, ſo that it might be equally illuminated by them all it appeared white. And in this laſt ſituation of the Paper, if ſome Colours were intercepted, the Paper lost its white Colour, and appeared of the Colour of the rest of the Light which was not intercepted. So then the Paper was illuminated with Lights of various Colours, namely, red, yellow, green, blue and violet, and every part of the Light retained its proper Colour, until it was incident on the Paper, and became reflected thence to the Eye; so that if it had been either alone (the rest of the Light being intercepted) or if it had abounded most and been predominant in the Light reflected from the Paper, it would have tinged the Paper with its own Colour; and yet being mixed with the rest of the Colours in a due proportion, it made the Paper look white, and therefore by a Composition with the rest produced that Colour. The several parts of the coloured Light reflected from the Spectrum, whilst they are propagated from thence through the Air, do perpetually retain their proper Colours, because wherever they fall upon the Eyes of any Spectator, they make the several parts of the Spectrum to appear under their proper Colours. They retain therefore their proper Colours when they fall upon the Paper V, and so by the confusion and perfect mixture of those Colours compound the whiteness of the Light reflected from thence.

*Exper.* 10. Let that Spectrum or solar Image PT [in *Fig.* 6.] fall now upon the Lens MN above four Inches broad, and about six Feet distant from the Prism ABC, and so figured that it may cause the coloured Light which divergeth from the Prism to converge and meet again

at

at its Focus G, about ſix or eight Feet diſtant from the Lens, and there to fall perpendicularly upon a white Paper DE. And if you move this Paper to and fro, you will perceive that near the Lens, as at *de*, the whole ſolar Image (ſuppoſe at *pt*) will appear upon it intenſely coloured after the manner above-explained, and that by receding from the Lens thoſe Colours will perpetually come towards one another, and by mixing more and more dilute one another continually, until at length the Paper come to the Focus G, where by a perfect mixture they will wholly vaniſh and be converted into whiteneſs, the whole Light appearing now upon the Paper like a little white Circle. And afterwards by receding farther from the Lens, the Rays which before converged will now croſs one another in the Focus G, and diverge from thence, and thereby make the Colours to appear again, but yet in a contrary order; ſuppoſe at $\delta\varepsilon$, where the red *t* is now above which before was below, and the violet *p* is below which before was above.

Let us now ſtop the Paper at the Focus G where the Light appears totally white and circular, and let us conſider its whiteneſs. I ſay, that this is compoſed of the converging Colours. For if any of thoſe Colours be intercepted at the Lens, the whiteneſs will ceaſe and degenerate into that Colour which ariſeth from the compoſition of the other Colours which are not intercepted. And then if the intercepted Colours be let paſs and fall upon that compound Colour, they mix with it, and by their mixture reſtore the whiteneſs. So if the violet, blue and green be intercepted, the remaining yellow, orange and red will compound upon the Paper an orange, and then if the intercepted Colours be let paſs they will fall upon this compounded orange, and together with it decompound a white. So alſo if the red and violet be intercepted, the remaining yellow, green and blue, will compound a green upon the Paper, and then the red and violet being let paſs will fall upon this green, and together with it decompound a white. And that in this Compoſition of white the ſeveral Rays do not ſuffer any Change in their colorific qualities by acting upon one another, but are only mixed, and by a mixture of their Colours produce white, may farther appear by theſe Arguments.

If the Paper be placed beyond the Focus G, ſuppoſe at $\delta\,\varepsilon$, and then the red Colour at the Lens be alternately intercepted, and let paſs again, the violet Colour on the Paper will not ſuffer any Change thereby, as it ought to do if the ſeveral ſorts of Rays acted upon one another in the Focus G, where they croſs. Neither will the red upon the Paper be changed by any alternate ſtopping, and letting paſs the violet which croſſeth it.

And if the Paper be placed at the Focus G, and the white round Image at G be viewed through the Priſm HIK, and by the Refraction of that Priſm be tranſlated to the place *r v*, and there appear tinged with various Colours, namely, the violet at *v* and red at *r*, and others between, and then the red Colour at the Lens be be often ſtopp'd and let paſs by turns, the red at *r* will accordingly diſappear and return as often, but the violet at *v* will not thereby ſuffer any change. And ſo by ſtopping and letting paſs alternately the blue at the Lens, the blue at *r* will accordingly diſappear and return, without any change made in the red at *r*. The red therefore depends on one ſort of Rays, and the blue on another ſort, which in the Focus G where they are commix'd do not act on one another. And there is the ſame reaſon of the other Colours.

I conſidered farther, that when the moſt refrangible Rays P *p*, and the leaſt refrangible ones T *t*, are by converging inclined to one another, the Paper, if held very oblique to thoſe Rays in the Focus G, might reflect one ſort of them more copiouſly than the other ſort, and by that means the reflected Light would be tinged in that Focus with the Colour of the predominant Rays, provided thoſe Rays ſeverally retained their Colours or colorific Qualities in the Compoſition of white made by them in that Focus. But if they did not retain them in that white, but became all of them ſeverally endued there with a diſpoſition to ſtrike the Senſe with the perception of white, then they could never loſe their whiteneſs by ſuch Reflexions. I inclined therefore the Paper to the Rays very obliquely, as in the ſecond Experiment of this Book, that the moſt refrangible Rays might be more copiouſly reflected than the reſt, and the whiteneſs at length changed ſucceſſively into blue, indigo and violet. Then I inclined it the

the contrary way, that the leaſt refrangible Rays might be more copious in the reflected Light than the reſt, and the whiteneſs turned ſucceſſively to yellow, orange and red.

Laſtly, I made an Inſtrument XY in faſhion of a Comb, whoſe Teeth being in number ſixteen were about an Inch and an half broad, and the Intervals of the Teeth about two Inches wide. Then by interpoſing ſucceſſively the Teeth of this Inſtrument near the Lens, I intercepted part of the Colours by the interpoſed Tooth, whilſt the reſt of them went on through the interval of the Teeth to the Paper DE, and there painted a round ſolar Image. But the Paper I had firſt placed ſo, that the Image might appear white as often as the Comb was taken away; and then the Comb being as was ſaid interpoſed, that whiteneſs by reaſon of the intercepted part of the Colours at the Lens did always change into the Colour compounded of thoſe Colours which were not intercepted, and that Colour was by the motion of the Comb perpetually varied ſo, that in the paſſing of every Tooth over the Lens all theſe Colours, red, yellow, green, blue and purple, did always ſucceed one another. I cauſed therefore all the Teeth to paſs ſucceſſively over the Lens, and when the Motion was ſlow, there appeared a perpetual ſucceſſion of the Colours upon the Paper: But if I ſo much accelerated the Motion, that the Colours by reaſon of their quick ſucceſſion could not be diſtinguiſhed from one another, the appearance of the ſingle Colours ceaſed. There was no red, no yellow, no

green,

green, no blue, nor purple to be ſeen any longer, but from a confuſion of them all there aroſe one uniform white Colour. Of the Light which now by the mixture of all the Colours appeared white, there was no part really white. One part was red, another yellow, a third green, a fourth blue, a fifth purple, and every part retains its proper Colour till it ſtrike the Senſorium. If the Impreſſions follow one another ſlowly, ſo that they may be ſeverally perceived, there is made a diſtinct Senſation of all the Colours one after another in a continual ſucceſſion. But if the Impreſſions follow one another ſo quickly that they cannot be ſeverally perceived, there ariſeth out of them all one common Senſation, which is neither of this Colour alone nor of that alone, but hath it ſelf indifferently to 'em all, and this is a Senſation of whiteneſs. By the quickneſs of the Succeſſions the Impreſſions of the ſeveral Colours are confounded in the Senſorium, and out of that confuſion ariſeth a mix'd Senſation. If a burning Coal be nimbly moved round in a Circle with Gyrations continually repeated, the whole Circle will appear like Fire; the reaſon of which is, that the Senſation of the Coal in the ſeveral places of that Circle remains impreſs'd on the Senſorium, until the Coal return again to the ſame place. And ſo in a quick conſecution of the Colours the Impreſſion of every Colour remains in the Senſorium, until a revolution of all the Colours be compleated, and that firſt Colour return again. The Impreſſions therefore of all the ſucceſſive Colours are at once in the

the Senſorium, and jointly ſtir up a Senſation of them all; and ſo it is manifeſt by this Experiment, that the commix'd Impreſſions of all the Colours do ſtir up and beget a Senſation of white, that is, that whiteneſs is compounded of all the Colours.

And if the Comb be now taken away, that all the Colours may at once paſs from the Lens to the Paper, and be there intermixed, and together reflected thence to the Spectators Eyes; their Impreſſions on the Senſorium being now more ſubtilly and perfectly commixed there, ought much more to ſtir up a Senſation of whiteneſs.

You may inſtead of the Lens uſe two Priſms HIK and LMN, which by refracting the coloured Light the contrary way to that of the firſt Refraction, may make the diverging Rays converge and meet again in G, as you ſee repreſented in the ſeventh Figure. For where they meet and mix they will compoſe a white Light, as when a Lens is uſed.

*Exper.* 11. Let the Sun's coloured Image PT [in *Fig.* 8.] fall upon the Wall of a dark Chamber, as in the third Experiment of the firſt Book, and let the ſame be viewed through a Priſm *abc*, held parallel to the Priſm ABC, by whoſe Refraction that Image was made, and let it now appear lower than before, ſuppoſe in the place S over againſt the red Colour T. And if you go near to the Image PT, the Spectrum S will appear oblong and coloured like the Image PT; but if you recede from it, the Colours of the Spectrum S will be contracted more and more, and at length vaniſh, that Spectrum S becoming perfectly round and white; and if you recede yet farther, the Colours will emerge again, but in a contrary order. Now that Spectrum S appears white in that caſe when the Rays of ſeveral ſorts which converge from the ſeveral parts of the Image P T, to the Priſm *abc*, are ſo refracted unequally by it, that in their paſſage from the Priſm to the Eye they may diverge from one and the ſame point of the Spectrum S, and ſo fall afterwards upon one and the ſame point in the bottom of the Eye, and there be mingled.

And farther, if the Comb be here made uſe of, by whoſe Teeth the Colours at the Image P T may be ſucceſſively intercepted; the Spectrum S when the Comb is moved ſlowly will be perpetually tinged with ſucceſſive Colours: But when by accelerating the motion of the Comb, the ſucceſſion of the Colours is ſo quick that they cannot be ſeverally ſeen, that Spectrum S, by a confuſed and mix'd Senſation of them all, will appear white.

*Exper.* 12. The Sun ſhining through a large Priſm A B C [in *Fig.* 9.] upon a Comb X Y, placed immediately behind the Priſm, his Light which paſſed through the Interſtices of the Teeth fell upon a white Paper D E. The breadths of the Teeth were equal to their Interſtices, and ſeven Teeth together with their Interſtices took up an Inch in breadth. Now when the Paper was about two or three Inches diſtant from the Comb, the Light which paſſed through its ſeveral Interſtices painted ſo many

many ranges of Colours, *k l*, *m n*, *o p*, *q r*, &c. which were parallel to one another and contiguous, and without any mixture of white. And these ranges of Colours, if the Comb was moved continually up and down with a reciprocal motion, ascended and descended in the Paper, and when the motion of the Comb was so quick, that the Colours could not be distinguished from one another, the whole Paper by their confusion and mixture in the Sensorium appeared white.

Let the Comb now rest, and let the Paper be removed farther from the Prism, and the several ranges of Colours will be dilated and expanded into one another more and more, and by mixing their Colours will dilute one another, and at length, when the distance of the Paper from the Comb is about a Foot, or a little more (suppose in the place 2 D 2 E) they will so far dilute one another as to become white.

With any obstacle let all the Light be now stopp'd which passes through any one interval of the Teeth, so that the range of Colours which comes from thence may be taken away, and you will see the Light of the rest of the ranges to be expanded into the place of the range taken away, and there to be coloured. Let the intercepted range pass on as before, and its Colours falling upon the Colours of the other ranges, and mixing with them, will restore the whiteness.

Let the Paper 2 D 2 E be now very much inclined to the Rays, so that the most refrangible Rays

Rays may be more copiously reflected than the rest, and the white Colour of the Paper through the Excess of those Rays will be changed into blue and violet. Let the Paper be as much inclined the contrary way, that the least refrangible Rays may be now more copiously reflected than the rest, and by their Excess the whiteness will be changed into yellow and red. The several Rays therefore in that white Light do retain their colorific qualities, by which those of any sort, when-ever they become more copious than the rest, do by their Excess and Predominance cause their proper Colour to appear.

And by the same way of arguing, applied to the third Experiment of this Book, it may be concluded, that the white Colour of all refracted Light at its very first Emergence, where it appears as white as before its Incidence, is compounded of various Colours.

*Exper.* 13. In the foregoing Experiment the several intervals of the Teeth of the Comb do the office of so many Prisms, every interval producing the Phænomenon of one Prism. Whence instead of those intervals using several Prisms, I try'd to compound whiteness by mixing their Colours, and did it by using only three Prisms, as also by using only two as follows. Let two Prisms A B C and *a b c*, [in *Fig.* 10.] whose refracting Angles B and *b* are equal, be so placed parallel to one another, that the refracting Angle B of the one may touch the Angle *c* at the Base of the other, and their Planes C B and *c b*, at which the Rays emerge, may lie in Directum.

rectum. Then let the Light trajected through them fall upon the Paper MN, distant about 8 or 12 Inches from the Prisms. And the Colours generated by the interior limits B and *c* of the two Prisms, will be mingled at PT, and there compound white. For if either Prism be taken away, the Colours made by the other will appear in that place PT, and when the Prism is restored to its place again, so that its Colours may there fall upon the Colours of the other, the mixture of them both will restore the whiteness.

This Experiment succeeds also, as I have tried, when the Angle *b* of the lower Prism, is a little greater than the Angle B of the upper, and between the interior Angles B and *c*, there intercedes some space B*c*, as is represented in the Figure, and the refracting Planes BC and *bc*, are neither in directum, nor parallel to one another. For there is nothing more requisite to the success of this Experiment, than that the Rays of all sorts may be uniformly mixed upon the Paper in the place PT. If the most refrangible Rays coming from the superior Prism take up all the space from M to P, the Rays of the same sort which come from the inferior Prism ought to begin at P, and take up all the rest of the space from thence towards N. If the least refrangible Rays coming from the superior Prism take up the space MT, the Rays of the same kind which come from the other Prism ought to begin at T, and take up the remaining space TN. If one sort of the Rays which have intermediate degrees of Refrangibility,

frangibility, and come from the superior Prism be extended through the space MQ, and another sort of those Rays through the space MR, and a third sort of them through the space MS, the same sorts of Rays coming from the lower Prism, ought to illuminate the remaining spaces QN, RN, SN, respectively. And the same is to be understood of all the other sorts of Rays. For thus the Rays of every sort will be scattered uniformly and eavenly thro' the whole space MN, and so being every where mix'd in the same proportion, they must every where produce the same Colour. And therefore since by this mixture they produce white in the exterior spaces MP and TN, they must also produce white in the interior space PT. This is the reason of the composition by which whiteness was produced in this Experiment, and by what other way soever I made the like composition the result was whiteness.

Lastly, If with the Teeth of a Comb of a due size, the coloured Lights of the two Prisms which fall upon the space PT be alternately intercepted, that space PT, when the motion of the Comb is slow, will always appear coloured, but by accelerating the motion of the Comb so much, that the successive Colours cannot be distinguished from one another, it will appear white.

*Exper.* 14. Hitherto I have produced whiteness by mixing the Colours of Prisms. If now the Colours of natural Bodies are to be mingled, let Water a little thicken'd with Soap be agitated to raise a Froth, and after that Froth has ſtood a little, there will appear to one that ſhall view it intently various Colours every where in the Surfaces of the ſeveral Bubbles; but to one that ſhall go ſo far off that he cannot diſtinguiſh the Colours from one another, the whole Froth will grow white with a perfect whiteneſs.

*Exper.* 15. Laſtly, in attempting to compound a white by mixing the coloured Powders which Painters uſe, I conſider'd that all colour'd Powders do ſuppreſs and ſtop in them a very conſiderable part of the Light by which they are illuminated. For they become colour'd by reflecting the Light of their own Colours more copiouſly, and that of all other Colours more ſparingly, and yet they do not reflect the Light of their own Colours ſo copiouſly as white Bodies do. If red Lead, for inſtance, and a white Paper, be placed in the red Light of the colour'd Spectrum made in a dark Chamber by the Refraction of a Priſm, as is deſcribed in the third Experiment of the firſt Book; the Paper will appear more lucid than the red Lead, and therefore reflects the red-making Rays more copiouſly than red Lead doth. And if they be held in the Light of any other Colour, the Light reflected by the Paper will exceed the Light reflected by the red Lead in a much greater proportion. And the like happens in Powders of other Colours. And therefore by mixing ſuch Powders we are not to expect a ſtrong and full white, ſuch as is that of Paper, but ſome dusky obſcure one, ſuch as might ariſe from a mixture of light and darkneſs, or from white and black, that is, a grey, or dun, or ruſſet brown, ſuch as are the Colours of a Man's Nail, of a Mouſe, of Aſhes, of ordinary Stones, of Mortar, of Duſt and Dirt in High-ways, and the like. And ſuch a dark white I have often produced by mixing colour'd Powders. For thus one part of red Lead, and five parts of *Viride Æris*, compoſed a dun Colour like that of a Mouſe. For theſe two Colours were ſeverally ſo compounded of others, that in both together were a mixture of all Colours; and there was leſs red Lead uſed than *Viride Æris*, becauſe of the fulneſs of its Colour. Again, one part of red Lead, and four parts of blue Biſe, compoſed a dun Colour verging a little to purple, and by adding to this a certain mixture of Orpiment and *Viride Æris* in a due proportion, the mixture loſt its purple tincture, and became perfectly dun. But the Experiment ſucceeded beſt without Minium thus. To Orpiment I added by little and little a certain full bright purple, which Painters uſe until the Orpiment ceaſed to be yellow, and became of a pale red. Then I diluted that red by adding a little *Viride Æris*, and a little more blue Biſe than *Viride Æris*, until it became of ſuch a grey or pale white, as verged to no one of the Colours more than to another. For thus it became of a Colour equal in whiteneſs to that of Aſhes or of Wood newly cut, or of a Man's Skin. The Orpiment reflected more Light than did any other of the Powders, and therefore conduced more to the whiteneſs of the compounded Colour than they.

To aſſign the Proportions accurately may be difficult, by reaſon of the different goodneſs of Powders of the ſame kind. Accordingly as the Colour of any Powder is more or leſs full and luminous, it ought to be uſed in a leſs or greater proportion.

Now conſidering that theſe grey and dun Colours may be alſo produced by mixing whites and blacks, and by conſequence differ from perfect whites not in ſpecies of Colours but only in degree of Luminouſneſs, it is manifeſt that there is nothing more requiſite to make them perfectly white than to increaſe their Light ſufficiently; and, on the contrary, if by increaſing their Light they can be brought to perfect whiteneſs, it will thence alſo follow, that they are of the ſame ſpecies of Colour with the beſt whites, and differ from them only in the quantity of Light. And this I tried as follows. I took the third of the abovemention'd grey Mixtures (that which was compounded of Orpiment, Purple, Biſe, and *Viride Æris)* and rubbed it thickly upon the Floor of my Chamber, where the Sun ſhone upon it through the opened Caſement; and by it, in the ſhadow, I laid a piece of white Paper of the ſame bigneſs. Then going from them to the diſtance of 12 or 18 Feet, ſo that I could not diſcern the uneavenneſs of the Surface of the Powder, nor the little Shadows let fall from the gritty Particles thereof; the Powder appeared intenſely white, ſo as to tranſcend even the Paper it ſelf in whiteneſs, eſpecially if the Paper were a little ſhaded from the Light of the Clouds, and then the Paper compared

pared with the Powder appeared of ſuch a grey Colour as the Powder had done before. But by laying the Paper where the Sun ſhines thro' the Glaſs of the Window, or by ſhutting the Window that the Sun might ſhine through the Glaſs upon the Powder, and by ſuch other fit means of increaſing or decreaſing the Lights wherewith the Powder and Paper were illuminated, the Light wherewith the Powder is illuminated may be made ſtronger in ſuch a due proportion than the Light wherewith the Paper is illuminated, that they ſhall both appear exactly alike in whiteneſs. For when I was trying this, a Friend coming to viſit me, I ſtopp'd him at the Door, and before I told him what the Colours were, or what I was doing; I asked him, Which of the two Whites were the beſt, and wherein they differed? And after he had at that diſtance viewed them well, he anſwer'd, That they were both good Whites, and that he could not ſay which was beſt, nor wherein their Colours differed. Now if you conſider, that this white of the Powder in the Sun-ſhine was compounded of the Colours which the component Powders (Orpiment, Purple, Biſe, and *Viride Æris*) have in the ſame Sun-ſhine, you muſt acknowledge by this Experiment, as well as by the former, that perfect whiteneſs may be compounded of Colours.

From what has been ſaid it is alſo evident, that the whiteneſs of the Sun's Light is compounded of all the Colours wherewith the ſeveral ſorts of Rays whereof that Light conſiſts, when by their ſeveral Refrangibilities they are separated from one another, do tinge Paper or any other white Body whereon they fall. For those Colours by *Prop.* 2. are unchangeable, and whenever all those Rays with those their Colours are mix'd again, they reproduce the same white Light as before.

## *PROP.* VI. PROB. II.

*In a mixture of primary Colours, the quantity and quality of each being given, to know the Colour of the Compound.*

WITH the Center O [in *Fig.* 11.] and Radius OD describe a Circle ADF, and distinguish its circumference into seven parts DE, EF, FG, GA, AB, BC, CD, proportional to the seven musical Tones or Intervals of the eight Sounds, *Sol, la, fa, sol, la, mi, fa, sol,* contained in an eight, that is, proportional to the number $\frac{1}{9}$, $\frac{1}{16}$, $\frac{1}{10}$, $\frac{1}{9}$, $\frac{1}{16}$, $\frac{1}{16}$, $\frac{1}{9}$. Let the first part DE represent a red Colour, the second EF orange, the third FG yellow, the fourth CA green, the fifth AB blue, the sixth BC indigo, and the seventh CD violet. And conceive that these are all the Colours of uncompounded Light gradually passing into one another, as they do when made by Prisms; the circumference DEFGABCD, representing the whole series of Colours from one end of the Sun's colour'd Image to the other, so that from D to E be all degrees of red, at E the mean Colour between red and orange, from E

to F

to F all degrees of orange, at F the mean between orange and yellow, from F to G all degrees of yellow, and ſo on. Let *p* be the center of gravity of the Arch DE, and *q*, *r*, *s*, *t*, *u*, *x*, the centers of gravity of the Arches EF, FG, GA, AB, BC and CD reſpectively, and about thoſe centers of gravity let Circles proportional to the number of Rays of each Colour in the given Mixture be deſcrib'd; that is, the Circle *p* proportional to the number of the red-making Rays in the Mixture, the Circle *q* proportional to the number of the orange-making Rays in the Mixture, and ſo of the reſt. Find the common center of gravity of all thoſe Circles *p*, *q*, *r*, *s*, *t*, *u*, *x*. Let that center be Z; and from the center of the Circle ADF, through Z to the circumference, drawing the right Line OY, the place of the Point Y in the circumference ſhall ſhew the Colour ariſing from the compoſition of all the Colours in the given Mixture, and the Line OZ ſhall be proportional to the fulneſs or intenſeneſs of the Colour, that is, to its diſtance from whiteneſs. As if Y fall in the middle between F and G, the compounded Colour ſhall be the beſt yellow; if Y verge from the middle towards F or G, the compound Colour ſhall accordingly be a yellow, verging towards orange or green. If Z fall upon the circumference the Colour ſhall be intenſe and florid in the higheſt degree; if it fall in the mid way between the circumference and center, it ſhall be but half ſo intenſe, that is, it ſhall be ſuch a Colour as would be made by diluting the intenſeſt yellow

 with

with an equal quantity of whiteneſs; and if it fall upon the center O, the Colour ſhall have loſt all its intenſeneſs, and become a white. But it is to be noted, That if the point Z fall in or near the line OD, the main ingredients being the red and violet, the Colour compounded ſhall not be any of the priſmatick Colours, but a purple, inclining to red or violet, accordingly as the point Z lieth on the ſide of the line DO towards E or towards C, and in general the compounded violet is more bright and more fiery than the uncompounded. Alſo if only two of the primary Colours which in the circle are oppoſite to one another be mixed in an equal proportion, the point Z ſhall fall upon the center O, and yet the Colour compounded of thoſe two ſhall not be perfectly white, but ſome faint anonymous Colour. For I could never yet by mixing only two primary Colours produce a perfect white. Whether it may be compounded of a mixture of three taken at equal diſtances in the circumference I do not know, but of four or five I do not much queſtion but it may. But theſe are Curioſities of little or no moment to the underſtanding the Phænomena of Nature. For in all whites produced by Nature, there uſes to be a mixture of all ſorts of Rays, and by conſequence a compoſition of all Colours.

To give an inſtance of this Rule; ſuppoſe a Colour is compounded of theſe homogeneal Colours, of violet one part, of indigo one part, of blue two parts, of green three parts, of yellow five parts, of orange ſix parts, and of red

ten

ten parts. Proportional to these parts describe the Circles *x*, *v*, *t*, *s*, *r*, *q*, *p*, respectively, that is, so that if the Circle *x* be one, the Circle *v* may be one, the Circle *t* two, the Circle *s* three, and the Circles *r*, *q* and *p*, five, six and ten. Then I find Z the common center of gravity of these Circles, and through Z drawing the Line OY, the Point Y falls upon the circumference between E and F, some thing nearer to E than to F, and thence I conclude, that the Colour compounded of these Ingredients will be an orange, verging a little more to red than to yellow. Also I find that OZ is a little less than one half of OY, and thence I conclude, that this orange hath a little less than half the fulness or intenseness of an uncompounded orange; that is to say, that it is such an orange as may be made by mixing an homogeneal orange with a good white in the proportion of the Line OZ to the Line ZY, this Proportion being not of the quantities of mixed orange and white Powders, but of the quantities of the Lights reflected from them.

This Rule I conceive accurate enough for practice, though not mathematically accurate; and the truth of it may be sufficiently proved to Sense, by stopping any of the Colours at the Lens in the tenth Experiment of this Book. For the rest of the Colours which are not stopp'd, but pass on to the Focus of the Lens, will there compound either accurately or very nearly such a Colour as by this Rule ought to result from their Mixture.

*PROP.*

## *PROP.* VII. Theor. V.

*All the Colours in the Universe which are made by Light, and depend not on the Power of Imagination, are either the Colours of homogeneal Lights, or compounded of these, and that either accurately or very nearly, according to the Rule of the foregoing Problem.*

FOR it has been proved (in *Prop.* 1. *Part.* 2.) that the changes of Colours made by Refractions do not arise from any new Modifications of the Rays impress'd by those Refractions, and by the various Terminations of Light and Shadow, as has been the constant and general Opinion of Philosophers. It has also been proved that the several Colours of the homogeneal Rays do constantly answer to their degrees of Refrangibility, (*Prop.* 1. *Part* 1. and *Prop.* 2. *Part* 2.) and that their degrees of Refrangibility cannot be changed by Refractions and Reflexions, (*Prop.* 2. *Part.* 1.) and by consequence that those their Colours are likewise immutable. It has also been proved directly by refracting and reflecting homogeneal Lights apart, that their Colours cannot be changed, (*Prop.* 2. *Part.* 2.) It has been proved also, that when the several sorts of Rays are mixed, and in crossing pass through the same space, they do not act on one another so as to change each others colorific qualities. (*Exper.* 10. *Part.* 2.) but by mixing their Actions in the Sensorium beget a Sensation differing from what either would do apart, that is a Sensation of a mean Colour be-

tween

tween their proper Colours; and particularly when by the concourse and mixtures of all sorts of Rays, a white Colour is produced, the white is a mixture of all the Colours which the Rays would have apart, (*Prop.* 5. *Part* 2.) The Rays in that mixture do not lose or alter their several colorific qualities, but by all their various kinds of Actions mix'd in the Sensorium, beget a Sensation of a middling Colour between all their Colours, which is whiteness. For whiteness is a mean between all Colours, having it self indifferently to them all, so as with equal facility to be tinged with any of them. A red Powder mixed with a little blue, or a blue with a little red, doth not presently lose its Colour, but a white Powder mix'd with any Colour is presently tinged with that Colour, and is equally capable of being tinged with any Colour whatever. It has been shewed also, that as the Sun's Light is mix'd of all sorts of Rays, so its whiteness is a mixture of the Colours of all sorts of Rays; those Rays having from the beginning their several colorific qualities as well as their several Refrangibilities, and retaining them perpetually unchanged notwithstanding any Refractions or Reflexions they may at any time suffer, and that whenever any sort of the Sun's Rays is by any means (as by Reflexion in *Exper.* 9 and 10. *Part* 1. or by Refraction as happens in all Refractions) separated from the rest, they then manifest their proper Colours. These things have been prov'd, and the sum of all this amounts to the Proposition here to be proved. For if the Sun's Light

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is mix'd of ſeveral ſorts of Rays, each of which have originally their ſeveral Refrangibilities and colorific Qualities, and notwithſtanding their Refractions and Reflexions, and their various Separations or Mixtures, keep thoſe their original Properties perpetually the ſame without alteration; then all the Colours in the World muſt be ſuch as conſtantly ought to ariſe from the original colorific qualities of the Rays whereof the Lights conſiſt by which thoſe Colours are ſeen. And therefore if the reaſon of any Colour whatever be required, we have nothing elſe to do than to conſider how the Rays in the Sun's Light have by Reflexions or Refractions, or other cauſes been parted from one another, or mixed together; or otherwiſe to find out what ſorts of Rays are in the Light by which that Colour is made, and in what proportion; and then by the laſt Problem to learn the Colour which ought to ariſe by mixing thoſe Rays (or their Colours) in that proportion. I ſpeak here of Colours ſo far as they ariſe from Light. For they appear ſometimes by other Cauſes, as when by the power of Phantaſy we ſee Colours in a dream, or a mad Man ſees things before him which are not there; or when we ſee Fire by ſtriking the Eye, or ſee Colours like the Eye of a Peacock's Feather, by preſſing our Eyes in either corner whilſt we look the other way. Where theſe and ſuch like Cauſes interpoſe not, the Colour always anſwers to the ſort or ſorts of the Rays whereof the Light conſiſts, as I have conſtantly found in whatever Phænomena of Colours I have hitherto been able to examine.

mine. I ſhall in the following Propoſitions give inſtances of this in the Phænomena of chiefeſt note.

## *PROP.* VIII. PROB. III.

*By the diſcovered Properties of Light to explain the Colours made by Priſms.*

LET ABC [in *Fig.* 12.] repreſent a Priſm refracting the Light of the Sun, which comes into a dark Chamber through a hole F $\phi$ almoſt as broad as the Priſm, and let MN repreſent a white Paper on which the refracted Light is caſt, and ſuppoſe the moſt refrangible or deepeſt violet-making Rays fall upon the Space P $\pi$, the leaſt refrangible or deepeſt red-making Rays upon the Space T 7, the middle ſort between the indigo-making and blue-making Rays upon the Space Q $\chi$, the middle ſort of the green-making Rays upon the Space R $\varrho$, the middle ſort between the yellow-making and orange-making Rays upon the Space S $\sigma$, and other intermediate ſorts upon intermediate Spaces. For ſo the Spaces upon which the ſeveral ſorts adequately fall will by reaſon of the different Refrangibility of thoſe ſorts be one lower than another. Now if the Paper MN be ſo near the Priſm that the Spaces PT and $\pi$ 7 do not interfere with one another, the diſtance between them T $\pi$ will be illuminated by all the ſorts of Rays in that proportion to one another which they have at their very firſt coming out of of the Prism, and consequently be white. But the Spaces PT and $\pi\tau$ on either hand, will not be illuminated by them all, and therefore will appear coloured. And particularly at P, where the outmost violet-making Rays fall alone, the Colour must be the deepest violet. At Q where the violet-making and indigo-making Rays are mixed, it must be a violet inclining much to indigo. At R where the violet-making, indigo-making, blue-making, and one half of the green-making Rays are mixed, their Colours must (by the construction of the second Problem) compound a middle Colour between indigo and blue. At S where all the Rays are mixed except the red-making and orange-making, their Colours ought by the same Rule to compound a faint blue, verging more to green than indigo. And in the progress from S to T, this blue will grow more and more faint and dilute, till at T, where all the Colours begin to be mixed, it ends in whiteness.

So again, on the other side of the white at $\tau$, where the least refrangible or utmost red-making Rays are alone, the Colour must be the deepest red. At $\sigma$ the mixture of red and orange will compound a red inclining to orange. At $\varrho$ the mixture of red, orange, yellow, and one half of the green must compound a middle Colour between orange and yellow. At $\chi$ the mixture of all Colours but violet and indigo will compound a faint yellow, verging more to green than to orange. And this yellow will grow more faint and dilute continually in its progress from

from $\chi$ to $\pi$, where by a mixture of all ſorts of Rays it will become white.

Theſe Colours ought to appear were the Sun's Light perfectly white: But becauſe it inclines to yellow, the Exceſs of the yellow-making Rays whereby 'tis tinged with that Colour, being mixed with the faint blue between S and T, will draw it to a faint green. And ſo the Colours in order from P to $\tau$ ought to be violet, indigo, blue, very faint green, white, faint yellow, orange, red. Thus it is by the computation: And they that pleaſe to view the Colours made by a Priſm will find it ſo in Nature.

Theſe are the Colours on both ſides the white when the Paper is held between the Priſm, and the Point X where the Colours meet, and the interjacent white vaniſhes. For if the Paper be held ſtill farther off from the Priſm, the moſt refrangible and leaſt refrangible Rays will be wanting in the middle of the Light, and the reſt of the Rays which are found there, will by mixture produce a fuller green than before. Alſo the yellow and blue will now become leſs compounded, and by conſequence more intenſe than before. And this alſo agrees with experience.

And if one look through a Priſm upon a white Object encompaſſed with blackneſs or darkneſs, the reaſon of the Colours ariſing on the edges is much the ſame, as will appear to one that ſhall a little conſider it. If a black Object be encompaſſed with a white one, the Colours which appear through the Priſm are to be derived from the Light of the white one, ſpreading

ing into the Regions of the black, and therefore they appear in a contrary order to that, when a white Object is ſurrounded with black. And the ſame is to be underſtood when an Object is viewed, whoſe parts are ſome of them leſs luminous than others. For in the borders of the more and leſs luminous parts, Colours ought always by the ſame Principles to ariſe from the Exceſs of the Light of the more luminous, and to be of the ſame kind as if the darker parts were black, but yet to be more faint and dilute.

What is ſaid of Colours made by Priſms may be eaſily applied to Colours made by the Glaſſes of Teleſcopes or Microſcopes, or by the Humours of the Eye. For if the Object-glaſs of a Teleſcope be thicker on one ſide than on the other, or if one half of the Glaſs, or one half of the Pupil of the Eye be cover'd with any opake ſubſtance: the Object-glaſs, or that part of it or of the Eye which is not cover'd, may be conſider'd as a Wedge with crooked Sides, and every Wedge of Glaſs or other pellucid Subſtance has the effect of a Priſm in refracting the Light which paſſes through it.

How the Colours in the ninth and tenth Experiments of the firſt Part ariſe from the different Reflexibility of Light, is evident by what was there ſaid. But it is obſervable in the ninth Experiment, that whilſt the Sun's direct Light is yellow, the Exceſs of the blue-making Rays in the reflected beam of Light MN, ſuffices only to bring that yellow to a pale white inclining to blue, and not to tinge it with a manifeſtly

festly blue Colour. To obtain therefore a better blue, I used instead of the yellow Light of the Sun the white Light of the Clouds, by varying a little the Experiment, as follows.

*Exper.* 16. Let HFG [in *Fig.* 13.] represent a Prism in the open Air, and S the Eye of the Spectator, viewing the Clouds by their Light coming into the Prism at the plane side FIGK, and reflected in it by its base HEIG, and thence going out through its plane side HEFK to the Eye. And when the Prism and Eye are conveniently placed, so that the Angles of Incidence and Reflexion at the Base may be about 40 Degrees, the Spectator will see a Bow MN of a blue Colour, running from one end of the Base to the other, with the concave side towards him, and the part of the Base IMNG beyond this Bow will be brighter than the other part EMNH on the other side of it. This blue Colour MN being made by nothing else than by reflexion of a specular Superficies, seems so odd a Phænomenon, and so difficult to be explained by the vulgar Hypothesis of Philosophers, that I could not but think it deserved to be taken notice of. Now for understanding the reason of it, suppose the Plane ABC to cut the plane Sides and Base of the Prism perpendicularly. From the Eye to the Line BC, wherein that Plane cuts the Base, draw the Lines S*p* and S*t*, in the Angles S*pc* 50 degr. $\frac{1}{9}$, and S*tc* 49 degr. $\frac{1}{28}$, and the Point *p* will be the limit beyond which none of the most refrangible Rays can pass through the Base of the Prism, and be refracted, whose Incidence is such that they may be reflected to the Eye; and the Point *t* will be the like limit for the least refrangible Rays, that is, beyond which none of them can pass through the Base, whose Incidence is such that by Reflexion they may come to the Eye. And the Point *r* taken in the middle way between *p* and *t*, will be the like limit for the meanly refrangible Rays. And therefore all the least refrangible Rays which fall upon the Base beyond *t*, that is, between *t* and B, and can come from thence to the Eye will be reflected thither: But on this side *t*, that is, between *t* and *c*, many of these Rays will be transmitted through the Base. And all the most refrangible Rays which fall upon the Base beyond *p*, that is, between *p* and B, and can by reflexion come from thence to the Eye, will be reflected thither, but every where between *p* and *c*, many of these Rays will get through the Base and be refracted; and the same is to be understood of the meanly refrangible Rays on either side of the Point *r*. Whence it follows, that the Base of the Prism must every where between *t* and B, by a total reflexion of all sorts of Rays to the Eye, look white and bright. And every where between *p* and C, by reason of the transmission of many Rays of every sort, look more pale, obscure and dark. But at *r*, and in other places between *p* and *t*, where all the more refrangible Rays are reflected to the Eye, and many of the less refrangible are transmitted, the Excess of the most refrangible in the reflected Light will tinge that Light with their Colour, which is violet and blue. And

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this happens by taking the Line C *prt* B any where between the ends of the Priſm HG and EI.

## *PROP.* IX. PROB. IV.

*By the diſcovered Properties of Light to explain the Colours of the Rain-bow.*

THIS Bow never appears but where it rains in the Sun-ſhine, and may be made artificially by ſpouting up Water which may break aloft, and ſcatter into drops, and fall down like Rain. For the Sun ſhining upon theſe drops certainly cauſes the Bow to appear to a Spectator ſtanding in a due poſition to the Rain and Sun. And hence it is now agreed upon, that this Bow is made by refraction of the Sun's Light in drops of falling Rain. This was underſtood by ſome of the Ancients, and of late more fully diſcover'd and explain'd by the famous *Antonius de Dominis* Archbiſhop of *Spalato*, in his Book *De Radiis Visûs & Lucis*, publiſhed by his Friend *Bartolus* at *Venice*, in the Year 1611, and written above 20 Years before. For he teaches there how the interior Bow is made in round drops of Rain by two Refractions of the Sun's Light, and one Reflexion between them, and the exterior by two Refractions and two ſorts of Reflexions between them in each drop of Water, and proves his Explications by Experiments made with a Phial full of Water, and with Globes of Glaſs filled with Water, and placed in the Sun to make the Colours of the two Bows appear in them. The same Explication *Des-Cartes* hath pursued in his Meteors, and mended that of the exterior Bow. But whilst they understood not the true origin of Colour's, it's necessary to pursue it here a little farther. For understanding therefore how the Bow is made, let a drop of Rain or any other spherical transparent Body be represented by the Sphere BNFG, [in *Fig.* 14.] described with the center C, and semi-diameter CN. And let AN be one of the Sun's Rays incident upon it at N, and thence refracted to F, where let it either go out of the Sphere by Refraction towards V, or be reflected to G; and at G let it either go out by Refraction to R, or be reflected to H; and at H let it go out by Refraction towards S, cutting the incident Ray in Y; produce AN and RG, till they meet in X, and upon AX and NF let fall the perpendiculars CD and CE, and produce CD till it fall upon the circumference at L. Parallel to the incident Ray AN draw the diameter BQ, and let the Sine of Incidence out of Air into Water be to the Sine of Refraction as I to R. Now if you suppose the Point of Incidence N to move from the Point B, continually till it come to L, the Arch QF will first increase and then decrease, and so will the Angle AXR which the Rays AN and GR contain; and the Arch QF and Angle AXR will be biggest when ND is to CN as $\sqrt{II-RR}$ to $\sqrt{3RR}$, in which case NE will be to ND as 2R to I. Also the Angle AYS which the Rays AN and HS contain

contain will first decrease, and then increase and grow least when ND is to CN as $\sqrt{11-RR}$ to $\sqrt{8RR}$, in which case NE will be to ND as 3 R to I. And so the Angle which the next emergent Ray (that is, the emergent Ray after three Reflexions) contains with the incident Ray AN will come to its limit when ND is to CN as $\sqrt{11-RR}$ to $\sqrt{15RR}$, in which case NE will be to ND as 4 R to I. And the Angle which the Ray next after that emergent, that is, the Ray emergent after four Reflexions, contains with the incident will come to its limit, when ND is to CN as $\sqrt{11-RR}$ to $\sqrt{24RR}$, in which case NE will be to ND as 5 R to I; and so on infinitely, the numbers 3, 8, 15, 24, *&c.* being gather'd by continual addition of the terms of the arithmetical Progression 3, 5, 7, 9, *&c.* The truth of all this Mathematicians will easily examine.

Now it is to be observed, that as when the Sun comes to his Tropicks, Days increase and decrease but a very little for a great while together; so when by increasing the distance CD, these Angles come to their limits, they vary their quantity but very little for some time together, and therefore a far greater number of the Rays which fall upon all the Points N in the Quadrant BL, shall emerge in the limits of these Angles, than in any other Inclinations. And farther it is to be observed, that the Rays which differ in Refrangibility will have different limits of their Angles of Emergence, and by consequence according to their different degrees of Refrangibility emerge most copiously in different Angles, and being ſeparated from one another appear each in their proper Colours. And what thoſe Angles are may be eaſily gather'd from the foregoing Theorem by computation.

For in the leaſt refrangible Rays the Sines I and R (as was found above) are 108 and 81, and thence by computation the greateſt Angle A X R will be found 42 Degrees and 2 Minutes, and the leaſt Angle AYS, 50 Degrees and 57 Minutes. And in the moſt refrangible Rays the Sines I and R are 109 and 81, and thence by computation the greateſt Angle A X R will be found 40 Degrees and 17 Minutes, and the leaſt Angle AYS 54 Degrees and 7 Minutes.

Suppoſe now that O [in *Fig.* 15.] is the Spectator's Eye, and OP a Line drawn parallel to the Sun's Rays, and let POE, POF, POG, POH, be Angles of 40 Degr. 17 Min. 42 Degr. 2 Min. 50 Degr. 57 Min. and 54 Degr. 7 Min. reſpectively, and theſe Angles turned about their common Side O P, ſhall with their other Sides OE, OF; OG, OH, deſcribe the Verges of two Rain-bows AFBE and CHDG. For if E, F, G, H, be drops placed any where in the conical Superficies deſcribed by OE, OF, OG, OH, and be illuminated by the Sun's Rays SE, SF, SG, SH; the Angle SEO being equal to the Angle POE or 40 Degr. 17 Min. ſhall be the greateſt Angle in which the moſt refrangible Rays can after one Reflexion be refracted to the Eye, and therefore all the drops in the Line OE ſhall ſend the moſt refrangible Rays moſt copiouſly to the Eye, and thereby

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ſtrike the Senſes with the deepeſt violet Colour in that Region. And in like manner the Angle SFO being equal to the Angle POF, or 42 Degr. 2 Min. ſhall be the greateſt in which the leaſt refrangible Rays after one Reflexion can emerge out of the drops, and therefore thoſe Rays ſhall come moſt copiouſly to the Eye from the drops in the Line OF, and ſtrike the Senſes with the deepeſt red Colour in that Region. And by the ſame Argument, the Rays which have intermediate degrees of Refrangibility ſhall come moſt copiouſly from drops between E and F, and ſtrike the Senſes with the intermediate Colours in the order which their degrees of Refrangibility require, that is in the progreſs from E to F, or from the inſide of the Bow to the outſide in this order, violet, indigo, blue, green, yellow, orange, red. But the violet, by the mixture of the white Light of the Clouds, will appear faint and incline to purple.

Again, the Angle SGO being equal to the Angle POG, or 50 Gr. 51 Min. ſhall be the leaſt Angle in which the leaſt refrangible Rays can after two Reflexions emerge out of the drops, and therefore the leaſt refrangible Rays ſhall come moſt copiouſly to the Eye from the drops in the Line OG, and ſtrike the Senſe with the deepeſt red in that Region. And the Angle SHO being equal to the Angle POH or 54 Gr. 7 Min. ſhall be the leaſt Angle in which the moſt refrangible Rays after two Reflexions can emerge out of the drops, and therefore thoſe Rays ſhall come moſt copiouſly to the Eye from the drops in the Line OH, and ſtrike the Senſes with the deepeſt violet in that Region. And by the ſame Argument, the drops in the Regions between G and H ſhall ſtrike the Senſe with the intermediate Colours in the order which their degrees of Refrangibility require, that is, in the progreſs from G to H, or from the inſide of the Bow to the outſide in this order, red, orange, yellow, green, blue, indigo, violet. And ſince theſe four Lines OE, OF, OG, OH, may be ſituated any where in the abovemention'd conical Superficies, what is ſaid of the Drops and Colours in theſe Lines is to be underſtood of the Drops and Colours every where in thoſe Superficies.

Thus ſhall there be made two Bows of Colours, an interior and ſtronger, by one Reflexion in the drops, and an exterior and fainter by two; for the Light becomes fainter by every Reflexion. And their Colours ſhall lie in a contrary order to one another, the red of both Bows bordering upon the Space GF which is between the Bows. The breadth of the interior Bow EOF meaſured croſs the Colours ſhall be 1 Degr. 45 Min. and the breadth of the exterior GOH ſhall be 3 Degr. 10 Min. and the diſtance between them GOF ſhall be 8 Gr. 15 Min. the greateſt Semi-diameter of the innermoſt, that is, the Angle POF being 42 Gr. 2 Min. and the leaſt Semi-diameter of the outermoſt POG, being 50 Gr. 57 Min. Theſe are the Meaſures of the Bows, as they would be were the Sun but a point; for by the breadth of his Body the breath of the Bows will be increaſed and their diſtance decreaſed by half a Degree,

Degree, and ſo the breadth of the interior Iris will be 2 Degr. 15 Min. that of the exterior 3 Degr. 40 Min. their diſtance 8 Degr. 25 Min. the greateſt Semi-diameter of the interior Bow 42 Degr. 17 Min. and the leaſt of the exterior 50 Degr. 42 Min. And ſuch are the Dimenſions of the Bows in the Heavens found to be very nearly, when their Colours appear ſtrong and perfect. For once, by ſuch means as I then had, I meaſured the greateſt Semi-diameter of the interior Iris about 42 Degrees, the breadth of the red, yellow and green in that Iris 63 or 64 Minutes, beſides the outmoſt faint red obſcured by the brightneſs of the Clouds, for which we may allow 3 or 4 Minutes more. The breadth of the blue was about 40 Minutes more beſides the violet, which was ſo much obſcured by the brightneſs of the Clouds, that I could not meaſure its breadth. But ſuppoſing the breadth of the blue and violet together to equal that of the red, yellow and green together, the whole breadth of this Iris will be about 2¼ Degrees, as above. The leaſt diſtance between this Iris and the exterior Iris was about 8 Degrees and 30 Minutes. The exterior Iris was broader than the interior, but ſo faint, eſpecially on the blue ſide, that I could not meaſure its breadth diſtinctly. At another time when both Bows appeared more diſtinct, I meaſured the breadth of the interior Iris 2 Gr. 10′, and the breadth of the red, yellow and green in the exterior Iris, was to the breadth of the ſame Colours in the interior as 3 to 2.

This Explication of the Rain-bow is yet farther confirmed by the known Experiment (made by *Antonius de Dominis* and *Des-Cartes*) of hanging up any where in the Sun-shine a Glass Globe filled with Water, and viewing it in such a posture that the Rays which come from the Globe to the Eye may contain with the Sun's Rays an Angle of either 42 or 50 Degrees. For if the Angle be about 42 or 43 Degrees, the Spectator (suppose at O) shall see a full red Colour in that side of the Globe opposed to the Sun as 'tis represented at F, and if that Angle become less (suppose by depressing the Globe to E) there will appear other Colours, yellow, green and blue successively in the same side of the Globe. But if the Angle be made about 50 Degrees (suppose by lifting up the Globe to G) there will appear a red Colour in that side of the Globe towards the Sun, and if the Angle be made greater (suppose by lifting up the Globe to H) the red will turn successively to the other Colours, yellow, green and blue. The same thing I have tried by letting a Globe rest, and raising or depressing the Eye, or otherwise moving it to make the Angle of a just magnitude.

I have heard it represented, that if the Light of a Candle be refracted by a Prism to the Eye; when the blue Colour falls upon the Eye the Spectator shall see red in the Prism, and when the red falls upon the Eye he shall see blue; and if this were certain, the Colours of the Globe and Rain-bow ought to appear in a contrary order to what we find. But the Colours

of

of the Candle being very faint, the miſtake ſeems to ariſe from the difficulty of diſcerning what Colours fall on the Eye. For, on the contrary, I have ſometimes had occaſion to obſerve in the Sun's Light refracted by a Priſm, that the Spectator always ſees that Colour in the Priſm which falls upon his Eye. And the ſame I have found true alſo in Candle-light. For when the Priſm is moved ſlowly from the Line which is drawn directly from the Candle to the Eye, the red appears firſt in the Priſm and then the blue, and therefore each of them is ſeen when it falls upon the Eye. For the red paſſes over the Eye firſt, and then the blue.

The Light which comes through drops of Rain by two Refractions without any Reflexion, ought to appear ſtrongeſt at the diſtance of about 26 Degrees from the Sun, and to decay gradually both ways as the diſtance from him increaſes and decreaſes. And the ſame is to be underſtood of Light tranſmitted through ſpherical Hail-ſtones. And if the Hail be a little flatted, as it often is, the Light tranſmitted may grow ſo ſtrong at a little leſs diſtance than that of 26 Degrees, as to form a Halo about the Sun or Moon; which Halo, as often as the Hail-ſtones are duly figured may be colour'd, and then it muſt be red within by the leaſt refrangible Rays, and blue without by the moſt refrangible ones, eſpecially if the Hail-ſtones have opake Globules of Snow in their center to intercept the Light within the Halo (as *Hugenius* has obſerv'd) and make the inſide thereof more diſtinctly defined than it would otherwiſe

wiſe be. For ſuch Hail-ſtones, though ſpherical, by terminating the Light by the Snow, may make a Halo red within and colourleſs without, and darker in the red than without, as Halos uſe to be. For of thoſe Rays which paſs cloſe by the Snow the Rubriform will be leaſt refracted, and ſo come to the Eye in the directeſt Lines.

The Light which paſſes through a drop of Rain after two Refractions, and three or more Reflexions, is ſcarce ſtrong enough to cauſe a ſenſible Bow; but in thoſe Cylinders of Ice by which *Hugenius* explains the *Parbelia*, it may perhaps be ſenſible.

## *PROP.* X. PROB. V.

*By the diſcovered Properties of Light to explain the permanent Colours of Natural Bodies.*

THESE Colours ariſe from hence, that ſome natural Bodies reflect ſome ſorts of Rays, others other ſorts more copiouſly than the reſt. Minium reflects the leaſt refrangible or red-making Rays moſt copiouſly, and thence appears red. Violets reflect the moſt refrangible, moſt copiouſly, and thence have their Colour, and ſo of other Bodies. Every Body reflects the Rays of its own Colour more copiouſly than the reſt, and from their exceſs and predominance in the reflected Light has its Colour.

*Exper.*

*Exper.* 17. For if in the homogeneal Lights obtained by the ſolution of the Problem propoſed in the fourth Propoſition of the firſt Part you place Bodies of ſeveral Colours, you will find, as I have done, that every Body looks moſt ſplendid and luminous in the Light of its own Colour. Cinnaber in the homogeneal red Light is moſt reſplendent, in the green Light it is manifeſtly leſs reſplendent, and in the blue Light ſtill leſs. Indigo in the violet blue Light is moſt reſplendent, and its ſplendor is gradually diminiſh'd as it is removed thence by degrees through the green and yellow Light to the red. By a Leek the green Light, and next that the blue and yellow which compound green, are more ſtrongly reflected than the other Colours red and violet, and ſo of the reſt. But to make theſe Experiments the more manifeſt, ſuch Bodies ought to be choſen as have the fulleſt and moſt vivid Colours, and two of thoſe Bodies are to be compared together. Thus, for inſtance, if Cinnaber and *ultra*-marine blue, or ſome other full blue be held together in the homogeneal Light, they will both appear red, but the Cinnaber will appear of a ſtrongly luminous and reſplendent red, and the *ultra*-marine blue of a faint obſcure and dark red; and if they be held together in the blue homogeneal Light they will both appear blue, but the *ultra*-marine will appear of a ſtrongly luminous and reſplendent blue, and the Cinnaber of a faint and dark blue. Which puts it out of diſpute, that the Cinnaber reflects the red Light much more copiouſly than the *ultra*-marine doth, and the

the *ultra*-marine reflects the blue Light much more copiously than the Cinnaber doth. The same Experiment may be tried successfully with red Lead and Indigo, or with any other two colour'd Bodies, if due allowance be made for the different strength or weakness of their Colour and Light.

And as the reason of the Colours of natural Bodies is evident by these Experiments, so it is farther confirmed and put past dispute by the two first Experiments of the first Part, whereby 'twas proved in such Bodies that the reflected Lights which differ in Colours do differ also in degrees of Refrangibility. For thence it's certain, that some Bodies reflect the more refrangible, others the less refrangible Rays more copiously.

And that this is not only a true reason of these Colours, but even the only reason may appear farther from this consideration, that the Colour of homogeneal Light cannot be changed by the Reflexion of natural Bodies.

For if Bodies by Reflexion cannot in the least change the Colour of any one sort of Rays, they cannot appear colour'd by any other means than by reflecting those which either are of their own Colour, or which by mixture must produce it.

But in trying Experiments of this kind care must be had that the Light be sufficiently homogeneal. For if Bodies be illuminated by the ordinary prismatick Colours, they will appear neither of their own Day-light Colours, nor of the Colour of the Light cast on them, but of ſome middle Colour between both, as I have found by Experience. Thus red Lead (for inſtance) illuminated with the ordinary priſmatick green will not appear either red or green, but orange or yellow, or between yellow and green, accordingly as the green Light by which 'tis illuminated is more or leſs compounded. For becauſe red Lead appears red when illuminated with white Light, wherein all ſorts of Rays are equally mix'd, and in the green Light all ſorts of Rays are not equally mix'd, the Exceſs of the yellow-making, green-making and blue-making Rays in the incident green Light, will cauſe thoſe Rays to abound ſo much in the reflected Light as to draw the Colour from red towards their Colour. And becauſe the red Lead reflects the red-making Rays moſt copiouſly in proportion to their number, and next after them the orange-making and yellow-making Rays; theſe Rays in the reflected Light will be more in proportion to the Light than they were in the incident green Light, and thereby will draw the reflected Light from green towards their Colour. And therefore the red Lead will appear neither red nor green, but of a Colour between both.

In tranſparently colour'd Liquors 'tis obſervable, that their Colour uſes to vary with their thickneſs. Thus, for inſtance, a red Liquor in a conical Glaſs held between the Light and the Eye, looks of a pale and dilute yellow at the bottom where 'tis thin, and a little higher where 'tis thicker grows orange, and where 'tis ſtill thicker becomes red, and where 'tis thickeſt

the

the red is deepeſt and darkeſt. For it is to be conceiv'd that ſuch a Liquor ſtops the indigo-making and violet-making Rays moſt eaſily, the blue-making Rays more difficultly, the green-making Rays ſtill more difficultly, and the red-making moſt difficultly: And that if the thickneſs of the Liquor be only ſo much as ſuffices to ſtop a competent number of the violet-making and indigo-making Rays, without diminiſhing much the number of the reſt, the reſt muſt (by *Prop.* 6. *Part* 2.) compound a pale yellow. But if the Liquor be ſo much thicker as to ſtop alſo a great number of the blue-making Rays, and ſome of the green-making, the reſt muſt compound an orange; and where it is ſo thick as to ſtop alſo a great number of the green-making and a conſiderable number of the yellow-making, the reſt muſt begin to compound a red, and this red muſt grow deeper and darker as the yellow-making and orange-making Rays are more and more ſtopp'd by increaſing the thickneſs of the Liquor, ſo that few Rays beſides the red-making can get through.

Of this kind is an Experiment lately related to me by Mr. *Halley*, who, in diving deep into the Sea in a diving Veſſel, found in a clear Sunſhine Day, that when he was ſunk many Fathoms deep into the Water, the upper part of his Hand on which the Sun ſhone directly through the Water and through a ſmall Glaſs Window in the Veſſel, like that of a Damask Roſe, and the Water below and the under part of his Hand illuminated by Light reflected from the Water below

below look'd green. For thence it may be gather'd, that the Sea Water reflects back the violet and blue-making Rays most easily, and lets the red-making Rays pass most freely and copiously to great depths. For thereby the Sun's direct Light at all great depths, by reason of the predominating red-making Rays, must appear red; and the greater the depth is, the fuller and intenser must that red be. And at such depths as the violet-making Rays scarce penetrate unto, the blue-making, green-making and yellow-making Rays being reflected from below more copiously than the red-making ones, must compound a green.

Now if there be two Liquors of full Colours, suppose a red and a blue, and both of them so thick as suffices to make their Colours sufficiently full; though either Liquor be sufficiently transparent apart, yet will you not be able to see through both together. For if only the red-making Rays pass through one Liquor, and only the blue-making through the other, no Rays can pass through both. This Mr. *Hook* tried casually with Glass Wedges filled with red and blue Liquors, and was surprized at the unexpected event, the reason of it being then unknown; which makes me trust the more to his Experiment, though I have not tried it my self. But he that would repeat it, must take care the Liquors be of very good and full Colours.

Now whilst Bodies become coloured by reflecting or transmitting this or that sort of Rays more copiously than the rest, it is to be conceived that they stop and stifle in themselves the Rays which they do not reflect or tranſmit. For if Gold be foliated and held between your Eye and the Light, the Light looks of a greeniſh blue, and therefore maſſy Gold lets into its Body the blue-making Rays to be reflected to and fro within it till they be ſtopp'd and ſtifled, whilſt it reflects the yellow-making outwards, and thereby looks yellow. And much after the ſame manner that Leaf Gold is yellow by reflected, and blue by tranſmitted Light, and maſſy Gold is yellow in all Poſitions of the Eye; there are ſome Liquors, as the Tincture of *Lignum Nephriticum*, and ſome ſorts of Glaſs which tranſmit one ſort of Light moſt copiouſly, and reflect another ſort, and thereby look of ſeveral Colours, according to the poſition of the Eye to the Light. But if theſe Liquors or Glaſſes were ſo thick and maſſy that no Light could get through them, I queſtion not but they would like all other opake Bodies appear of one and the ſame Colour in all Poſitions of the Eye, though this I cannot yet affirm by experience. For all colour'd Bodies, ſo far as my Obſervation reaches, may be ſeen through if made ſufficiently thin, and therefore are in ſome meaſure tranſparent, and differ only in degrees of Tranſparency from tinged tranſparent Liquors; theſe Liquors, as well as thoſe Bodies, by a ſufficient thickneſs becoming opake. A tranſparent Body which looks of any Colour by tranſmitted Light, may alſo look of the ſame Colour by reflected Light, the Light of that Colour being reflected by the farther Surface of the Body, or by the Air beyond it. And

then

then the reflected Colour will be diminished, and perhaps cease, by making the Body very thick, and pitching it on the backside to diminish the Reflexion of its farther Surface, so that the Light reflected from the tinging Particles may predominate. In such cases, the Colour of the reflected Light will be apt to vary from that of the Light transmitted. But whence it is that tinged Bodies and Liquors reflect some sort of Rays, and intromit or transmit other sorts, shall be said in the next Book. In this Proposition I content my self to have put it past dispute, that Bodies have such Properties, and thence appear colour'd.

## *PROP.* XI. Prob. VI.

*By mixing colour'd Lights to compound a beam of Light of the same Colour and Nature with a beam of the Sun's direct Light, and therein to experience the Truth of the foregoing Propositions.*

LET ABC *abc* [in *Fig.* 16.] represent a Prism by which the Sun's Light let into a dark Chamber through the Hole F, may be refracted towards the Lens MN, and paint upon it at *p*, *q*, *r*, *s* and *t*, the usual Colours violet, blue, green, yellow and red, and let the diverging Rays by the Refraction of this Lens converge again towards X, and there, by the mixture of all those their Colours, compound a white according to what was shewn above.

Then let another Prism DEG *deg*, parallel to the former, be placed at X, to refract that white Light upwards towards Y. Let the refracting Angles of the Prisms, and their distances from the Lens be equal, so that the Rays which converged from the Lens towards X, and without Refraction, would there have crossed and diverged again, may by the Refraction of the second Prism be reduced into Parallelism and diverge no more. For then those Rays will recompose a beam of white Light XY. If the refracting Angle of either Prism be the bigger, that Prism must be so much the nearer to the Lens. You will know when the Prisms and the Lens are well set together, by observing if the beam of Light XY which comes out of the second Prism be perfectly white to the very edges of the Light, and at all distances from the Prism continue perfectly and totally white like a beam of the Sun's Light. For till this happens, the position of the Prisms and Lens to one another must be corrected, and then if by the help of a long beam of Wood, as is represented in the Figure, or by a Tube, or some other such Instrument made for that purpose, they be made fast in that situation, you may try all the same Experiments in this compounded beam of Light XY, which have been made in the Sun's direct Light. For this compounded beam of Light has the same appearance, and is endow'd with all the same Properties with a direct beam of the Sun's Light, so far as my Observation reaches. And in trying Experiments in this beam you may by stopping any of the Colours *p*, *q*, *r*, *s* and *t*, at the Lens, ſee how the Colours produced in the Experiments are no other than thoſe which the Rays had at the Lens before they enter the compoſition of this Beam: And by conſequence that they ariſe not from any new modifications of the Light by Refractions and Reflexions, but from the various Separations and Mixtures of the Rays originally endow'd with their colour-making qualities.

So, for inſtance, having with a Lens $4\frac{1}{4}$ Inches broad, and two Priſms on either hand $6\frac{1}{4}$ Feet diſtant from the Lens, made ſuch a beam of compounded Light: to examin the reaſon of the Colours made by Priſms, I refracted this compounded beam of Light XY with another Priſm HIK *kh*, and thereby caſt the uſual priſmatick Colours PQRST upon the Paper LV placed behind. And then by ſtopping any of the Colours *p*, *q*, *r*, *s*, *t*, at the Lens, I found that the ſame Colour would vaniſh at the Paper. So if the purple *p* was ſtopp'd at the Lens, the purple P upon the Paper would vaniſh, and the reſt of the Colours would remain unalter'd, unleſs perhaps the blue, ſo far as ſome purple latent in it at the Lens might be ſeparated from it by the following Refractions. And ſo by intercepting the green upon the Lens, the green R upon the Paper would vaniſh, and ſo of the reſt; which plainly ſhews, that as the white beam of Light XY was compounded of ſeveral Lights variouſly colour'd at the Lens, ſo the Colours which afterwards emerge out of it by new Refractions are no other than thoſe of which its whiteneſs was compounded. The

Refraction of the Prism HIK *kh* generates the Colours PQRST upon the Paper, not by changing the colorific qualities of the Rays, but by separating the Rays which had the very same colorific qualities before they enter'd the Composition of the refracted beam of white Light XY. *For otherwise the Rays which were of one Colour at the Lens might be of another upon the Paper, contrary to what we find.

So again, to examin the reason of the Colours of natural Bodies, I placed such Bodies in the Beam of Light XY, and found that they all appeared there of those their own Colours which they have in Day-light, and that those Colours depend upon the Rays which had the same Colours at the Lens before they enter'd the Composition of that beam. Thus, for instance, Cinnaber illuminated by this beam appears of the same red Colour as in Day-light; and if at the Lens you intercept the green-making and blue-making Rays, its redness will become more full and lively: But if you there intercept the red-making Rays, it will not any longer appear red, but become yellow or green, or of some other Colour, according to the sorts of Rays which you do not intercept. So Gold in this Light XY appears of the same yellow Colour as in Day-light, but by intercepting at the Lens a due quantity of the yellow-making Rays it will appear white like Silver (as I have tried) which shews that its yellowness arises from the Excess of the intercepted Rays tinging that whiteness with their Colour when they are let pass. So the infusion of *Lignum Nephriti-*

*Fig: 1.*

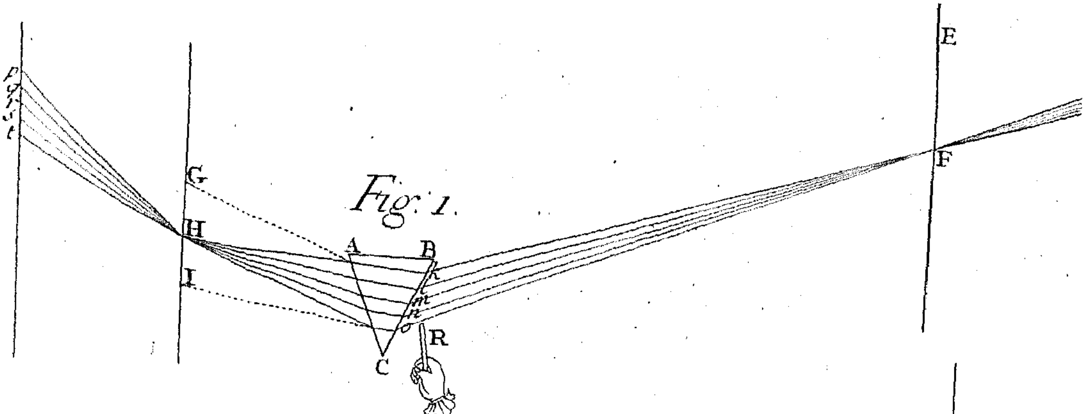



*Fig: 2.*

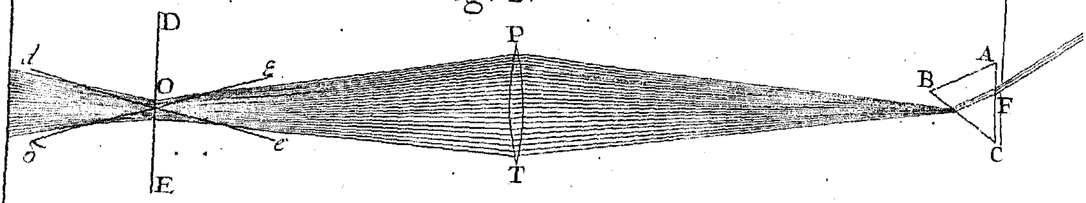



*Fig: 3.*

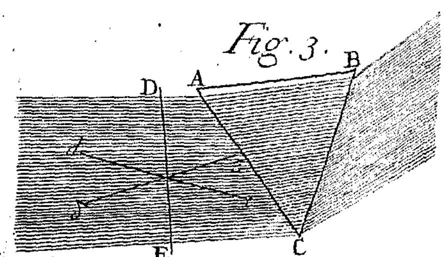



*Fig. 4.*

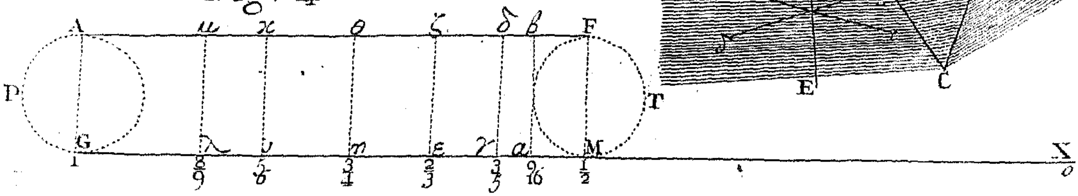
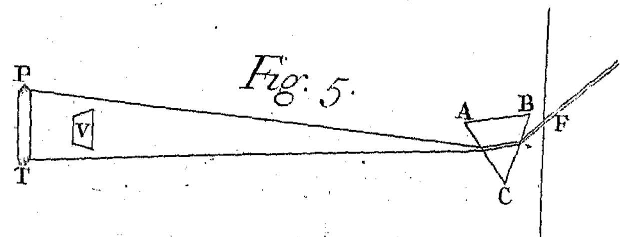



*Fig: 5.*



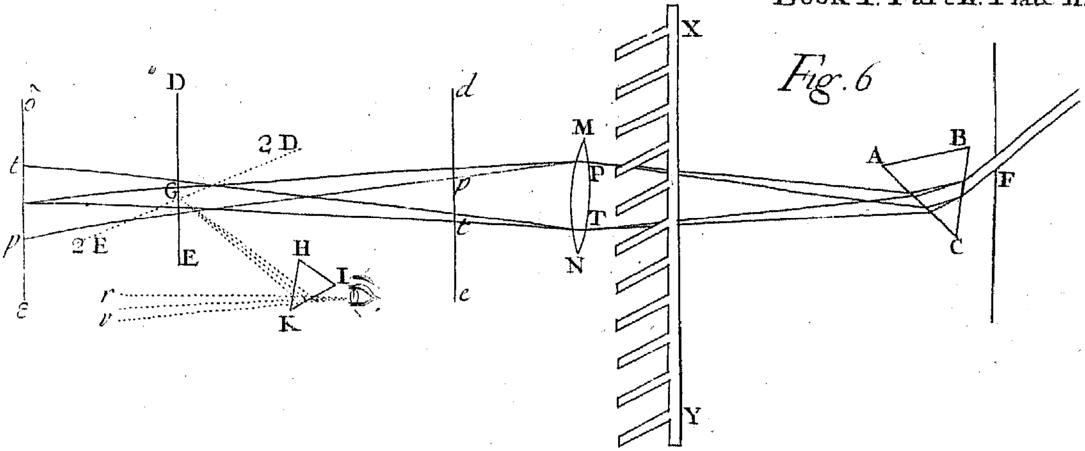



Fig. 6

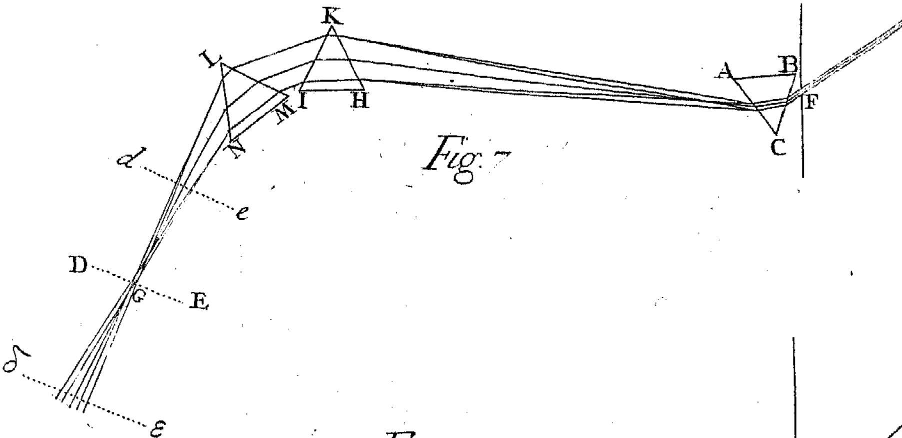



Fig. 7

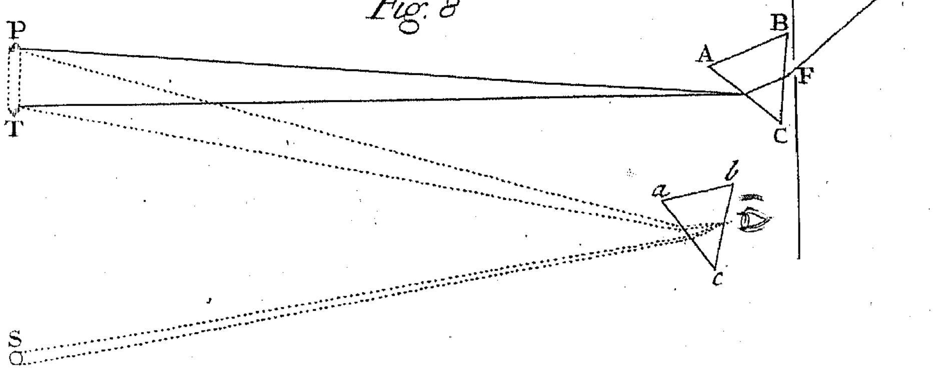



Fig. 8

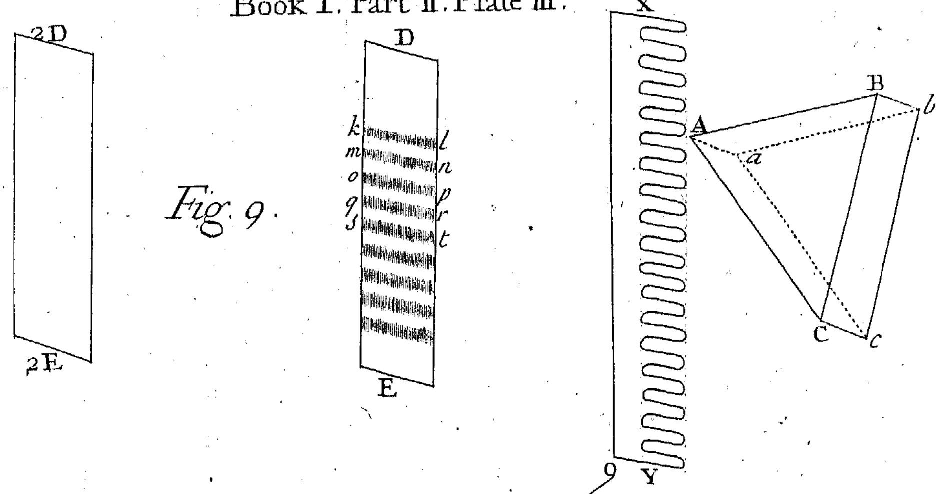



Fig. 9.

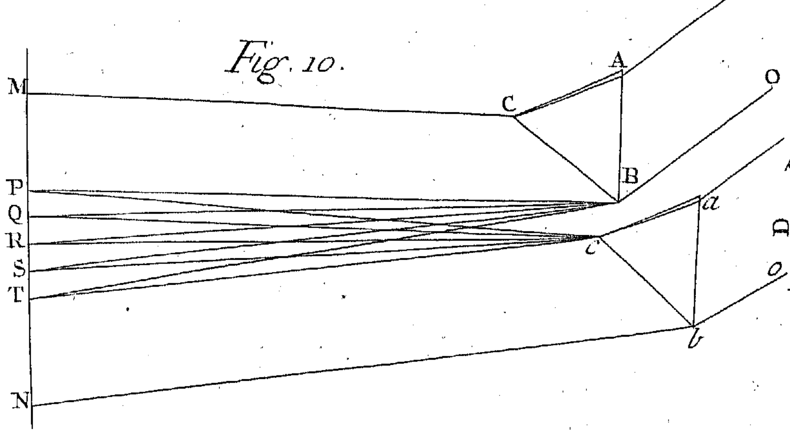



Fig. 10.

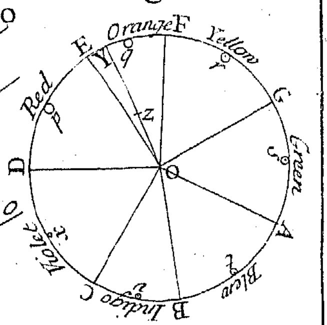



Fig. 11.

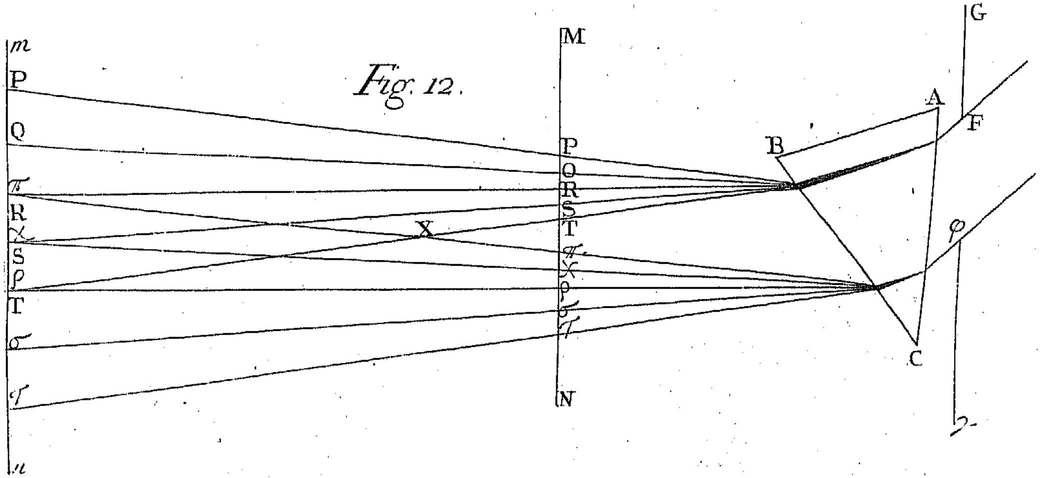



Fig. 12.

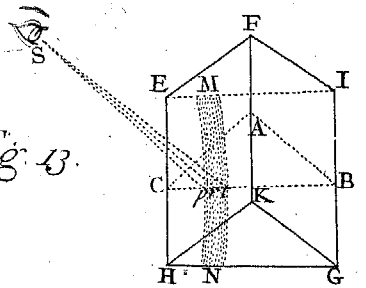



Fig. 13.

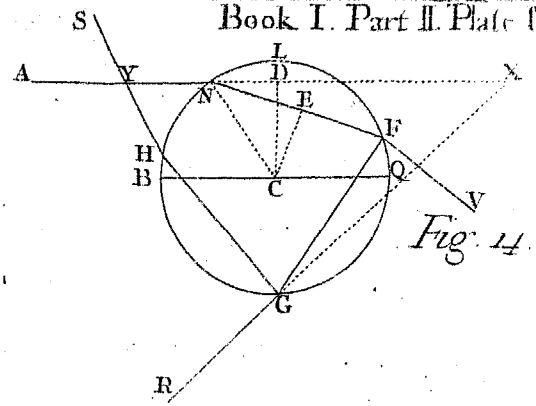



Fig. 14.

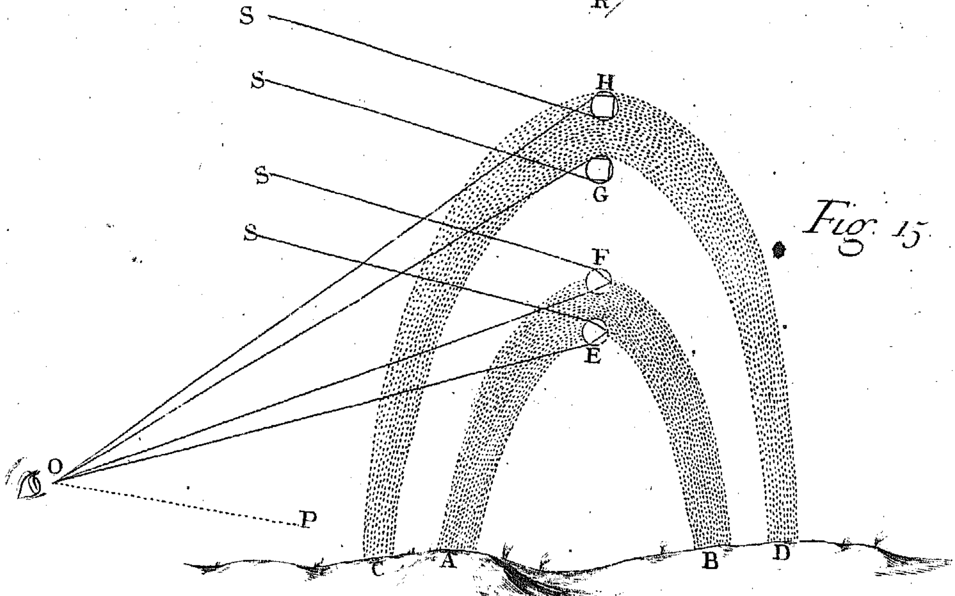



Fig. 15.

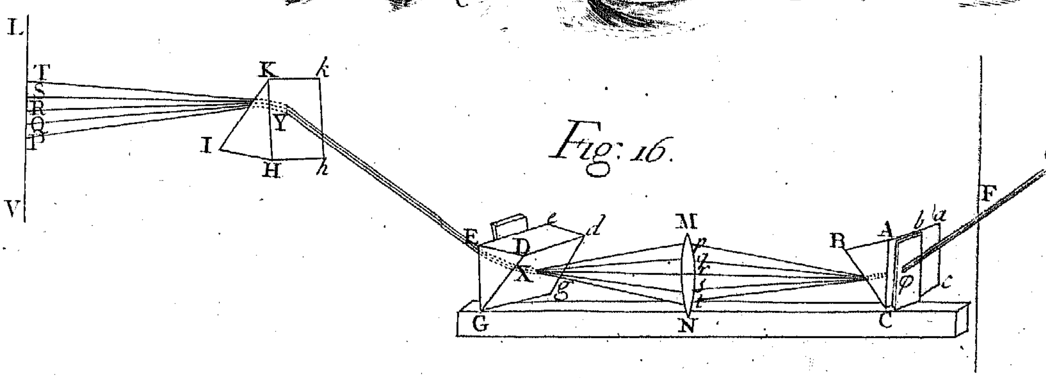



Fig. 16.

*cum* (as I have alſo tried) when held in this beam of Light X Y, looks blue by the reflected part of the Light, and red by the tranſmitted part of it, as when 'tis view'd in Day-light, but if you intercept the blue at the Lens the infuſion will loſe its reflected blue Colour, whilſt its tranſmitted red remains perfect and by the loſs of ſome blue-making Rays wherewith it was allay'd becomes more intenſe and full. And, on the contrary, if the red and orange-making Rays be intercepted at the Lens, the Infuſion will loſe its tranſmitted red, whilſt its blue will remain and become more full and perfect. Which ſhews, that the Infuſion does not tinge the Rays with blue and red, but only tranſmit thoſe moſt copiouſly which were red-making before, and reflects thoſe moſt copiouſly which were blue-making before. And after the ſame manner may the Reaſons of other Phænomena be examined, by trying them in this artificial beam of Light X Y.

# THE SECOND BOOK OF OPTICKS.

## PART I.

*Observations concerning the Reflexions, Refractions, and Colours of thin transparent Bodies.*

IT has been observed by others, that transparent Substances, as Glass, Water, Air, &c. when made very thin by being blown into Bubbles, or otherwise formed into Plates, do exhibit various Colours according to their various thinness, although at a greater a greater thickneſs they appear very clear and colourleſs. In the former Book I forbore to treat of theſe Colours, becauſe they ſeemed of a more difficult Conſideration, and were not neceſſary for eſtabliſhing the Properties of Light there diſcourſed of. But becauſe they may conduce to farther Diſcoveries for completing the Theory of Light, eſpecially as to the conſtitution of the parts of natural Bodies, on which their Colours or Tranſparency depend; I have here ſet down an account of them. To render this Diſcourſe ſhort and diſtinct, I have firſt deſcribed the principal of my Obſervations, and then conſider'd and made uſe of them. The Obſervations are theſe.

*Obſ.* 1. Compreſſing two Priſms hard together that their ſides (which by chance were a very little convex) might ſomewhere touch one another: I found the place in which they touched to become abſolutely tranſparent, as if they had there been one continued piece of Glaſs. For when the Light fell ſo obliquely on the Air, which in other places was between them, as to be all reflected; it ſeemed in that place of contact to be wholly tranſmitted, inſomuch that when look'd upon, it appeared like a black or dark ſpot, by reaſon that little or no ſenſible Light was reflected from thence, as from other places; and when looked through it ſeemed (as it were) a hole in that Air which was formed into a thin Plate, by being compreſs'd between the Glaſſes. And through this hole Objects that were beyond might be ſeen diſtinctly, which could not at all be ſeen through other parts of the

the Glaſſes where the Air was interjacent. Although the Glaſſes were a little convex, yet this tranſparent ſpot was of a conſiderable breadth, which breadth ſeemed principally to proceed from the yielding inwards of the parts of the Glaſſes, by reaſon of their mutual preſſure. For by preſſing them very hard together it would become much broader than otherwiſe.

*Obſ.* 2. When the Plate of Air, by turning the Priſms about their common Axis, became ſo little inclined to the incident Rays, that ſome of them began to be tranſmitted, there aroſe in it many ſlender Arcs of Colours which at firſt were ſhaped almoſt like the Conchoid, as you ſee them delineated in the firſt Figure. And by continuing the Motion of the Priſms, theſe Arcs increaſed and bended more and more about the ſaid tranſparent ſpot, till they were completed into Circles or Rings incompaſſing it, and afterwards continually grew more and more contracted.

Theſe Arcs at their firſt appearance were of a violet and blue Colour, and between them were white Arcs of Circles, which preſently by continuing the Motion of the Priſms became a little tinged in their inward Limbs with red and yellow, and to their outward Limbs the blue was adjacent. So that the order of theſe Colours from the central dark ſpot, was at that time white, blue, violet; black, red, orange, yellow, white, blue, violet, &c. But the yellow and red were much fainter than the blue and violet.

The Motion of the Prisms about their Axis being continued, these Colours contracted more and more, shrinking towards the whiteness on either side of it, until they totally vanished into it. And then the Circles in those parts appear'd black and white, without any other Colours intermix'd. But by farther moving the Prisms about, the Colours again emerged out of the whiteness, the violet and blue at its inward Limb, and at its outward Limb the red and yellow. So that now their order from the central Spot was white, yellow, red; black; violet, blue, white, yellow, red, &c. contrary to what it was before.

*Obs.* 3. When the Rings or some parts of them appeared only black and white, they were very distinct and well defined, and the backness seemed as intense as that of the central Spot. Also in the Borders of the Rings, where the Colours began to emerge out of the whiteness, they were pretty distinct, which made them visible to a very great multitude. I have sometimes number'd above thirty Successions (reckoning every black and white Ring for one Succession) and seen more of them, which by reason of their smalness I could not number. But in other Positions of the Prisms, at which the Rings appeared of many Colours, I could not distinguish above eight or nine of them, and the Exterior of those were very confused and dilute.

In these two Observations to see the Rings distinct, and without any other Colour than black and white, I found it necessary to hold my Eye

at

at a good diſtance from them. For by approaching nearer, although in the ſame inclination of my Eye to the Plane of the Rings, there emerged a blueiſh Colour out of the white, which by dilating it ſelf more and more into the black, render'd the Circles leſs diſtinct, and left the white a little tinged with red and yellow. I found alſo by looking through a ſlit or oblong hole, which was narrower than the Pupil of my Eye, and held cloſe to it parallel to the Priſms, I could ſee the Circles much diſtincter and viſible to a far greater number than otherwiſe.

*Obſ.* 4. To obſerve more nicely the order of the Colours which aroſe out of the white Circles as the Rays became leſs and leſs inclined to the Plate of Air; I took two Object-glaſſes, the one a Plano-convex for a fourteen Foot Teleſcope, and the other a large double Convex for one of about fifty Foot; and upon this, laying the other with its plane ſide downwards, I preſſed them ſlowly together, to make the Colours ſucceſſively emerge in the middle of the Circles, and then ſlowly lifted the upper Glaſs from the lower to make them ſucceſſively vaniſh again in the ſame place. The Colour, which by preſſing the Glaſſes together emerged laſt in the middle of the other Colours, would upon its firſt appearance look like a Circle of a Colour almoſt uniform from the circumference to the center, and by compreſſing the Glaſſes ſtill more, grow continually broader until a new Colour emerged in its center, and thereby it became a Ring encompaſſing that new Colour. And by

com-

compressing the Glasses still more, the diameter of this Ring would increase, and the breadth of its Orbit or Perimeter decrease until another new Colour emerged in the center of the last: And so on until a third, a fourth, a fifth, and other following new Colours successively emerged there, and became Rings encompassing the innermost Colour, the last of which was the black Spot. And, on the contrary, by lifting up the upper Glass from the lower, the diameter of the Rings would decrease, and the breadth of their Orbit increase, until their Colours reached successively to the center; and then they being of a considerable breadth, I could more easily discern and distinguish their Species than before. And by this means I observ'd their Succession and Quantity to be as followeth.

Next to the pellucid central Spot made by the contact of the Glasses succeeded blue, white, yellow, and red. The blue was so little in quantity that I could not discern it in the Circles made by the Prisms, nor could I well distinguish any violet in it, but the yellow and red were pretty copious, and seemed about as much in extent as the white, and four or five times more than the blue. The next Circuit in order of Colours immediately encompassing these were violet, blue, green, yellow, and red: and these were all of them copious and vivid, excepting the green, which was very little in quantity, and seemed much more faint and dilute than the other Colours. Of the other four, the violet was the least in extent, and the blue less than the yellow or red. The third Circuit or Order

Order was purple, blue, green, yellow, and red; in which the purple ſeemed more reddiſh than the violet in the former Circuit, and the green was much more conſpicuous, being as briſk and copious as any of the other Colours, except the yellow; but the red began to be a little faded, inclining very much to purple. After this ſucceeded the fourth Circuit of green and red. The green was very copious and lively, inclining on the one ſide to blue, and on the other ſide to yellow. But in this fourth Circuit there was neither violet, blue, nor yellow, and the red was very imperfect and dirty. Alſo the ſucceeding Colours became more and more imperfect and dilute, till after three or four revolutions they ended in perfect whiteneſs. Their form, when the Glaſſes were moſt compreſs'd ſo as to make the black Spot appear in the center, is delineated in the ſecond Figure; where *a, b, c, d, e : f, g, h, i, k : l, m, n, o, p : q, r : s, t : v, x : y, z* denote the Colours reckon'd in order from the center, black, blue, white, yellow, red: violet, blue, green, yellow, red: purple, blue, green, yellow, red: green, red: greeniſh blue, red: greeniſh blue, pale red: greeniſh blue, reddiſh white.

*Obſ.* 5. To determine the interval of the Glaſſes, or thickneſs of the interjacent Air, by which each Colour was produced, I meaſured the Diameters of the firſt ſix Rings at the moſt lucid part of their Orbits, and ſquaring them, I found their Squares to be in the arithmetical Progreſſion of the odd Numbers, 1, 3, 5, 7, 9, 11.

And

And ſince one of theſe Glaſſes was plane, and the other ſpherical, their Intervals at thoſe Rings muſt be in the ſame Progreſſion. I meaſured alſo the Diameters of the dark or faint Rings between the more lucid Colours, and found their Squares to be in the arithmetical Progreſſion of the even Numbers, 2, 4, 6, 8, 10, 12. And it being very nice and difficult to take theſe meaſures exactly; I repeated them divers times at divers parts of the Glaſſes, that by their Agreement I might be confirmed in them. And the ſame method I uſed in determining ſome others of the following Obſervations.

*Obſ.* 6. The Diameter of the ſixth Ring at the moſt lucid part of its Orbit was $\frac{58}{100}$ parts of an Inch, and the Diameter of the Sphere on which the double convex Object-glaſs was ground was about 102 Feet, and hence I gathered the thickneſs of the Air or Aereal Interval of the Glaſſes at that Ring. But ſome time after, ſuſpecting that in making this Obſervation I had not determined the Diameter of the Sphere with ſufficient accurateneſs, and being uncertain whether the Plano-convex Glaſs was truly plane, and not ſomething concave or convex on that ſide which I accounted plane; and whether I had not preſſed the Glaſſes together, as I often did, to make them touch; (For by preſſing ſuch Glaſſes together their parts eaſily yield inwards, and the Rings thereby become ſenſibly broader than they would be, did the Glaſſes keep their Figures.) I repeated the Experiment, and found the Diameter of the

ſixth

ſixth lucid Ring about $\frac{55}{100}$ parts of an Inch. I repeated the Experiment alſo with ſuch an Object-glaſs of another Teleſcope as I had at hand. This was a double Convex ground on both ſides to one and the ſame Sphere, and its Focus was diſtant from it $83\frac{2}{5}$ Inches. And thence, if the Sines of Incidence and Refraction of the bright yellow Light be aſſumed in proportion as 11 to 17, the Diameter of the Sphere to which the Glaſs was figured will by computation be found 182 Inches. This Glaſs I laid upon a flat one, ſo that the black Spot appeared in the middle of the Rings of Colours without any other Preſſure than that of the weight of the Glaſs. And now meaſuring the Diameter of the fifth dark Circle as accurately as I could, I found it the fifth part of an Inch preciſely. This Meaſure was taken with the points of a pair of Compaſſes on the upper Surface on the upper Glaſs, and my Eye was about eight or nine Inches diſtance from the Glaſs, almoſt perpendicularly over it, and the Glaſs was $\frac{1}{6}$ of an Inch thick, and thence it is eaſy to collect that the true Diameter of the Ring between the Glaſſes was greater than its meaſur'd Diameter above the Glaſſes in the Proportion of 80 to 79, or thereabouts, and by conſequence equal to $\frac{16}{79}$ part of an Inch, and its true Semi-diameter equal to $\frac{8}{79}$ parts. Now as the Diameter of the Sphere (182 Inches) is to the Semi-diameter of this fifth dark Ring ($\frac{8}{79}$ parts of an Inch) ſo is this Semi-diameter to the thickneſs of the Air at this fifth dark Ring; which is there-

therefore $\frac{32}{567931}$ or $\frac{100}{1774784}$ parts of an Inch; and the fifth part thereof, *viz.* the $\frac{1}{88739}$ part of an Inch, is the thickneſs of the Air at the firſt of theſe dark Rings.

The ſame Experiment I repeated with another double convex Object-glaſs ground on both ſides to one and the ſame Sphere. Its Focus was diſtant from it $168\frac{1}{2}$ Inches, and therefore the Diameter of that Sphere was 184 Inches. This Glaſs being laid upon the ſame plain Glaſs, the Diameter of the fifth of the dark Rings, when the black Spot in their center appear'd plainly without preſſing the Glaſſes, was by the meaſure of the Compaſſes upon the upper Glaſs $\frac{121}{600}$ parts of an Inch, and by conſequence between the Glaſſes it was $\frac{1222}{6000}$. For the upper Glaſs was $\frac{1}{8}$ of an Inch thick, and my Eye was diſtant from it 8 Inches. And a third proportional to half this from the Diameter of the Sphere is $\frac{5}{88850}$ parts of an Inch. This is therefore the thickneſs of the Air at this Ring, and a fifth part thereof, *viz.* the $\frac{1}{88850}$th part of an Inch is the thickneſs thereof at the firſt of the Rings, as above.

I tried the ſame thing by laying theſe Object-glaſſes upon flat pieces of a broken Looking-glaſs, and found the ſame Meaſures of the Rings: Which makes me rely upon them till they can be determin'd more accurately by Glaſſes ground to larger Spheres, though in ſuch Glaſſes greater care muſt be taken of a true Plane.

Theſe Dimenſions were taken when my Eye was placed almoſt perpendicularly over the Glaſſes, being about an Inch, or an Inch and a quarter, diſtant from the incident Rays, and eight Inches diſtant from the Glaſs; ſo that the Rays were inclined to the Glaſs in an Angle of about four Degrees. Whence by the following Obſervation you will underſtand, that had the Rays been perpendicular to the Glaſſes, the thickneſs of the Air at theſe Rings would have been leſs in the proportion of the Radius to the Secant of four Degrees, that is of 10000 to 10024. Let the thickneſſes found be therefore diminiſh'd in this Proportion, and they will become $\frac{1}{88952}$ and $\frac{1}{89063}$, or (to uſe the neareſt round number) the $\frac{1}{89000}$th part of an Inch. This is the thickneſs of the Air at the darkeſt part of the firſt dark Ring made by perpendicular Rays, and half this thickneſs multiplied by the Progreſſion, 1, 3, 5, 7, 9, 11, *&c.* gives the thickneſſes of the Air at the moſt luminous parts of all the brighteſt Rings, *viz.* $\frac{1}{178000}$, $\frac{3}{178000}$, $\frac{5}{178000}$, $\frac{7}{178000}$, *&c.* their arithmetical Means $\frac{2}{178000}$, $\frac{4}{178000}$, $\frac{6}{178000}$, *&c.* being its thickneſſes at the darkeſt parts of all the dark ones.

*Obs.* 7. The Rings were leaſt when my Eye was placed perpendicularly over the Glaſſes in the Axis of the Rings: And when I view'd them obliquely they became bigger, continually ſwelling as I removed my Eye farther from the Axis. And partly by meaſuring the Diameter of the ſame Circle at ſeveral Obliquities of my Eye, partly by other means, as alſo by making uſe of the two Priſms for very great Obliquities, I found its Diameter, and conſequently the thickneſs of the Air at its Perimeter in all thoſe Obliquities to be very nearly in the Proportions expreſs'd in this Table.

| *Angle of Incidence on the Air.* | | *Angle of Refraction into the Air.* | | *Diameter of the Ring.* | *Thickneſs of the Air.* |
|---|---|---|---|---|---|
| Deg. | Min. | | | | |
| 00 | 00 | 00 | 00 | 10 | 10 |
| 06 | 26 | 10 | 00 | $10\frac{1}{13}$ | $10\frac{2}{13}$ |
| 12 | 45 | 20 | 00 | $10\frac{1}{3}$ | $10\frac{2}{3}$ |
| 18 | 49 | 30 | 00 | $10\frac{3}{4}$ | $11\frac{1}{2}$ |
| 24 | 30 | 40 | 00 | $11\frac{2}{5}$ | 13 |
| 29 | 37 | 50 | 00 | $12\frac{1}{2}$ | $15\frac{1}{2}$ |
| 33 | 58 | 60 | 00 | 14 | 20 |
| 35 | 47 | 65 | 00 | $15\frac{1}{4}$ | $23\frac{1}{4}$ |
| 37 | 19 | 70 | 00 | $16\frac{4}{5}$ | $28\frac{1}{4}$ |
| 38 | 33 | 75 | 00 | $19\frac{1}{4}$ | 37 |
| 39 | 27 | 80 | 00 | $22\frac{6}{7}$ | $52\frac{1}{4}$ |
| 40 | 00 | 85 | 00 | 29 | $84\frac{1}{12}$ |
| 40 | 11 | 90 | 00 | 35 | $122\frac{1}{2}$ |

In the two first Columns are expreſs'd the Obliquities of the incident and emergent Rays to the Plate of the Air, that is, their Angles of Incidence and Refraction. In the third Column the Diameter of any colour'd Ring at thoſe Obliquities is expreſſed in parts, of which ten conſtitute that Diameter when the Rays are perpendicular. And in the fourth Column the thickneſs of the Air at the circumference of that Ring is expreſſed in parts of which alſo ten conſtitute its thickneſs when the Rays are perpendicular.

And from theſe Meaſures I ſeem to gather this Rule: That the thickneſs of the Air is proportional to the ſecant of an Angle, whoſe Sine is a certain mean Proportional between the Sines of Incidence and Refraction. And that mean Proportional, ſo far as by theſe Meaſures I can determine it, is the firſt of an hundred and ſix arithmetical mean Proportionals between thoſe Sines counted from the bigger Sine, that is, from the Sine of Refraction when the Refraction is made out of the Glaſs into the Plate of Air, or from the Sine of Incidence when the Refraction is made out of the Plate of Air into the Glaſs.

*Obſ.* 8. The dark Spot in the middle of the Rings increaſed alſo by the Obliquation of the Eye, although almoſt inſenſibly. But if inſtead of the Object-glaſſes the Priſms were made uſe of, its Increaſe was more manifeſt when viewed ſo obliquely that no Colours appear'd about it. It was leaſt when the Rays were incident moſt obliquely on the interjacent Air, and as the obliquity decreaſed it increaſed more and more until the colour'd Rings appear'd, and then decreaſed again, but not ſo much as it increaſed before. And hence it is evident, that the Tranſparency was not only at the abſolute Contact of the Glaſſes, but alſo where they had ſome little Interval. I have ſometimes obſerved the Diameter of that Spot to be between half and two fifth parts of the Diameter of the exterior Circumference of the red in the firſt Circuit or Revolution of Colours when view'd almoſt perpendicularly; whereas when view'd obliquely it hath wholly vaniſh'd and become opake and white like the other parts of the Glaſs; whence it may be collected that the Glaſſes did then ſcarcely, or not at all, touch one another, and that their Interval at the perimeter of that Spot when view'd perpendicularly was about a fifth or ſixth part of their Interval at the circumference of the ſaid red.

*Obſ.* 9. By looking through the two contiguous Object-glaſſes, I found that the interjacent Air exhibited Rings of Colours, as well by tranſmitting Light as by reflecting it. The central Spot was now white, and from it the order of the Colours were yellowiſh red; black, violet, blue, white, yellow, red; violet, blue, green, yellow, red, *&c.* But theſe Colours were very faint and dilute, unleſs when the Light was trajected very obliquely through the Glaſſes: For by that means they became pretty vivid. Only the firſt yellowiſh red, like the blue in the fourth Obſervation, was ſo little and faint as ſcarcely to be diſcern'd. Comparing

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the colour'd Rings made by Reflexion, with these made by transmission of the Light; I found that white was opposite to black, red to blue, yellow to violet, and green to a Compound of red and violet. That is, those parts of the Glass were black when looked through, which when looked upon appear'd white, and on the contrary. And so those which in one case exhibited blue, did in the other case exhibit red. And the like of the other Colours. The manner you have represented in the third Figure, where AB, CD, are the Surfaces of the Glasses contiguous at E, and the black Lines between them are their Distances in arithmetical Progression, and the Colours written above are seen by reflected Light, and those below by Light transmitted.

*Obs.* 10. Wetting the Object-glasses a little at their edges, the Water crept in slowly between them, and the Circles thereby became less and the Colours more faint: Insomuch that as the Water crept along one half of them at which it first arrived would appear broken off from the other half, and contracted into a less Room. By measuring them I found the Proportions of their Diameters to the Diameters of the like Circles made by Air to be about seven to eight, and consequently the Intervals of the Glasses at like Circles, caused by those two Mediums Water and Air, are as about three to four. Perhaps it may be a general Rule, That if any other Medium more or less dense than Water be compress'd between the Glasses, their Intervals at the Rings caused thereby will be to their

Intervals

Intervals caused by interjacent Air, as the Sines are which measure the Refraction made out of that Medium into Air.

*Obs.* 11. When the Water was between the Glasses, if I pressed the upper Glass variously at its edges to make the Rings move nimbly from one place to another, a little white Spot would immediately follow the center of them, which upon creeping in of the ambient Water into that place would presently vanish. Its appearance was such as interjacent Air would have caused, and it exhibited the same Colours. But it was not Air, for where any Bubbles of Air were in the Water they would not vanish. The Reflexion must have rather been caused by a subtiler Medium, which could recede through the Glasses at the creeping in of the Water.

*Obs.* 12. These Observations were made in the open Air. But farther to examine the Effects of colour'd Light falling on the Glasses, I darken'd the Room, and view'd them by Reflexion of the Colours of a Prism cast on a Sheet of white Paper, my Eye being so placed that I could see the colour'd Paper by Reflexion in the Glasses, as in a Looking-glass. And by this means the Rings became distincter and visible to a far greater number than in the open Air. I have sometimes seen more than twenty of them, whereas in the open Air I could not discern above eight or nine.

*Obs.* 13. Appointing an Assistant to move the Prism to and fro about its Axis, that all the Colours might successively fall on that part of the Paper which I saw by Reflexion from that part of the Glasses, where the Circles appear'd, so that all the Colours might be successively reflected from the Circles to my Eye whilst I held it immovable, I found the Circles which the red Light made to be manifestly bigger than those which were made by the blue and violet. And it was very pleasant to see them gradually swell or contract accordingly as the Colour of the Light was changed. The Interval of the Glasses at any of the Rings when they were made by the utmost red Light, was to their Interval at the same Ring when made by the utmost violet, greater than as 3 to 2, and less than as 13 to 8. By the most of my Observations it was as 14 to 9. And this Proportion seem'd very nearly the same in all Obliquities of my Eye; unless when two Prisms were made use of instead of the Object-glasses. For then at a certain great obliquity of my Eye, the Rings made by the several Colours seem'd equal, and at a greater obliquity those made by the violet would be greater than the same Rings made by the red: the Refraction of the Prism in this case causing the most refrangible Rays to fall more obliquely on that plate of the Air than the least refrangible ones. Thus the Experiment succeeded in the colour'd Light, which was sufficiently strong and copious to make the Rings sensible. And thence it may be gather'd, that if the most refrangible and least refrangible Rays had been copious enough to make the Rings sensible without the mixture of other Rays, the Proportion which here was 14 to 9 would have been a little greater, suppose $14\frac{1}{4}$ or $14\frac{1}{3}$ to 9.

Obs.

*Obs.* 14. Whilst the Prism was turn'd about its Axis with an uniform Motion, to make all the several Colours fall successively upon the Object-glasses, and thereby to make the Rings contract and dilate: The Contraction or Dilatation of each Ring thus made by the variation of its Colour was swiftest in the red, and slowest in the violet, and in the intermediate Colours it had intermediate degrees of Celerity. Comparing the quantity of Contraction and Dilatation made by all the degrees of each Colour, I found that it was greatest in the red; less in the yellow, still less in the blue, and least in the violet. And to make as just an Estimation as I could of the Proportions of their Contractions or Dilatations, I observ'd that the whole Contraction or Dilatation of the Diameter of any Ring made by all the degrees of red, was to that of the Diameter of the same Ring made by all the degrees of violet, as about four to three, or five to four, and that when the Light was of the middle Colour between yellow and green, the Diameter of the Ring was very nearly an arithmetical Mean between the greatest Diameter of the same Ring made by the outmost red, and the least Diameter thereof made by the outmost violet: Contrary to what happens in the Colours of the oblong Spectrum made by the Refraction of a Prism, where the red is most contracted, the violet most expanded, and in the midst of all the Colours is the Confine of green and blue. And hence I seem to collect that the thicknesses of the Air between the Glasses there, where the Ring is successively-

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ly made by the limits of the five principal Colours (red, yellow, green, blue, violet) in order (that is, by the extreme red, by the limit of red and yellow in the middle of the orange, by the limit of yellow and green, by the limit of green and blue, by the limit of blue and violet in the middle of the indigo, and by the extreme violet) are to one another very nearly as the ſix lengths of a Chord which ſound the Notes in a ſixth Major, *ſol, la, mi, fa, ſol, la.* But it agrees ſomething better with the Obſervation to ſay, that the thickneſſes of the Air between the Glaſſes there, where the Rings are ſucceſſively made by the limits of the ſeven Colours, red, orange, yellow, green, blue, indigo, violet in order, are to one another as the Cube Roots of the Squares of the eight lengths of a Chord, which ſound the Notes in an eighth, *ſol, la, fa, ſol, la, mi, fa, ſol*; that is, as the Cube Roots of the Squares of the Numbers, 1, $\frac{8}{9}$, $\frac{5}{6}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{9}{16}$, $\frac{1}{2}$.

*Obſ.* 15. Theſe Rings were not of various Colours like thoſe made in the open Air, but appeared all over of that priſmatick Colour only with which they were illuminated. And by projecting the priſmatick Colours immediately upon the Glaſſes, I found that the Light which fell on the dark Spaces which were between the colour'd Rings, was tranſmitted through the Glaſſes without any variation of Colour. For on a white Paper placed behind, it would paint Rings of the ſame Colour with thoſe which were reflected, and of the bigneſs of their immediate Spaces. And from thence the origin

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of theſe Rings is manifeſt; namely, that the Air between the Glaſſes, according to its various thickneſs, is diſpoſed in ſome places to reflect, and in others to tranſmit the Light of any one Colour (as you may ſee repreſented in the fourth Figure) and in the ſame place to reflect that of one Colour where it tranſmits that of another.

*Obſ.* 16. The Squares of the Diameters of theſe Rings made by any priſmatick Colour were in arithmetical Progreſſion, as in the fifth Obſervation. And the Diameter of the ſixth Circle, when made by the citrine yellow, and viewed almoſt perpendicularly, was about $\frac{58}{100}$ parts of an Inch, or a little leſs, agreeable to the ſixth Obſervation.

The precedent Obſervations were made with a rarer thin Medium, terminated by a denſer, ſuch as was Air or Water compreſs'd between two Glaſſes. In thoſe that follow are ſet down the Appearances of a denſer Medium thin'd within a rarer, ſuch as are Plates of Muſcovy Glaſs, Bubbles of Water, and ſome other thin Subſtances terminated on all ſides with Air.

*Obſ.* 17. If a Bubble be blown with Water firſt made tenacious by diſſolving a little Soap in it, 'tis a common Obſervation, that after a while it will appear tinged with a great variety of Colours. To defend theſe Bubbles from being agitated by the external Air (whereby their Colours are irregularly moved one among another; ſo that no accurate Obſervation can be made of them,) as ſoon as I had blown any of them

them I cover'd it with a clear Glaſs, and by that means its Colours emerged in a very regular order, like ſo many concentrick Rings encompaſſing the top of the Bubble. And as the Bubble grew thinner by the continual ſubſiding of the Water, theſe Rings dilated ſlowly and overſpread the whole Bubble, deſcending in order to the bottom of it, where they vaniſh'd ſucceſſively. In the mean while, after all the Colours were emerged at the top, there grew in the center of the Rings a ſmall round black Spot, like that in the firſt Obſervation, which continually dilated it ſelf till it became ſometimes more than $\frac{1}{2}$ or $\frac{3}{4}$ of an Inch in breadth before the Bubble broke. At firſt I thought there had been no Light reflected from the Water in that place, but obſerving it more curiouſly, I ſaw within it ſeveral ſmaller round Spots, which appeared much blacker and darker than the reſt, whereby I knew that there was ſome Reflexion at the other places which were not ſo dark as thoſe Spots. And by farther Tryal I found that I could ſee the Images of ſome things (as of a Candle or the Sun) very faintly reflected, not only from the great black Spot, but alſo from the little darker Spots which were within it.

Beſides the aforeſaid colour'd Rings there would often appear ſmall Spots of Colours, aſcending and deſcending up and down the ſides of the Bubble, by reaſon of ſome Inequalities in the ſubſiding of the Water. And ſometimes ſmall black Spots generated at the ſides would

aſcend

aſcend up to the larger black Spot at the top of the Bubble, and unite with it.

*Obſ.* 18. Becauſe the Colours of theſe Bubbles were more extended and lively than thoſe of the Air thinn'd between two Glaſſes, and ſo more eaſy to be diſtinguiſh'd, I ſhall here give you a farther deſcription of their order, as they were obſerv'd in viewing them by Reflexion of the Skies when of a white Colour, whilſt a black ſubſtance was placed behind the Bubble. And they were theſe, red, blue; red, blue; red, blue; red, green; red, yellow, green, blue, purple; red, yellow, green, blue, violet; red, yellow, white, blue, black.

The three firſt Succeſſions of red and blue were very dilute and dirty, eſpecially the firſt, where the red ſeem'd in a manner to be white. Among theſe there was ſcarce any other Colour ſenſible beſides red and blue, only the blues (and principally the ſecond blue) inclined a little to green.

The fourth red was alſo dilute and dirty, but not ſo much as the former three; after that ſucceeded little or no yellow, but a copious green, which at firſt inclined a little to yellow, and then became a pretty briſk and good willow green, and afterwards changed to a bluiſh Colour; but there ſucceeded neither blue nor violet.

The fifth red at firſt inclined very much to purple, and afterwards became more bright and briſk, but yet not very pure. This was ſucceeded with a very bright and intenſe yellow, which was but little in quantity, and ſoon chang'd chang'd to green: But that green was copious and something more pure, deep and lively, than the former green. After that follow'd an excellent blue of a bright Sky-colour, and then a purple, which was less in quantity than the blue, and much inclined to red.

The sixth red was at first of a very fair and lively Scarlet, and soon after of a brighter Colour, being very pure and brisk, and the best of all the reds. Then after a lively orange follow'd an intense bright and copious yellow, which was also the best of all the yellows; and this changed first to a greenish yellow, and then to a greenish blue; but the green between the yellow and the blue, was very little and dilute, seeming rather a greenish white than a green. The blue which succeeded became very good, and of a very fair bright Sky-colour, but yet something inferior to the former blue; aud the violet was intense and deep with little or no redness in it. And less in quantity than the blue.

In the last red appeared a tincture of scarlet next to violet, which soon changed to a brighter Colour, inclining to an orange; and the yellow which follow'd was at first pretty good and lively, but afterwards it grew more dilute, until by degrees it ended in perfect whiteness. And this whiteness, if the Water was very tenacious and well temper'd, would slowly spread and dilate it self over the greater part of the Bubble; continually growing paler at the top, where at length it would crack in many places, and those cracks, as they dilated, would appear

of

of a pretty good, but yet obſcure and dark Sky-colour; the white between the blue Spots diminiſhing, until it reſembled the Threds of an irregular Net-work, and ſoon after vaniſh'd and left all the upper part of the Bubble of the ſaid dark blue Colour. And this Colour, after the aforeſaid manner, dilated it ſelf downwards, until ſometimes it hath overſpread the whole Bubble. In the mean while at the top, which was of a darker blue than the bottom, and appear'd alſo full of many round blue Spots, ſomething darker than the reſt, there would emerge one or more very black Spots, and within thoſe, other Spots of an intenſer blackneſs, which I mention'd in the former Obſervation; and theſe continually dilated themſelves until the Bubble broke.

If the Water was not very tenacious the black Spots would break forth in the white, without any ſenſible intervention of the blue. And ſometimes they would break forth within the precedent yellow, or red, or perhaps within the blue of the ſecond order, before the intermediate Colours had time to diſplay themſelves.

By this deſcription you may perceive how great an affinity theſe Colours have with thoſe of Air deſcribed in the fourth Obſervation, although ſet down in a contrary order, by reaſon that they begin to appear when the Bubble is thickeſt, and are moſt conveniently reckon'd from the loweſt and thickeſt part of the Bubble upwards.

*Obſ.* 19. Viewing in ſeveral oblique Poſitions of my Eye the Rings of Colours emerging on the

the top of the Bubble, I found that they were ſenſibly dilated by increaſing the obliquity, but yet not ſo much by far as thoſe made by thinn'd Air in the ſeventh Obſervation. For there they were dilated ſo much as, when view'd moſt obliquely, to arrive at a part of the Plate more than twelve times thicker than that where they appear'd when viewed perpendicularly; whereas in this caſe the thickneſs of the Water, at which they arrived when viewed moſt obliquely, was to that thickneſs which exhibited them by perpendicular Rays, ſomething leſs than as 8 to 5. By the beſt of my Obſervations it was between 15 and 15½ to 10; an increaſe about 24 times leſs than in the other caſe.

Sometimes the Bubble would become of an uniform thickneſs all over, except at the top of it near the black Spot, as I knew, becauſe it would exhibit the ſame appearance of Colours in all Poſitions of the Eye. And then the Colours which were ſeen at its apparent circumference by the obliqueſt Rays, would be different from thoſe that were ſeen in other places, by Rays leſs oblique to it. And divers Spectators might ſee the ſame part of it of differing Colours, by viewing it at very differing Obliquities. Now obſerving how much the Colours at the ſame places of the Bubble, or at divers places of equal thickneſs, were varied by the ſeveral Obliquities of the Rays; by the aſſiſtance of the 4th, 14th, 16th and 18th Obſervations, as they are hereafter explain'd, I collect the thickneſs of the Water requiſite to exhibit any one and the ſame Colour, at ſeveral Obliquities,

to

to be very nearly in the Proportion expreſſed in this Table.

| *Incidence on the Water.* | | *Refraction into the Water.* | | *Thickneſs of the Water.* |
|---|---|---|---|---|
| Deg. | Min. | Deg. | Min. | |
| 00 | 00 | 00 | 00 | 10 |
| 15 | 00 | 11 | 11 | $10\frac{1}{4}$ |
| 30 | 00 | 22 | 1 | $10\frac{4}{5}$ |
| 45 | 00 | 32 | 2 | $11\frac{4}{5}$ |
| 60 | 00 | 40 | 30 | 13 |
| 75 | 00 | 46 | 25 | $14\frac{1}{2}$ |
| 90 | 00 | 48 | 35 | $15\frac{1}{5}$ |

In the two firſt Columns are expreſs'd the Obliquities of the Rays to the Superficies of the Water, that is, their Angles of Incidence and Refraction. Where I ſuppoſe that the Sines which meaſure them are in round Numbers, as 3 to 4, though probably the diſſolution of Soap in the Water, may a little alter its refractive Virtue. In the third Column the thickneſs of the Bubble, at which any one Colour is exhibited in thoſe ſeveral Obliquities, is expreſs'd in parts, of which ten conſtitute its thickneſs when the Rays are perpendicular. And the Rule found by the ſeventh Obſervation agrees well with theſe Meaſures, if duly apply'd; namely, that the thickneſs of a Plate of Water requiſite to exhibit one and the ſame Colour at ſeveral Obliquities of the Eye, is proportional to the ſecant of an Angle whoſe Sine is the firſt of an hundred and ſix arithmetical mean Proportionals between the Sines of Incidence and Refraction counted from the leſſer Sine, that is, from the Sine of Refraction when the Refraction is made out of Air into Water, otherwiſe from the Sine of Incidence.

I have ſometimes obſerv'd, that the Colours which ariſe on poliſh'd Steel by heating it, or on Bell-metal, and ſome other metalline Subſtances, when melted and pour'd on the ground, where they may cool in the open Air, have, like the Colours of Water-bubbles, been a little changed by viewing them at divers Obliquities, and particularly that a deep blue, or violet, when view'd very obliquely, hath been changed to a deep red. But the Changes of theſe Colours are not ſo great and ſenſible as of thoſe made by Water. For the Scoria or vitrified part of the Metal, which moſt Metals when heated or melted do continually protrude, and ſend out to their Surface, and which by covering the Metals in form of a thin glaſſy Skin, cauſes theſe Colours, is much denſer than Water; and I find that the Change made by the Obliquation of the Eye is leaſt in Colours of the denſeſt thin Subſtances.

*Obſ.* 20. As in the ninth Obſervation, ſo here, the Bubble, by tranſmitted Light, appear'd of a contrary Colour to that which it exhibited by Reflexion. Thus when the Bubble being look'd on by the Light of the Clouds reflected from it, ſeemed red at its apparent circumference, if the Clouds at the ſame time, or immediately after, were view'd through it, the Colour at its circumference would be blue. And, on the contrary,

contrary, when by reflected Light it appeared blue, it would appear red by tranſmitted Light.

*Obſ.* 21. By wetting very thin Plates of Muſcovy Glaſs, whoſe thinneſs made the like Colours appear, the Colours became more faint and languid, eſpecially by wetting the Plates on that ſide oppoſite to the Eye: But I could not perceive any variation of their Species. So then the thickneſs of a Plate requiſite to produce any Colour, depends only on the denſity of the Plate, and not on that of the ambient Medium. And hence, by the 10th and 16th Obſervations, may be known the thickneſs which Bubbles of Water, or Plates of Muſcovy Glaſs, or other Subſtances, have at any Colour produced by them.

*Obſ.* 22. A thin tranſparent Body, which is denſer than its ambient Medium, exhibits more briſk and vivid Colours than that which is ſo much rarer; as I have particularly obſerved in the Air and Glaſs. For blowing Glaſs very thin at a Lamp Furnace, thoſe Plates encompaſſed with Air did exhibit Colours much more vivid than thoſe of Air made thin between two Glaſſes.

*Obſ.* 23. Comparing the quantity of Light reflected from the ſeveral Rings, I found that it was moſt copious from the firſt or inmoſt, and in the exterior Rings became gradually leſs and leſs. Alſo the whiteneſs of the firſt Ring was ſtronger than that reflected from thoſe parts of the thin Medium or Plate which were without the Rings; as I could manifeſtly perceive by viewing at a diſtance the Rings made

O 2 by

by the two Object-glasses; or by comparing two Bubbles of Water blown at distant times, in the first of which the whiteness appear'd, which succeeded all the Colours, and in the other, the whiteness which preceded them all.

*Obs.* 24. When the two Object-glasses were lay'd upon one another, so as to make the Rings of the Colours appear, though with my naked Eye I could not discern above eight or nine of those Rings, yet by viewing them through a Prism I have seen a far greater multitude, insomuch that I could number more than forty, besides many others, that were so very small and close together, that I could not keep my Eye steady on them severally so as to number them, but by their Extent I have sometimes estimated them to be more than an hundred. And I believe the Experiment may be improved to the discovery of far greater Numbers. For they seem to be really unlimited, though visible only so far as they can be separated by the Refraction, as I shall hereafter explain.

But it was but one side of these Rings, namely, that towards which the Refraction was made, which by that Refraction was render'd distinct, and the other side became more confused than when view'd by the naked Eye, insomuch that there I could not discern above one or two, and sometimes none of those Rings, of which I could discern eight or nine with my naked Eye. And their Segments or Arcs, which on the other side appear'd so numerous, for the most part exceeded not the third part of a Circle. If the Refraction was very great, or the

Prism

Priſm very diſtant from the Object-glaſſes, the middle part of thoſe Arcs became alſo confuſed, ſo as to diſappear and conſtitute an even whiteneſs, whilſt on either ſide their ends, as alſo the whole Arcs fartheſt from the center, became diſtincter than before, appearing in the form as you ſee them deſign'd in the fifth Figure.

The Arcs, where they ſeem'd diſtincteſt, were only white and black ſucceſſively, without any other Colours intermix'd. But in other places there appeared Colours, whoſe order was inverted by the Refraction in ſuch manner, that if I firſt held the Priſm very near the Object-glaſſes, and then gradually removed it farther off towards my Eye, the Colours of the 2d, 3d, 4th, and following Rings ſhrunk towards the white that emerged between them, until they wholly vaniſh'd into it at the middle of the Arcs, and afterwards emerged again in a contrary order. But at the ends of the Arcs they retain'd their order unchanged.

I have ſometimes ſo lay'd one Object-glaſs upon the other, that to the naked Eye they have all over ſeem'd uniformly white, without the leaſt appearance of any of the colour'd Rings; and yet by viewing them through a Priſm, great multitudes of thoſe Rings have diſcover'd themſelves. And in like manner Plates of Muſcovy Glaſs, and Bubbles of Glaſs blown at a Lamp Furnace, which were not ſo thin as to exhibit any Colours to the naked Eye, have through the Priſm exhibited a great variety of them ranged irregularly up and down in the form of Waves. And so Bubbles of Water, before they began to exhibit their Colours to the naked Eye of a By-stander, have appeared through a Prism, girded about with many parallel and horizontal Rings; to produce which Effect, it was necessary to hold the Prism parallel, or very nearly parallel to the Horizon, and to dispose it so that the Rays might be refracted upwards.

Fig. 1.

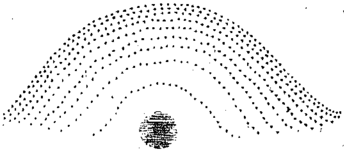


Fig. 2.

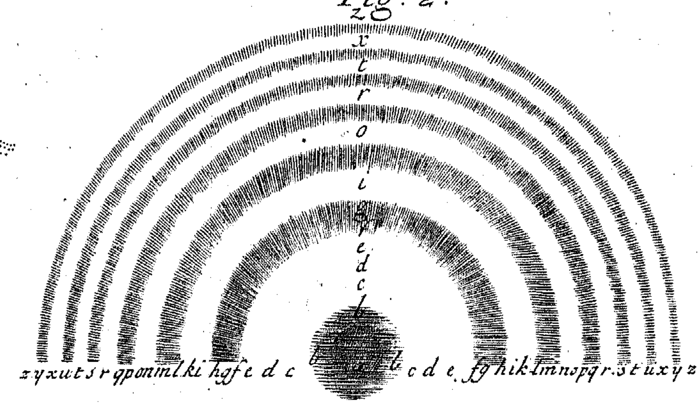



Fig. 3.

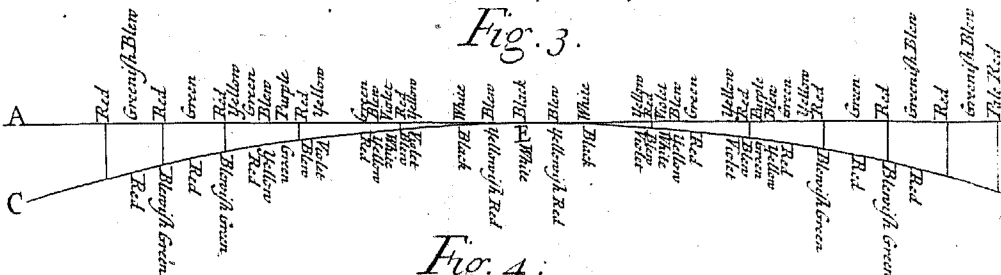



Fig. 4.

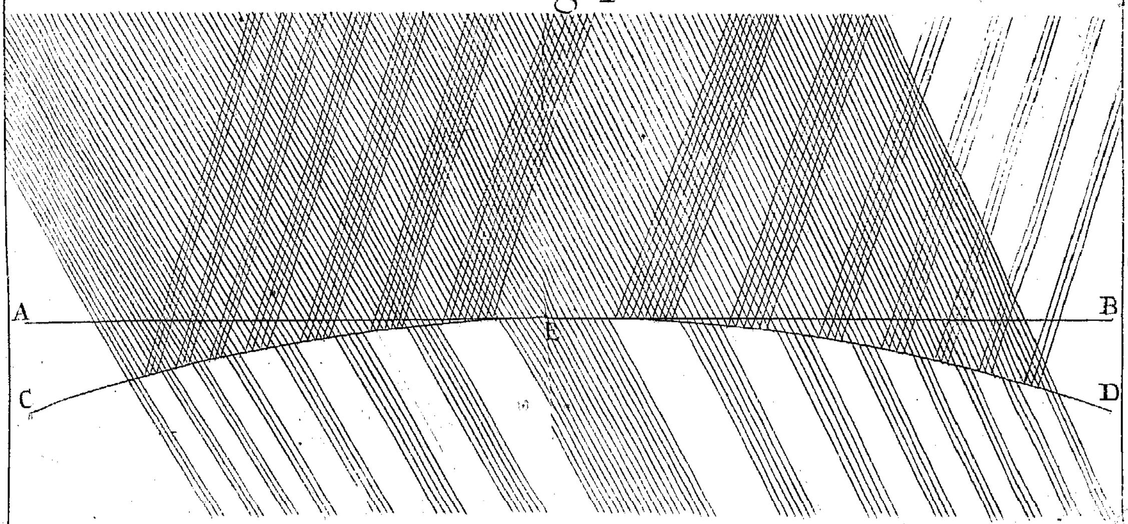


Fig. 5.

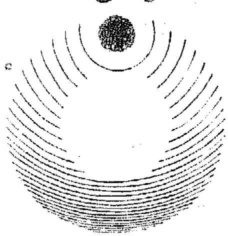
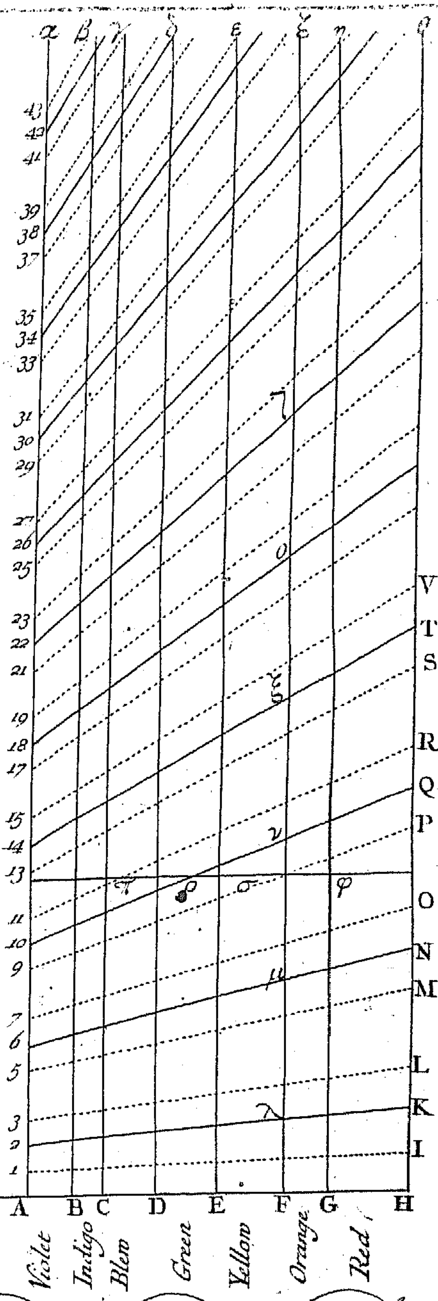


Fig: 6.



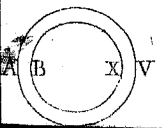
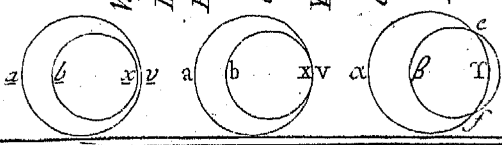




Fig. 7



# THE SECOND BOOK OF OPTICKS.

## PART II.

*Remarks upon the foregoing Observations.*

HAVING given my Obſervations of theſe Colours, before I make uſe of them to unfold the Cauſes of the Colours of natural Bodies, it is convenient that by the ſimpleſt of them, ſuch as are the 2d, 3d, 4th, 9th, 12th, 18th, 20th, and 24th, I firſt explain the more compounded. And first to shew how the Colours in the fourth and eighteenth Observations are produced, let there be taken in any right Line from the Point Y, [in *Fig.* 6.] the lengths YA, YB, YC, YD, YE, YF, YG, YH, in proportion to one another, as the Cube Roots of the Squares of the Numbers, $\frac{1}{2}$, $\frac{9}{16}$, $\frac{3}{5}$, $\frac{2}{3}$, $\frac{3}{4}$, $\frac{5}{6}$, $\frac{8}{9}$, 1, whereby the lengths of a musical Chord to sound all the Notes in an eighth are represented; that is, in the proportion of the Numbers 6300, 6814, 7114, 7631, 8255, 8855, 9243, 10000. And at the Points A, B, C, D, E, F, G, H, let perpendiculars A$\alpha$, B$\beta$, &c. be erected, by whose Intervals the Extent of the several Colours set underneath against them, is to be represented. Then divide the Line A$\alpha$ in such proportion as the Numbers 1, 2, 3, 5, 6, 7, 9, 10, 11, &c. set at the Points of Division denote. And through those Divisions from Y draw Lines 1 I, 2 K, 3 L, 5 M, 6 N, 7 O, &c.

Now if A 2 be supposed to represent the thickness of any thin transparent Body, at which the outmost violet is most copiously reflected in the first Ring, or Series of Colours, then by the 13th Observation, HK will represent its thickness, at which the utmost red is most copiously reflected in the same Series. Also by the 5th and 16th Observations, A 6 and HN will denote the thicknesses at which those extreme Colours are most copiously reflected in the second Series, and A 10 and HQ the thicknesses, at which they are most copiously reflected in the third Series, and so on. And the thickness at which any of the intermediate Colours

lours are reflected most copiously, will, according to the 14th Observation, be defined by the distance of the Line AH from the intermediate parts of the Lines 2K, 6N, 10Q, &c. against which the Names of those Colours are written below.

But farther, to define the Latitude of these Colours in each Ring or Series, let A 1 design the least thickness, and A 3 the greatest thickness, at which the extreme violet in the first Series is reflected, and let HI, and HL, design the like limits for the extreme red, and let the intermediate Colours be limited by the intermediate parts of the Lines 1 I, and 3 L, against which the Names of those Colours are written, and so on: But yet with this caution, that the Reflexions be supposed strongest at the intermediate Spaces, 2 K, 6 N, 10Q, &c. and from thence to decrease gradually towards these limits, 1I, 3L, 5M, 7O, &c. on either side; where you must not conceive them to be precisely limited, but to decay indefinitely. And whereas I have assign'd the same Latitude to every Series, I did it, because although the Colours in the first Series seem to be a little broader than the rest, by reason of a stronger Reflexion there, yet that inequality is so insensible as scarcely to be determin'd by Observation.

Now according to this Description, conceiving that the Rays originally of several Colours are by turns reflected at the Spaces 1 I L 3, 5 M O 7, 9 P R 11, &c. and transmitted at the Spaces AHI 1, 3 L M 5, 7 O P 9, &c. it is easy to know

what

what Colour must in the open Air be exhibited at any thickness of a transparent thin Body. For if a Ruler be applied parallel to AH, at that distance from it by which the thickness of the Body is represented the alternate Spaces 1 I L 3, 5 M O 7, &c. which it crosseth will denote the reflected original Colours, of which the Colour exhibited in the open Air is compounded. Thus if the constitution of the green in the third Series of Colours be desired, apply the Ruler as you see at $\pi\varrho\sigma\phi$, and by its passing through some of the blue at $\pi$ and yellow at $\sigma$, as well as through the green at $\varrho$, you may conclude that the green exhibited at that thickness of the Body is principally constituted of original green, but not without a mixture of some blue and yellow.

By this means you may know how the Colours from the center of the Rings outward ought to succeed in order as they were described in the 4th and 18th Observations. For if you move the Ruler gradually from AH through all distances, having pass'd over the first Space which denotes little or no Reflexion to be made by thinnest Substances, it will first arrive at 1 the violet, and then very quickly at the blue and green, which together with that violet compound blue, and then at the yellow and red, by whose farther addition that blue is converted into whiteness, which whiteness continues during the transit of the edge of the Ruler from I to 3, and after that by the successive deficience of its component Colours, turns first to compound yellow, and then to red, and last of

all

all the red ceaseth at L. Then begin the Colours of the second Series, which succeed in order during the transit of the edge of the Ruler from 5 to O, and are more lively than before, because more expanded and severed. And for the same reason, instead of the former white there intercedes between the blue and yellow a mixture of orange, yellow, green, blue and indigo, all which together ought to exhibit a dilute and imperfect green. So the Colours of the third Series all succeed in order; first, the violet, which a little interferes with the red of the second order, and is thereby inclined to a reddish purple; then the blue and green, which are less mix'd with other Colours, and consequently more lively than before, especially the green: Then follows the yellow, some of which towards the green is distinct and good, but that part of it towards the succeeding red, as also that red is mix'd with the violet and blue of the fourth Series, whereby various degrees of red very much inclining to purple are compounded. This violet and blue, which should succeed this red, being mixed with, and hidden in it, there succeeds a green. And this at first is much inclined to blue, but soon becomes a good green, the only unmix'd and lively Colour in this fourth Series. For as it verges towards the yellow, it begins to interfere with the Colours of the fifth Series, by whose mixture the succeeding yellow and red are very much diluted and made dirty, especially the yellow, which being the weaker Colour is scarce able to shew it self.

After

After this the ſeveral Series interfere more and more, and their Colours become more and more intermix'd, till after three or four more revolutions (in which the red and blue predominate by turns) all ſorts of Colours are in all places pretty equally blended, and compound an even whiteneſs.

And ſince by the 15th Obſervation the Rays endued with one Colour are tranſmitted, where thoſe of another Colour are reflected, the reaſon of the Colours made by the tranſmitted Light in the 9th and 20th Obſervations is from hence evident.

If not only the Order and Species of theſe Colours, but alſo the preciſe thickneſs of the Plate, or thin Body at which they are exhibited, be deſired in parts of an Inch, that may be alſo obtained by aſſiſtance of the 6th or 16th Obſervations. For according to thoſe Obſervations the thickneſs of the thinned Air, which between two Glaſſes exhibited the moſt luminous parts of the firſt ſix Rings were $\frac{1}{178000}$, $\frac{3}{178000}$, $\frac{5}{178000}$, $\frac{7}{178000}$, $\frac{9}{178000}$, $\frac{11}{178000}$ parts of an Inch. Suppoſe the Light reflected moſt copiouſly at theſe thickneſſes be the bright citrine yellow, or confine of yellow and orange, and theſe thickneſſes will be F$\mu$, F$\nu$, F$\xi$, F$o$, F$\tau$. And this being known, it is eaſy to determine what thickneſs of Air is repreſented by G$\varphi$, or by any other diſtance of the Ruler from AH.

But farther, ſince by the 10th Obſervation the thickneſs of Air was to the thickneſs of Water, which

which between the ſame Glaſſes exhibited the ſame Colour, as 4 to 3, and by the 21ſt Obſervation the Colours of thin Bodies are not varied by varying the ambient Medium; the thickneſs of a Bubble of Water, exhibiting any Colour, will be $\frac{3}{4}$ of the thickneſs of Air producing the ſame Colour. And ſo according to the ſame 10th and 21ſt Obſervations the thickneſs of a Plate of Glaſs, whoſe Refraction of the mean refrangible Ray, is meaſured by the proportion of the Sines 31 to 20, may be $\frac{20}{31}$ of the thickneſs of Air producing the ſame Colours; and the like of other Mediums. I do not affirm, that this proportion of 20 to 31, holds in all the Rays; for the Sines of other ſorts of Rays have other Proportions. But the differences of thoſe Proportions are ſo little that I do not here conſider them. On theſe Grounds I have compoſed the following Table, wherein the thickneſs of Air, Water, and Glaſs, at which each Colour is moſt intenſe and ſpecifick, is expreſſed in parts of an Inch divided into ten hundred thouſand equal parts.

*The*

*The thickness of colour'd Plates and Particles of*

| | | Air. | Water. | Glass. |
|---|---|---|---|---|
| Their Colours of the first Order, | Very black | $\frac{1}{2}$ | $\frac{3}{8}$ | $\frac{10}{31}$ |
| | Black | 1 | $\frac{3}{4}$ | $\frac{20}{31}$ |
| | Beginning of Black | 2 | $1\frac{1}{2}$ | $1\frac{2}{7}$ |
| | Blue | $2\frac{2}{5}$ | $1\frac{4}{5}$ | $1\frac{11}{22}$ |
| | White | $5\frac{1}{4}$ | $3\frac{7}{8}$ | $3\frac{2}{5}$ |
| | Yellow | $7\frac{1}{9}$ | $5\frac{1}{3}$ | $4\frac{3}{5}$ |
| | Orange | 8 | 6 | $5\frac{1}{6}$ |
| | Red | 9 | $6\frac{3}{4}$ | $5\frac{4}{5}$ |
| Of the second Order, | Violet | $11\frac{1}{6}$ | $8\frac{3}{8}$ | $7\frac{1}{5}$ |
| | Indigo | $12\frac{5}{6}$ | $9\frac{5}{8}$ | $8\frac{2}{11}$ |
| | Blue | 14 | $10\frac{1}{2}$ | 9 |
| | Green | $15\frac{1}{8}$ | $11\frac{1}{3}$ | $9\frac{5}{7}$ |
| | Yellow | $16\frac{2}{7}$ | $12\frac{1}{5}$ | $10\frac{2}{5}$ |
| | Orange | $17\frac{2}{9}$ | 13 | $11\frac{1}{9}$ |
| | Bright red | $18\frac{1}{3}$ | $13\frac{3}{4}$ | $11\frac{5}{6}$ |
| | Scarlet | $19\frac{2}{3}$ | $14\frac{3}{4}$ | $12\frac{2}{3}$ |
| Of the third Order, | Purple | 21 | $15\frac{3}{4}$ | $13\frac{11}{20}$ |
| | Indigo | $22\frac{1}{10}$ | $16\frac{4}{7}$ | $14\frac{1}{4}$ |
| | Blue | $23\frac{2}{5}$ | $17\frac{11}{20}$ | $15\frac{1}{10}$ |
| | Green | $25\frac{1}{5}$ | $18\frac{2}{10}$ | $16\frac{1}{4}$ |
| | Yellow | $27\frac{1}{7}$ | $20\frac{1}{3}$ | $17\frac{1}{2}$ |
| | Red | 29 | $21\frac{3}{4}$ | $18\frac{5}{7}$ |
| | Bluish red | 32 | 24 | $20\frac{2}{3}$ |
| Of the fourth Order, | Bluish green | 34 | $25\frac{1}{2}$ | 22 |
| | Green | $35\frac{2}{7}$ | $26\frac{1}{2}$ | $22\frac{3}{4}$ |
| | Yellowish green | 36 | 27 | $23\frac{2}{9}$ |
| | Red | $40\frac{1}{3}$ | $30\frac{1}{4}$ | 26 |
| Of the fifth Order, | Greenish blue | 46 | $34\frac{1}{2}$ | $29\frac{2}{3}$ |
| | Red | $52\frac{1}{2}$ | $39\frac{3}{8}$ | 34 |
| Of the sixth Order, | Greenish blue | $58\frac{3}{4}$ | 44 | 38 |
| | Red | 65 | $48\frac{3}{4}$ | 42 |
| Of the seventh Order, | Greenish blue | 71 | $53\frac{1}{4}$ | $45\frac{4}{5}$ |
| | Ruddy white | 77 | $57\frac{3}{4}$ | $49\frac{2}{3}$ |

Now

Now if this Table be compared with the 6th Scheme, you will there ſee the conſtitution of each Colour, as to its Ingredients, or the original Colours of which it is compounded, and thence be enabled to judge of its Intenſeneſs or Imperfection; which may ſuffice in explication of the 4th and 18th Obſervations, unleſs it be farther deſired to delineate the manner how the Colours appear, when the two Object-glaſſes are laid upon one another. To do which, let there be deſcribed a large Arc of a Circle, and a ſtreight Line which may touch that Arc, and parallel to that Tangent ſeveral occult Lines, at ſuch diſtances from it, as the Numbers ſet againſt the ſeveral Colours in the Table denote. For the Arc, and its Tangent, will repreſent the Superficies of the Glaſſes terminating the interjacent Air; and the places where the occult Lines cut the Arc will ſhow at what diſtances from the center, or Point of contact, each Colour is reflected.

There are alſo other Uſes of this Table: For by its aſſiſtance the thickneſs of the Bubble in the 19th Obſervation was determin'd by the Colours which it exhibited. And ſo the bigneſs of the parts of natural Bodies may be conjectured by their Colours, as ſhall be hereafter ſhewn. Alſo, if two or more very thin Plates be laid one upon another, ſo as to compoſe one Plate equalling them all in thickneſs, the reſulting Colour may be hereby determin'd. For inſtance, Mr. *Hook* obſerved, as is mentioned in his *Micrographia*, that a faint yellow Plate of Muſcovy Glaſs laid upon a blue one, conſtituted

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a very deep purple. The yellow of the first Order is a faint one, and the thickness of the Plate exhibiting it, according to the Table is $4\frac{3}{5}$, to which add 9, the thickness exhibiting blue of the second Order, and the Sum will be $13\frac{3}{5}$, which is the thickness exhibiting the purple of the third Order.

To explain, in the next place, the circumstances of the 2d and 3d Observations; that is, how the Rings of the Colours may (by turning the Prisms about their common Axis the contrary way to that expressed in those Observations) be converted into white and black Rings, and afterwards into Rings of Colours again, the Colours of each Ring lying now in an inverted order; it must be remember'd, that those Rings of Colours are dilated by the obliquation of the Rays to the Air which intercedes the Glasses, and that according to the Table in the 7th Observation, their Dilatation or Increase of their Diameter is most manifest and speedy when they are obliquest. Now the Rays of yellow being more refracted by the first Superficies of the said Air than those of red, are thereby made more oblique to the second Superficies, at which they are reflected to produce the colour'd Rings, and consequently the yellow Circle in each Ring will be more dilated than the red; and the Excess of its Dilatation will be so much the greater, by how much the greater is the obliquity of the Rays, until at last it become of equal extent with the red of the same Ring. And for the same reason the green, blue and violet, will be also so much dilated by the

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ſtill greater obliquity of their Rays, as to become all very nearly of equal extent with the red, that is, equally diſtant from the center of the Rings. And then all the Colours of the ſame Ring muſt be coincident, and by their mixture exhibit a white Ring. And theſe white Rings muſt have black and dark Rings between them, becauſe they do not ſpread and interfere with one another as before. And for that reaſon alſo they muſt become diſtincter and viſible to far greater numbers. But yet the violet being obliqueſt will be ſomething more dilated in proportion to its extent than the other Colours, and ſo very apt to appear at the exterior Verges of the white.

Afterwards, by a greater obliquity of the Rays, the violet and blue become more ſenſibly dilated than the red and yellow, and ſo being farther removed from the center of the Rings, the Colours muſt emerge out of the white in an order contrary to that which they had before, the violet and blue at the exterior Limbs of each Ring, and the red and yellow at the interior. And the violet, by reaſon of the greateſt obliquity of its Rays, being in proportion moſt of all expanded, will ſooneſt appear at the exterior Limb of each white Ring, and become more conſpicuous than the reſt. And the ſeveral Series of Colours belonging to the ſeveral Rings, will by their unfolding and ſpreading, begin again to interfere, and thereby render the Rings leſs diſtinct, and not viſible to ſo great numbers.

If instead of the Prisms the Object-glasses be made use of, the Rings which they exhibit become not white and distinct by the obliquity of the Eye, by reason that the Rays in their passage through that Air which intercedes the Glasses are very nearly parallel to those Lines in which they were first incident on the Glasses, and consequently the Rays endued with several Colours are not inclined one more than another to that Air, as it happens in the Prisms.

There is yet another circumstance of these Experiments to be consider'd, and that is why the black and white Rings which when view'd at a distance appear distinct, should not only become confused by viewing them near at hand, but also yield a violet Colour at both the edges of every white Ring. And the reason is, that the Rays which enter the Eye at several parts of the Pupil, have several Obliquities to the Glasses, and those which are most oblique, if consider'd apart, would represent the Rings bigger than those which are the least oblique. Whence the breadth of the Perimeter of every white Ring is expanded outwards by the obliquest Rays, and inwards by the least oblique. And this Expansion is so much the greater by how much the greater is the difference of the Obliquity; that is, by how much the Pupil is wider, or the Eye nearer to the Glasses. And the breadth of the violet must be most expanded, because the Rays apt to excite a Sensation of that Colour are most oblique to a second, or farther Superficies of the thinn'd Air at which they are reflected, and have also the greatest variation of Obliquity, which makes that Colour sooneſt emerge out of the edges of the white. And as the breadth of every Ring is thus augmented, the dark Intervals muſt be diminiſh'd, until the neighbouring Rings become continuous, and are blended, the exterior firſt, and then thoſe nearer the center, ſo that they can no longer be diſtinguiſh'd apart, but ſeem to conſtitute an even and uniform whiteneſs.

Among all the Obſervations there is none accompanied with ſo odd circumſtances as the twenty fourth. Of thoſe the principal are, that in thin Plates, which to the naked Eye ſeem of an even and uniform tranſparent whiteneſs, without any terminations of Shadows, the Refraction of a Priſm ſhould make Rings of Colours appear, whereas it uſually makes Objects appear colour'd only there where they are terminated with Shadows, or have parts unequally luminous; and that it ſhould make thoſe Rings exceedingly diſtinct and white, although it uſually renders Objects confuſed and coloured. The Cauſe of theſe things you will underſtand by conſidering, that all the Rings of Colours are really in the Plate, when view'd with the naked Eye, although by reaſon of the great breadth of their Circumferences they ſo much interfere and are blended together, that they ſeem to conſtitute an uniform whiteneſs. But when the Rays paſs through the Priſm to the Eye, the Orbits of the ſeveral Colours in every Ring are refracted, ſome more than others, according to their degrees of Refrangibility: By which means the Colours on one ſide of the

Ring (that is on one ſide of its center) become more unfolded and dilated, and thoſe on the other ſide more complicated and contracted. And where by a due Refraction they are ſo much contracted, that the ſeveral Rings become narrower than to interfere with one another, they muſt appear diſtinct, and alſo white, if the conſtituent Colours be ſo much contracted as to be wholly coincident. But, on the other ſide, where the Orbit of every Ring is made broader by the farther unfolding of its Colours, it muſt interfere more with other Rings than before, and ſo become leſs diſtinct.

To explain this a little farther, ſuppoſe the concentrick Circles AV, and BX, [in *Fig.* 7.] repreſent the red and violet of any Order, which, together with the intermediate Colours, conſtitute any one of theſe Rings. Now theſe being view'd through a Priſm, the violet Circle BX, will by a greater Refraction be farther tranſlated from its place than the red AV, and ſo approach nearer to it on that ſide of the Circles, towards which the Refractions are made. For inſtance, if the red be tranſlated to *av*, the violet may be tranſlated to *bx*, ſo as to approach nearer to it at *x* than before, and if the red be farther tranſlated to a v, the violet may be ſo much farther tranſlated to b x as to convene with it at x, and if the red be yet farther tranſlated to $\alpha \Upsilon$, the violet may be ſtill ſo much farther tranſlated to $\beta \xi$ as to paſs beyond it at $\xi$, and convene with it at *e* and *f*. And this being underſtood not only of the red and violet, but of all the other intermediate Colours,

and

and alſo of every revolution of thoſe Colours, you will eaſily perceive how thoſe of the ſame revolution or order, by their nearneſs at *x v* and Υ ξ, and their coincidence at x v, *e* and *f*, ought to conſtitute pretty diſtinct Arcs of Circles, eſpecially at x v, or at *e* and *f*, and that they will appear ſeverally at *x v*, and at x v exhibit whiteneſs by their coincidence, and again appear ſeveral at Υ ξ, but yet in a contrary order to that which they had before, and ſtill retain beyond *e* and *f*. But, on the other ſide, at *a b*, a b, or α β, theſe Colours muſt become much more confuſed by being dilated and ſpread ſo, as to interfere with thoſe of other Orders. And the ſame confuſion will happen at Υ ξ between *e* and *f*, if the Refraction be very great, or the Priſm very diſtant from the Object-glaſſes: In which caſe no parts of the Rings will be ſeen, ſave only two little Arcs at *e* and *f*, whoſe diſtance from one another, will be augmented by removing the Priſm ſtill farther from the Object-glaſſes: And theſe little Arcs muſt be diſtincteſt and whiteſt at their middle, and at their ends, where they begin to grow confuſed they muſt be colour'd. And the Colours at one end of every Arc muſt be in a contrary order to thoſe at the other end, by reaſon that they croſs in the intermediate white; namely, their ends, which verge towards Υ ξ, will be red and yellow on that ſide next the center, and blue and violet on the other ſide. But their other ends which verge from Υ ξ will on the contrary be blue and violet on that ſide towards the center, and on the other side red and yellow.

Now as all these things follow from the properties of Light by a mathematical way of reasoning, so the truth of them may be manifested by Experiments. For in a dark Room, by viewing these Rings through a Prism, by reflexion of the several prismatick Colours, which an assistant causes to move to and fro upon a Wall or Paper from whence they are reflected, whilst the Spectator's Eye, the Prism and the Object-glasses (as in the 13th Observation) are placed steady: the Position of the Circles made successively by the several Colours, will be found such, in respect of one another, as I have described in the Figures *abxv*, or abxv, or αβξΥ. And by the same method the truth of the Explications of other Observations may be examined.

By what hath been said, the like Phænomena of Water, and thin Plates of Glass may be understood. But in small fragments of those Plates, there is this farther observable, that where they lye flat upon a Table and are turned about their centers whilst they are viewed through a Prism, they will in some postures exhibit Waves of various Colours, and some of them exhibit these Waves in one or two Positions only, but the most of them do in all Positions exhibit them, and make them for the most part appear almost all over the Plates. The reason is, that the Superficies of such Plates are not even, but have many Cavities and Swellings, which how shallow soever do a little vary the thickness of the

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the Plate. For at the ſeveral ſides of thoſe Cavities, for the Reaſons newly deſcribed, there ought to be produced Waves in ſeveral poſtures of the Priſm. Now though it be but ſome very ſmall, and narrower parts of the Glaſs, by which theſe Waves for the moſt part are cauſed, yet they may ſeem to extend themſelves over the whole Glaſs, becauſe from the narroweſt of thoſe parts there are Colours of ſeveral Orders, that is of ſeveral Rings, confuſedly reflected, which by Refraction of the Priſm are unfolded, ſeparated, and according to their degrees of Refraction, diſperſed to ſeveral places, ſo as to conſtitute ſo many ſeveral Waves, as there were divers orders of Colours promiſcuouſly reflected from that part of the Glaſs.

Theſe are the principal Phænomena of thin Plates or Bubbles, whoſe Explications depend on the properties of Light, which I have heretofore deliver'd. And theſe you ſee do neceſſarily follow from them, and agree with them, even to their very leaſt circumſtances; and not only ſo, but do very much tend to their proof. Thus, by the 24th Obſervation, it appears, that the Rays of ſeveral Colours made as well by thin Plates or Bubbles, as by Refractions of a Priſm, have ſeveral degrees of Refrangibility, whereby thoſe of each order, which at the reflexion from the Plate or Bubble are intermix'd with thoſe of other Orders, are ſeparated from them by Refraction, and aſſociated together ſo as to become viſible by themſelves like Arcs of Circles. For if the Rays were all alike refrangible, 'tis impoſſible that the whiteneſs, which to the naked Senſe appears uniform, ſhould by Refraction have its parts tranſpoſed and ranged into thoſe black and white Arcs.

It appears alſo that the unequal Refractions of difform Rays proceed not from any contingent irregularities; ſuch as are Veins, an uneven Poliſh, or fortuitous Poſition of the Pores of Glaſs; unequal and caſual Motions in the Air or Æther, the ſpreading, breaking, or dividing the ſame Ray into many diverging parts, or the like. For, admitting any ſuch irregularities, it would be impoſſible for Refractions to render thoſe Rings ſo very diſtinct, and well defined, as they do in the 24th Obſervation. It is neceſſary therefore that every Ray have its proper and conſtant degree of Refrangibility connate with it, according to which its refraction is ever juſtly and regularly perform'd, and that ſeveral Rays have ſeveral of thoſe degrees.

And what is ſaid of their Refrangibility may be alſo underſtood of their Reflexibility, that is of their Diſpoſitions to be reflected ſome at a greater, and others at a leſs thickneſs, of thin Plates or Bubbles, namely, that thoſe Diſpoſitions are alſo connate with the Rays, and immutable; as may appear by the 13th, 14th, and 15th Obſervations compared with the fourth and eighteenth.

By the precedent Obſervations it appears alſo, that whiteneſs is a diſſimilar mixture of all Colours, and that Light is a mixture of Rays endued with all thoſe Colours. For conſidering the multitude of the Rings of Colours, in the 3d, 12th and 24th Obſervations, it is manifeſt,

feſt, that although in the 4th and 18th Obſervations there appear no more than eight or nine of thoſe Rings, yet there are really a far greater number, which ſo much interfere and mingle with one another, as after thoſe eight or nine revolutions to dilute one another wholly, and conſtitute an even and ſenſibly uniform whiteneſs. And conſequently that whiteneſs muſt be allow'd a mixture of all Colours, and the Light which conveys it to the Eye muſt be a mixture of Rays endued with all thoſe Colours.

But farther, by the 24th Obſervation, it appears, that there is a conſtant relation between Colours and Refrangibility, the moſt refrangible Rays being violet, the leaſt refrangible red, and thoſe of intermediate Colours having proportionably intermediate degrees of Refrangibility. And by the 13th, 14th and 15th Obſervations, compared with the 4th or 18th, there appears to be the ſame conſtant relation between Colour and Reflexibility, the violet being in like circumſtances reflected at leaſt thickneſſes of any thin Plate or Bubble, the red at greateſt thickneſſes, and the intermediate Colours at intermediate thickneſſes. Whence it follows, that the colorifick Diſpoſitions of Rays are alſo connate with them and immutable, and by conſequence that all the Productions and Appearances of Colours in the World are derived not from any phyſical Change cauſed in Light by Refraction or Reflexion, but only from the various Mixtures or Separations of Rays, by virtue of their different Refrangibility or Reflexibility. And in this reſpect the Science of Colours becomes a Speculation as truly mathematical as any other part of Opticks. I mean ſo far as they depend on the Nature of Light, and are not produced or alter'd by the Power of Imagination, or by ſtriking or preſſing the Eye.

# THE SECOND BOOK OF OPTICKS.

## PART III.

*Of the permanent Colours of natural Bodies, and the Analogy between them and the Colours of thin transparent Plates.*

I AM now come to another part of this Design, which is to consider how the Phænomena of thin transparent Plates stand related to those of all other natural Bodies. Of these Bodies I have already told you that they appear of divers Colours,

lours, accordingly as they are disposed to reflect most copiously the Rays originally endued with those Colours. But their Constitutions, whereby they reflect some Rays more copiously than others, remain to be discover'd, and these I shall endeavour to manifest in the following Propositions.

### PROP. I.

*Those Superficies of transparent Bodies reflect the greatest quantity of Light, which have the greatest refracting Power; that is, which intercede Mediums that differ most in their refractive Densities. And in the Confines of equally refracting Mediums there is no Reflexion.*

THE Analogy between Reflexion and Refraction will appear by considering, that when Light passeth obliquely out of one Medium into another which refracts from the perpendicular, the greater is the difference of their refractive Density, the less Obliquity of Incidence is requisite to cause a total Reflexion. For as the Sines are which measure the Refraction, so is the Sine of Incidence at which the total Reflexion begins, to the Radius of the Circle, and consequently that Angle of Incidence is least where there is the greatest difference of the Sines. Thus in the passing of Light out of Water into Air, where the Refraction is measured by the Ratio of the Sines 3 to 4, the total Reflexion begins when the Angle of Incidence is about 48 Degrees 35 Minutes.

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In passing out of Glass into Air, where the Refraction is measured by the Ratio of the Sines 20 to 31, the total Reflexion begins when the Angle of Incidence is 40 Degrees 10 Minutes; and so in passing out of Crystal, or more strongly refracting Mediums into Air, there is still a less Obliquity requisite to cause a total Reflexion. Superficies therefore which refract most do soonest reflect all the Light which is incident on them, and so must be allowed most strongly reflexive.

But the truth of this Proposition will farther appear by observing, that in the Superficies interceding two transparent Mediums, (such as are Air, Water, Oil, common Glass, Crystal, metalline Glasses, Island Glasses, white transparent Arsenick, Diamonds, *&c.*) the Reflexion is stronger or weaker accordingly, as the Superficies hath a greater or less refracting Power. For in the Confine of Air and Sal-gem 'tis stronger than in the Confine of Air and Water, and still stronger in the Confine of Air and common Glass or Crystal, and stronger in the Confine of Air and a Diamond. If any of these, and such like transparent Solids, be immerged in Water, its Reflexion becomes much weaker than before, and still weaker if they be immerged in the more strongly refracting Liquors of well rectified Oil of Vitriol or Spirit of Turpentine. If Water be distinguish'd into two parts, by any imaginary Surface, the Reflexion in the Confine of those two parts is none at all. In the Confine of Water and Ice 'tis very little, in that of Water and Oil 'tis something greater,

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in that of Water and Sal-gem ſtill greater, and in that of Water and Glaſs, or Cryſtal, or other denſer Subſtances ſtill greater, accordingly as thoſe Mediums differ more or leſs in their refracting Powers. Hence in the Confine of common Glaſs and Cryſtal, there ought to be a weak Reflexion, and a ſtronger Reflexion in the Confine of common and metalline Glaſs, though I have not yet tried this. But, in the Confine of two Glaſſes of equal denſity, there is not any ſenſible Reflexion, as was ſhewn in the firſt Obſervation. And the ſame may be underſtood of the Superficies interceding two Cryſtals, or two Liquors, or any other Subſtances in which no Refraction is cauſed. So then the reaſon why uniform pellucid Mediums, (ſuch as Water, Glaſs, or Cryſtal) have no ſenſible Reflexion but in their external Superficies, where they are adjacent to other Mediums of a different denſity, is becauſe all their contiguous parts have one and the ſame degree of denſity.

## PROP. II.

*The leaſt parts of almoſt all natural Bodies are in ſome meaſure tranſparent: And the Opacity of thoſe Bodies ariſeth from the multitude of Reflexions cauſed in their internal Parts.*

THAT this is ſo has been obſerved by others, and will eaſily be granted by them that have been converſant with Microſcopes. And it may be alſo tried by applying any ſubſtance

ſtance to a hole through which ſome Light is immitted into a dark Room. For how opake ſoever that Subſtance may ſeem in the open Air, it will by that means appear very manifeſtly tranſparent, if it be of a ſufficient thinneſs. Only white metalline Bodies muſt be excepted, which by reaſon of their exceſſive denſity ſeem to reflect almoſt all the Light incident on their firſt Superficies, unleſs by ſolution in Menſtruums they be reduced into very ſmall Particles, and then they become tranſparent.

### Prop. III.

*Between the parts of opake and colour'd Bodies are many Spaces, either empty or repleniſh'd, with Mediums of other Denſities; as Water between the tinging Corpuſcles wherewith any Liquor is impregnated, Air between the aqueous Globules that conſtitute Clouds or Miſts; and for the moſt part Spaces void of both Air and Water, but yet perhaps not wholly void of all Subſtance, between the parts of hard Bodies.*

THE truth of this is evinced by the two precedent Propoſitions: For by the ſecond Propoſition there are many Reflexions made by the internal parts of Bodies, which, by the firſt Propoſition, would not happen if the parts of thoſe Bodies were continued without any ſuch Interſtices between them, becauſe Reflexions are cauſed only in Superficies, which intercede Mediums of a differing denſity by *Prop.* I.

But

But farther, that this discontinuity of parts is the principal Cause of the opacity of Bodies, will appear by considering, that opake Substances become transparent by filling their Pores with any Substance of equal or almost equal density with their parts. Thus Paper dipped in Water or Oil, the *Oculus Mundi* Stone steep'd in Water, Linen Cloth oiled or varnish'd, and many other Substances soaked in such Liquors as will intimately pervade their little Pores, become by that means more transparent than otherwise; so, on the contrary, the most transparent Substances may by evacuating their Pores, or separating their parts, be render'd sufficiently opake, as Salts or wet Paper, or the *Oculus Mundi* Stone by being dried, Horn by being scraped, Glass by being reduced to Powder, or otherwise flawed, Turpentine by being stirred about with Water till they mix imperfectly, and Water by being form'd into many small Bubbles, either alone in the form of Froth, or by shaking it together with Oil of Turpentine, or Oil Olive, or with some other convenient Liquor, with which it will not perfectly incorporate. And to the increase of the opacity of these Bodies it conduces something, that by the 23d Observation the Reflexions of very thin transparent Substances are considerably stronger than those made by the same Substances of a greater thickness.

PROP.

## Prop. IV.

*The parts of Bodies and their Interſtices muſt not be leſs than of ſome definite bigneſs, to render them opake and colour'd.*

FOR the opakeſt Bodies, if their parts be ſubtily divided, (as Metals by being diſſolved in acid Menſtruums, &c.) become perfectly tranſparent. And you may alſo remember, that in the eighth Obſervation there was no ſenſible reflexion at the Superficies of the Object-glaſſes where they were very near one another, though they did not abſolutely touch. And in the 17th Obſervation the Reflexion of the Water-bubble where it became thinneſt was almoſt inſenſible, ſo as to cauſe very black Spots to appear on the top of the Bubble by the want of reflected Light.

On theſe grounds I perceive it is that Water, Salt, Glaſs, Stones, and ſuch like Subſtances, are tranſparent. For, upon divers Conſiderations, they ſeem to be as full of Pores or Interſtices between their parts as other Bodies are, but yet their Parts and Interſtices to be too ſmall to cauſe Reflexions in their common Surfaces.

## Prop. V.

*The transparent parts of Bodies according to their several sizes reflect Rays of one Colour, and transmit those of another, on the same grounds that thin Plates or Bubbles do reflect or transmit those Rays. And this I take to be the ground of all their Colours.*

FOR if a thinn'd or plated Body, which being of an even thickness, appears all over of one uniform Colour, should be slit into Threds, or broken into Fragments, of the same thickness with the Plate; I see no reason why every Thred or Fragment should not keep its Colour, and by consequence why a heap of those Threds or Fragments should not constitute a Mass or Powder of the same Colour, which the Plate exhibited before it was broken. And the parts of all natural Bodies being like so many Fragments of a Plate, must on the same grounds exhibit the same Colours.

Now that they do so, will appear by the affinity of their Properties. The finely colour'd Feathers of some Birds, and particularly those of Peacocks Tails, do in the very same part of the Feather appear of several Colours in several Positions of the Eye, after the very same manner that thin Plates were found to do in the 7th and 19th Observations, and therefore their Colours arise from the thinness of the transparent parts of the Feathers; that is, from the slenderness of the very fine Hairs, or *Capillamenta*, which grow out of the sides of the groſſer lateral Branches or Fibres of thoſe Feathers. And to the ſame purpoſe it is, that the Webs of ſome Spiders by being ſpun very fine have appeared colour'd, as ſome have obſerv'd, and that the colour'd Fibres of ſome Silks by varying the Poſition of the Eye do vary their Colour. Alſo the Colours of Silks, Cloths, and other Subſtances, which Water or Oil can intimately penetrate, become more faint and obſcure by being immerged in thoſe Liquors, and recover their Vigour again by being dried, much after the manner declared of thin Bodies in the 10th and 21ſt Obſervations. Leaf Gold, ſome ſorts of painted Glaſs, the Infuſion of *Lignum Nephriticum*, and ſome other Subſtances reflect one Colour, and tranſmit another, like thin Bodies in the 9th and 20th Obſervations. And ſome of thoſe colour'd Powders which Painters uſe, may have their Colours a little changed, by being very elaborately and finely ground. Where I ſee not what can be juſtly pretended for thoſe changes, beſides the breaking of their parts into leſs parts by that contrition after the ſame manner that the Colour of a thin Plate is changed by varying its thickneſs. For which reaſon alſo it is that the colour'd Flowers of Plants and Vegetables by being bruiſed uſually become more tranſparent than before, or at leaſt in ſome degree or other change their Colours. Nor is it much leſs to my purpoſe, that by mixing divers Liquors very odd and remarkable Productions and Changes of Colours may be effected, of which no cauſe can be more obvious and rational than the ſaline Corpuſcles of one Liquor do variouſly act upon or unite with the tinging Corpuſcles of another, ſo as to make them ſwell, or ſhrink (whereby not only their bulk but their denſity alſo may be changed) or to divide them into ſmaller Corpuſcles, (whereby a colour'd Liquor may become tranſparent) or to make many of them aſſociate into one cluſter, whereby two tranſparent Liquors may compoſe a colour'd one. For we ſee how apt thoſe ſaline Menſtruums are to penetrate and diſſolve Subſtances to which they are applied, and ſome of them to precipitate what others diſſolve. In like manner, if we conſider the various Phænomena of the Atmoſphere, we may obſerve, that when Vapours are firſt raiſed, they hinder not the tranſparency of the Air, being divided into parts too ſmall to cauſe any Reflexion in their Superficies. But when in order to compoſe Drops of Rain they begin to coaleſce and conſtitute Globules of all intermediate ſizes, thoſe Globules when they become of a convenient ſize to reflect ſome Colours and tranſmit others, may conſtitute Clouds of various Colours according to their ſizes. And I ſee not what can be rationally conceived in ſo tranſparent a Subſtance as Water for the production of theſe Colours, beſides the various ſizes of its fluid and globular Parcels.

## Prop. VI.

*The parts of Bodies on which their Colours depend, are denſer than the Medium, which pervades their Interſtices.*

THIS will appear by conſidering, that the Colour of a Body depends not only on the Rays which are incident perpendicularly on its parts, but on thoſe alſo which are incident at all other Angles. And that according to the 7th Obſervation, a very little variation of obliquity will change the reflected Colour where the thin Body or ſmall Particle is rarer than the ambient Medium, inſomuch that ſuch a ſmall Particle will at diverſly oblique Incidences reflect all ſorts of Colours, in ſo great a variety that the Colour reſulting from them all, confuſedly reflected from a heap of ſuch Particles, muſt rather be a white or grey than any other Colour, or at beſt it muſt be but a very imperfect and dirty Colour. Whereas if the thin Body or ſmall Particle be much denſer than the ambient Medium, the Colours according to the 19th Obſervation are ſo little changed by the variation of obliquity, that the Rays which are reflected leaſt obliquely may predominate over the reſt ſo much as to cauſe a heap of ſuch Particles to appear very intenſly of their Colour.

It conduces alſo ſomething to the confirmation of this Propoſition, that, according to the 22d Obſervation, the Colours exhibited by the denſer thin Body within the rarer, are more brisk than those exhibited by the rarer within the denser.

## Prop. VII.

*The bigness of the component parts of natural Bodies may be conjectured by their Colours.*

FOR since the parts of these Bodies by *Prop.* 5. do most probably exhibit the same Colours with a Plate of equal thickness, provided they have the same refractive density; and since their parts seem for the most part to have much the same density with Water or Glass, as by many circumstances is obvious to collect; to determine the sizes of those parts you need only have recourse to the precedent Tables, in which the thickness of Water or Glass exhibiting any Colour is expressed. Thus if it be desired to know the diameter of a Corpuscle, which being of equal density with Glass shall reflect green of the third Order; the Number $16\frac{1}{4}$ shews it to be $\frac{16\frac{1}{4}}{10000}$ parts of an Inch.

The greatest difficulty is here to know of what order the Colour of any Body is. And for this end we must have recourse to the 4th and 18th Observations; from whence may be collected these particulars.

*Scarlets*, and other *reds*, *oranges* and *yellows*, if they be pure and intense are most probably of the second order. Those of the first and third order also may be pretty good, only the yellow of the first order is faint, and the orange

orange and red of the third order have a great mixture of violet and blue.

There may be good *greens* of the fourth order, but the pureſt are of the third. And of this order the green of all Vegetables ſeem to be, partly by reaſon of the intenſeneſs of their Colours, and partly becauſe when they wither ſome of them turn to a greeniſh yellow, and others to a more perfect yellow or orange, or perhaps to red, paſſing firſt through all the aforeſaid intermediate Colours. Which Changes ſeem to be effected by the exhaling of the moiſture which may leave the tinging Corpuſcles more denſe, and ſomething augmented by the accretion of the oily and earthy part of that moiſture. Now the green without doubt is of the ſame order with thoſe Colours into which it changeth, becauſe the Changes are gradual, and thoſe Colours, though uſually not very full, yet are often too full and lively to be of the fourth order.

*Blues* and *purples* may be either of the ſecond or third order, but the beſt are of the third. Thus the Colour of violets ſeems to be of that order, becauſe their Syrup by acid Liquors turns red, and by urinous and alcalizate turns green. For ſince it is of the nature of Acids to diſſolve or attenuate, and of Alcalies to precipitate or incraſſate, if the purple Colour of the Syrup was of the ſecond order, an acid Liquor by attenuating its tinging Corpuſcles would change it to a red of the firſt order, and an Alcali by incraſſating them would change it to a green of the ſecond order;

which red and green, especially the green, seem too imperfect to be the Colours produced by these Changes. But if the said purple be supposed of the third order, its Change to red of the second, and green of the third, may without any inconvenience be allow'd.

If there be found any Body of a deeper and less reddish purple than that of the violets, its Colour most probably is of the second order. But yet there being no Body commonly known whose Colour is constantly more deep than theirs, I have made use of their name to denote the deepest and least reddish purples, such as manifestly transcend their Colour in purity.

The *blue* of the first order, though very faint and little, may possibly be the Colour of some Substances; and particularly the azure Colour of the Skies seems to be of this order. For all Vapours when they begin to condense and coalesce into small parcels, become first of that bigness whereby such an Azure must be reflected before they can constitute Clouds of other Colours. And so this being the first Colour which Vapours begin to reflect, it ought to be the Colour of the finest and most transparent Skies in which Vapours are not arrived to that grossness requisite to reflect other Colours, as we find it is by experience.

*Whiteness*, if most intense and luminous, is that of the first order, if less strong and luminous a mixture of the Colours of several orders. Of this last kind is the whiteness of Froth, Paper, Linen, and most white Substances; of the former I reckon that of white

Metals

Metals to be. For whilſt the denſeſt of Metals, Gold, if foliated, is tranſparent, and all Metals become tranſparent if diſſolved in Menſtruums or vitrified, the opacity of white Metals ariſeth not from their denſity alone. They being leſs denſe than Gold would be more tranſparent than it, did not ſome other Cauſe concur with their denſity to make them opake. And this cauſe I take to be ſuch a bigneſs of their Particles as fits them to reflect the white of the firſt order. For if they be of other thickneſſes they may reflect other Colours, as is manifeſt by the Colours which appear upon hot Steel in tempering it, and ſometimes upon the Surface of melted Metals in the Skin or Scoria which ariſes upon them in their cooling. And as the white of the firſt order is the ſtrongeſt which can be made by Plates of tranſparent Subſtances, ſo it ought to be ſtronger in the denſer Subſtances of Metals than in the rarer of Air, Water and Glaſs. Nor do I ſee but that metallic Subſtances of ſuch a thickneſs as may fit them to reflect the white of the firſt order, may, by reaſon of their great denſity (according to the tenour of the firſt of theſe Propoſitions) reflect all the Light incident upon them, and ſo be as opake and ſplendent as it's poſſible for any Body to be. Gold, or Copper mix'd with leſs than half their weight of Silver, or Tin, or Regulus of Antimony, in fuſion, or amalgamed with a very little Mercury, become white; which ſhews both that the Particles of white Metals have much more Superficies, and ſo are ſmaller, than thoſe of Gold and Copper,

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and alſo that they are ſo opake as not to ſuffer the Particles of Gold or Copper to ſhine through them. Now it is ſcarce to be doubted, but that the Colours of Gold and Copper are of the ſecond or third order, and therefore the Particles of white Metals cannot be much bigger than is requiſite to make them reflect the white of the firſt order. The volatility of Mercury argues that they are not much bigger, nor may they be much leſs, leſt they loſe their opacity, and become either tranſparent as they do when attenuated by vitrification, or by Solution in Menſtruums, or black as they do when ground ſmaller, by rubbing Silver, or Tin, or Lead, upon other Subſtances to draw black Lines. The firſt and only Colour which white Metals take by grinding their Particles ſmaller, is black, and therefore their white ought to be that which borders upon the black Spot in the center of the Rings of Colours, that is, the white of the firſt order. But if you would hence gather the bigneſs of metallic Particles, you muſt allow for their denſity. For were Mercury tranſparent, its denſity is ſuch that the Sine of Incidence upon it (by my computation) would be to the Sine of its Refraction, as 71 to 20, or 7 to 2. And therefore the thickneſs of its Particles, that they may exhibit the ſame Colours with thoſe of Bubbles of Water, ought to be leſs than the thickneſs of the Skin of thoſe Bubbles in the proportion of 2 to 7. Whence it's poſſible that the Particles of Mercury may be as little as the Particles of

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ſome tranſparent and volatile Fluids, and yet reflect the white of the firſt order.

Laſtly, for the production of *black*, the Corpuſcles muſt be leſs than any of thoſe which exhibit Colours. For at all greater ſizes there is too much Light reflected to conſtitute this Colour. But if they be ſuppoſed a little leſs than is requiſite to reflect the white and very faint blue of the firſt order, they will, according to the 4th, 8th, 17th and 18th Obſervations, reflect ſo very little Light as to appear intenſly black, and yet may perhaps variouſly refract it to and fro within themſelves ſo long, until it happen to be ſtifled and loſt, by which means they will appear black in all poſitions of the Eye without any tranſparency. And from hence may be underſtood why Fire, and the more ſubtile diſſolver Putrefaction, by dividing the Particles of Subſtances, turn them to black; why ſmall quantities of black Subſtances impart their Colour very freely and intenſly to other Subſtances to which they are applied; the minute Particles of theſe, by reaſon of their very great number, eaſily overſpreading the groſs Particles of others; why Glaſs ground very elaborately with Sand on a Copper Plate, 'till it be well poliſh'd, makes the Sand, together with what is worn off from the Glaſs and Copper, become very black: why black Subſtances do ſooneſt of all others become hot in the Sun's Light and burn, (which Effect may proceed partly from the multitude of Refractions in a little room, and partly from the eaſy Commotion of ſo very ſmall Corpuſcles;) and why blacks are uſually a little inclined to a bluiſh Colour. For that they are ſo may be ſeen by illuminating white Paper by Light reflected from black Subſtances. For the Paper will uſually appear of a bluiſh white; and the reaſon is, that black Borders on the obſcure blue of the firſt order deſcribed in the 18th Obſervation, and therefore reflects more Rays of that Colour than of any other.

In theſe Deſcriptions I have been the more particular, becauſe it is not impoſſible but that Microſcopes may at length be improved to the diſcovery of the Particles of Bodies on which their Colours depend, if they are not already in ſome meaſure arrived to that degree of perfection. For if thoſe Inſtruments are or can be ſo far improved as with ſufficient diſtinctneſs to repreſent Objects five or ſix hundred times bigger than at a Foot diſtance they appear to our naked Eyes, I ſhould hope that we might be able to diſcover ſome of the greateſt of thoſe Corpuſcles. And by one that would magnify three or four thouſand times perhaps they might all be diſcover'd, but thoſe which produce blackneſs. In the mean while I ſee nothing material in this Diſcourſe that may rationally be doubted of, excepting this Poſition. That tranſparent Corpuſcles of the ſame thickneſs and denſity with a Plate, do exhibit the ſame Colour. And this I would have underſtood not without ſome Latitude, as well becauſe thoſe Corpuſcles may be of irregular Figures, and many Rays muſt be obliquely incident on them, and ſo have a ſhorter way through them than the length of their Diameters, as becauſe the

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ſtraitneſs of the Medium pent in on all ſides within ſuch Corpuſcles may a little alter its Motions or other qualities on which the Reflexion depends. But yet I cannot much ſuſpect the laſt, becauſe I have obſerved of ſome ſmall Plates of Muſcovy Glaſs which were of an even thickneſs, that through a Microſcope they have appeared of the ſame Colour at their edges and corners where the included Medium was terminated, which they appeared of in other places. However it will add much to our Satiſfaction, if thoſe Corpuſcles can be diſcover'd with Microſcopes; which if we ſhall at length attain to, I fear it will be the utmoſt improvement of this Senſe. For it ſeems impoſſible to ſee the more ſecret and noble Works of Nature within the Corpuſcles by reaſon of their tranſparency.

## PROP. VIII.

*The Cauſe of Reflexion is not the impinging of Light on the ſolid or impervious parts of Bodies, as is commonly believed.*

THIS will appear by the following Conſiderations. Firſt, That in the paſſage of Light out of Glaſs into Air there is a Reflexion as ſtrong as in its paſſage out of Air into Glaſs, or rather a little ſtronger, and by many degrees ſtronger than in its paſſage out of Glaſs into Water. And it ſeems not probable that Air ſhould have more reflecting parts than Water or Glaſs. But if that ſhould poſſibly be ſuppoſed, yet it will avail nothing; for the Reflexion

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is as ſtrong or ſtronger when the Air is drawn away from the Glaſs, (ſuppoſe in the Air-Pump invented by Mr. *Boyle*) as when it is adjacent to it. Secondly, If Light in its paſſage out of Glaſs into Air be incident more obliquely than at an Angle of 40 or 41 Degrees it is wholly reflected, if leſs obliquely it is in great meaſure tranſmitted. Now it is not to be imagined that Light at one degree of obliquity ſhould meet with Pores enough in the Air to tranſmit the greater part of it, and at another degree of obliquity ſhould meet with nothing but parts to reflect it wholly, eſpecially conſidering that in its paſſage out of Air into Glaſs, how oblique ſoever be its Incidence, it finds Pores enough in the Glaſs to tranſmit a great part of it. If any Man ſuppoſe that it is not reflected by the Air, but by the outmoſt ſuperficial parts of the Glaſs, there is ſtill the ſame difficulty: Beſides, that ſuch a Suppoſition is unintelligible, and will alſo appear to be falſe by applying Water behind ſome part of the Glaſs inſtead of Air. For ſo in a convenient obliquity of the Rays, ſuppoſe of 45 or 46 Degrees, at which they are all reflected where the Air is adjacent to the Glaſs, they ſhall be in great meaſure tranſmitted where the Water is adjacent to it; which argues, that their Reflexion or Tranſmiſſion depends on the conſtitution of the Air and Water behind the Glaſs, and not on the ſtriking of the Rays upon the parts of the Glaſs. Thirdly, If the Colours made by a Priſm placed at the entrance of a Beam of Light into a darken'd Room be ſucceſſively caſt on a ſecond Priſm placed

placed at a greater diſtance from the former, in ſuch manner that they are all alike incident upon it, the ſecond Priſm may be ſo inclined to the incident Rays, that thoſe which are of a blue Colour ſhall be all reflected by it, and yet thoſe of a red Colour pretty copiouſly tranſmitted. Now if the Reflexion be cauſed by the parts of Air or Glaſs, I would ask, why at the ſame Obliquity of Incidence the blue ſhould wholly impinge on thoſe parts ſo as to be all reflected, and yet the red find Pores enough to be in a great meaſure tranſmitted. Fourthly, Where two Glaſſes touch one another, there is no ſenſible Reflexion as was declared in the firſt Obſervation; and yet I ſee no reaſon why the Rays ſhould not impinge on the parts of Glaſs as much when contiguous to other Glaſs as when contiguous to Air. Fifthly, When the top of a Water-Bubble (in the 17th Obſervation) by the continual ſubſiding and exhaling of the Water grew very thin, there was ſuch a little and almoſt inſenſible quantity of Light reflected from it, that it appeared intenſly black; whereas round about that black Spot, where the Water was thicker, the Reflexion was ſo ſtrong as to make the Water ſeem very white. Nor is it only at the leaſt thickneſs of thin Plates or Bubbles, that there is no manifeſt Reflexion, but at many other thickneſſes continually greater and greater. For in the 15th Obſervation the Rays of the ſame Colour were by turns tranſmitted at one thickneſs, and reflected at another thickneſs, for an indeterminate number of Succeſſions. And yet in in the Superficies of the thinned Body, where it is of any one thickneſs, there are as many parts for the Rays to impinge on, as where it is of any other thickneſs. Sixthly, If Reflexion were cauſed by the parts of reflecting Bodies, it would be impoſſible for thin Plates or Bubbles at one and the ſame place to reflect the Rays of one Colour and tranſmit thoſe of another, as they do according to the 13th and 15th Obſervations. For it is not to be imagined that at one place the Rays which for inſtance exhibit a blue Colour, ſhould have the fortune to daſh upon the parts, and thoſe which exhibit a red to hit upon the Pores of the Body; and then at another place, where the Body is either a little thicker, or a little thinner, that on the contrary the blue ſhould hit upon its pores, and the red upon its parts. Laſtly, were the Rays of Light reflected by impinging on the ſolid parts of Bodies, their Reflexions from poliſh'd Bodies could not be ſo regular as they are. For in poliſhing Glaſs with Sand, Putty or Tripoly, it is not to be imagined that thoſe Subſtances can by grating and fretting the Glaſs bring all its leaſt Particles to an accurate Poliſh; ſo that all their Surfaces ſhall be truly plain or truly ſpherical, and look all the ſame way, ſo as together to compoſe one even Surface. The ſmaller the Particles of thoſe Subſtances are, the ſmaller will be the Scratches by which they continually fret and wear away the Glaſs until it be poliſh'd, but be they never ſo ſmall they can wear away the Glaſs no otherwiſe than by grating and ſcratching it, and breaking the Protu-

Protuberances, and therefore poliſh it no otherwiſe than by bringing its roughneſs to a very fine Grain, ſo that the Scratches and Frettings of the Surface become too ſmall to be viſible. And therefore if Light were reflected by impinging upon the ſolid parts of the Glaſs, it would be ſcatter'd as much by the moſt poliſh'd Glaſs as by the rougheſt. So then it remains a Problem, how Glaſs poliſh'd by fretting Subſtances can reflect Light ſo regularly as it does. And this Problem is ſcarce otherwiſe to be ſolved than by ſaying, that the Reflexion of a Ray is effected, not by a ſingle point of the reflecting Body, but by ſome power of the Body which is evenly diffuſed all over its Surface, and by which it acts upon the Ray without immediate Contact. For that the parts of Bodies do act upon Light at a diſtance ſhall be ſhewn hereafter.

Now if Light be reflected not by impinging on the ſolid parts of Bodies, but by ſome other principle; it's probable that as many of its Rays as impinge on the ſolid parts of Bodies are not reflected but ſtifled and loſt in the Bodies. For otherwiſe we muſt allow two ſorts of Reflexions. Should all the Rays be reflected which impinge on the internal parts of clear Water or Cryſtal, thoſe Subſtances would rather have a cloudy Colour than a clear Tranſparency. To make Bodies look black, it's neceſſary that many Rays be ſtopp'd, retained and loſt in them, and it ſeems not probable that any Rays can be ſtopp'd and ſtifled in them which do not impinge on their parts.

And hence we may underſtand that Bodies are much more rare and porous than is commonly believed. Water is nineteen times lighter, and by conſequence nineteen times rarer than Gold, and Gold is ſo rare as very readily and without the leaſt oppoſition to tranſmit the magnetick Effluvia, and eaſily to admit Quickſilver into its Pores, and to let Water paſs through it. For a concave Sphere of Gold filled with Water, and ſoder'd up, has upon preſſing the Sphere with great force, let the Water ſqueeze through it, and ſtand all over its outſide in multitudes of ſmall Drops, like Dew, without burſting or cracking the Body of the Gold as I have been inform'd by an Eye witneſs. From all which we may conclude, that Gold has more Pores than ſolid parts, and by conſequence that Water has above forty times more Pores that Parts. And he that ſhall find out an Hypotheſis, by which Water may be ſo rare, and yet not be capable of compreſſion by force, may doubtleſs by the ſame Hypotheſis make Gold and Water, and all other Bodies as much rarer as he pleaſes, ſo that Light may find a ready paſſage through tranſparent Subſtances.

The Magnet acts upon Iron through all denſe Bodies not magnetick nor red hot, without any diminution of its virtue; as for inſtance, through Gold, Silver, Lead, Glaſs, Water. The gravitating Power of the Sun is tranſmitted through the vaſt Bodies of the Planets without any diminution, ſo as to act upon all their parts to their very centers with the ſame Force

and

and according to the ſame Laws as if the part upon which it acts were not ſurrounded with the Body of the Planet. The Rays of Light whether they be very ſmall Bodies projected, or only Motion or Force propagated, are moved in right Lines; and whenever a Ray of Light is by any Obſtacle turned out of its rectilinear way, it will never return into the ſame rectilinear way, unleſs perhaps by very great accident. And yet Light is tranſmitted through pellucid ſolid Bodies in right Lines to very great diſtances. How Bodies can have a ſufficient quantity of Pores for producing theſe Effects is very difficult to conceive, but perhaps not altogether impoſſible. For the Colours of Bodies ariſe from the Magnitudes of the Particles which reflect them, as was explained above. Now if we conceive theſe Particles of Bodies to be ſo diſpoſed amongſt themſelves, that the Intervals or empty Spaces between them may be equal in magnitude to them all; and that theſe Particles may be compoſed of other Particles much ſmaller, which have as much empty Space between them as equals all the Magnitudes of theſe ſmaller Particles: And that in like manner theſe ſmaller Particles are again compoſed of others much ſmaller, all which together are equal to all the Pores or empty Spaces between them; and ſo on perpetually till you come to ſolid Particles, ſuch as have no Pores or empty Spaces within them: And if in any groſs Body there be, for inſtance, three ſuch degrees of Particles, the leaſt of which are ſolid; this Body will have ſeven times more Pores than ſolid

Parts. But if there be four ſuch degrees of Particles, the leaſt of which are ſolid, the Body will have fifteen times more Pores than ſolid Parts. If there be five degrees, the Body will have one and thirty times more Pores than ſolid Parts. If ſix degrees, the Body will have ſixty and three times more Pores than ſolid Parts. And ſo on perpetually. And there are other ways of conceiving how Bodies may be exceeding porous. But what is really their inward Frame is not yet known to us.

## PROP. IX.

*Bodies reflect and refract Light by one and the ſame power variouſly exerciſed in various Circumſtances.*

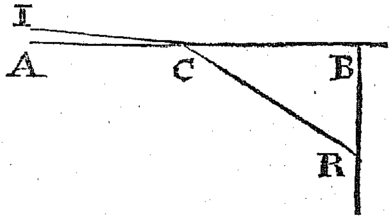
THIS appears by ſeveral Conſiderations. Firſt, Becauſe when Light goes out of Glaſs into Air, as obliquely as it can poſſibly do, if its Incidence be made ſtill more oblique, it becomes totally reflected. For the power of the Glaſs after it has refracted the Light as obliquely as is poſſible if the Incidence be ſtill made more oblique, becomes too ſtrong to let any of its Rays go through, and by conſequence cauſes total Reflexions. Secondly, Becauſe Light is alternately reflected and and tranſmitted by thin Plates of Glaſs for many Succeſſions accordingly as the thickneſs of the Plate increaſes in an arithmetical Progreſſion. For here the thickneſs of the Glaſs determines whether that Power by which Glaſs acts upon Light ſhall cauſe it to be reflected, or ſuffer it to be tranſ-

transmitted. And, Thirdly, because those Surfaces of transparent Bodies which have the greatest refracting Power, reflect the greatest quantity of Light, as was shew'd in the first Proposition.

## PROP. X.

*If Light be swifter in Bodies than in Vacuo in the proportion of the Sines which measure the Refraction of the Bodies, the Forces of the Bodies to reflect and refract Light, are very nearly proportional to the densities of the same Bodies, excepting that unctuous and sulphureous Bodies refract more than others of this same density.*

LET AB represent the refracting plane Surface of any Body, and IC a Ray incident very obliquely upon the Body in C, so that the




Angle ACI may be infinitely little, and let CR be the refracted Ray. From a given Point B perpendicular to the refracting Surface erect BR meeting with the refracted Ray CR in R, and if CR represent the Motion of the refracted Ray, and this Motion be distinguish'd into two Motions CB and BR, whereof CB is paral-



lel

lel to the refracting Plane, and BR perpendicular to it: CB ſhall repreſent the Motion of the incident Ray, and BR the Motion generated by the Refraction, as Opticians have of late explain'd.

Now if any Body or thing, in moving through any Space of a given breadth terminated on both ſides by two parallel Planes, be urged forward in all parts of that Space by Forces tending directly forwards towards the laſt Plane, and before its Incidence on the firſt Plane, had no Motion towards it, or but an infinitely little one; and if the Forces in all parts of that Space, between the Planes be at equal diſtances from the Planes equal to one another, but at ſeveral diſtances be bigger or leſs in any given Proportion, the Motion generated by the Forces in the whole paſſage of the Body or thing through that Space ſhall be in a ſubduplicate Proportion of the Forces, as Mathematicians will eaſily underſtand. And therefore if the Space of activity of the refracting Superficies of the Body be conſider'd as ſuch a Space, the Motion of the Ray generated by the refracting Force of the Body, during its paſſage through that Space, that is the Motion BR, muſt be in a ſubduplicate Proportion of that refracting Force. I ſay therefore that the Square of the Line BR, and by conſequence the refracting Force of the Body is very nearly as the denſity of the ſame Body. For this will appear by the following Table, wherein the Proportion of the Sines which meaſure the Refractions of ſeveral Bodies, the Square of BR ſuppoſing CB an unite, the Denſities

ſities of the Bodies eſtimated by their ſpecifick gravities, and their refractive Power in reſpect of their denſities are ſet down in ſeveral Columns.

| The refracting Bodies. | *The Proportion of the Sines of Incidence and Refraction of yellow Light.* | *The Square of BR, to which the refracting force of the Body is proportionate* | *The denſity and ſpecifick gravity of the Body.* | *The refractive Power of the Body in reſpect of its denſity.* |
|---|---|---|---|---|
| A Pſeudo-Topazius, being a natural, pellucid, brittle, hairy Stone, of a yellow Colour. | 23 to 14 | 1'699 | 4'27 | 3979 |
| Air. | 3201 to 3200 | 0'000625 | 0'0012 | 5208 |
| Glaſs of Antimony. | 17 to 9 | 2'568 | 5'28 | 4864 |
| A Selenitis. | 61 to 41 | 1'213 | 2'252 | 5386 |
| Glaſs vulgar. | 31 to 20 | 1'4025 | 2'58 | 5436 |
| Cryſtal of the Rock. | 25 to 16 | 1'445 | 2'65 | 5450 |
| Iſland Cryſtal. | 5 to 3 | 1'778 | 2'72 | 6536 |
| Sal Gemmæ. | 17 to 11 | 1'388 | 2'143 | 6477 |
| Alume. | 35 to 24 | 1'1267 | 1'714 | 6570 |
| Borax. | 22 to 15 | 1'1511 | 1'714 | 6716 |
| Niter. | 32 to 21 | 1'345 | 1'9 | 7079 |
| Dantzick Vitriol. | 303 to 200 | 1'295 | 1'715 | 7551 |
| Oil of Vitriol. | 10 to 7 | 1'041 | 1'7 | 6124 |
| Rain Water. | 529 to 396 | 0'7845 | 1' | 7845 |
| Gum Arabick. | 31 to 21 | 1'179 | 1'375 | 8574 |
| Spirit of Wine well rectified. | 100 to 73 | 0'8765 | 0'866 | 10121 |
| Camphire. | 3 to 2 | 1'25 | 0'996 | 12551 |
| Oil Olive. | 22 to 15 | 1'1511 | 0'913 | 12607 |
| Linſeed Oil. | 40 to 27 | 1'1948 | 0'932 | 12819 |
| Spirit of Turpentine. | 25 to 17 | 1'1626 | 0'874 | 13222 |
| Ambar. | 14 to 9 | 1'42 | 1'04 | 13654 |
| A Diamond. | 100 to 41 | 4'949 | 3'4 | 14556 |

The Refraction of the Air in this Table is determin'd by that of the Atmoſphere obſerved by by Aſtronomers. For if Light paſs through many refracting Subſtances or Mediums gradually denſer and denſer, and terminated with parallel Surfaces, the ſum of all the Refractions will be equal to the ſingle Refraction which it would have ſuffer'd in paſſing immediately out of the firſt Medium into the laſt. And this holds true, though the number of the refracting Subſtances be increaſed to infinity, and the diſtances from one another as much decreaſed, ſo that the Light may be refracted in every point of its Paſſage, and by continual Refractions bent into a curve Line. And therefore the whole Refraction of Light in paſſing through the Atmoſphere from the higheſt and rareſt part thereof down to the loweſt and denſeſt part, muſt be equal to the Refraction which it would ſuffer in paſſing at like obliquity out of a Vacuum immediately into Air of equal denſity with that in the loweſt part of the Atmoſphere.

Now, although a Pſeudo-Topaz, a Selenitis, Rock Cryſtal, Iſland Cryſtal, Vulgar Glaſs (that is, Sand melted together) and Glaſs of Antimony, which are terreſtrial ſtony alcalizate Concretes, and Air which probably ariſes from ſuch Subſtances by Fermentation, be Subſtances very differing from one another in denſity, yet by this Table, they have their refractive Powers almoſt in the ſame proportion to one another as their denſities are, excepting that the Refraction of that ſtrange Subſtance Iſland Cryſtal is a little bigger than the reſt. And particularly Air, which is 3500 times rarer than the Pſeudo-Topaz, and 4400 times rarer than Glaſs

Glass of Antimony, and 2000 times rarer than the Selenitis, Glass vulgar, or Crystal of the Rock, has notwithstanding its rarity the same refractive Power in respect of its density which those very dense Substances have in respect of theirs, excepting so far as those differ from one another.

Again, the Refraction of Camphire, Oil Olive, Linseed Oil, Spirit of Turpentine and Ambar, which are fat sulphureous unctuous Bodies, and a Diamond, which probably is an unctuous Substance coagulated, have their refractive Powers in proportion to one another as their densities without any considerable variation. But the refractive Powers of these unctuous Substances are two or three times greater in respect of their densities than the refractive Powers of the former Substances in respect of theirs.

Water has a refractive Power in a middle degree between those two sorts of Substances, and probably is of a middle nature. For out of it grow all vegetable and animal Substances, which consist as well of sulphureous fat and inflamable parts, as of earthy lean and alcalizate ones.

Salts and Vitriols have refractive Powers in a middle degree between those of earthy Substances and Water, and accordingly are composed of those two sorts of Substances. For by distillation and rectification of their Spirits a great part of them goes into Water, and a great part remains behind in the form of a dry fix'd Earth capable of vitrification.

Spirit

Spirit of Wine has a refractive Power in a middle degree between those of Water and oily Substances, and accordingly seems to be composed of both, united by Fermentation; the Water, by means of some saline Spirits with which 'tis impregnated, dissolving the Oil, and volatizing it by the action. For Spirit of Wine is inflamable by means of its oily parts, and being distilled often from Salt of Tartar, grows by every distillation more and more aqueous and phlegmatick. And Chymists observe, that Vegetables (as Lavender, Rue, Marjoram, &c.) distilled *per se*, before fermentation yield Oils without any burning Spirits, but after fermentation yield ardent Spirits without Oils: Which shews, that their Oil is by fermentation converted into Spirit. They find also, that if Oils be poured in small quantity upon fermentating Vegetables, they distil over after fermentation in the form of Spirits.

So then, by the foregoing Table, all Bodies seem to have their refractive Powers proportional to their densities, (or very nearly;) excepting so far as they partake more or less of sulphureous oily Particles, and thereby have their refractive Power made greater or less. Whence it seems rational to attribute the refractive Power of all Bodies chiefly, if not wholly, to the sulphureous parts with which they abound. For it's probable that all Bodies abound more or less with Sulphurs. And as Light congregated by a Burning-glass acts most upon sulphureous Bodies, to turn them into Fire and Flame; so, since all action is mutual, Sulphurs ought to act moſt upon Light. For that the action between Light and Bodies is mutual, may appear from this Conſideration; That the denſeſt Bodies which refract and reflect Light moſt ſtrongly grow hotteſt in the Summer Sun, by the action of the refracted or reflected Light.

I have hitherto explain'd the Power of Bodies to reflect and refract, and ſhew'd, that thin tranſparent Plates, Fibres and Particles do, according to their ſeveral thickneſſes and denſities, reflect ſeveral ſorts of Rays, and thereby appear of ſeveral Colours, and by conſequence that nothing more is requiſite for producing all the Colours of natural Bodies than the ſeveral ſizes and denſities of their tranſparent Particles. But whence it is that theſe Plates, Fibres and Particles do, according to their ſeveral thickneſſes and denſities, reflect ſeveral ſorts of Rays, I have not yet explain'd. To give ſome inſight into this matter, and make way for underſtanding the next part of this Book, I ſhall conclude this Part with a few more Propoſitions. Thoſe which preceded reſpect the nature of Bodies, theſe the nature of Light: For both muſt be underſtood before the reaſon of their actions upon one another can be known. And becauſe the laſt Propoſition depended upon the velocity of Light, I will begin with a Propoſition of that kind.

PROP.

## Prop. XI.

*Light is propagated from luminous Bodies in time, and spends about seven or eight Minutes of an Hour in passing from the Sun to the Earth.*

THIS was observed first by *Roemer*, and and then by others, by means of the Eclipses of the Satellites of *Jupiter*. For these Eclipses, when the Earth is between the Sun and *Jupiter*, happen about seven or eight Minutes sooner than they ought to do by the Tables, and when the Earth is beyond the Sun they happen about seven or eight Minutes later than they ought to do; the reason being, that the Light of the Satellites has farther to go in the latter case than in the former by the Diameter of the Earth's Orbit. Some inequalities of time may arise from the Excentricities of the Orbs of the Satellites; but those cannot answer in all the Satellites, and at all times to the position and distance of the Earth from the Sun. The mean motions of *Jupiter*'s Satellites is also swifter in his descent from his Aphelium to his Perihelium, than in his ascent in the other half of his Orb: But this inequality has no respect to the position of the Earth, and in the three interior Satellites is insensible, as I find by computation from the Theory of their gravity.

## Prop. XII.

*Every Ray of Light in its passage through any refracting Surface is put into a certain transient Constitution or State, which in the progress of the Ray returns at equal Intervals, and disposes the Ray at every return to be easily transmitted through the next refracting Surface, and between the returns to be easily reflected by it.*

THIS is manifest by the 5th, 9th, 12th, and 15th Observations. For by those Observations it appears, that one and the same sort of Rays at equal Angles of Incidence on any thin transparent Plate, is alternately reflected and transmitted for many Successions accordingly as the thickness of the Plate increases in arithmetical Progression of the Numbers, 0, 1, 2, 3, 4, 5, 6, 7, 8, *&c.* so that if the first Reflexion (that which makes the first or innermost of the Rings of Colours there described) be made at the thickness 1, the Rays shall be transmitted at the thicknesses 0, 2, 4, 6, 8, 10, 12, *&c.* and thereby make the central Spot and Rings of Light, which appear by transmission, and be reflected at the thickness 1, 3, 5, 7, 9, 11, *&c.* and thereby make the Rings which appear by Reflexion. And this alternate Reflexion and Transmission, as I gather by the 24th Observation, continues for above an hundred vicissitudes, and by the Observations in the next part of this Book, for many thousands, being propagated from one Surface of a Glass Plate to the

the other, though the thickneſs of the Plate be a quarter of an Inch or above: So that this alternation ſeems to be propagated from every refracting Surface to all diſtances without end or limitation.

This alternate Reflexion and Refraction depends on both the Surfaces of every thin Plate, becauſe it depends on their diſtance. By the 21ſt Obſervation, if either Surface of a thin Plate of Muſcovy Glaſs be wetted, the Colours cauſed by the alternate Reflexion and Refraction grow faint, and therefore it depends on them both.

It is therefore perform'd at the ſecond Surface; for if it were perform'd at the firſt, before the Rays arrive at the ſecond, it would not depend on the ſecond.

It is alſo influenced by ſome action or diſpoſition, propagated from the firſt to the ſecond, becauſe otherwiſe at the ſecond it would not depend on the firſt. And this action or diſpoſition, in its propagation, intermits and returns by equal Intervals, becauſe in all its progreſs it inclines the Ray at one diſtance from the firſt Surface to be reflected by the ſecond, at another to be tranſmitted by it, and that by equal Intervals for innumerable viciſſitudes. And becauſe the Ray is diſpoſed to Reflexion at the diſtances 1, 3, 5, 7, 9, *&c.* and to Tranſmiſſion at the diſtances 0, 2, 4, 6, 8, 10, *&c.* (for its tranſmiſſion through the firſt Surface, is at the diſtance 0, and it is tranſmitted through both together, if their diſtance be infinitely little or much leſs than 1) the diſpoſition to be tranſ-

mitted

mitted at the distances 2, 4, 6, 8, 10, *&c.* is to be accounted a return of the same disposition which the Ray first had at the distance 0, that is at its transmission through the first refracting Surface. All which is the thing I would prove.

What kind of action or disposition this is; Whether it consists in a circulating or a vibrating motion of the Ray, or of the Medium, or something else, I do not here enquire. Those that are averse from assenting to any new Discoveries, but such as they can explain by an Hypothesis, may for the present suppose, that as Stones by falling upon Water put the Water into an undulating Motion, and all Bodies by percussion excite vibrations in the Air; so the Rays of Light, by impinging on any refracting or reflecting Surface, excite vibrations in the refracting or reflecting Medium or Substance, and by exciting them agitate the solid parts of the refracting or reflecting Body, and by agitating them cause the Body to grow warm or hot; that the vibrations thus excited are propagated in the refracting or reflecting Medium or Substance, much after the manner that vibrations are propagated in the Air for causing Sound, and move faster than the Rays so as to overtake them; and that when any Ray is in that part of the vibration which conspires with its Motion, it easily breaks through a refracting Surface, but when it is in the contrary part of the vibration which impedes its Motion, it is easily reflected; and, by consequence, that every Ray is successively disposed to be easily reflected, or easily transmitted, by every vibration

tion which overtakes it. But whether this Hypothesis be true or false I do not here consider. I content my self with the bare Discovery, that the Rays of Light are by some cause or other alternately disposed to be reflected or refracted for many vicissitudes.

## DEFINITION.

*The returns of the disposition of any Ray to be reflected I will call its* Fits of easy Reflexion, *and those of its disposition to be transmitted its* Fits of easy Transmission, *and the space it passes between every return and the next return, the* Interval of its Fits.

## PROP. XIII.

*The reason why the Surfaces of all thick transparent Bodies reflect part of the Light incident on them, and refract the rest, is, that some Rays at their Incidence are in Fits of easy Reflexion, and others in Fits of easy Transmission.*

THIS may be gather'd from the 24th Observation, where the Light reflected by thin Plates of Air and Glass, which to the naked Eye appear'd evenly white all over the Plate, did through a Prism appear waved with many Successions of Light and Darkness made by alternate Fits of easy Reflexion and easy Transmission, the Prism severing and distinguishing the Waves of which the white reflected Light was composed, as was explain'd above.

And

And hence Light is in Fits of easy Reflexion and easy Transmission, before its Incidence on transparent Bodies. And probably it is put into such Fits at its first emission from luminous Bodies, and continues in them during all its progress. For these Fits are of a lasting nature, as will appear by the next part of this Book.

In this Proposition I suppose the transparent Bodies to be thick, because if the thickness of the Body be much less than the Interval of the Fits of easy Reflexion and Transmission of the Rays, the Body loseth its reflecting power. For if the Rays, which at their entering into the Body are put into Fits of easy Transmission, arrive at the farthest Surface of the Body before they be out of those Fits they must be transmitted. And this is the reason why Bubbles of Water lose their reflecting power when they grow very thin, and why all opake Bodies when reduced into very small parts become transparent.

## PROP. XIV.

*Those Surfaces of transparent Bodies, which if the Ray be in a Fit of Refraction do refract it most strongly, if the Ray be in a Fit of Reflexion do reflect it most easily.*

FOR we shewed above in *Prop.* 8. that the cause of Reflexion is not the impinging of Light on the solid impervious parts of Bodies, but some other Power by which those solid parts act on Light at a distance. We shewed also in *Prop.* 9. that Bodies reflect and refract

Light by one and the ſame Power variouſly exerciſed in various circumſtances, and in *Prop.* 1. that the moſt ſtrongly refracting Surfaces reflect the moſt Light: All which compared together evince and ratify both this and the laſt Propoſition.

## Prop. XV.

*In any one and the ſame ſort of Rays emerging in any Angle out of any refracting Surface into one and the ſame Medium, the Interval of the following Fits of eaſy Reflexion and Tranſmiſſion are either accurately or very nearly, as the Rectangle of the Secant of the Angle of Refraction, and of the Secant of another Angle, whoſe Sine is the firſt of* 106 *arithmetical mean Proportionals, between the Sines of Incidence and Refraction counted from the Sine of Refraction.*

THIS is manifeſt by the 7th and 19th Obſervations.

## Prop. XVI.

*In ſeveral ſorts of Rays emerging in equal Angles out of any refracting Surface into the ſame Medium, the Intervals of the following Fits of eaſy Reflexion and eaſy Tranſmiſſion are either accurately, or very nearly, as the Cube-Roots of the Squares of the lengths of a Chord, which ſound the Notes in an Eight,* ſol, la, fa, ſol, la, mi, fa, ſol, *with all their intermediate degrees anſwering to the Colours of thoſe Rays, according to the Analogy deſcribed in the ſeventh Experiment of the ſecond Part of the firſt Book.*

THIS is manifeſt by the 13th and 14th Obſervations.

## Prop. XVII.

*If Rays of any ſort paſs perpendicularly into ſeveral Mediums, the Intervals of the Fits of eaſy Reflexion and Tranſmiſſion in any one Medium, are to thoſe Intervals in any other as the Sine of Incidence to the Sine of Refraction, when the Rays paſs out of the firſt of thoſe two Mediums into the ſecond.*

This is manifeſt by the 10th Obſervation.

## Prop. XVIII.

*If the Rays which paint the Colour in the Confine of yellow and orange pass perpendicularly out of any Medium into Air, the Intervals of their Fits of easy Reflexion are the $\frac{1}{89000}$th part of an Inch. And of the same length are the Intervals of their Fits of easy Transmission.*

THIS is manifest by the 6th Observation.

From these Propositions it is easy to collect the Intervals of the Fits of easy Reflexion and easy Transmission of any sort of Rays refracted in any Angle into any Medium, and thence to know, whether the Rays shall be reflected or transmitted at their subsequent Incidence upon any other pellucid Medium. Which thing being useful for understanding, the next part of this Book was here to be set down. And for the same reason I add the two following Propositions.

## PROP. XIX.

*If any sort of Rays falling on the polite Surface of any pellucid Medium be reflected back, the Fits of easy Reflexion which they have at the point of Reflexion, shall still continue to return, and the returns shall be at distances from the point of Reflexion in the arithmetical progression of the Numbers* 2, 4, 6, 8, 10, 12, &c. *and between these Fits the Rays shall be in Fits of easy Transmission.*

FOR since the Fits of easy Reflexion and easy Transmission are of a returning nature, there is no reason why these Fits, which continued till the Ray arrived at the reflecting Medium, and there inclined the Ray to Reflexion, should there cease. And if the Ray at the point of Reflexion was in a Fit of easy Reflexion, the progression of the distances of these Fits from that point must begin from 0, and so be of the Numbers 0, 2, 4, 6, 8, *&c.* And therefore the progression of the distances of the intermediate Fits of easy Transmission reckon'd from the same point, must be in the progression of the odd Numbers 1, 3, 5, 7, 9, *&c.* contrary to what happens when the fits are propagated from points of Refraction.

## PROP. XX.

*The Intervals of the Fits of easy Reflexion and easy Transmission, propagated from points of Reflexion into any Medium, are equal to the Intervals of the like Fits which the same Rays would have, if refracted into the same Medium in Angles of Refraction equal to their Angles of Reflexion.*

FOR when Light is reflected by the second Surface of thin Plates, it goes out afterwards freely at the first Surface to make the Rings of Colours which appear by Reflexion, and by the freedom of its egress, makes the Colours of these Rings more vivid and strong than those which appear on the other side of the Plates by the transmitted Light. The reflected Rays are therefore in Fits of easy Transmission at their egress; which would not always happen, if the Intervals of the Fits within the Plate after Reflexion were not equal both in length and number to their Intervals before it. And this confirms also the Proportions set down in the former Proposition. For if the Rays both in going in and out at the first Surface be in Fits of easy Transmission, and the Intervals and Numbers of those Fits between the first and second Surface, before and after Reflexion, be equal; the distances of the Fits of easy Transmission from either Surface, must be in the same progression after Reflexion as before; that is, from the first Surface which transmitted them, in the progression of the even Numbers

bers

bers 0, 2, 4, 6, 8, &c. and from the ſecond which reflected them, in that of the odd Numbers 1, 3, 5, 7, &c. But theſe two Propoſitions will become much more evident by the Obſervations in the following part of this Book.

# THE SECOND BOOK OF OPTICKS.

## PART IV.

*Observations concerning the Reflexions and Colours of thick transparent polish'd Plates.*

THERE is no Glass or Speculum how well soever polish'd, but, besides the Light which it refracts or reflects regularly, scatters every way irregularly a faint Light, by means of which the polish'd Surface, when illuminated in a dark room by a beam

beam of the Sun's Light, may be easily seen in all positions of the Eye. There are certain Phænomena of this scatter'd Light, which when I first observed them, seem'd very strange and surprising to me. My Observations were as follows.

*Obs.* 1. The Sun shining into my darken'd Chamber through a hole one third of an Inch wide, I let the intromitted beam of Light fall perpendicularly upon a Glass Speculum ground concave on one side and convex on the other, to a Sphere of five Feet and eleven Inches Radius, and Quick-silver'd over on the convex side. And holding a white opake Chart, or a Quire of Paper at the center of the Spheres to which the Speculum was ground, that is, at the distance of about five Feet and eleven Inches from the Speculum, in such manner, that the beam of Light might pass through a little hole made in the middle of the Chart to the Speculum, and thence be reflected back to the same hole: I observed upon the Chart four or five concentric Irises or Rings of Colours, like Rainbows, encompassing the hole much after the manner that those, which in the fourth and following Observations of the first part of this third Book appear'd between the Object-glasses, encompassed the black Spot, but yet larger and fainter than those. These Rings as they grew larger and larger became diluter and fainter, so that the fifth was scarce visible. Yet sometimes, when the Sun shone very clear, there appear'd faint Lineaments of a sixth and seventh. If the distance of the Chart from the

Specu-

Speculum was much greater or much leſs than that of ſix Feet, the Rings became dilute and vaniſh'd. And if the diſtance of the Speculum from the Window was much greater than that of ſix Feet, the reflected beam of Light would be ſo broad at the diſtance of ſix Feet from the Speculum where the Rings appear'd, as to obſcure one or two of the innermoſt Rings. And therefore I uſually placed the Speculum at about ſix Feet from the Window; ſo that its Focus might there fall in with the center of its concavity at the Rings upon the Chart. And this Poſture is always to be underſtood in the following Obſervations where no other is expreſs'd.

*Obſ.* 2. The Colours of theſe Rain-bows ſucceeded one another from the center outwards, in the ſame form and order with thoſe which were made in the ninth Obſervation of the firſt Part of this Book by Light not reflected, but tranſmitted through the two Object-glaſſes. For, firſt, there was in their common center a white round Spot of faint Light, ſomething broader than the reflected beam of Light, which beam ſometimes fell upon the middle of the Spot, and ſometimes by a little inclination of the Speculum receded from the middle, and left the Spot white to the center.

This white Spot was immediately encompaſſed with a dark grey or ruſſet, and that dark grey with the Colours of the firſt Iris; which Colour on the inſide next the dark grey were a little violet and indigo, and next to that a blue, which on the outſide grew pale, and then ſucceeded a little

little greenish yellow, and after that a brighter yellow, and then on the outward edge of the Iris a red which on the outside inclined to purple.

This Iris was immediately encompassed with a second, whose Colours were in order from the inside outwards, purple, blue, green, yellow, light red, a red mix'd with purple.

Then immediately follow'd the Colours of the third Iris, which were in order outwards a green inclining to purple, a good green, and a red more bright than that of the former Iris.

The fourth and fifth Iris seem'd of a bluish green within, and red without, but so faintly that it was difficult to discern the Colours.

*Obs.* 3. Measuring the Diameters of these Rings upon the Chart as accurately as I could, I found them also in the same proportion to one another with the Rings made by Light transmitted through the two Object-glasses. For the Diameters of the four first of the bright Rings measured between the brightest parts of their Orbits, at the distance of six Feet from the Speculum were $1\frac{11}{16}$, $2\frac{3}{8}$, $2\frac{11}{12}$, $3\frac{3}{8}$ Inches, whose Squares are in arithmetical progression of the numbers 1, 2, 3, 4. If the white circular Spot in the middle be reckon'd amongst the Rings, and its central Light, where it seems to be most luminous, be put equipollent to an infinitely little Ring; the Squares of the Diameters of the Rings will be in the progression 0, 1, 2, 3, 4, &c. I measured also the Diameters of the dark Circles between these luminous ones, and found their Squares in the progression of the numbers

bers $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$, $3\frac{1}{2}$, *&c.* the Diameters of the first four at the distance of six Feet from the Speculum, being $1\frac{3}{16}$, $2\frac{1}{16}$, $2\frac{2}{3}$, $3\frac{1}{20}$ Inches. If the distance of the Chart from the Speculum was increased or diminished, the Diameters of the Circles were increased or diminished proportionally.

*Obs.* 4. By the analogy between these Rings and those described in the Observations of the first Part of this Book, I suspected that there were many more of them which spread into one another, and by interfering mix'd their Colours, and diluted one another so that they could not be seen apart. I viewed them therefore through a Prism, as I did those in the 24th Observation of the first Part of this Book. And when the Prism was so placed as by refracting the Light of their mix'd Colours to separate them, and distinguish the Rings from one another, as it did those in that Observation, I could then see them distincter than before, and easily number eight or nine of them, and sometimes twelve or thirteen. And had not their Light been so very faint, I question not but that I might have seen many more.

*Obs.* 5. Placing a Prism at the Window to refract the intromitted beam of Light, and cast the oblong Spectrum of Colours on the Speculum: I covered the Speculum with a black Paper which had in the middle of it a hole to let any one of the Colours pass through to the Speculum, whilst the rest were intercepted by the Paper. And now I found Rings of that Colour only which fell upon the Speculum. If the

the Speculum was illuminated with red, the Rings were totally red with dark Intervals, if with blue they were totally blue, and so of the other Colours. And when they were illuminated with any one Colour, the Squares of their Diameters measured between their most luminous parts, were in the arithmetical progression of the numbers 0, 1, 2, 3, 4, and the Squares of the Diameters of their dark Intervals in the progression of the intermediate numbers $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$, $3\frac{1}{2}$. But if the Colour was varied they varied their magnitude. In the red they were largest, in the indigo and violet least, and in the intermediate Colours yellow, green and blue, they were of several intermediate bignesses answering to the Colour, that is, greater in yellow than in green, and greater in green than in blue. And hence I knew that when the Speculum was illuminated with white Light, the red and yellow on the outside of the Rings were produced by the least refrangible Rays, and the blue and violet by the most refrangible, and that the Colours of each Ring spread into the Colours of the neighbouring Rings on either side, after the manner explain'd in the first and second Part of this Book, and by mixing diluted one another so that they could not be distinguish'd, unless near the center where they were least mix'd. For in this Observation I could see the Rings more distinctly, and to a greater number than before, being able in the yellow Light to number eight or nine of them, besides a faint shadow of a tenth. To satisfy my self how much the Colours of the several Rings

spread

ſpread into one another, I meaſured the Diameters of the ſecond and third Rings, and found them when made by the Confine of the red and orange to be to the ſame Diameters when made by the Confine of blue and indigo, as 9 to 8, or thereabouts. For it was hard to determine this Proportion accurately. Alſo the Circles made ſucceſſively by the red, yellow and green, differ'd more from one another than thoſe made ſucceſſively by the green, blue and indigo. For the Circle made by the violet was too dark to be ſeen. To carry on the computation, let us therefore ſuppoſe that the differences of the Diameters of the Circles made by the outmoſt red, the Confine of red and orange, the Confine of orange and yellow, the Confine of yellow and green, the Confine of green and blue, the Confine of blue and indigo, the Confine of indigo and violet, and outmoſt violet, are in proportion as the differences of the lengths of a Monochord which ſound the Tones in an Eight; *ſol, la, fa, ſol, la, mi, fa, ſol,* that is, as the numbers $\frac{1}{9}$, $\frac{1}{18}$, $\frac{1}{12}$, $\frac{1}{12}$, $\frac{2}{27}$, $\frac{1}{27}$, $\frac{1}{18}$. And if the Diameter of the Circle made by the Confine of red and orange be 9 A, and that of the Circle made by the Confine of blue and indigo be 8 A as above, their difference 9 A — 8 A will be to the difference of the Diameters of the Circles made by the outmoſt red, and by the Confine of red and orange, as $\frac{1}{18} + \frac{1}{12} + \frac{1}{12} + \frac{2}{27}$ to $\frac{1}{9}$, that is as $\frac{8}{27}$ to $\frac{1}{9}$, or 8 to 3, and to the difference of the Circles made by the outmoſt violet, and by the Confine of blue and indigo, as $\frac{1}{18} + \frac{1}{12} + \frac{1}{12} + \frac{2}{27}$ to $\frac{1}{27} + \frac{1}{18}$, that is, as $\frac{8}{27}$ to $\frac{5}{54}$, or or as 16 to 5. And therefore these differences will be $\frac{3}{8}$ A and $\frac{5}{16}$ A. Add the first to 9 A and subduct the last from 8 A, and you will have the Diameters of the Circles made by the least and most refrangible Rays $\frac{75}{8}$ A and $\frac{61\frac{1}{2}}{8}$ A. These Diameters are therefore to one another as 75 to $61\frac{1}{2}$ or 50 to 41, and their Squares as 2500 to 1681, that is, as 3 to 2 very nearly. Which proportion differs not much from the proportion of the Diameters of the Circles made by the outmost red and outmost violet in the 13th Observation of the first Part of this Book.

*Obs.* 6. Placing my Eye where these Rings appear'd plainest, I saw the Speculum tinged all over with Waves of Colours (red, yellow, green, blue;) like those which in the Observations of the first Part of this Book appeared between the Object-glasses and upon Bubbles of Water, but much larger. And after the manner of those, they were of various Magnitudes in various Positions of the Eye, swelling and shrinking as I moved my Eye this way and that way. They were formed like Arcs of concentrick Circles as those were, and when my Eye was over against the center of the concavity of the Speculum (that is, 5 Feet and 10 Inches distant from the Speculum) their common center was in a right Line with that center of concavity, and with the hole in the Window. But in other postures of my Eye their center had other positions. They appear'd by the Light of the Clouds propagated to the Speculum through the hole in the Window, and when the Sun shone through that hole upon the Speculum, his Light upon it

was

was of the Colour of the Ring whereon it fell, but by its ſplendor obſcured the Rings made by the Light of the Clouds, unleſs when the Speculum was removed to a great diſtance from the Window, ſo that his Light upon it might be broad and faint. By varying the poſition of my Eye, and moving it nearer to or farther from the direct beam of the Sun's Light, the Colour of the Sun's reflected Light conſtantly varied upon the Speculum, as it did upon my Eye, the ſame Colour always appearing to a By-ſtander upon my Eye which to me appear'd upon the Speculum. And thence I knew that the Rings of Colours upon the Chart were made by theſe reflected Colours propagated thither from the Speculum in ſeveral Angles, and that their production depended not upon the termination of Light and Shadow.

*Obſ.* 7. By the Analogy of all theſe Phænomena with thoſe of the like Rings of Colours deſcribed in the firſt Part of this Book, it ſeemed to me that theſe Colours were produced by this thick Plate of Glaſs, much after the manner that thoſe were produced by very thin Plates. For, upon tryal, I found that if the Quick-ſilver were rubb'd off from the backſide of the Speculum, the Glaſs alone would cauſe the ſame Rings of Colours, but much more faint than before; and therefore the Phænomenon depends not upon the Quick-ſilver, unleſs ſo far as the Quick-ſilver by increaſing the Reflexion of the backſide of the Glaſs increaſes the Light of the Rings of Colours. I found alſo that a Speculum of Metal without Glaſs made ſome

Years

Years ſince for optical uſes, and very well wrought, produced none of thoſe Rings; and thence I underſtood that theſe Rings ariſe not from one ſpecular Surface alone, but depend upon the two Surfaces of the Plate of Glaſs whereof the Speculum was made, and upon the thickneſs of the Glaſs between them. For as in the 7th and 19th Obſervations of the firſt Part of this Book a thin Plate of Air, Water, or Glaſs of an even thickneſs appeared of one Colour when the Rays were perpendicular to it, of another when they were a little oblique, of another when more oblique, of another when ſtill more oblique, and ſo on; ſo here, in the ſixth Obſervation, the Light which emerged out of the Glaſs in ſeveral Obliquities, made the Glaſs appear of ſeveral Colours, and being propagated in thoſe Obliquities to the Chart, there painted Rings of thoſe Colours. And as the reaſon why a thin Plate appeared of ſeveral Colours in ſeveral Obliquities of the Rays, was, that the Rays of one and the ſame ſort are reflected by the thin Plate at one obliquity and tranſmitted at another, and thoſe of other ſorts tranſmitted where theſe are reflected, and reflected where theſe are tranſmitted: So the reaſon why the thick Plate of Glaſs whereof the Speculum was made did appear of various Colours in various Obliquities, and in thoſe Obliquities propagated thoſe Colours to the Chart, was, that the Rays of one and the ſame ſort did at one Obliquity emerge out of the Glaſs, at another did not emerge but were reflected back towards the Quick-ſilver by the hither Surface of the Glaſs, and accordingly as the Obliquity became greater and greater emerged and were reflected alternately for many Succeſſions, and that in one and the ſame Obliquity the Rays of one ſort were reflected, and thoſe of another tranſmitted. This is manifeſt by the fifth Obſervation of this Part of this Book. For in that Obſervation, when the Speculum was illuminated by any one of the priſmatick Colours, that Light made many Rings of the ſame Colour upon the Chart with dark Intervals, and therefore at its emergence out of the Speculum was alternately tranſmitted and not tranſmitted from the Speculum to the Chart for many Succeſſions, according to the various Obliquities of its Emergence. And when the Colour caſt on the Speculum by the Priſm was varied, the Rings became of the Colour caſt on it, and varied their bigneſs with their Colour, and therefore the Light was now alternately tranſmitted and not tranſmitted from the Speculum to the Chart at other Obliquities than before. It ſeemed to me therefore that theſe Rings were of one and the ſame original with thoſe of thin Plates, but yet with this difference, that thoſe of thin Plates are made by the alternate Reflexions and Tranſmiſſions of the Rays at the ſecond Surface of the Plate after one paſſage through it, but here the Rays go twice through the Plate before they are alternately reflected and tranſmitted. Firſt, they go through it from the firſt Surface to the Quick-ſilver, and then return through it from the Quick-ſilver to the firſt Surface, and there are either tranſmitted

mitted to the Chart or reflected back to the Quick-ſilver, accordingly as they are in their Fits of eaſy Reflexion or Tranſmiſſion when they arrive at that Surface. For the Intervals of the Fits of the Rays which fall perpendicularly on the Speculum, and are reflected back in the ſame perpendicular Lines, by reaſon of the equality of theſe Angles and Lines, are of the ſame length and number within the Glaſs after Reflexion as before by the 19th Propoſition of the third Part of this Book. And therefore ſince all the Rays that enter through the firſt Surface are in their Fits of eaſy Tranſmiſſion at their entrance, and as many of theſe as are reflected by the ſecond are in their Fits of eaſy Reflexion there, all theſe muſt be again in their Fits of eaſy Tranſmiſſion at their return to the firſt, and by conſequence there go out of the Glaſs to the Chart, and form upon it the white Spot of Light in the center of the Rings. For the reaſon holds good in all ſorts of Rays, and therefore all ſorts muſt go out promiſcuouſly to that Spot, and by their mixture cauſe it to be white. But the Intervals of the Fits of thoſe Rays which are reflected more obliquely than they enter, muſt be greater after Reflexion than before by the 15th and 20th Propoſitions. And thence it may happen that the Rays at their return to the firſt Surface, may in certain Obliquities be in Fits of eaſy Reflexion, and return back to the Quick-ſilver, and in other intermediate Obliquities be again in Fits of eaſy Tranſmiſſion, and ſo go out to the Chart, and paint on it the Rings of Colours about the white Spot.

And becauſe the Intervals of the Fits at equal Obliquities are greater and fewer in the leſs refrangible Rays, and leſs and more numerous in the more refrangible, therefore the leſs refrangible at equal Obliquities ſhall make fewer Rings than the more refrangible, and the Rings made by thoſe ſhall be larger than the like number of Rings made by theſe; that is, the red Rings ſhall be larger than the yellow, the yellow than the green, the green than the blue, and the blue than the violet, as they were really found to be in the fifth Obſervation. And therefore the firſt Ring of all Colours encompaſſing the white Spot of Light ſhall be red without any violet within, and yellow and green and blue in the middle, as it was found in the ſecond Obſervation; and theſe Colours in the ſecond Ring, and thoſe that follow ſhall be more expanded till they ſpread into one another, and blend one another by interfering.

Theſe ſeem to be the Reaſons of theſe Rings in general; and this put me upon obſerving the thickneſs of the Glaſs, and conſidering whether the Dimenſions and Proportions of the Rings may be truly derived from it by computation.

*Obſ.* 8. I meaſured therefore the thickneſs of this concavo-convex Plate of Glaſs, and found it every where $\frac{1}{4}$ of an Inch preciſely. Now, by the ſixth Obſervation of the firſt Part of this Book, a thin Plate of Air tranſmits the brighteſt Light of the firſt Ring, that is the bright yellow, when its thickneſs is the $\frac{1}{89000}$th part of an Inch, and by the tenth Obſervation of the ſame Part,

Part, a thin Plate of Glaſs tranſmits the ſame Light of the ſame Ring when its thickneſs is leſs in proportion of the Sine of Refraction to the Sine of Incidence, that is, when its thickneſs is the $\frac{11}{1513000}$th or $\frac{1}{137545}$th part of an Inch, ſuppoſing the Sines are as 11 to 17. And if this thickneſs be doubled it tranſmits the ſame bright Light of the ſecond Ring, if trippled it tranſmits that of the third, and ſo on, the bright yellow Light in all theſe caſes being in its Fits of Tranſmiſſion. And therefore if its thickneſs be multiplied 34386 times ſo as to become $\frac{1}{4}$ of an Inch it tranſmits the ſame bright Light of the 34386th Ring. Suppoſe this be the bright yellow Light tranſmitted perpendicularly from the reflecting convex ſide of the Glaſs through the concave ſide to the white Spot in the center of the Rings of Colours on the Chart: And by a Rule in the 7th and 19th Obſervations in the firſt Part of this Book, and by the 15th and 20th Propoſitions of the third Part of this Book, if the Rays be made oblique to the Glaſs, the thickneſs of the Glaſs requiſite to tranſmit the ſame bright Light of the ſame Ring in any Obliquity is to this thickneſs of $\frac{1}{4}$ of an Inch, as the Secant of a certain Angle to the Radius, the Sine of which Angle is the firſt of an hundred and ſix arithmetical Means between the Sines of Incidence and Refraction, counted from the Sine of Incidence when the Refraction is made out of any plated Body into any Medium encompaſſing it, that is, in this caſe, out of Glaſs into Air. Now if the thickneſs of the Glaſs be increased by degrees, so as to bear to its first thickness, (*viz.* that of a quarter of an Inch) the Proportions which 34386 (the number of Fits of the perpendicular Rays in going through the Glass towards the white Spot in the center of the Rings,) hath to 34385, 34384, 34383 and 34382 (the numbers of the Fits of the oblique Rays in going through the Glass towards the first, second, third and fourth Rings of Colours,) and if the first thickness be divided into 100000000 equal parts, the increased thicknesses will be 100002908, 100005816, 100008725 and 100011633, and the Angles of which these thicknesses are secants will be 26′ 13″, 37′ 5″, 45′ 6″ and 52′ 26″, the Radius being 100000000; and the Sines of these Angles are 762, 1079, 1321 and 1525, and the proportional Sines of Refraction 1172, 1659, 2031 and 2345, the Radius being 100000. For since the Sines of Incidence out of Glass into Air are to the Sines of Refraction as 11 to 17, and to the above-mentioned Secants as 11 to the first of 106 arithmetical Means between 11 and 17, that is, as 11 to $11\frac{6}{106}$, those Secants will be to the Sines of Refraction as $11\frac{6}{106}$ to 17, and by this Analogy will give these Sines. So then if the Obliquities of the Rays to the concave Surface of the Glass be such that the Sines of their Refraction in passing out of the Glass through that Surface into the Air be 1172, 1659, 2031, 2345, the bright Light of the 34386th Ring shall emerge at the thicknesses of the Glass which are to to $\frac{1}{4}$ of an Inch as 34386 to 34385, 34384, 34383, 34382, refpectively. And therefore if the thicknefs in all thefe cafes be $\frac{1}{4}$ of an Inch (as it is in the Glafs of which the Speculum was made) the bright Light of the 34385th Ring fhall emerge where the Sine of Refraction is 1172, and that of the 34384th, 384383th and 34382th Ring where the Sine is 1659, 2031, and 2345 refpectively. And in thefe Angles of Refraction the Light of thefe Rings fhall be propagated from the Speculum to the Chart, and there paint Rings about the white central round Spot of Light which we faid was the Light of the 34386th Ring. And the Semidiameters of thefe Rings fhall fubtend the Angles of Refraction made at the concave Surface of the Speculum, and by confequence their Diameters fhall be to the diftance of the Chart from the Speculum as thofe Sines of Refraction doubled are to the Radius, that is, as 1172, 1659, 2031, and 2345, doubled are to 100000. And therefore if the diftance of the Chart from the concave Surface of the Speculum be fix Feet (as it was in the third of thefe Obfervations) the Diameters of the Rings of this bright yellow Light upon the Chart fhall be 1'688, 2'389, 2'925, 3'375 Inches: For thefe Diameters are to fix Feet, as the abovemention'd Sines doubled are to the Radius. Now thefe Diameters of the bright yellow Rings, thus found by computation are the very fame with thofe found in the third of thefe Obfervations by meafuring them, *viz.* with $1\frac{11}{17}$, $2\frac{3}{8}$, $2\frac{11}{12}$, and $3\frac{3}{8}$ Inches, and therefore the Theory of deriving thefe Rings from the thickneſs of the Plate of Glaſs of which the Speculum was made, and from the Obliquity of the emerging Rays agrees with the Obſervation. In this computation I have equalled the Diameters of the bright Rings made by Light of all Colours, to the Diameters of the Rings made by the bright yellow. For this yellow makes the brighteſt part of the Rings of all Colours. If you deſire the Diameters of the Rings made by the Light of any other unmix'd Colour, you may find them readily by putting them to the Diameters of the bright yellow ones in a ſubduplicate proportion of the Intervals of the Fits of the Rays of thoſe Colours when equally inclined to the refracting or reflecting Surface which cauſed thoſe Fits, that is, by putting the Diameters of the Rings made by the Rays in the Exremities and Limits of the ſeven Colours, red, orange, yellow, green, blue, indigo, violet, proportional to the Cube-roots of the Numbers, 1, $\frac{8}{9}$, $\frac{5}{6}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{9}{16}$, $\frac{1}{2}$, which expreſs the lengths of a Monochord ſounding the Notes in an Eighth: For by this means the Diameters of the Rings of theſe Colours will be found pretty nearly in the ſame proportion to one another, which they ought to have by the fifth of theſe Obſervations.

And thus I ſatisfy'd my ſelf that theſe Rings were of the ſame kind and original with thoſe of thin Plates, and by conſequence that the Fits or alternate Diſpoſitions of the Rays to be reflected and tranſmitted are propagated to great diſtances from every reflecting and refracting Surface. But yet to put the matter

ter out of doubt, I added the following Obſervation.

*Obſ.* 9. If theſe Rings thus depend on the thickneſs of the Plate of Glaſs, their Diameters at equal diſtances from ſeveral Speculums made of ſuch concavo-convex Plates of Glaſs as are ground on the ſame Sphere, ought to be reciprocally in a ſubduplicate proportion of the thickneſſes of the Plates of Glaſs. And if this Proportion be found true by experience it will amount to a demonſtration that theſe Rings (like thoſe formed in thin Plates) do depend on the thickneſs of the Glaſs. I procured therefore another concavo-convex Plate of Glaſs ground on both ſides to the ſame Sphere with the former Plate. Its thickneſs was $\frac{5}{62}$ parts of an Inch; and the Diameters of the three firſt bright Rings meaſured between the brighteſt parts of their Orbits at the diſtance of ſix Feet from the Glaſs were 3. $4\frac{1}{6}$. $5\frac{1}{8}$. Inches. Now the thickneſs of the other Glaſs being $\frac{1}{4}$ of an Inch was to the thickneſs of this Glaſs as $\frac{1}{4}$ to $\frac{5}{62}$, that is as 31 to 10, or 310000000 to 100000000, and the Roots of theſe Numbers are 17607 and 10000, and in the proportion of the firſt of theſe Roots to the ſecond are the Diameters of the bright Rings made in this Obſervation by the thinner Glaſs, 3. $4\frac{1}{6}$. $5\frac{1}{8}$, to the Diameters of the ſame Rings made in the third of theſe Obſervations by the thicker Glaſs $1\frac{11}{16}$. $2\frac{3}{8}$. $2\frac{11}{12}$, that is, the Diameters of the Rings are reciprocally in a ſubduplicate proportion of the thickneſſes of the Plates of Glaſs.

So then in Plates of Glaſs which are alike con-

concave on one ſide, and alike convex on the other ſide, and alike quick-ſilver'd on the convex ſides, and differ in nothing but their thickneſs, the Diameters of the Rings are reciprocally in a ſubduplicate proportion of the thickneſſes of the Plates. And this ſhews ſufficiently that the Rings depend on both the Surfaces of the Glaſs. They depend on the convex Surface becauſe they are more luminous when that Surface is quick-ſilver'd over than when it is without Quick-ſilver. They depend alſo upon the concave Surface, becauſe without that Surface a Speculum makes them not. They depend on both Surfaces and on the diſtances between them, becauſe their bigneſs is varied by varying only that diſtance. And this dependance is of the ſame kind with that which the Colours of thin Plates have on the diſtance of the Surfaces of thoſe Plates, becauſe the bigneſs of the Rings and their proportion to one another, and the variation of their bigneſs ariſing from the variation of the thickneſs of the Glaſs, and the orders of their Colours, is ſuch as ought to reſult from the Propoſitions in the end of the third Part of this Book, derived from the Phænomena of the Colours of thin Plates ſet down in the firſt Part.

There are yet other Phænomena of theſe Rings of Colours but ſuch as follow from the ſame Propoſitions, and therefore confirm both the truth of thoſe Propoſitions, and the Analogy between theſe Rings and the Rings of Colours made by very thin Plates. I ſhall ſubjoin ſome of them.

*Obſ.*

*Obs.* 10. When the beam of the Sun's Light was reflected back from the Speculum not directly to the hole in the Window, but to a place a little distant from it, the common center of that Spot, and of all the Rings of Colours fell in the middle way between the beam of the incident Light, and the beam of the reflected Light, and by consequence in the center of the spherical concavity of the Speculum, whenever the Chart on which the Rings of Colours fell was placed at that center. And as the beam of reflected Light by inclining the Speculum receded more and more from the beam of incident Light and from the common center of the colour'd Rings between them, those Rings grew bigger and bigger, and so also did the white round Spot, and new Rings of Colours emerged successively out of their common center, and the white Spot became a white Ring encompassing them; and the incident and reflected beams of Light always fell upon the opposite parts of this white Ring, illuminating its Perimeter like two mock Suns in the opposite parts of an Iris. So then the Diameter of this Ring, measured from the middle of its Light on one side to the middle of its Light on the other side, was always equal to the distance between the middle of the incident beam of Light, and the middle of the reflected beam measured at the Chart on which the Rings appeared: And the Rays which form'd this Ring were reflected by the Speculum in Angles equal to their Angles of Incidence, and by consequence to their Angles of Refraction at their entrance into the Glaſs, but yet their Angles of Reflexion were not in the ſame Planes with their Angles of Incidence.

*Obſ.* 11. The Colours of the new Rings were in a contrary order to thoſe of the former, and aroſe after this manner. The white round Spot of Light in the middle of the Rings continued white to the center till the diſtance of the incident and reflected beams at the Chart was about $\frac{7}{8}$ parts of an Inch, and then it began to grow dark in the middle. And when that diſtance was about $1\frac{3}{16}$ of an Inch, the white Spot was become a Ring encompaſſing a dark round Spot which in the middle inclined to violet and indigo. And the luminous Rings encompaſſing it were grown equal to thoſe dark ones which in the four firſt Obſervations encompaſſed them, that is to ſay, the white Spot was grown a white Ring equal to the firſt of thoſe dark Rings, and the firſt of thoſe luminous Rings was now grown equal to the ſecond of thoſe dark ones, and the ſecond of thoſe luminous ones to the third of thoſe dark ones, and ſo on. For the Diameters of the luminous Rings were now $1\frac{3}{16}$, $2\frac{1}{16}$, $2\frac{2}{3}$, $3\frac{3}{20}$, *&c.* Inches.

When the diſtance between the incident and reflected beams of Light became a little bigger, there emerged out of the middle of the dark Spot after the indigo a blue, and then out of that blue a pale green, and ſoon after a yellow and red. And when the Colour at the center was brighteſt, being between yellow and red, the bright Rings were grown equal to thoſe Rings which in the four firſt Obſervations next encom-

encompaſſed them; that is to ſay, the white Spot in the middle of thoſe Rings was now become a white Ring equal to the firſt of thoſe bright Rings, and the firſt of thoſe bright ones was now become equal to the ſecond of thoſe, and ſo on. For the Diameters of the white Ring, and of the other luminous Rings encompaſſing it, were now $1\frac{11}{16}$, $2\frac{3}{8}$, $2\frac{11}{12}$, $3\frac{3}{8}$, *&c.* or thereabouts.

When the diſtance of the two beams of Light at the Chart was a little more increaſed, there emerged out of the middle in order after the red, a purple, a blue, a green, a yellow, and a red inclining much to purple, and when the Colour was brighteſt being between yellow and red, the former indigo, blue, green, yellow and red, were become an Iris or Ring of Colours equal to the firſt of thoſe luminous Rings which appeared in the four firſt Obſervations, and the white Ring which was now become the ſecond of the luminous Rings was grown equal to the ſecond of thoſe, and the firſt of thoſe which was now become the third Ring was become equal to the third of thoſe, and ſo on. For their Diameters were $1\frac{11}{16}$, $2\frac{3}{8}$, $2\frac{11}{12}$, $3\frac{3}{8}$ Inches, the diſtance of the two beams of Light, and the Diameter of the white Ring being $2\frac{3}{8}$ Inches.

When theſe two beams became more diſtant there emerged out of the middle of the purpliſh red, firſt a darker round Spot, and then out of the middle of that Spot a brighter. And now the former Colours (purple, blue, green, yellow, and purpliſh red) were become a Ring

equal

equal to the firſt of the bright Rings mention-ed in the four firſt Obſervations, and the Rings about this Ring were grown equal to the Rings about that reſpectively; the diſtance between the two beams of Light and the Diameter of the white Ring (which was now become the third Ring) being about 3 Inches.

The Colours of the Rings in the middle began now to grow very dilute, and if the diſtance between the two Beams was increaſed half an Inch, or an Inch more, they vaniſh'd whilſt the white Ring, with one or two of the Rings next it on either ſide, continued ſtill viſible. But if the diſtance of the two beams of Light was ſtill more increaſed, theſe alſo vaniſhed: For the Light which coming from ſeveral parts of the hole in the Window fell upon the Speculum in ſeveral Angles of Incidence, made Rings of ſeveral bigneſſes, which diluted and blotted out one another, as I knew by intercepting ſome part of that Light. For if I intercepted that part which was neareſt to the Axis of the Speculum the Rings would be leſs, if the other part which was remoteſt from it they would be bigger.

*Obſ.* 12. When the Colours of the Priſm were caſt ſucceſſively on the Speculum, that Ring which in the two laſt Obſervations was white, was of the ſame bigneſs in all the Colours, but the Rings without it were greater in the green than in the blue, and ſtill greater in the yellow, and greateſt in the red. And, on the contrary, the Rings within that white Circle were leſs in the green than in the blue, and ſtill

leſs

leſs in the yellow, and leaſt in the red. For the Angles of Reflexion of thoſe Rays which made this Ring, being equal to their Angles of Incidence, the Fits of every reflected Ray within the Glaſs after Reflexion are equal in length and number to the Fits of the ſame Ray within the Glaſs before its Incidence on the reflecting Surface. And therefore ſince all the Rays of all ſorts at their entrance into the Glaſs were in a Fit of Tranſmiſſion, they were alſo in a Fit of Tranſmiſſion at their returning to the ſame Surface after Reflexion; and by conſequence were tranſmitted and went out to the white Ring on the Chart. This is the reaſon why that Ring was of the ſame bigneſs in all the Colours, and why in a mixture of all it appears white. But in Rays which are reflected in other Angles, the Intervals of the Fits of the leaſt refrangible being greateſt, make the Rings of their Colour in their progreſs from this white Ring, either outwards or inwards, increaſe or decreaſe by the greateſt ſteps; ſo that the Rings of this Colour without are greateſt, and within leaſt. And this is the reaſon why in the laſt Obſervation, when the Speculum was illuminated with white Light, the exterior Rings made by all Colours appeared red without and blue within, and the interior blue without and red within.

Theſe are the Phænomena of thick convexo-concave Plates of Glaſs, which are every where of the ſame thickneſs. There are yet other Phænomena when theſe Plates are a little thicker on one ſide than on the other, and others when the Plates are more or leſs concave than convex, or plano-convex, or double-convex. For in all theſe caſes the Plates make Rings of Colours, but after various manners; all which, ſo far as I have yet obſerved, follow from the Propoſitions in the end of the third part of this Book, and ſo conſpire to confirm the truth of thoſe Propoſitions. But the Phænomena are too various, and the Calculations whereby they follow from thoſe Propoſitions too intricate to be here proſecuted. I content my ſelf with having proſecuted this kind of Phænomena ſo far as to diſcover their Cauſe, and by diſcovering it to ratify the Propoſitions in the third Part of this Book.

*Obſ.* 13. As Light reflected by a Lens quickſilver'd on the backſide makes the Rings of Colours above deſcribed, ſo it ought to make the like Rings of Colours in paſſing through a drop of Water. At the firſt Reflexion of the Rays within the drop, ſome Colours ought to be tranſmitted, as in the caſe of a Lens, and others to be reflected back to the Eye. For inſtance, if the Diameter of a ſmall drop or globule of Water be about the 500th part of an Inch, ſo that a red-making Ray in paſſing through the middle of this globule has 250 Fits of eaſy Tranſmiſſion within the globule, and that all the red-making Rays which are at a certain diſtance from this middle Ray round about it have 249 Fits within the globule, and all the like Rays at a certain farther diſtance round about it have 248 Fits, and all thoſe at a certain farther diſtance 247 Fits, and ſo on; theſe concen-

concentrick Circles of Rays after their tranſmiſſion, falling on a white Paper, will make concentrick Rings of red upon the Paper, ſuppoſing the Light which paſſes through one ſingle globule, ſtrong enough to be ſenſible. And, in like manner, the Rays of other Colours will make Rings of other Colours. Suppoſe now that in a fair Day the Sun ſhines through a thin Cloud of ſuch globules of Water or Hail, and that the globules are all of the ſame bigneſs; and the Sun ſeen through this Cloud ſhall appear encompaſſed with the like concentrick Rings of Colours, and the Diameter of the firſt Ring of red ſhall be 7¼ Degrees, that of the ſecond 10¼ Degrees, that of the third 12 Degrees 33 Minutes. And accordingly as the Globules of Water are bigger or leſs, the Rings ſhall be leſs or bigger. This is the Theory, and Experience anſwers it. For in *June* 1692. I ſaw by reflexion in a Veſſel of ſtagnating Water three Halos, Crowns, or Rings of Colours about the Sun, like three little Rain-bows, concentrick to his Body. The Colours of the firſt or innermoſt Crown were blue next the Sun, red without, and white in the middle between the blue and red. Thoſe of the ſecond Crown were purple and blue within, and pale red without, and green in the middle. And thoſe of the third were pale blue within, and pale red without; theſe Crowns encloſed one another immediately, ſo that their Colours proceeded in this continual order from the Sun outward: blue, white, red; purple, blue, green, pale yellow and red; pale blue, pale red. The Diameter of the second Crown measured from the middle of the yellow and red on one side of the Sun, to the middle of the same Colour on the other side was $9\frac{1}{3}$ Degrees, or thereabouts. The Diameters of the first and third I had not time to measure, but that of the first seemed to be about five or six Degrees, and that of the third about twelve. The like Crowns appear sometimes about the Moon; for in the beginning of the Year 1664, *Febr.* 19th at Night, I saw two such Crowns about her. The Diameter of the first or innermost was about three Degrees, and that of the second about five Degrees and an half. Next about the Moon was a Circle of white, and next about that the inner Crown which was of a bluish green within next the white, and of a yellow and red without, and next about these Colours were blue and green on the inside of the outward Crown, and red on the outside of it. At the same time there appear'd a Halo about 22 Degrees 35′ distant from the center of the Moon. It was elliptical, and its long Diameter was perpendicular to the Horizon, verging below farthest from the Moon. I am told that the Moon has sometimes three or more concentrick Crowns of Colours encompassing one another next about her Body. The more equal the globules of Water or Ice are to one another, the more Crowns of Colours will appear, and the Colours will be the more lively. The Halo at the distance of $22\frac{1}{2}$ Degrees from the

the Moon is of another ſort. By its being oval and remoter from the Moon below than above, I conclude, that it was made by Refraction in ſome ſort of Hail or Snow floating in the Air in an horizontal poſture, the refracting Angle being about 58 or 60 Degrees.

# THE THIRD BOOK OF OPTICKS.

## PART I.

*Observations concerning the Inflexions of the Rays of Light, and the Colours made thereby.*

GRIMALDO has inform'd us, that if a beam of the Sun's Light be let into a dark Room through a very small hole, the Shadows of things in this Light will be larger than they ought to be if the Rays went on by the Bodies in strait Lines, and

and that theſe Shadows have three parallel Fringes, Bands or Ranks of colour'd Light adjacent to them. But if the Hole be enlarged the Fringes grow broad and run into one another, ſo that they cannot be diſtinguiſh'd. Theſe broad Shadows and Fringes have been reckon'd by ſome to proceed from the ordinary refraction of the Air, but without due examination of the Matter. For the circumſtances of the Phænomenon, ſo far as I have obſerved them, are as follows.

*Obſ.* 1. I made in a piece of Lead a ſmall Hole with a Pin, whoſe breadth was the 42d part of an Inch. For 21 of thoſe Pins laid together took up the breadth of half an Inch. Through this Hole I let into my darken'd Chamber a beam of the Sun's Light, and found that the Shadows of Hairs, Thred, Pins, Straws, and ſuch like ſlender Subſtances placed in this beam of Light, were conſiderably broader than they ought to be, if the Rays of Light paſſed on by theſe Bodies in right Lines. And particularly a Hair of a Man's Head, whoſe breadth was but the 280th part of an Inch, being held in this Light, at the diſtance of about twelve Feet from the Hole, did caſt a Shadow which at the diſtance of four Inches from the Hair was the ſixtieth part of an Inch broad, that is, above four times broader than the Hair, and at the diſtance of two Feet from the Hair was about the eight and twentieth part of an Inch broad, that is, ten times broader than the Hair, and at the diſtance of ten Feet was the eighth part of an Inch broad, that is 35 times broader.

Nor is it material whether the Hair be encompassed with Air, or with any other pellucid Substance. For I wetted a polish'd Plate of Glass, and laid the Hair in the Water upon the Glass, and then laying another polish'd Plate of Glass upon it, so that the Water might fill up the space between the Glasses, I held them in the aforesaid beam of Light, so that the Light might pass through them perpendicularly, and the Shadow of the Hair was at the same distances as big as before. The Shadows of Scratches made in polish'd Plates of Glass were also much broader than they ought to be, and the Veins in polish'd Plates of Glass did also cast the like broad Shadows. And therefore the great breadth of these Shadows proceeds from some other cause than the Refraction of the Air.

Let the Circle X [in *Fig.* 1.] represent the middle of the Hair; ADG, BEH, CFI, three Rays passing by one side of the Hair at several distances; KNQ, LOR, MPS, three other Rays passing by the other side of the Hair at the like distances; D, E, F, and N, O, P, the places where the Rays are bent in their passage by the Hair; G, H, I and Q, R, S, the places where the Rays fall on a Paper GQ; I S the breadth of the Shadow of the Hair cast on the Paper, and TI, VS, two Rays passing to the Points I and S without bending when the Hair is taken away. And it's manifest that all the Light between these two Rays TI and VS is bent in passing by the Hair, and turned aside from the Shadow IS, because if any part of this Light were not bent it would fall on the Paper within the Shadow, and there illuminate the Paper, contrary to experience. And because when the Paper is at a great diſtance from the Hair, the Shadow is broad, and therefore the Rays TI and VS are at a great diſtance from one another, it follows that the Hair acts upon the Rays of Light at a good diſtance in their paſſing by it. But the action is ſtrongeſt on the Rays which paſs by at leaſt diſtances, and grows weaker and weaker accordingly as the Rays paſs by at diſtances greater and greater, as is repreſented in the Scheme: For thence it comes to paſs, that the Shadow of the Hair is much broader in proportion to the diſtance of the Paper from the Hair, when the Paper is nearer the Hair, than when it is at a great diſtance from it.

*Obſ.* 2. The Shadows of all Bodies (Metals, Stones, Glaſs, Wood, Horn, Ice, *&c.*) in this Light were border'd with three parallel Fringes or Bands of colour'd Light, whereof that which was contiguous to the Shadow was broadeſt and moſt luminous, and that which was remoteſt from it was narroweſt, and ſo faint, as not eaſily to be viſible. It was difficult to diſtinguiſh the Colours unleſs when the Light fell very obliquely upon a ſmooth Paper, or ſome other ſmooth white Body, ſo as to make them appear much broader than they would otherwiſe do. And then the Colours were plainly viſible in this Order: The firſt or innermoſt Fringe was violet and deep blue next the Shadow, and then light blue, green and yellow in the middle, and red without. The ſecond Fringe was almoſt contiguous to the firſt, and the third to the ſecond, and both were blue within and yellow and red without, but their Colours were very faint, eſpecially thoſe of the third. The Colours therefore proceeded in this order from the Shadow; violet, indigo, pale blue, green, yellow, red; blue, yellow, red; pale blue, pale yellow and red. The Shadows made by Scratches and Bubbles in poliſh'd Plates of Glaſs were border'd with the like Fringes of colour'd Light. And if Plates of Looking-glaſs ſloop'd off near the edges with a Diamond-cut, be held in the ſame beam of Light, the Light which paſſes through the parallel Planes of the Glaſs will be border'd with the like Fringes of Colours where thoſe Planes meet with the Diamond-cut, and by this means there will ſometimes appear four or five Fringes of Colours. Let AB, CD [in *Fig.* 2.] repreſent the parallel Planes of a Looking-glaſs, and BD the Plane of the Diamond-cut, making at B a very obtuſe Angle with the Plane AB. And let all the Light between the Rays ENI and FBM paſs directly through the parallel Planes of the Glaſs, and fall upon the Paper between I and M, and all the Light between the Rays GO and HD be refracted by the oblique Plane of the Diamond-cut BD, and fall upon the Paper between K and L; and the Light which paſſes directly through the parallel Planes of the Glaſs, and falls upon the Paper between I and M, will be border'd with three or more Fringes at M.

So by looking on the Sun through a Feather or black Riband held close to the Eye, several Rain-bows will appear; the Shadows which the Fibres or Threds cast on the *Tunica Retina*, being border'd with the like Fringes of Colours.

*Obs.* 3. When the Hair was twelve Feet distant from this Hole, and its Shadow fell obliquely upon a flat white Scale of Inches and parts of an Inch placed half a Foot beyond it, and also when the Shadow fell perpendicularly upon the same Scale placed nine Feet beyond it; I measured the breadth of the Shadow and Fringes as accurately as I could, and found them in parts of an Inch as follows.

| *At the distance of* | *half a Foot* | *nine Feet* |
|---|---|---|
| The breadth of the Shadow | $\frac{1}{54}$ | $\frac{1}{9}$ |
| The breadth between the Middles of the brightest Light of the innermost Fringes on either side the Shadow | $\frac{1}{38}$ or $\frac{1}{39}$ | $\frac{7}{50}$ |
| The breadth between the Middles of the brightest Light of the middlemost Fringes on either side the Shadow | $\frac{1}{23\frac{1}{2}}$ | $\frac{4}{17}$ |
| The breadth between the Middles of the brightest Light of the outmost Fringes on either side the Shadow | $\frac{1}{18}$ or $\frac{1}{18\frac{1}{2}}$ | $\frac{3}{10}$ |
| The distance between the Middles of the brightest Light of the first and second Fringes. | $\frac{1}{120}$ | $\frac{1}{21}$ |
| The distance between the Middles of the brightest Light of the second and third Fringes | $\frac{1}{170}$ | $\frac{1}{31}$ |
| The breadth of the luminous part (green, white, yellow and red) of the first Fringe | $\frac{1}{170}$ | $\frac{1}{32}$ |
| The breadth of the darker Space between the first and second Fringes | $\frac{1}{240}$ | $\frac{1}{45}$ |
| The breadth of the luminous part of the second Fringe | $\frac{1}{290}$ | $\frac{1}{55}$ |
| The breadth of the darker Space between the second and third Fringes | $\frac{1}{340}$ | $\frac{1}{63}$ |

These Meaſures I took by letting the Shadow of the Hair at half a Foot diſtance fall ſo obliquely on the Scale as to appear twelve times broader than when it fell perpendicularly on it at the ſame diſtance, and ſetting down in this Table the twelfth part of the Meaſures I then took.

*Obſ.* 4. When the Shadow and Fringes were caſt obliquely upon a ſmooth white Body, and that Body was removed farther and farther from the Hair, the firſt Fringe began to appear and look brighter than the reſt of the Light at the diſtance of leſs than a quarter of an Inch from the Hair, and the dark Line or Shadow between that and the ſecond Fringe began to appear at a leſs diſtance from the Hair than that of the third part of an Inch. The ſecond Fringe began to appear at a diſtance from the Hair of leſs than half an Inch, and the Shadow between that and the third Fringe at a diſtance leſs than an Inch, and the third Fringe at a diſtance leſs than three Inches. At greater diſtances they became much more ſenſible, but kept very nearly the ſame proportion of their breadths and intervals which they had at their firſt appearing. For the diſtance between the middle of the firſt and middle of the ſecond Fringe, was to the diſtance between the middle of the ſecond and middle of the third Fringe, as three to two, or ten to ſeven. And the laſt of theſe two diſtances was equal to the breadth of the bright Light or luminous part of the firſt Fringe. And this breadth was to the breadth of the bright Light of the ſecond Fringe as ſeven to four,

four, and to the dark Interval of the firſt and ſecond Fringe as three to two, and to the like dark Interval between the ſecond and third as two to one. For the breadths of the Fringes ſeem'd to be in the progreſſion of the Numbers 1, $\sqrt{\frac{1}{3}}$, $\sqrt{\frac{1}{5}}$, and their Intervals to be in the ſame progreſſion with them; that is, the Fringes and their Intervals together to be in the continual progreſſion of the Numbers 1, $\sqrt{\frac{1}{2}}$, $\sqrt{\frac{1}{3}}$, $\sqrt{\frac{1}{4}}$, $\sqrt{\frac{1}{5}}$, or thereabouts. And theſe Proportions held the ſame very nearly at all diſtances from the Hair; the dark Intervals of the Fringes being as broad in proportion to the breadth of the Fringes at their firſt appearance as afterwards at great diſtances from the Hair, though not ſo dark and diſtinct.

*Obſ.* 5. The Sun ſhining into my darken'd Chamber through a Hole a quarter of an Inch broad; I placed at the diſtance of two or three Feet from the Hole a Sheet of Paſtboard, which was black'd all over on both ſides, and in the middle of it had a Hole about three quarters of an Inch ſquare for the Light to paſs through. And behind the Hole I faſten'd to the Paſtboard with Pitch the Blade of a ſharp Knife, to intercept ſome part of the Light which paſſed through the Hole. The Planes of the Paſtboard and Blade of the Knife were parallel to one another, and perpendicular to the Rays. And when they were ſo placed that none of the Sun's Light fell on the Paſtboard, but all of it paſſed through the Hole to the Knife, and there part of it fell upon the Blade of the Knife, and part of it paſſed by its edge: I let this part of the

the Light which paſſed by, fall on a white Paper two or three Feet beyond the Knife, and there ſaw two ſtreams of faint Light ſhoot out both ways from the beam of Light into the ſhadow like the Tails of Comets. But becauſe the Sun's direct Light by its brightneſs upon the Paper obſcured theſe faint ſtreams, ſo that I could ſcarce ſee them, I made a little hole in the midſt of the Paper for that Light to paſs through and fall on a black Cloth behind it; and then I ſaw the two ſtreams plainly. They were like one another, and pretty nearly equal in length and breadth, and quantity of Light. Their Light at that end next the Sun's direct Light was pretty ſtrong for the ſpace of about a quarter of an Inch, or half an Inch, and in all its progreſs from that direct Light decreaſed gradually till it became inſenſible. The whole length of either of theſe ſtreams meaſured upon the Paper at the diſtance of three Feet from the Knife was about ſix or eight Inches; ſo that it ſubtended an Angle at the edge of the Knife of about 10 or 12, or at moſt 14 Degrees. Yet ſometimes I thought I ſaw it ſhoot three or four Degrees farther, but with a Light ſo very faint that I could ſcarce perceive it, and ſuſpected it might (in ſome meaſure at leaſt) ariſe from ſome other cauſe than the two ſtreams did. For placing my Eye in that Light beyond the end of that ſtream which was behind the Knife, and looking towards the Knife, I could ſee a line of Light upon its edge, and that not only when my Eye was in the line of the Streams, but alſo when it was without that line either towards

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the point of the Knife, or towards the handle. This line of Light appear'd contiguous to the edge of the Knife, and was narrower than the Light of the innermoſt Fringe, and narroweſt when my Eye was fartheſt from the direct Light, and therefore ſeem'd to paſs between the Light of that Fringe and the edge of the Knife, and that which paſſed neareſt the edge to be moſt bent, though not all of it.

*Obſ.* 6. I placed another Knife by this, ſo that their edges might be parallel and look towards one another, and that the beam of Light might fall upon both the Knives, and ſome part of it paſs between their edges. And when the diſtance of their edges was about the 400th part of an Inch the ſtream parted in the middle, and left a Shadow between the two parts. This Shadow was ſo black and dark that all the Light which paſſed between the Knives ſeem'd to be bent, and turn'd aſide to the one hand or to the other. And as the Knives ſtill approached one another the Shadow grew broader, and the Streams ſhorter at their inward ends which were next the Shadow, until upon the contact of the Knives the whole Light vaniſh'd leaving its place to the Shadow.

And hence I gather that the Light which is leaſt bent, and goes to the inward ends of the Streams, paſſes by the edges of the Knives at the greateſt diſtance, and this diſtance when the Shadow begins to appear between the Streams is about the 800 part of an Inch. And the Light which paſſes by the edges of the Knives at diſtances ſtill leſs and leſs is more and more bent, and goes to thoſe parts of the Streams which are farther and farther from the direct Light, becauſe when the Knives approach one another till they touch, thoſe parts of the Streams vaniſh laſt which are fartheſt from the direct Light.

*Obſ.* 7. In the fifth Obſervation the Fringes did not appear, but by reaſon of the breadth of the hole in the Window became ſo broad as to run into one another, and by joining, to make one continued Light in the beginning of the Streams. But in the ſixth, as the Knives approached one another, a little before the Shadow appear'd between the two Streams, the Fringes began to appear on the inner ends of the Streams on either ſide of the direct Light, three on one ſide made by the edge of one Knife, and three on the other ſide made by the edge of the other Knife. They were diſtincteſt when the Knives were placed at the greateſt diſtance from the hole in the Window, and ſtill became more diſtinct by making the hole leſs, inſomuch that I could ſometimes ſee a faint Lineament of a fourth Fringe beyond the three above mention'd. And as the Knives continually approach'd one another, the Fringes grew diſtincter and larger until they vaniſh'd. The outmoſt Fringe vaniſh'd firſt, and the middlemoſt next, and the innermoſt laſt. And after they were all vaniſh'd, and the line of Light which was in the middle between them was grown very broad, enlarging it ſelf on both ſides into the Streams of Light deſcribed in the fifth Obſervation, the above mention'd Shadow began

gan to appear in the middle of this line, and divide it along the middle into two lines of Light, and increaſed until the whole Light vaniſh'd. This enlargement of the Fringes was ſo great that the Rays which go to the innermoſt Fringe ſeem'd to be bent above twenty times more when this Fringe was ready to vaniſh, than when one of the Knives was taken away.

And from this and the former Obſervation compared, I gather, that the Light of the firſt Fringe paſſed by the edge of the Knife at a diſtance greater than the 800th part of an Inch, and the Light of the ſecond Fringe paſſed by the edge of the Knife at a greater diſtance than the Light of the firſt Fringe did, and that of the third at a greater diſtance than that of the ſecond, and that of the Streams of Light deſcribed in the fifth and ſixth Obſervations paſſed by the edges of the Knives at leſs diſtances than that of any of the Fringes.

*Obſ.* 8. I cauſed the edges of two Knives to be ground truly ſtrait, and pricking their points into a Board ſo that their edges might look towards one another, and meeting near their points contain a rectilinear Angle, I faſten'd their Handles together with Pitch to make this Angle invariable. The diſtance of the edges of the Knives from one another at the diſtance of four Inches from the angular Point, where the edges of the Knives met, was the eighth part of an Inch, and therefore the Angle contain'd by the edges, was about 1 Degree 54′. The Knives thus fix'd together I placed in a beam of of the Sun's Light, let into my darken'd Chamber through a hole the 42d part of an Inch wide, at the diſtance of 10 or 15 Feet from the hole, and let the Light which paſſed between their edges fall very obliquely upon a ſmooth white Ruler at the diſtance of half an Inch, or an Inch from the Knives, and there ſaw the Fringes made by the two edges of the Knives run along the edges of the Shadows of the Knives in lines parallel to thoſe edges without growing ſenſibly broader, till they met in Angles equal to the Angle contained by the edges of the Knives, and where they met and joined they ended without croſſing one another. But if the Ruler was held at a much greater diſtance from the Knives, the Fringes where they were farther from the place of their meeting, were a little narrower, and became ſomething broader and broader as they approach'd nearer and nearer to one another, and after they met they croſs'd one another, and then became much broader than before.

Whence I gather that the diſtances at which the Fringes paſs by the Knives are not increaſed nor alter'd by the approach of the Knives, but the Angles in which the Rays are there bent are much increaſed by that approach; and that the Knife which is neareſt any Ray determines which way the Ray ſhall be bent, and the other Knife increaſes the bent.

*Obſ.* 9. When the Rays fell very obliquely upon the Ruler at the diſtance of the third part of an Inch from the Knives, the dark line between the firſt and ſecond Fringe of the Sha-

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dow of one Knife, and the dark line between the first and second Fringe of the Shadow of the other Knife met with one another, at the distance of the fifth part of an Inch from the end of the Light which passed between the Knives at the concourse of their edges. And therefore the distance of the edges of the Knives at the meeting of these dark lines was the 160th part of an Inch. For as four Inches to the eighth part of an Inch, so is any length of the edges of the Knives measured from the point of their concourse to the distance of the edges of the Knives at the end of that length, and so is the fifth part of an Inch to the 160th part. So then the dark lines above mention'd meet in the middle of the Light which passes between the Knives where they are distant the 160th part of an Inch, and the one half of that Light passes by the edge of one Knife at a distance not greater than the 320th part of an Inch, and falling upon the Paper makes the Fringes of the Shadow of that Knife, and the other half passes by the edge of the other Knife, at a distance not greater than the 320th part of an Inch, and falling upon the Paper makes the Fringes of the Shadow of the other Knife. But if the Paper be held at a distance from the Knives greater than the third part of an Inch, the dark lines above mention'd meet at a greater distance than the fifth part of an Inch from the end of the Light which passed between the Knives at the concourse of their edges; and therefore the Light which falls upon the Paper where those dark lines meet passes between the

Knives where their edges are diſtant above the 160th part of an Inch.

For at another time when the two Knives were diſtant eight Feet and five Inches from the little hole in the Window, made with a ſmall Pin as above, the Light which fell upon the Paper where the aforeſaid dark lines met, paſſed between the Knives, where the diſtance between their edges was as in the following Table, when the diſtance of the Paper from the Knives was alſo as follows.

| *Diſtances of the Paper from the Knives in Inches.* | *Diſtances between the edges of the Knives in milleſimal parts of an Inch.* |
|---|---|
| $1\frac{1}{2}$. | 0'012 |
| $3\frac{1}{3}$. | 0'020 |
| $8\frac{3}{5}$. | 0'034 |
| 32. | 0'057 |
| 96. | 0'081 |
| 131. | 0'087 |

And hence I gather that the Light which makes the Fringes upon the Paper is not the ſame Light at all diſtances of the Paper from the Knives, but when the Paper is held near the Knives, the Fringes are made by Light which paſſes by the edges of the Knives at a leſs diſtance, and is more bent than when the Paper is held at a greater diſtance from the Knives.

*Obſ.* 10. When the Fringes of the Shadows of the Knives fell perpendicularly upon a Paper at a great diſtance from the Knives, they were in the form of Hyperbolas, and their Dimenſions were as follows. Let CA, CB [in *Fig.* 3.] repreſent lines drawn upon the Paper parallel to the edges of the Knives, and between which all the Light would fall, if it paſſed between the edges of the Knives without inflexion; DE a right line drawn through C making the Angles ACD, BCE, equal to one another, and terminating all the Light which falls upon the Paper from the point where the edges of the Knives meet; *e i s*, *f k t*, and *g l v*, three hyperbolical lines repreſenting the Terminus of the Shadow of one of the Knives, the dark line between the firſt and ſecond Fringes of that Shadow, and the dark line between the ſecond and third Fringes of the ſame Shadow; *x i p*, *y k q* and *z l r*, three other hyperbolical lines repreſenting the Terminus of the Shadow of the other Knife, the dark line between the firſt and ſecond Fringes of that Shadow, and the dark line between the ſecond and third Fringes of the ſame Shadow. And conceive that theſe three Hyperbolas are like and equal to the former three, and croſs them in the points *i*, *k* and *l*, and that the Shadows of the Knives are terminated and diſtinguiſh'd from the firſt luminous Fringes by the lines *e i s* and *x i p*, until the meeting and croſſing of the Fringes, and then thoſe lines croſs the Fringes in the form of dark lines, terminating the firſt luminous Fringes within ſide, and diſtinguiſhing them from another Light which begins

begins to appear at *i*, and illuminates all the triangular ſpace *ip*DE*s* comprehended by theſe dark lines, and the ri ht line DE. Of theſe Hyperbolas one Aſymptote is the line DE, and their other Aſymptotes are parallel to the lines CA and CB. Let *rv* repreſent a line drawn any where upon the Paper parallel to the Aſymptote DE, and let this line croſs the right lines AC in *m* and BC in *n*, and the ſix dark hyperbolical lines in *p*, *q*, *r*; *s*, *t*, *v*; and by meaſuring the diſtances *ps*, *qt*, *rv*, and thence collecting the lengths of the Ordinates *np*, *nq*, *nr* or *ms*, *mt*, *mv*, and doing this at ſeveral diſtances of the line *rv* from the Aſymptote DD, you may find as many points of theſe Hyperbolas as you pleaſe, and thereby know that theſe curve lines are Hyperbolas differing little from the conical Hyperbola. And by meaſuring the lines C*i*, C*k*, C*l*, you may find other points of theſe Curves.

For inſtance, when the Knives were diſtant from the hole in the Window ten Feet, and the Paper from the Knives nine Feet, and the Angle contained by the edges of the Knives to which the Angle ACB is equal, was ſubtended by a Chord which was to the Radius as 1 to 32, and the diſtance of the line *rv* from the Aſymptote DE was half an Inch: I meaſured the lines *ps*, *qt*, *rv*, and found them 0'35, 0'65, 0'98 Inches reſpectively, and by adding to their halfs the line $\frac{1}{2}$ *mn* (which here was the 128th part of an Inch, or 0'0078 Inches) the Sums *np*, *nq*, *nr*, were 0'1828, 0'3328, 0'4978 Inches. I meaſured alſo the diſtances of the

 brighteſt

brighteſt parts of the Fringes which run between *p q* and *s t*, *q r* and *t v*, and next beyond *r* and *v*, and found them 0'5, 0'8, and 1'17 Inches.

*Obſ.* 11. The Sun ſhining into my darken'd Room through a ſmall round hole made in a Plate of Lead with a ſlender Pin as above; I placed at the hole a Priſm to refract the Light, and form on the oppoſite Wall the Spectrum of Colours, deſcribed in the third Experiment of the firſt Book. And then I found that the Shadows of all Bodies held in the colour'd Light between the Priſm and the Wall, were border'd with Fringes of the Colour of that Light in which they were held. In the full red Light they were totally red without any ſenſible blue or violet, and in the deep blue Light they were totally blue without any ſenſible red or yellow; and ſo in the green Light they were totally green, excepting a little yellow and blue, which were mix'd in the green Light of the Priſm. And comparing the Fringes made in the ſeveral colour'd Lights, I found that thoſe made in the red Light where largeſt, thoſe made in the violet were leaſt, and thoſe made in the green were of a middle bigneſs. For the Fringes with which the Shadow of a Man's Hair were border'd, being meaſured croſs the Shadow at the diſtance of ſix Inches from the Hair; the diſtance between the middle and moſt luminous part of the firſt or innermoſt Fringe on one ſide of the Shadow, and that of the like Fringe on the other ſide of the Shadow was in the full red Light $\frac{1}{37\frac{1}{4}}$ of an Inch, and in the full

violet

violet $\frac{1}{46}$. And the like diſtance between the middle and moſt luminous parts of the ſecond Fringes on either ſide the Shadow was in the full red Light $\frac{1}{22}$, and in the violet $\frac{1}{27}$ of an Inch. And theſe diſtances of the Fringes held the ſame proportion at all diſtances from the Hair without any ſenſible variation.

So then the Rays which made theſe Fringes in the red Light paſſed by the Hair at a greater diſtance than thoſe did which made the like Fringes in the violet; and therefore the Hair in cauſing theſe Fringes acted alike upon the red Light or leaſt refrangible Rays at a greater diſtance, and upon the violet or moſt refrangible Rays at a leſs diſtance, and by thoſe actions diſpoſed the red Light into larger Fringes, and the violet into ſmaller, and the Lights of intermediate Colours into Fringes of intermediate bigneſſes without changing the Colour of any ſort of Light.

When therefore the Hair in the firſt and ſecond of theſe Obſervations was held in the white beam of the Sun's Light, and caſt a Shadow which was border'd with three Fringes of colour'd Light, thoſe Colours aroſe not from any new modifications impreſs'd upon the Rays of Light by the Hair, but only from the various inflexions whereby the ſeveral ſorts of Rays were ſeparated from one another, which before ſeparation by the mixture of all their Colours, compoſed the white beam of the Sun's Light, but whenever ſeparated compoſe Lights of the ſeveral Colours which they are originally diſpoſed to exhibit. In this 11th Obſervation, where the Colours are ſeparated before the Light paſſes by the Hair, the leaſt refrangible Rays, which when ſeparated from the reſt make red, were inflected at a greater diſtance from the Hair, ſo as to make three red Fringes at a greater diſtance from the middle of the Shadow of the Hair; and the moſt refrangible Rays which when ſeparated make violet, were inflected at a leſs diſtance from the Hair, ſo as to make three violet Fringes at a leſs diſtance from the middle of the Shadow of the Hair. And other Rays of intermediate degrees of Refrangibility were inflected at intermediate diſtances from the Hair, ſo as to make Fringes of intermediate Colours at intermediate diſtances from the middle of the Shadow of the Hair. And in the ſecond Obſervation, where all the Colours are mix'd in the white Light which paſſes by the Hair, theſe Colours are ſeparated by the various inflexions of the Rays, and the Fringes which they make appear all together, and the innermoſt Fringes being contiguous make one broad Fringe compoſed of all the Colours in due order, the violet lying on the inſide of the Fringe next the Shadow, the red on the outſide fartheſt from the Shadow, and the blue, green and yellow, in the middle. And, in like manner, the middlemoſt Fringes of all the Colours lying in order, and being contiguous, make another broad Fringe compoſed of all the Colours; and the outmoſt Fringes of all the Colours lying in order, and being contiguous, make a third broad Fringe compoſed of all the Colours. Theſe are the three Fringes of colour'd lour'd Light with which the Shadows of all Bodies are border'd in the ſecond Obſervation.

When I made the foregoing Obſervations, I deſign'd to repeat moſt of them with more care and exactneſs, and to make ſome new ones for determining the manner how the Rays of Light are bent in their paſſage by Bodies for making the Fringes of Colours with the dark lines between them. But I was then interrupted, and cannot now think of taking theſe things into farther conſideration. And ſince I have not finiſh'd this part of my Deſign, I ſhall conclude, with propoſing only ſome Queries in order to a farther ſearch to be made by others.

*Query* 1. Do not Bodies act upon Light at a diſtance, and by their action bend its Rays, and is not this action *(cæteris paribus)* ſtrongeſt at the leaſt diſtance?

*Qu.* 2. Do not the Rays which differ in Refrangibility differ alſo in Flexibility, and are they not by their different Inflexions ſeparated from one another, ſo as after ſeparation to make the Colours in the three Fringes above deſcribed? And after what manner are they inflected to make thoſe Fringes?

*Qu.* 3. Are not the Rays of Light in paſſing by the edges and ſides of Bodies, bent ſeveral times backwards and forwards, with a motion like that of an Eel? And do not the three Fringes of colour'd Light above mention'd, ariſe from three ſuch bendings?

*Qu.* 4. Do not the Rays of Light which fall upon Bodies, and are reflected or refracted, begin

gin to bend before they arrive at the Bodies; and are they not reflected, refracted and inflected by one and the same Principle, acting variously in various Circumstances?

*Qu.* 5. Do not Bodies and Light act mutually upon one another, that is to say, Bodies upon Light in emitting, reflecting, refracting and inflecting it, and Light upon Bodies for heating them, and putting their parts into a vibrating motion wherein heat consists?

*Qu.* 6. Do not black Bodies conceive heat more easily from Light than those of other Colours do, by reason that the Light falling on them is not reflected outwards, but enters the Bodies, and is often reflected and refracted within them, until it be stifled and lost?

*Qu.* 7. Is not the strength and vigour of the action between Light and sulphureous Bodies observed above, one reason why sulphureous Bodies take fire more readily, and burn more vehemently, than other Bodies do?

*Qu.* 8. Do not all fix'd Bodies when heated beyond a certain degree, emit Light and shine, and is not this Emission perform'd by the vibrating Motions of their parts? And do not all Bodies which abound with terrestrial parts, and especially with sulphureous ones, emit Light as often as those parts are sufficiently agitated; whether that agitation be made by Heat, or by Friction, or Percussion, or Putrefaction, or by any vital Motion, or any other Cause? As for instance; Sea Water in a raging Storm; Quicksilver agitated in *vacuo*; the Back of a Cat, or Neck of a Horse obliquely struck or rubbed in a dark a dark place; Wood, Flesh and Fish while they putrefy; Vapours arising from putrefy'd Waters, usually call'd *Ignes Fatui*; Stacks of moist Hay or Corn growing hot by fermentation; Glow-worms and the Eyes of some Animals by vital Motions; the vulgar *Phosphorus* agitated by the attrition of any Body, or by the acid Particles of the Air; Ambar and some Diamonds by striking, pressing or rubbing them; Scrapings of Steel struck off with a Flint; Iron hammer'd very nimbly till it become so hot as to kindle Sulphur thrown upon it; the Axletrees of Chariots taking fire by the rapid rotation of the Wheels; and some Liquors mix'd with one another whose Particles come together with an Impetus, as Oil of Vitriol distilled from its weight of Nitre, and then mix'd with twice its weight of Oil of Anniseeds. So also a Globe of Glass about 8 or 10 Inches in diameter, being put into a Frame where it may be swiftly turn'd round its Axis, will in turning shine where it rubs against the palm of ones Hand apply'd to it: And if at the same time a piece of white Paper or white Cloth, or the end of ones Finger be held at the distance of about a quarter of an Inch or half an Inch from that part of the Glass where it is most in motion, the electrick Vapour which is excited by the friction of the Glass against the Hand, will by dashing against the white Paper, Cloth or Finger, be put into such an agitation as to emit Light, and make the white Paper, Cloth or Finger, appear lucid like a Glow-worm; and in rushing out of the Glass will sometimes push

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against the Finger so as to be felt. And the same things have been found by rubbing a long and large Cylinder of Glass or Ambar with a Paper held in ones hand, and continuing the friction till the Glass grew warm.

*Qu.* 9. Is not Fire a Body heated so hot as to emit Light copiously? For what else is a red hot Iron than Fire? And what else is a burning Coal than red hot Wood?

*Qu.* 10. Is not Flame a Vapour, Fume or Exhalation heated red hot, that is, so hot as to shine? For Bodies do not flame without emitting a copious Fume, and this Fume burns in the Flame. The *Ignis Fatuus* is a Vapour shining without heat, and is there not the same difference between this Vapour and Flame, as between rotten Wood shining without heat and burning Coals of Fire? In distilling hot Spirits, if the Head of the Still be taken off, the Vapour which ascends out of the Still will take fire at the Flame of a Candle, and turn into Flame, and the Flame will run along the Vapour from the Candle to the Still. Some Bodies heated by Motion or Fermentation, if the heat grow intense, fume copiously, and if the heat be great enough the Fumes will shine and become Flame. Metals in fusion do not flame for want of a copious Fume, except Spelter, which fumes copiously, and thereby flames. All flaming Bodies, as Oil, Tallow, Wax, Wood, fossil Coals, Pitch, Sulphur, by flaming waste and vanish into burning Smoke, which Smoke, if the Flame be put out, is very thick and visible, and sometimes smells strongly, but in the Flame loses its

smell

ſmell by burning, and according to the nature of the Smoke the Flame is of ſeveral Colours, as that of Sulphur blue, that of Copper open'd with ſublimate green, that of Tallow yellow, that of Camphire white. Smoke paſſing through Flame cannot but grow red hot, and red hot Smoke can have no other appearance than that of Flame. When Gun-powder takes fire, it goes away into flaming Smoke. For the Charcoal and Sulphur eaſily take fire, and ſet fire to the Nitre, and the Spirit of the Nitre being thereby rarified into Vapour, ruſhes out with Exploſion much after the manner that the Vapour of Water ruſhes out of an Æolipile; the Sulphur alſo being volatile is converted into Vapour, and augments the Exploſion. And the acid Vapour of the Sulphur (namely that which diſtils under a Bell into Oil of Sulphur,) entring violently into the fix't Body of the Nitre, ſets looſe the Spirit of the Nitre, and excites a great Fermentation, whereby the Heat is farther augmented, and the fix'd Body of the Nitre is alſo rarified into Fume, and the Exploſion is thereby made more vehement and quick. For if Salt of Tartar be mix'd with Gun-powder, and that Mixture be warm'd till it takes fire, the Exploſion will be more violent and quick than that of Gun-powder alone; which cannot proceed from any other cauſe than the action of the Vapour of the Gun-powder upon the Salt of Tartar, whereby that Salt is rarified. The Exploſion of Gun-powder ariſes therefore from the violent action whereby all the Mixture being quickly and vehemently heated, is rarified and converted into Fume and Vapour: which Vapour, by the violence of that action, becoming so hot as to shine, appears in the form of Flame.

*Qu.* 11. Do not great Bodies conserve their heat the longest, their parts heating one another, and may not great dense and fix'd Bodies, when heated beyond a certain degree, emit Light so copiously, as by the Emission and Re-action of its Light, and the Reflexions and Refractions of its Rays within its Pores to grow still hotter, till it comes to a certain period of heat, such as is that of the Sun? And are not the Sun and fix'd Stars great Earths vehemently hot, whose heat is conserved by the greatness of the Bodies, and the mutual Action and Re-action between them, and the Light which they emit, and whose parts are kept from fuming away, not only by their fixity, but also by the vast weight and density of the Atmospheres incumbent upon them, and very strongly compressing them, and condensing the Vapours and Exhalations which arise from them? For if Water be made warm in any pellucid Vessel emptied of Air, that Water in the *Vacuum* will bubble and boil as vehemently as it would in the open Air in a Vessel set upon the Fire till it conceives a much greater heat. For the weight of the incumbent Atmosphere keeps down the Vapours, and hinders the Water from boiling, until it grow much hotter than is requisite to made in boil *in vacuo*. Also a mixture of Tin and Lead being put upon a red hot Iron *in vacuo* emits a Fume and Flame, but the same

ſame Mixture in the open Air, by reaſon of the incumbent Atmoſphere, does not ſo much as emit any Fume which can be perceived by Sight. In like manner the great weight of the Atmoſphere which lies upon the Globe of the Sun may hinder Bodies there from riſing up and going away from the Sun in the form of Vapours and Fumes, unleſs by means of a far greater heat than that which on the Surface of our Earth would very eaſily turn them into Vapours and Fumes. And the ſame great weight may condenſe thoſe Vapours and Exhalations as ſoon as they ſhall at any time begin to aſcend from the Sun, and make them preſently fall back again into him, and by that action increaſe his Heat much after the manner that in our Earth the Air increaſes the Heat of a culinary Fire. And the ſame weight may hinder the Globe of the Sun from being diminiſh'd, unleſs by the Emiſſion of Light, and a very ſmall quantity of Vapours and Exhalations.

*Qu*. 12. Do not the Rays of Light in falling upon the bottom of the Eye excite Vibrations in the *Tunica Retina*? Which Vibrations, being propagated along the ſolid Fibres of the optick Nerves into the Brain, cauſe the Senſe of ſeeing. For becauſe denſe Bodies conſerve their Heat a long time, and the denſeſt Bodies conſerve their Heat the longeſt, the Vibrations of their parts are of a laſting nature, and therefore may be propagated along ſolid Fibres of uniform denſe Matter to a great diſtance, for conveying into the Brain the impreſſions made upon all the Organs of Senſe. For that Motion

which

which can continue long in one and the same part of a Body, can be propagated a long way from one part to another, supposing the Body homogeneal, so that the Motion may not be reflected, refracted, interrupted or disorder'd by any unevenness of the Body.

*Qu.* 13. Do not several sorts of Rays make Vibrations of several bignesses, which according to their bignesses excite Sensations of several Colours, much after the manner that the Vibrations of the Air, according to their several bignesses excite Sensations of several Sounds? And particularly do not the most refrangible Rays excite the shortest Vibrations for making a Sensation of deep violet, the least refrangible the largest for making a Sensation of deep red, and the several intermediate sorts of Rays, Vibrations of several intermediate bignesses to make Sensations of the several intermediate Colours?

*Qu.* 14. May not the harmony and discord of Colours arise from the proportions of the Vibrations propagated through the Fibres of the optick Nerves into the Brain, as the harmony and discord of Sounds arise from the proportions of the Vibrations of the Air? For some Colours, if they be view'd together, are agreeable to one another, as those of Gold and Indigo, and others disagree.

*Qu.* 15. Are not the Species of Objects seen with both Eyes united where the optick Nerves meet before they come into the Brain, the Fibres on the right side of both Nerves uniting there, and after union going thence into the Brain in the Nerve which is on the right side of the

the Head, and the Fibres on the left ſide of both Nerves uniting in the ſame place, and after union going into the Brain in the Nerve which is on the left ſide of the Head, and theſe two Nerves meeting in the Brain in ſuch a manner that their Fibres make but one entire Species or Picture, half of which on the right ſide of the Senſorium comes from the right ſide of both Eyes through the right ſide of both optick Nerves to the place where the Nerves meet, and from thence on the right ſide of the Head into the Brain, and the other half on the left ſide of the Senſorium comes in like manner from the left ſide of both Eyes. For the optick Nerves of ſuch Animals as look the ſame way with both Eyes (as of Men, Dogs, Sheep, Oxen, *&c.*) meet before they come into the Brain, but the optick Nerves of ſuch Animals as do not look the ſame way with both Eyes (as of Fiſhes and of the Chameleon) do not meet, if I am rightly inform'd.

*Qu.*16. When a Man in the dark preſſes either corner of his Eye with his Finger, and turns his Eye away from his Finger, he will ſee a Circle of Colours like thoſe in the Feather of a Peacock's Tail. If the Eye and the Finger remain quiet theſe Colours vaniſh in a ſecond Minute of Time, but if the Finger be moved with a quavering Motion they appear again. Do not theſe Colours ariſe from ſuch Motions excited in the bottom of the Eye by the Preſſure and Motion of the Finger, as at other times are excited there by Light for cauſing Viſion? And do not the Motions once excited continue about a Second of Time before they ceafe? And when a Man by a ftroke upon his Eye fees a flafh of Light, are not the like Motions excited in the *Retina* by the ftroke? And when a Coal of Fire moved nimbly in the circumference of a Circle, makes the whole circumference appear like a Circle of Fire: Is it not becaufe the Motions excited in the bottom of the Eye by the Rays of Light are of a lafting nature, and continue till the Coal of Fire in going round returns to its former place? And confidering the laftingnefs of the Motions excited in the bottom of the Eye by Light, are they not of a vibrating nature?

*Qu.* 17. If a Stone be thrown into ftagnating Water, the Waves excited thereby continue fome time to arife in the place where the Stone fell into the Water, and are propagated from thence in concentrick Circles upon the Surface of the Water to great diftances. And the Vibrations or Tremors excited in the Air by percuffion, continue a little time to move from the place of percuffion in concentrick Spheres to great diftances. And in like manner, when a Ray of Light falls upon the Surface of any pellucid Body, and is there refracted or reflected; may not Waves of Vibrations, or Tremors, be thereby excited in the refracting or reflecting Medium at the point of Incidence, and continue to arife there, and to be propagated from thence as long as they continue to do fo, when they are excited in the bottom of the Eye by the Preffure or Motion of the Finger, or by the Light which comes from the Coal of Fire in the Experiments

periments above mention'd? And are not these Vibrations propagated from the point of Incidence to great distances? And do they not overtake the Rays of Light, and by overtaking them successively, do they not put them into the Fits of easy Reflexion and easy Transmission described above? For if the Rays endeavour to recede from the densest part of the Vibration, they may be alternately accelerated and retarded by the Vibrations overtaking them.

*Qu.* 18. If in two large tall cylindrical Vessels of Glass inverted, two little Thermometers be suspended so as not to touch the Vessels, and the Air be drawn out of one of these Vessels, and these Vessels thus prepared be carried out of a cold place into a warm one; the Thermometer *in vacuo* will grow warm as much, and almost as soon as the Thermometer which is not *in vacuo*. And when the Vessels are carried back into the cold place, the Thermometer *in vacuo* will grow cold almost as soon as the other Thermometer. Is not the Heat of the warm Room convey'd through the *Vacuum* by the Vibrations of a much subtiler Medium than Air, which after the Air was drawn out remained in the *Vacuum*? And is not this Medium the same with that Medium by which Light is refracted and reflected, and by whose Vibrations Light communicates Heat to Bodies, and is put into Fits of easy Reflexion and easy Transmission? And do not the Vibrations of this Medium in hot Bodies contribute to the intenseness and duration of their Heat? And do not hot Bodies communicate their Heat to contiguous cold ones, by the Vibrations of this Medium propagated from them into the cold ones? And is not this Medium exceedingly more rare and ſubtile than the Air, and exceedingly more elaſtick and active? And doth it not readily pervade all Bodies? And is it not (by its elaſtick force) expanded through all the Heavens?

*Qu.* 19. Doth not the Refraction of Light proceed from the different denſity of this Æthereal Medium in different places, the Light receding always from the denſer parts of the Medium? And is not the denſity thereof greater in free and open Spaces void of Air and other groſſer Bodies, than within the Pores of Water, Glaſs, Cryſtal, Gems, and other compact Bodies? For when Light paſſes through Glaſs or Cryſtal, and falling very obliquely upon the farther Surface thereof is totally reflected, the total Reflexion ought to proceed rather from the denſity and vigour of the Medium without and beyond the Glaſs, than from the rarity and weakneſs thereof.

*Qu.* 20. Doth not this Æthereal Medium in paſſing out of Water, Glaſs, Cryſtal, and other compact and denſe Bodies into empty Spaces, grow denſer and denſer by degrees, and by that means refract the Rays of Light not in a point, but by bending them gradually in curve Lines? And doth not the gradual condenſation of this Medium extend to ſome diſtance from the Bodies, and thereby cauſe the Inflexions of the Rays of Light, which paſs by the edges of denſe Bodies, at ſome diſtance from the Bodies?

*Qu.*

*Qu.* 21. Is not this Medium much rarer within the denſe Bodies of the Sun, Stars, Planets and Comets, than in the empty celeſtial Spaces between them? And in paſſing from them to great diſtances, doth it not grow denſer and denſer perpetually, and thereby cauſe the gravity of thoſe great Bodies towards one another, and of their parts towards the Bodies; every Body endeavouring to go from the denſer parts of the Medium towards the rarer? For if this Medium be rarer within the Sun's Body than at its Surface, and rarer there than at the hundredth part of an Inch from its Body, and rarer there than at the fiftieth part of an Inch from its Body, and rarer there than at the Orb of *Saturn*; I ſee no reaſon why the Increaſe of denſity ſhould ſtop any where, and not rather be continued through all diſtances from the Sun to *Saturn*, and beyond. And though this Increaſe of denſity may at great diſtances be exceeding ſlow, yet if the elaſtick force of this Medium be exceeding great, it may ſuffice to impel Bodies from the denſer parts of the Medium towards the rarer, with all that power which we call Gravity. And that the elaſtick force of this Medium is exceeding great, may be gather'd from the ſwiftneſs of its Vibrations. Sounds move about 1140 *Engliſh* Feet in a ſecond Minute of Time, and in ſeven or eight Minutes of Time they move about one hundred *Engliſh* Miles. Light moves from the Sun to us in about ſeven or eight Minutes of Time, which diſtance is about 70000000 *Engliſh* Miles, ſuppoſing the horizontal Parallax of the Sun to be about 12″. And the Vibrations or Pulses of this Medium, that they may cause the alternate Fits of easy Transmission and easy Reflexion, must be swifter than Light, and by consequence above 700000 times swifter than Sounds. And therefore the elastick force of this Medium, in proportion to its density, must be above 700000 x 700000 (that is, above 490000000000) times greater than the elastick force of the Air is in proportion to its density. For the Velocities of the Pulses of elastick Mediums are in a subduplicate *Ratio* of the Elasticities and the Rarities of the Mediums taken together.

As Attraction is stronger in small Magnets than in great ones in proportion to their bulk, and Gravity is greater in the Surfaces of small Planets than in those of great ones in proportion to their bulk, and small Bodies are agitated much more by electric attraction than great ones; so the smallness of the Rays of Light may contribute very much to the the power of the Agent by which they are refracted. And so if any one should suppose that *Æther* (like our Air) may contain Particles which endeavour to recede from one another (for I do not know what this *Æther* is) and that its Particles are exceedingly smaller than those of Air, or even than those of Light: The exceeding smallness of its Particles may contribute to the greatness of the force by which those Particles may recede from one another, and thereby make that Medium exceedingly more rare and elastick than Air, and by consequence exceedingly less able to resist the motions of Projectiles, and exceed-

exceedingly more able to preſs upon groſs Bodies, by endeavouring to expand it ſelf.

*Qu.* 22. May not Planets and Comets, and all groſs Bodies, perform their Motions more freely, and with leſs reſiſtance in this Æthereal Medium than in any Fluid, which fills all Space adequately without leaving any Pores, and by conſequence is much denſer than Quick-ſilver or Gold? And may not its reſiſtance be ſo ſmall, as to be inconſiderable? For inſtance; If this *Æther* (for ſo I will call it) ſhould be ſuppoſed 700000 times more elaſtick than our Air, and above 700000 times more rare; its reſiſtance would be above 600000000 times leſs than that of Water. And ſo ſmall a reſiſtance would ſcarce make any ſenſible alteration in the Motions of the Planets in ten thouſand Years. If any one would ask how a Medium can be ſo rare, let him tell me how the Air, in the upper parts of the Atmoſphere, can be above an hundred thouſand thouſand times rarer than Gold. Let him alſo tell me, how an electrick Body can by Friction emit an Exhalation ſo rare and ſubtile, and yet ſo potent, as by its Emiſſion to cauſe no ſenſible Diminution of the weight of the electrick Body, and to be expanded through a Sphere, whoſe Diameter is above two Feet, and yet to be able to agitate and carry up Leaf Copper, or Leaf Gold, at the diſtance of above a Foot from the electrick Body? And how the Effluvia of a Magnet can be ſo rare and ſubtile, as to paſs through a Plate of Glaſs without any Reſiſtance or Diminution of their Force, and yet ſo potent as to turn a magnetick Needle beyond the Glaſs?

*Qu.* 23. Is not Vision perform'd chiefly by the Vibrations of this Medium, excited in the bottom of the Eye by the Rays of Light, and propagated through the solid, pellucid and uniform Capillamenta of the optick Nerves into the place of Sensation? And is not Hearing perform'd by the Vibrations either of this or some other Medium, excited in the auditory Nerves by the Tremors of the Air, and propagated through the solid, pellucid and uniform Capillamenta of those Nerves into the place of Sensation? And so of the other Senses.

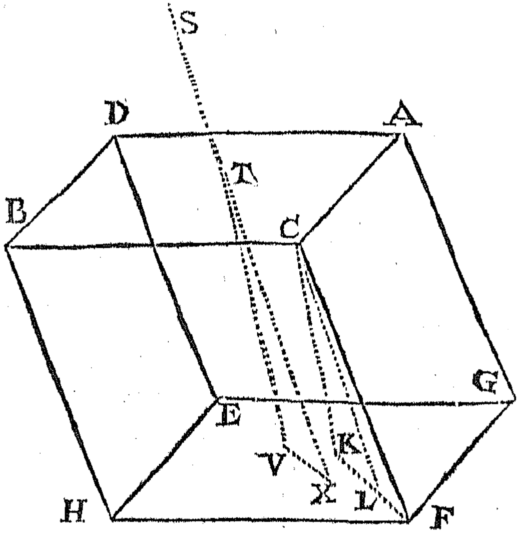
*Qu.* 24. Is not Animal Motion perform'd by the Vibrations of this Medium, excited in the Brain by the power of the Will, and propagated from thence through the solid, pellucid and uniform Capillamenta of the Nerves into the Muscles, for contracting and dilating them? I suppose that the Capillamenta of the Nerves are each of them solid and uniform, that the vibrating Motion of the Æthereal Medium may be propagated along them from one end to the other uniformly, and without interruption: For Obstructions in the Nerves create Palsies. And that they may be sufficiently uniform, I suppose them to be pellucid when view'd singly, tho' the Reflexions in their cylindrical Surfaces may make the whole Nerve (composed of many Capillamenta) appear opake and white. For opacity arises from reflecting Surfaces, such as may disturb and interrupt the Motions of this Medium.

*Qu.* 25. Are there not other original Properties of the Rays of Light, besides those already described? An instance of another original Pro-

Property we have in the Refraction of Island Crystal, described first by *Erasmus Bartholine*, and afterwards more exactly by *Hugenius*, in his Book *De la Lumiere*. This Crystal is a pellucid fissile Stone, clear as Water or Crystal of the Rock, and without Colour; enduring a red Heat without losing its transparency, and in a very strong Heat calcining without Fusion. Steep'd a Day or two in Water, it loses its natural Polish. Being rubb'd on Cloth, it attracts pieces of Straws and other light things, like Ambar or Glass; and with *Aqua fortis* it makes an Ebullition. It seems to be a sort of Talk, and is found in form of an oblique Parallelopiped, with six parallelogram Sides and eight solid Angles. The obtuse Angles of the Parallelograms are each of them 101 Degrees and 52 Minutes; the acute ones 78 Degrees and 8 Minutes. Two of the solid Angles opposite to one another, as C and E, are compassed each of them with three of these obtuse Angles, and each of the other six with one obtuse and two acute ones. It cleaves easily in Planes parallel to any of its Sides, and not in any other Planes. It cleaves with a glossy polite Surface not perpectly plane, but with some little unevenness. It is easily scratch'd, and by reason of its softness it takes a Polish very difficultly. It polishes better upon polish'd Looking-glass than upon Metal, and perhaps better upon Pitch, Leather or Parchment. Afterwards it must be rubb'd with a little Oil or White of an Egg, to fill up its Scratches; whereby it will become very transparent

*See the following Scheme.*

parent and polite. But for ſeveral Experiments, it is not neceſſary to poliſh it. If a piece of this cryſtalline Stone be laid upon a Book, every Letter of the Book ſeen through it will appear double, by means of a double Refraction. And if any beam of Light falls either perpendicularly, or in any oblique Angle upon any Surface of this Cryſtal, it becomes divided into two beams by means of the ſame double Refraction. Which beams are of the ſame Colour with the incident beam of Light, and ſeem equal to one another in the quantity of their Light, or very nearly equal. One of theſe Refractions is perform'd by the uſual Rule of Opticks, the Sine of Incidence out of Air into this Cryſtal being to the Sine of Refraction, as five to three. The other Refraction, which may be called the unuſual Refraction, is perform'd by the following Rule.




Let ADBC repreſent the refracting Surface of of the Cryſtal, C the biggeſt ſolid Angle at that Surface, GEHF the oppoſite Surface, and CK a perpendicular on that Surface. This perpendicular makes with the edge of the Cryſtal CF, an Angle of 19 Degr. 3′. Join KF, and in it take KL, ſo that the Angle KCL be 6 Degr. 40′. and the Angle LCF 12 Degr. 23′. And if ST repreſent any beam of Light incident at T in any Angle upon the refracting Surface ADBC, let TV be the refracted beam determin'd by the given Proportion of the Sines 5 to 3, according to the uſual Rule of Opticks. Draw VX parallel and equal to KL. Draw it the ſame way from V in which L lieth from K; and joining TX, this line TX ſhall be the other refracted beam carried from T to X, by the unuſual Refraction.

If therefore the incident beam ST be perpendicular to the refracting Surface, the two beams TV and TX, into which it ſhall become divided, ſhall be parallel to the lines CK and CL; one of thoſe beams going through the Cryſtal perpendicularly, as it ought to do by the uſual Laws of Opticks, and the other TX by an unuſual Refraction diverging from the perpendicular, and making with it an Angle VTX of about $6\frac{2}{3}$ Degrees, as is found by experience. And hence, the Plane VTX, and ſuch like Planes which are parallel to the Plane CFK, may be called the Planes of perpendicular Refraction. And the Coaſt towards which the lines KL and VX are drawn, may be call'd the Coaſt of unuſual Refraction.

In like manner Cryſtal of the Rock has a double

double Refraction: But the difference of the two Refractions is not ſo great and manifeſt as in Iſland Cryſtal.

When the beam ST incident on Iſland Cryſtal, is divided into two beams TV and TX, and theſe two beams arrive at the farther Surface of the Glaſs; the beam TV, which was refracted at the firſt Surface after the uſual manner, ſhall be again refracted entirely after the uſual manner at the ſecond Surface; and the beam TX, which was refracted after the unuſual manner in the firſt Surface, ſhall be again refracted entirely after the unuſual manner in the ſecond Surface; ſo that both theſe beams ſhall emerge out of the ſecond Surface in lines parallel to the firſt incident beam ST.

And if two pieces of Iſland Cryſtal be placed one after another, in ſuch manner that all the Surfaces of the latter be parallel to all the correſponding Surfaces of the former: The Rays which are refracted after the uſual manner in the firſt Surface of the firſt Cryſtal ſhall be refracted after the uſual manner in all the following Surfaces; and the Rays which are refracted after the unuſual manner in the firſt Surface, ſhall be refracted after the unuſual manner in all the following Surfaces. And the ſame thing happens, though the Surfaces of the Cryſtals be any ways inclined to one another, provided that their Planes of perpendicular Refraction be parallel to one another.

And therefore there is an original difference in the Rays of Light, by means of which ſome Rays are in this Experiment conſtantly refract-

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ed after the usual manner, and others constantly after the unusual manner: For if the difference be not original, but arises from new Modifications impress'd on the Rays at their first Refraction, it would be alter'd by new Modifications in the three following Refractions; whereas it suffers no alteration, but is constant, and has the same effect upon the Rays in all the Refractions. The unusual Refraction is therefore perform'd by an original property of the Rays. And it remains to be enquired, whether the Rays have not more original Properties than are yet discover'd.

*Qu.* 26. Have not the Rays of Light several sides, endued with several original Properties? For if the Planes of perpendicular Refraction of the second Crystal, be at right Angles with the Planes of perpendicular Refraction of the first Crystal, the Rays which are refracted after the usual manner in passing through the first Crystal, will be all of them refracted after the unusual manner in passing through the second Crystal; and the Rays which are refracted after the unusual manner in passing through the first Crystal, will be all of them refracted after the usual manner in passing through the second Crystal. And therefore there are not two sorts of Rays differing in their nature from one another, one of which is constantly and in all Positions refracted after the usual manner, and the other constantly and in all Positions after the unusual manner. The difference between the two sorts of Rays in the Experiment mention'd in the 25th Question, was only in the Positions of of the Sides of the Rays to the Planes of perpendicular Refraction. For one and the ſame Ray is here refracted ſometimes after the uſual, and ſometimes after the unuſual manner, according to the Poſition which its Sides have to the Cryſtals. If the ſides of the Rays are poſited the ſame way to both Cryſtals, it is refracted after the ſame manner in them both: But if that ſide of the Ray which looks towards the Coaſt of the unuſual Refraction of the firſt Cryſtal, be 90 Degrees from that ſide of the ſame Ray which looks towards the Coaſt of the unuſual Refraction of the ſecond Cryſtal, (which may be effected by varying the Poſition of the ſecond Cryſtal to the firſt, and by conſequence to the Rays of Light) the Ray ſhall be refracted after ſeveral manners in the ſeveral Cryſtals. There is nothing more required to determine whether the Rays of Light which fall upon the ſecond Cryſtal, ſhall be refracted after the uſual or after the unuſual manner, but to turn about this Cryſtal, ſo that the Coaſt of this Cryſtal's unuſual Refraction may be on this or on that ſide of the Ray. And therefore every Ray may be conſider'd as having four Sides or Quarters, two of which oppoſite to one another incline the Ray to be refracted after the unuſual manner, as often as either of them are turn'd towards the Coaſt of unuſual Refraction; and the other two, whenever either of them are turn'd towards the Coaſt of unuſual Refraction, do not incline it to be otherwiſe refracted than after the uſual manner. The two firſt may therefore be call'd the Sides of unuſual Refraction.

And

And ſince theſe Diſpoſitions were in the Rays before their Incidence on the ſecond, third and fourth Surfaces of the two Cryſtals, and ſuffered no alteration (ſo far as appears) by the Refraction of the Rays in their paſſage through thoſe Surfaces, and the Rays were refracted by the ſame Laws in all the four Surfaces; it appears that thoſe Diſpoſitions were in the Rays originally, and ſuffer'd no alteration by the firſt Refraction, and that by means of thoſe Diſpoſitions the Rays were refracted at their Incidence on the firſt Surface of the firſt Cryſtal, ſome of them after the uſual, and ſome of them after the unuſual manner, accordingly as their Sides of unuſual Refraction were then turn'd towards the Coaſt of the unuſual Refraction of that Cryſtal, or ſideways from it.

Every Ray of Light has therefore two oppoſite Sides, originally endued with a Property on which the unuſual Refraction depends, and the other two oppoſite Sides not endued with that Property. And it remains to be enquired, whether there are not more Properties of Light by which the Sides of the Rays differ, and are diſtinguiſh'd from one another.

In explaining the difference of the Sides of the Rays above mention'd, I have ſuppoſed that the Rays fall perpendicularly on the firſt Cryſtal. But if they fall obliquely on it, the Succeſs is the ſame. Thoſe Rays which are refracted after the uſual manner in the firſt Cryſtal, will be refracted after the unuſual manner in the ſecond Cryſtal, ſuppoſing the Planes of perpendicular Refraction to be at right Angles with

 one

one another, as above: and on the contrary.

If the Planes of the perpendicular Refraction of the two Cryſtals be neither parallel nor perpendicular to one another, but contain an acute Angle: The two beams of Light which emerge out of the firſt Cryſtal, will be each of them divided into two more at their Incidence on the ſecond Cryſtal. For in this caſe the Rays in each of the two Beams will ſome of them have their Sides of unuſual Refraction, and ſome of them their other Sides turn'd towards the Coaſt of the unuſual Refraction of the ſecond Cryſtal.

*Qu.* 27. Are not all Hypotheſes erroneous which have hitherto been invented for explaining the Phenomena of Light, by new Modifications of the Rays? For thoſe Phenomena depend not upon new Modifications, as has been ſuppoſed, but upon the original and unchangeable Properties of the Rays.

*Qu.* 28. Are not all Hypotheſes erroneous, in which Light is ſuppoſed to conſiſt in Preſſion or Motion, propagated through a fluid Medium? For in all theſe Hypotheſes, the Phenomena of Light have been hitherto explain'd by ſuppoſing that they ariſe from new Modifications of the Rays; which is an erroneous Suppoſition.

If Light conſiſted only in Preſſion propagated without actual Motion, it would not be able to agitate and heat the Bodies which refract and reflect it. If it conſiſted in Motion propagated to all diſtances in an inſtant, it would require an infinite force every moment, in every

ſhining

ſhining Particle, to generate that Motion. And if it conſiſted in Preſſion or Motion, propagated either in an inſtant or in time, it would bend into the Shadow. For Preſſion or Motion cannot be propagated in a Fluid in right Lines beyond an Obſtacle which ſtops part of the Motion, but will bend and ſpread every way into the quieſcent Medium which lies beyond the Obſtacle. Gravity tends downwards, but the Preſſure of Water ariſing from Gravity tends every way with equal force, and is propagated as readily, and with as much force ſideways as downwards, and through crooked paſſages as through ſtrait ones. The Waves on the Surface of ſtagnating Water, paſſing by the ſides of a broad Obſtacle which ſtops part of them, bend afterwards and dilate themſelves gradually into the quiet Water behind the Obſtacle. The Waves, Pulſes or Vibrations of the Air, wherein Sounds conſiſt, bend manifeſtly, though not ſo much as the Waves of Water. For a Bell or a Canon may be heard beyond a Hill which intercepts the ſight of the ſounding Body, and Sounds are propagated as readily through crooked Pipes as through ſtreight ones. But Light is never known to follow crooked Paſſages nor to bend into the Shadow. For the fix'd Stars by the Interpoſition of any of the Planets ceaſe to be ſeen. And ſo do the Parts of the Sun by the Interpoſition of the Moon, *Mercury* or *Venus*. The Rays which paſs very near to the edges of any Body, are bent a little by the action of the Body, as we ſhew'd above; but this bending is not towards but from the Shadow, and is perform'd only in the paſſage of the Ray by the Body, and at a very ſmall diſtance from it. So ſoon as the Ray is paſt the Body, it goes right on.

To explain the unuſual Refraction of Iſland Cryſtal by Preſſion or Motion propagated, has not hitherto been attempted (to my knowledge) except by *Huygens*, who for that end ſuppoſed two ſeveral vibrating Mediums within that Cryſtal. But when he tried the Refractions in two ſucceſſive pieces of that Cryſtal, and found them ſuch as is mention'd above: He confeſſed himſelf at a loſs for explaining them. For Preſſions or Motions, propagated from a ſhining Body through an uniform Medium, muſt be on all ſides alike; whereas by thoſe Experiments it appears, that the Rays of Light have different Properties in their different Sides. He ſuſpected that the Pulſes of *Æther* in paſſing through the firſt Cryſtal might receive certain new Modifications, which might determine them to be propagated in this or that Medium within the ſecond Cryſtal, according to the Poſition of that Cryſtal. But what Modifications thoſe might be he could not ſay, nor think of any thing ſatisfactory in that Point. And if he had known that the unuſual Refraction depends not on new Modifications, but on the original and unchangeable Diſpoſitions of the Rays, he would have found it as difficult to explain how thoſe Diſpoſitions which he ſuppoſed to be impreſs'd on

*Mais pour dire comment cela ſe fait, je n'ay rien trove juſqu' ici qui me ſatisfaſſe.* C. H. de la lumiere. c. 5. p. 91.

on the Rays by the firſt Cryſtal, could be in them before their Incidence on that Cryſtal; and in general, how all Rays emitted by ſhining Bodies, can have thoſe Diſpoſitions in them from the beginning. To me, at leaſt, this ſeems inexplicable, if Light be nothing elſe than Preſſion or Motion propagated through *Æther*.

And it is as difficult to explain by theſe Hypotheſes, how Rays can be alternately in Fits of eaſy Reflexion and eaſy Tranſmiſſion; unleſs perhaps one might ſuppoſe that there are in all Space two Æthereal vibrating Mediums, and that the Vibrations of one of them conſtitute Light, and the Vibrations of the other are ſwifter, and as often as they overtake the Vibrations of the firſt, put them into thoſe Fits. But how two *Æthers* can be diffuſed through all Space, one of which acts upon the other, and by conſequence is re-acted upon, without retarding, ſhattering, diſperſing and confounding one anothers Motions, is inconceivable. And againſt filling the Heavens with fluid Mediums, unleſs they be exceeding rare, a great Objection ariſes from the regular and very laſting Motions of the Planets and Comets in all manner of Courſes through the Heavens. For thence it is manifeſt, that the Heavens are void of all ſenſible Reſiſtance, and by conſequence of all ſenſible Matter.

For the reſiſting Power of fluid Mediums ariſes partly from the Attrition of the Parts of the Medium, and partly from the *Vis inertiæ* of the Matter. That part of the Reſiſtance of

 a ſphea ſpherical Body which ariſes from the Attrition of the Parts of the Medium is very nearly as the Diameter, or, at the moſt, as the *Factum* of the Diameter, and the Velocity of the ſpherical Body together. And that part of the Reſiſtance which ariſes from the *Vis inertiæ* of the Matter, is as the Square of that *Factum*. And by this difference the two ſorts of Reſiſtance may be diſtinguiſh'd from one another in any Medium; and theſe being diſtinguiſh'd, it will be found that almoſt all the Reſiſtance of Bodies of a competent Magnitude moving in Air, Water, Quick-ſilver, and ſuch like Fluids with a competent Velocity, ariſes from the *Vis inertiæ* of the Parts of the Fluid.

Now that part of the reſiſting Power of any Medium which ariſes from the Tenacity, Friction or Attrition of the Parts of the Medium, may be diminiſh'd by dividing the Matter into ſmaller Parts, and making the Parts more ſmooth and ſlippery: But that part of the Reſiſtance which ariſes from the *Vis inertiæ*, is proportional to the Denſity of the Matter, and cannot be diminiſh'd by dividing the Matter into ſmaller Parts, nor by any other means than by decreaſing the Denſity of the Medium. And for theſe Reaſons the Denſity of fluid Mediums is very nearly proportional to their Reſiſtance. Liquors which differ not much in Denſity, as Water, Spirit of Wine, Spirit of Turpentine, hot Oil, differ not much in Reſiſtance. Water is thirteen or fourteen times lighter than Quickſilver, and by conſequence thirteen or fourteen times rarer, and its Reſiſtance is leſs than that

of

of Quick-ſilver in the ſame Proportion, or thereabouts, as I have found by Experiments made with Pendulums. The open Air in which we breathe is eight or nine hundred times lighter than Water, and by conſequence eight or nine hundred times rarer, and accordingly its Reſiſtance is leſs than that of Water in the ſame Proportion, or thereabouts; as I have alſo found by Experiments made with Pendulums. And in thinner Air the Reſiſtance is ſtill leſs, and at length, by rarifying the Air, becomes inſenſible. For ſmall Feathers falling in the open Air meet with great Reſiſtance, but in a tall Glaſs well emptied of Air, they fall as faſt as Lead or Gold, as I have ſeen tried ſeveral times. Whence the Reſiſtance ſeems ſtill to decreaſe in proportion to the Denſity of the Fluid. For I do not find by any Experiments, that Bodies moving in Quick-ſilver, Water or Air, meet with any other ſenſible Reſiſtance than what ariſes from the Denſity and Tenacity of thoſe ſenſible Fluids, as they would do if the Pores of thoſe Fluids, and all other Spaces, were filled with a denſe and ſubtile Fluid. Now if the Reſiſtance in a Veſſel well emptied of Air, was but an hundred times leſs than in the open Air, it would be about a million of times leſs than in Quick-ſilver. But it ſeems to be much leſs in ſuch a Veſſel, and ſtill much leſs in the Heavens, at the height of three or four hundred Miles from the Earth, or above. For Mr. *Boyle* has ſhew'd that Air may be rarified above ten thouſand times in Veſſels of Glaſs; and the Heavens are much emptier of Air than any *Va-*

*cuum* we can make below. For ſince the Air is compreſs'd by the weight of the incumbent Atmoſphere, and the Denſity of Air is proportional to the Force compreſſing it, it follows by Computation, that at the height of about ſeven *Engliſh* Miles from the Earth, the Air is four times rarer than at the Surface of the Earth; and at the height of 14 Miles, it is ſixteen times rarer than that at the Surface of the Earth; and at the height of 21, 28, or 35 Miles, it is reſpectively 64, 256, or 1024 times rarer, or thereabouts; and at the height of 70, 140, 210 Miles, it is about 1000000, 1000000000000 or 1000000000000000000 times rarer; and ſo on.

Heat promotes Fluidity very much, by diminiſhing the Tenacity of Bodies. It makes many Bodies fluid which are not fluid in cold, and increaſes the Fluidity of tenacious Liquids, as of Oil, Balſam and Honey, and thereby decreaſes their Reſiſtance. But it decreaſes not the Reſiſtance of Water conſiderably, as it would do if any conſiderable part of the Reſiſtance of Water aroſe from the Attrition or Tenacity of its Parts. And therefore the Reſiſtance of Water ariſes principally and almoſt entirely from the *Vis inertiæ* of its Matter; and by conſequence, if the Heavens were as denſe as Water, they would not have much leſs Reſiſtance than Water; if as denſe as Quick-ſilver, they would not have much leſs Reſiſtance than Quick-ſilver; if abſolutely denſe, or full of Matter without any *Vacuum*, let the Matter be never ſo ſubtile and fluid, they would have a greater

Reſiſtance

Resistance than Quick-silver. A solid Globe in such a Medium would lose above half its Motion in moving three times the length of its Diameter, and a Globe not solid (such as are the Planets) would be retarded sooner. And therefore to make way for the regular and lasting Motions of the Planets and Comets, it's necessary to empty the Heavens of all Matter, except perhaps some very thin Vapours, Steams or Effluvia, arising from the Atmospheres of the Earth, Planets and Comets, and from such an exceedingly rare Æthereal Medium as we described above. A dense Fluid can be of no use for explaining the Phænomena of Nature, the Motions of the Planets and Comets being better explain'd without it. It serves only to disturb and retard the Motions of those great Bodies, and make the Frame of Nature languish: And in the Pores of Bodies, it serves only to stop the vibrating Motions of their Parts, wherein their Heat and Activity consists. And as it is of no use, and hinders the Operations of Nature, and makes her languish, so there is no evidence for its Existence, and therefore it ought to be rejected. And if it be rejected, the Hypotheses that Light consists in Pression or Motion propagated through such a Medium, are rejected with it.

And for rejecting such a Medium, we have the Authority of those the oldest and most celebrated Philosophers of *Greece* and *Phœnicia*, who made a *Vacuum* and Atoms, and the Gravity of Atoms, the first Principles of their Philosophy; tacitly attributing Gravity to some other Cauſe than denſe Matter. Later Philoſophers baniſh the Conſideration of ſuch a Cauſe out of Natural Philoſophy, feigning Hypotheſes for explaining all things mechanically, and referring other Cauſes to Metaphyſicks: Whereas the main Buſineſs of Natural Philoſophy is to argue from Phænomena without feigning Hypotheſes, and to deduce Cauſes from Effects, till we come to the very firſt Cauſe, which certainly is not mechanical; and not only to unfold the Mechaniſm of the World, but chiefly to reſolve theſe and ſuch like Queſtions. What is there in places almoſt empty of Matter, and whence is it that the Sun and Planets gravitate towards one another, without denſe Matter between them? Whence is it that Nature doth nothing in vain; and whence ariſes all that Order and Beauty which we ſee in the World? To what end are Comets, and whence is it that Planets move all one and the ſame way in Orbs concentrick, while Comets move all manner of ways in Orbs very excentrick, and what hinders the fix'd Stars from falling upon one another? How came the Bodies of Animals to be contrived with ſo much Art, and for what ends were their ſeveral Parts? Was the Eye contrived without Skill in Opticks, and the Ear without Knowledge of Sounds? How do the Motions of the Body follow from the Will, and whence is the Inſtinct in Animals? Is not the Senſory of Animals that place to which the ſenſitive Subſtance is preſent, and into which the ſenſible Species of Things are carried through the Nerves and Brain, that there they may be perceived

by

by their immediate preſence to that Subſtance? And theſe things being rightly diſpatch'd, does it not appear from Phænomena that there is a Being incorporeal, living, intelligent, omnipreſent, who in infinite Space, as it were in his Senſory, ſees the things themſelves intimately, and throughly perceives them, and comprehends them wholly by their immediate preſence to himſelf: Of which things the Images only carried through the Organs of Senſe into our little Senſoriums, are there ſeen and beheld by that which in us perceives and thinks. And tho' every true Step made in this Philoſophy brings us not immediately to the Knowledge of the firſt Cauſe, yet it brings us nearer to it, and on that account is to be highly valued.

*Qu*. 29. Are not the Rays of Light very ſmall Bodies emitted from ſhining Subſtances? For ſuch Bodies will paſs through uniform Mediums in right Lines without bending into the Shadow, which is the Nature of the Rays of Light. They will alſo be capable of ſeveral Properties, and be able to conſerve their Properties unchanged in paſſing through ſeveral Mediums, which is another Condition of the Rays of Light. Pellucid Subſtances act upon the Rays of Light at a diſtance in refracting, reflecting and inflecting them, and the Rays mutually agitate the Parts of thoſe Subſtances at a diſtance for heating them; and this Action and Re-action at a diſtance, very much reſembles an attractive Force between Bodies. If Refraction be perform'd by Attraction of the Rays, the Sines of Incidence muſt be to the Sines of Refraction

fraction in a given Proportion, as we ſhew'd in our Principles of Philoſophy: And this Rule is true by Experience. The Rays of Light in going out of Glaſs into a *Vacuum*, are bent towards the Glaſs; and if they fall too obliquely on the *Vacuum* they are bent backwards into the Glaſs, and totally reflected; and this Reflexion cannot be aſcribed to the Reſiſtance of an abſolute *Vacuum*, but muſt be cauſed by the Power of the Glaſs attracting the Rays at their going out of it into the *Vacuum*, and bringing them back. For if the farther Surface of the Glaſs be moiſten'd with Water or clear Oil, or liquid and clear Honey; the Rays which would otherwiſe be reflected, will go into the Water, Oil, or Honey, and therefore are not reflected before they arrive at the farther Surface of the Glaſs, and begin to go out of it. If they go out of it into the Water, Oil or Honey, they go on, becauſe the Attraction of the Glaſs is almoſt balanced and render'd ineffectual by the contrary Attraction of the Liquor. But if they go out of it into a *Vacuum* which has no Attraction to balance that of the Glaſs, the Attraction of the Glaſs either bends and refracts them, or brings them back and reflects them. And this is ſtill more evident by laying together two Priſms of Glaſs, or two Object-glaſſes of of very long Teleſcopes, the one plane the other a little convex, and ſo compreſſing them that they do not fully touch, nor are too far aſunder. For the Light which falls upon the farther Surface of the firſt Glaſs where the Interval between the Glaſſes is not above the ten

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hundred thouſandth part of an Inch, will go through that Surface, and through the Air or *Vacuum* between the Glaſſes, and enter into the ſecond Glaſs, as was explain'd in the firſt, fourth and eighth Obſervations of the firſt Part of the ſecond Book. But if the ſecond Glaſs be taken away, the Light which goes out of the ſecond Surface of the firſt Glaſs into the Air or *Vacuum*, will not go on forwards, but turns back into the firſt Glaſs, and is reflected; and therefore it is drawn back by the Power of the firſt Glaſs, there being nothing elſe to turn it back. Nothing more is requiſite for producing all the variety of Colours and degrees of Refrangibility, than that the Rays of Light be Bodies of different Sizes, the leaſt of which may make violet the weakeſt and darkeſt of the Colours, and be more eaſily diverted by refracting Surfaces from the right Courſe; and the reſt as they are bigger and bigger, may make the ſtronger and more lucid Colours, blue, green, yellow and red, and be more and more difficultly diverted. Nothing more is requiſite for putting the Rays of Light into Fits of eaſy Reflexion and eaſy Tranſmiſſion, than that they be ſmall Bodies which by their attractive Powers, or ſome other Force, ſtir up Vibrations in what they act upon, which Vibrations being ſwifter than the Rays, overtake them ſucceſſively, and agitate them ſo as by turns to increaſe and decreaſe their Velocities, and thereby put them into thoſe Fits. And laſtly, the unuſual Refraction of Iſland Cryſtal looks very much as if it were perform'd by ſome kind of attractive virtue

tue lodged in certain Sides both of the Rays, and of the Particles of the Cryſtal. For were it not for ſome kind of Diſpoſition or Virtue lodged in ſome Sides of the Particles of the Cryſtal, and not in their other Sides, and which inclines and bends the Rays towards the Coaſt of unuſual Refraction, the Rays which fall perpendicularly on the Cryſtal, would not be refracted towards that Coaſt rather than towards any other Coaſt, both at their Incidence and at their Emergence, ſo as to to emerge perpendicularly by a contrary Situation of the Coaſt of unuſual Refraction at the ſecond Surface; the Cryſtal acting upon the Rays after they have paſs'd through it, and are emerging into the Air; or, if you pleaſe, into a *Vacuum*. And ſince the Cryſtal by this Diſpoſition or Virtue does not act upon the Rays, unleſs when one of their Sides of unuſual Refraction looks towards that Coaſt, this argues a Virtue or Diſpoſition in thoſe Sides of the Rays, which anſwers to and ſympathizes with that Virtue or Diſpoſition of the Cryſtal, as the Poles of two Magnets anſwer to one another. And as Magnetiſm may be intended and remitted, and is found only in the Magnet and in Iron: So this Virtue of refracting the perpendicular Rays is greater in Iſland Cryſtal, leſs in Cryſtal of the Rock, and is not yet found in other Bodies. I do not ſay that this Virtue is magnetical: It ſeems to be of another kind. I only ſay, that what ever it be, it's difficult to conceive how the Rays of Light, unleſs they be Bodies, can have a permanent Virtue in two of their Sides which

which is not in their other Sides, and this without any regard to their Poſition to the Space or Medium through which they paſs.

What I mean in this Queſtion by a *Vacuum*, and by the Attractions of the Rays of Light towards Glaſs or Cryſtal, may be underſtood by what was ſaid in the 18th, 19th and 20th Queſtions.

*Qu.* 30. Are not groſs Bodies and Light convertible into one another, and may not Bodies receive much of their activity from the Particles of Light which enter their Compoſition? For all fix'd Bodies being heated emit Light ſo long as they continue ſufficiently hot, and Light mutually ſtops in Bodies as often as its Rays ſtrike upon their Parts, as we ſhew'd above. I know no Body leſs apt to ſhine than Water; and yet Water by frequent Diſtillations changes into fix'd Earth, as Mr. *Boyle* has tried; and then this Earth being enabled to endure a ſufficient Heat, ſhines by Heat like other Bodies.

The changing of Bodies into Light, and Light into Bodies, is very conformable to the Courſe of Nature, which ſeems delighted with Tranſmutations. Water, which is a very fluid taſtleſs Salt, ſhe changes by Heat into Vapour, which is a ſort of Air, and by Cold into Ice, which is a hard, pellucid, brittle, fuſible Stone: and this Stone returns into Water by Heat, and Vapour returns into Water by Cold. Earth by Heat becomes Fire, and by Cold returns into Earth. Denſe Bodies by Fermentation rarify into ſeveral ſorts of Air, and this Air by Fermentation, and ſometimes without it, returns into denſe

Bodies.

Bodies. Mercury appears ſometimes in the form of a fluid Metal, ſometimes in the form of a hard brittle Metal, ſometimes in the form of a corroſive pellucid Salt call'd Sublimate, ſometimes in the form of a taſtleſs, pellucid, volatile white Earth, call'd *Mercurius dulcis*; or in that of a red opake volatile Earth, call'd Cinnaber; or in that of a red or white Precipitate, or in that of a fluid Salt; and in Diſtillation it turns into Vapour, and being agitated *in vacuo*, it ſhines like Fire. And after all theſe Changes it returns again into its firſt form of Mercury. Eggs grow from inſenſible Magnitudes, and change into Animals; Tadpoles into Frogs; and Worms into Flies. All Birds, Beaſts and Fiſhes, Inſects, Trees, and other Vegetables, with their ſeveral parts, grow out of Water and watry Tinctures and Salts, and by Putrefaction return again into watry Subſtances. And Water ſtanding a few Days in the open Air, yields a Tincture, which (like that of Mault) by ſtanding longer yields a Sediment and a Spirit, but before Putrefaction is fit Nouriſhment for Animals and Vegetables. And among ſuch various and ſtrange Tranſmutations, why may not Nature change Bodies into Light, and Light into Bodies?

*Qu.* 31. Have not the ſmall Particles of Bodies certain Powers, Virtues or Forces, by which they act at a diſtance, not only upon the Rays of Light for reflecting, refracting and inflecting them, but alſo upon one another for producing a great part of the Phænomena of Nature? For it's well known that Bodies act

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one upon another by the Attractions of Gravity, Magnetiſm and Electricity; and theſe Inſtances ſhew the Tenor and Courſe of Nature, and make it not improbable but that there may be more attractive Powers than theſe. For Nature is very conſonant and conformable to her ſelf. How theſe Attractions may be perform'd, I do not here conſider. What I call Attraction may be perform'd by impulſe, or by ſome other means unknown to me. I uſe that Word here to ſignify only in general any Force by which Bodies tend towards one another, whatſoever be the Cauſe. For we muſt learn from the Phænomena of Nature what Bodies attract one another, and what are the Laws and Properties of the Attraction, before we enquire the Cauſe by which the Attraction is perform'd. The Attractions of Gravity, Magnetiſm and Electricity, reach to very ſenſible diſtances, and ſo have been obſerved by vulgar Eyes, and there may be others which reach to ſo ſmall diſtances as hitherto eſcape Obſervation; and perhaps electrical Attraction may reach to ſuch ſmall diſtances, even without being excited by Friction.

For when Salt of Tartar runs *per deliquium*, is not this done by an Attraction between the Particles of the Salt of Tartar, and the Particles of the Water which float in the Air in the form of Vapours? And why does not common Salt, or Salt-petre, or Vitriol, run *per deliquium*, but for want of ſuch an Attraction? Or why does not Salt of Tartar draw more Water out of the Air than in a certain Proportion to its quantity, but for want of an attractive Force

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after it is ſatiated with Water? And whence is it but from this attractive Power that Water which alone diſtils with a gentle lukewarm Heat, will not diſtil from Salt of Tartar without a great Heat? And is it not from the like attractive Power between the Particles of Oil of Vitriol and the Particles of Water, that Oil of Vitriol draws to it a good quantity of Water out of the Air, and after it is ſatiated draws no more, and in Diſtillation lets go the Water very difficultly? And when Water and Oil of Vitriol poured ſucceſſively into the ſame Veſſel grow very hot in the mixing, does not this Heat argue a great Motion in the parts of the Liquors? And does not this Motion argue that the Parts of the two Liquors in mixing coaleſce with Violence, and by conſequence ruſh towards one another with an accelerated Motion? And when *Aqua fortis* or Spirit of Vitriol poured upon Filings of Iron, diſſolves the Filings with a great Heat and Ebullition, is not this Heat and Ebullition effected by a violent Motion of the Parts, and does not that Motion argue that the acid Parts of the Liquor ruſh towards the Parts of the Metal with violence, and run forcibly into its Pores till they get between its outmoſt Particles and the main Maſs of the Metal, and ſurrounding thoſe Particles looſen them from the main Maſs, and ſet them at liberty to float off into the Water? And when the acid Particles which alone would diſtil with an eaſy Heat, will not ſeparate from the Particles of the Metal without a very violent

lent Heat, does not this confirm the Attraction between them?

When Spirit of Vitriol poured upon common Salt or Salt-petre makes an Ebullition with the Salt and unites with it, and in Distillation the Spirit of the common Salt or Salt-petre comes over much easier than it would do before; and the acid part of the Spirit of Vitriol stays behind; does not this argue that the fix'd Alcaly of the Salt attracts the acid Spirit of the Vitriol more strongly than its own Spirit, and not being able to hold them both, lets go its own? And when Oil of Vitriol is drawn off from its weight of Nitre, and from both the Ingredients a compound Spirit of Nitre is distilled, and two parts of this Spirit are poured on one part of Oil of Cloves or Caraway Seeds, or of any ponderous Oil of vegetable or animal Substances, or Oil of Turpentine thicken'd with a little Balsam of Sulphur, and the Liquors grow so very hot in mixing, as presently to send up a burning Flame: Does not this very great and sudden Heat argue that the two Liquors mix with violence, and that their Parts in mixing run towards one another with an accelerated Motion, and clash with the greatest Force? And is it not for the same reason that well rectified Spirit of Wine poured on the same compound Spirit flashes; and that the *Pulvis fulminans*, composed of Sulphur, Nitre, and Salt of Tartar, goes off with a more sudden and violent Explosion than Gun-powder, the acid Spirits of the Sulphur and Nitre rushing towards one another, and towards the Salt of Tartar, with so great a violence, as by the shock to turn the whole at once into Vapour and Flame? Where the Dissolution is slow, it makes a slow Ebullition and a gentle Heat; and where it is quicker, it makes a greater Ebullition with more Heat; and where it is done at once, the Ebullition is contracted into a sudden Blast or violent Explosion, with a Heat equal to that of Fire and Flame. So when a Drachm of the above mention'd compound Spirit of Nitre was poured upon half a Drachm of Oil of Caraway Seeds *in vacuo*; the Mixture immediately made a flash like Gun-powder, and burst the exhausted Receiver, which was a Glass six Inches wide, and eight Inches deep. And even the gross Body of Sulphur powder'd, and with an equal weight of Iron Filings, and a little Water made into Paste, acts upon the Iron, and in five or six Hours grows too hot to be touch'd, and emits a Flame. And by these Experiments compared with the great quantity of Sulphur with which the Earth abounds, and the warmth of the interior Parts of the Earth, and hot Springs, and burning Mountains, and with Damps, mineral Coruscations, Earthquakes, hot suffocating Exhalations, Hurricanes and Spouts; we may learn that sulphureous Steams abound in the Bowels of the Earth and ferment with Minerals, and sometimes take Fire with a sudden Coruscation and Explosion; and if pent up in subterraneous Caverns, burst the Caverns with a great shaking of the Earth, as in springing of a Mine. And then the Vapour generated by the Explosion, expiring through the Pores of the

 Earth,

Earth, feels hot and suffocates, and makes Tempests and Hurricanes, and sometimes causes the Land to slide, or the Sea to boil, and carries up the Water thereof in Drops, which by their weight fall down again in Spouts. Also some sulphureous Steams, at all times when the Earth is dry, ascending into the Air, ferment there with nitrous Acids, and sometimes taking fire cause Lightening and Thunder, and fiery Meteors. For the Air abounds with acid Vapours fit to promote Fermentations, as appears by the rusting of Iron and Copper in it, the kindling of Fire by blowing, and the beating of the Heart by means of Respiration. Now the above mention'd Motions are so great and violent as to shew that in Fermentations, the Particles of Bodies which almost rest, are put into new Motions by a very potent Principle, which acts upon them only when they approach one another, and causes them to meet and clash with great violence, and grow hot with the Motion, and dash one another into pieces, and vanish into Air, and Vapour, and Flame.

When Salt of Tartar *per deliquium*, being poured into the Solution of any Metal, precipitates the Metal, and makes it fall down to the bottom of the Liquor in the form of Mud: Does not this argue that the acid Particles are attracted more strongly by the Salt of Tartar than by the Metal, and by the stronger Attraction go from the Metal to the Salt of Tartar? And so when a Solution of Iron in *Aqua fortis* dissolves the *Lapis Calaminaris* and lets go the Iron, or a Solution of Copper dissolves Iron immersed in it and lets go the Copper, or a Solution of Silver dissolves Copper and lets go the Silver, or a Solution of Mercury in *Aqua fortis* being poured upon Iron, Copper, Tin or Lead, dissolves the Metal and lets go the Mercury, does not this argue that the acid Particles of the *Aqua fortis* are attracted more strongly by the *Lapis Calaminaris* than by Iron, and more strongly by Iron than by Copper, and more strongly by Copper than by Silver, and more strongly by Iron, Copper, Tin and Lead, than by Mercury? And is it not for the same reason that Iron requires more *Aqua fortis* to dissolve it than Copper, and Copper more than the other Metals; and that of all Metals, Iron is dissolved most easily, and is most apt to rust; and next after Iron, Copper?

When Oil of Vitriol is mix'd with a little Water, or is run *per deliquium*, and in Distillation the Water ascends difficultly, and brings over with it some part of the Oil of Vitriol in the form of Spirit of Vitriol, and this Spirit being poured upon Iron, Copper, or Salt of Tartar, unites with the Body and lets go the Water, doth not this shew that the acid Spirit is attracted by the Water, and more attracted by the fix'd Body than by the Water, and therefore lets go the Water to close with the fix'd Body? And is it not for the same reason that the Water and acid Spirits which are mix'd together in Vinegar, *Aqua fortis*, and Spirit of Salt, cohere and rise together in Distillation; but if the *Menstruum* be poured on Salt of Tartar, or on Lead or Iron, or any fix'd Body which

which it can dissolve, the Acid by a stronger Attraction adheres to the Body, and lets go the Water? And is it not also from a mutual Attraction that the Spirits of Soot and Sea-Salt unite and compose the Particles of Sal-armoniac, which are less volatile than before, because grosser and freer from Water; and that the Particles of Sal-armoniac in Sublimation carry up the Particles of Antimony, which will not sublime alone; and that the Particles of Mercury uniting with the acid Particles of Spirit of Salt compose Mercury sublimate, and with the Particles of Sulphur, compose Cinnaber; and that the Particles of Spirit of Wine and Spirit of Urine well rectified unite, and letting go the Water which dissolved them, compose a consistent Body; and that in subliming Cinnaber from Salt of Tartar, or from quick Lime, the Sulphur by a stronger Attraction of the Salt or Lime lets go the Mercury, and stays with the fix'd Body; and that when Mercury sublimate is sublimed from Antimony, or from Regulus of Antimony, the Spirit of Salt lets go the Mercury, and unites with the antimonial Metal which attracts it more strongly, and stays with it till the Heat be great enough to make them both ascend together, and then carries up the Metal with it in the form of a very fusible Salt, called Butter of Antimony, although the Spirit of Salt alone be almost as volatile as Water, and the Antimony alone as fix'd as Lead?

When *Aqua fortis* dissolves Silver and not Gold, and *Aqua regia* dissolves Gold and not

Silver, may it not be ſaid that *Aqua fortis* is ſubtile enough to penetrate Gold as well as Silver, but wants the attractive Force to give it Entrance; and that *Aqua regia* is ſubtile enough to penetrate Silver as well as Gold, but wants the attractive Force to give it Entrance? For *Aqua regia* is nothing elſe than *Aqua fortis* mix'd with ſome Spirit of Salt, or with Sal-armoniac; and even common Salt diſſolved in *Aqua fortis*, enables the *Menſtruum* to diſſolve Gold, though the Salt be a groſs Body. When therefore Spirit of Salt precipitates Silver out of *Aqua fortis*, is it not done by attracting and mixing with the *Aqua fortis*, and not attracting, or perhaps repelling Silver? And when Water precipitates Antimony out of the Sublimate of Antimony and Sal-armoniac, or out of Butter of Antimony, is it not done by its diſſolving, mixing wit , and weakening the Sal-armoniac or Spirit of Salt, and its not attracting, or perhaps repelling the Antimony? And is it not for want of an attractive Virtue between the Parts of Water and Oil, of Quick-ſilver and Antimony, of Lead and Iron, that theſe Subſtances do not mix; and by a weak Attraction, that Quick-ſilver and Copper mix difficultly; and from a ſtrong one, that Quick-ſilver and Tin, Antimony and Iron, Water and Salts, mix readily? And in general, is it not from the ſame Principle that Heat congregates homogeneal Bodies, and ſeparates heterogeneal ones?

When Arſnick with Soap gives a Regulus, and with Mercury ſublimate a volatile fuſible Salt,

Salt, like Butter of Antimony, doth not this ſhew that Arſnick, which is a Subſtance totally volatile, is compounded of fix'd and volatile Parts, ſtrongly cohering by a mutual Attraction, ſo that the volatile will not aſcend without carrying up the fixed? And ſo, when an equal weight of Spirit of Wine and Oil of Vitriol are digeſted together, and in Diſtillation yield two fragrant and volatile Spirits which will not mix with one another, and a fix'd black Earth remains behind; doth not this ſhew that Oil of Vitriol is compoſed of volatile and fix'd Parts ſtrongly united by Attraction, ſo as to aſcend together in form of a volatile, acid, fluid Salt, until the Spirit of Wine attracts and ſeparates the volatile Parts from the fixed? And therefore, ſince Oil of Sulphur *per campanam* is of the ſame Nature with Oil of Vitriol, may it not be inferred, that Sulphur is alſo a mixture of volatile and fix'd Parts ſo ſtrongly cohering by Attraction, as to aſcend together in Sublimation. By diſſolving Flowers of Sulphur in Oil of Turpentine, and diſtilling the Solution, it is found that Sulphur is compoſed of an inflamable thick Oil or fat Bitumen, an acid Salt, a very fix'd Earth, and a little Metal. The three firſt were found not much unequal to one another, the fourth in ſo ſmall a quantity as ſcarce to be worth conſidering. The acid Salt diſſolved in Water, is the ſame with Oil of Sulphur *per campanam*, and abounding much in the Bowels of the Earth, and particularly in Markaſites, unites it ſelf to the other Ingredients of the Markaſite, which are, Bitumen, I-

 ron,

ron, Copper and Earth, and with them compounds Alume, Vitriol and Sulphur. With the Earth alone it compounds Alume; with the Metal alone, or Metal and Earth together, it compounds Vitriol; and with the Bitumen and Earth it compounds Sulphur. Whence it comes to paſs that Markaſites abound with thoſe three Minerals. And is it not from the mutual Attraction of the Ingredients that they ſtick together for compounding theſe Minerals, and that the Bitumen carries up the other Ingredients of the Sulphur, which without it would not ſublime? And the ſame Queſtion may be put concerning all, or almoſt all the groſs Bodies in Nature. For all the Parts of Animals and Vegetables are compoſed of Subſtances volatile and fix'd, fluid and ſolid, as appears by their Analyſis: and ſo are Salts and Minerals, ſo far as Chymiſts have been hitherto able to examine their Compoſition.

When Mercury ſublimate is reſublimed with freſh Mercury, and becomes *Mercurius dulcis*, which is a white taſtleſs Earth ſcarce diſſolvable in Water, and *Mercurius dulcis* reſublimed with Spirit of Salt returns into Mercury ſublimate; and when Metals corroded with a little acid turn into Ruſt, which is an Earth taſtleſs and indiſſolvable in Water, and this Earth imbibed with more Acid becomes a metallick Salt; and when ſome Stones, as Spar of Lead, diſſolved in proper *Menſtruums* become Salts; do not theſe things ſhew that Salts are dry Earth and watry Acid united by Attraction, and that the Earth will not become a Salt without ſo much

much Acid as makes it dissolvable in Water? Do not the sharp and pungent Tastes of Acids arise from the strong Attraction whereby the acid Particles rush upon and agitate the Particles of the Tongue? And when Metals are dissolved in acid *Menstruums*, and the Acids in conjunction with the Metal act after a different manner, so that the Compound has a different taste much milder than before, and sometimes a sweet one; is it not because the Acids adhere to the metallick Particles, and thereby lose much of their Activity? And if the Acid be in too small a Proportion to make the Compound dissolvable in Water, will it not by adhering strongly to the Metal become unactive and lose its taste, and the Compound be a tastless Earth? For such things as are not dissolvable by the Moisture of the Tongue, act not upon the Taste.

As Gravity makes the Sea flow round the denser and weightier Parts of the Globe of the Earth, so the Attraction may make the watry Acid flow round the denser and compacter Particles of Earth for composing the Particles of Salt. For otherwise the Acid would not do the office of a Medium between the Earth and common Water, for making Salts dissolvable in the Water; nor would Salt of Tartar readily draw off the Acid from dissolved Metals, nor Metals the Acid from Mercury. Now as in the great Globe of the Earth and Sea, the densest Bodies by their Gravity sink down in Water, and always endeavour to go towards the Center of the Globe; so in Particles of Salt, the densest

denſeſt Matter may always endeavour to approach the Center of the Particle: So that a Particle of Salt may be compared to a Chaos; being denſe, hard, dry, and earthy in the Center; and rare, ſoft, moiſt, and watry in the Circumference. And hence it ſeems to be that Salts are of a laſting nature, being ſcarce deſtroy'd, unleſs by drawing away their watry Parts by violence, or by letting them ſoak into the Pores of the central Earth by a gentle Heat in Putrefaction, until the Earth be diſſolved by the Water, and ſeparated into ſmaller Particles, which by reaſon of their ſmallneſs make the rotten Compound appear of a black Colour. Hence alſo it may be that the Parts of Animals and Vegetables preſerve their ſeveral Forms, and aſſimilate their Nouriſhment; the ſoft and moiſt Nouriſhment eaſily changing its Texture by a gentle Heat and Motion, till it becomes like the denſe, hard, dry, and durable Earth in the Center of each Particle. But when the Nouriſhment grows unfit to be aſſimilated, or the central Earth grows too feeble to aſſimilate it, the Motion ends in Confuſion, Putrefaction and Death.

If a very ſmall quantity of any Salt or Vitriol be diſſolved in a great quantity of Water, the Particles of the Salt or Vitriol will not ſink to the bottom, though they be heavier in Specie than the Water, but will evenly diffuſe themſelves into all the Water, ſo as to make it as ſaline at the top as at the bottom. And does not this imply that the Parts of the Salt or Vitriol recede from one another, and endeavour to expand

pand themſelves, and get as far aſunder as the quantity of Water, in which they float, will allow? And does not this Endeavour imply that they have a repulſive Force by which they fly from one another, or at leaſt, that they attract the Water more ſtrongly than they do one another? For as all things aſcend in Water which are leſs attracted than Water, by the gravitating Power of the Earth; ſo all the Particles of Salt which float in Water, and are leſs attracted than Water by any one Particle of Salt, muſt recede from that Particle, and give way to the more attracted Water.

When any ſaline Liquor is evaporated to a Cuticle and let cool, the Salt concretes in regular Figures; which argues, that the Particles of the Salt before they concreted, floated in the Liquor at equal diſtances in rank and file, and by conſequence that they acted upon one another by ſome Power which at equal diſtances is equal, at unequal diſtances unequal. For by ſuch a Power they will range themſelves uniformly, and without it they will float irregularly, and come together as irregularly. And ſince the Particles of Iſland Cryſtal act all the ſame way upon the Rays of Light for cauſing the unuſual Refraction, may it not be ſuppoſed that in the Formation of this Cryſtal, the Particles not only ranged themſelves in rank and file for concreting in regular Figures, but alſo by ſome kind of polar Virtue turned their homogeneal Sides the ſame way.

The Parts of all homogeneal hard Bodies which fully touch one another, ſtick together very

very ſtrongly. And for explaining how this may be, ſome have invented hooked Atoms, which is begging the Queſtion; and others tell us that Bodies are glued together by reſt, that is, by an occult Quality, or rather by nothing; and others, that they ſtick together by conſpiring Motions, that is, by relative reſt amongſt themſelves. I had rather infer from their Coheſion, that their Particles attract one another by ſome Force, which in immediate Contact is exceeding ſtrong, at ſmall diſtances performs the chymical Operations above mention'd, and reaches not far from the Particles with any ſenſible Effect.

All Bodies ſeem to be compoſed of hard Particles: For otherwiſe Fluids would not congeal; as Water, Oils, Vinegar, and Spirit or Oil of Vitriol do by freezing; Mercury by Fumes of Lead; Spirit of Nitre and Mercury, by diſſolving the Mercury and evaporating the Flegm; Spirit of Wine and Spirit of Urine, by deflegming and mixing them; and Spirit of Urine and Spirit of Salt, by ſubliming them together to make Sal-armoniac. Even the Rays of Light ſeem to be hard Bodies; for otherwiſe they would not retain different Properties in their different Sides. And therefore Hardneſs may be reckon'd the Property of all uncompounded Matter. At leaſt, this ſeems to be as evident as the univerſal Impenetrability of Matter. For all Bodies, ſo far as Experience reaches, are either hard, or may be harden'd; and we have no other Evidence of univerſal Impenetrability, beſides a large Experience without an experimental

mental Exception. Now if compound Bodies are ſo very hard as we find ſome of them to be, and yet are very porous, and conſiſt of Parts which are only laid together; the ſimple Particles which are void of Pores, and were never yet divided, muſt be much harder. For ſuch hard Particles being heaped up together, can ſcarce touch one another in more than a few Points, and therefore muſt be ſeparable by much leſs Force than is requiſite to break a ſolid Particle, whoſe Parts touch in all the Space between them, without any Pores or Interſtices to weaken their Coheſion. And how ſuch very hard Particles which are only laid together and touch only in a few Points, can ſtick together, and that ſo firmly as they do, without the aſſiſtance of ſomething which cauſes them to be attracted or preſs'd towards one another, is very difficult to conceive.

The ſame thing I infer alſo from the cohering of two poliſh'd Marbles *in vacuo*, and from the ſtanding of Quick-ſilver in the Barometer at the height of 50, 60 or 70 Inches, or above, when ever it is well purged of Air and carefully poured in, ſo that its Parts be every where contiguous both to one another and to the Glaſs. The Atmoſphere by its weight preſſes the Quick-ſilver into the Glaſs, to the height of 29 or 30 Inches. And ſome other Agent raiſes it higher, not by preſſing it into the Glaſs, but by making its Parts ſtick to the Glaſs, and to one another. For upon any diſcontinuation of Parts, made either by Bubbles or by ſhaking the Glaſs,

Glaſs, the whole Mercury falls down to the height of 29 or 30 Inches.

And of the ſame kind with theſe Experiments are thoſe that follow. If two plane poliſh'd Plates of Glaſs (ſuppoſe two pieces of a poliſh'd Looking-glaſs) be laid together, ſo that their ſides be parallel and at a very ſmall diſtance from one another, and then their lower edges be dipped into Water, the Water will riſe up between them. And the leſs the diſtance of the Glaſſes is, the greater will be the height to which the Water will riſe. If the diſtance be about the hundredth part of an Inch, the Water will riſe to the height of about an Inch; and if the diſtance be greater or leſs in any Proportion, the height will be reciprocally proportional to the diſtance very nearly. For the attractive Force of the Glaſſes is the ſame, whether the diſtance between them be greater or leſs; and the weight of the Water drawn up is the ſame, if the height of it be reciprocally proportional to the height of the Glaſſes. And in like manner, Water aſcends between two Marbles poliſh'd plane, when their poliſhed ſides are parallel, and at a very little diſtance from one another. And if ſlender Pipes of Glaſs be dipped at one end into ſtagnating Water, the Water will riſe up within the Pipe, and the height to which it riſes will be reciprocally proportional to the Diameter of the Cavity of the Pipe, and will equal the height to which it riſes between two Planes of Glaſs, if the Semidiameter of the Cavity of the Pipe be equal to the diſtance between the Planes, or thereabouts.

And

And these Experiments succeed after the same manner *in vacuo* as in the open Air, (as hath been tried before the Royal Society,) and therefore are not influenced by the Weight or Pressure of the Atmosphere.

And if a large Pipe of Glass be filled with sifted Ashes well pressed together in the Glass, and one end of the Pipe be dipped into stagnating Water, the Water will rise up slowly in the Ashes, so as in the space of a Week or Fortnight to reach up within the Glass, to the height of 30 or 40 Inches above the stagnating Water. And the Water rises up to this height by the Action only of those Particles of the Ashes which are upon the Surface of the elevated Water; the Particles which are within the Water, attracting or repelling it as much downwards as upwards. And therefore the Action of the Particles is very strong. But the Particles of the Ashes being not so dense and close together as those of Glass, their Action is not so strong as that of Glass, which keeps Quick-silver suspended to the height of 60 or 70 Inches, and therefore acts with a Force which would keep Water suspended to the height of above 60 Feet.

By the same Principle, a Sponge sucks in Water, and the Glands in the Bodies of Animals, according to their several Natures and Dispositions, suck in various Juices from the Blood.

If two plane polish'd Plates of Glass three or four Inches broad, and twenty or twenty five long, be laid, one of them parallel to the Horizon,

rizon, the other upon the first, so as at one of their ends to touch one another, and contain an Angle of about 10 or 15 Minutes, and the same be first moisten'd on their inward sides with a clean Cloth dipp'd into Oil of Oranges or Spirit of Turpentime, and a Drop or two of the Oil or Spirit be let fall upon the lower Glass at the other end; so soon as the upper Glass is laid down upon the lower so as to touch it at one end as above, and to touch the Drop at the other end, making with the lower Glass an Angle of about 10 or 15 Minutes; the Drop will begin to move towards the Concourse of the Glasses, and will continue to move with an accelerated Motion, till it arrives at that Concourse of the Glasses. For the two Glasses attract the Drop, and make it run that way towards which the Attractions incline. And if when the Drop is in motion you lift up that end of the Glasses where they meet, and towards which the Drop moves, the Drop will ascend between the Glasses, and therefore is attracted. And as you lift up the Glasses more and more, the Drop will ascend slower and slower, and at length rest, being then carried downward by its Weight, as much as upwards by the Attraction. And by this means you may know the Force by which the Drop is attracted at all distances from the Concourse of the Glasses.

Now by some Experiments of this kind, (made by Mr. *Hawksby*) it has been found that the Attraction is almost reciprocally in a duplicate Proportion of the distance of the middle of the Drop from the Concourse of the Glasses,

*viz.*

*viz.* reciprocally in a ſimple Proportion, by reaſon of the ſpreading of the Drop, and its touching each Glaſs in a larger Surface; and again reciprocally in a ſimple Proportion, by reaſon of the Attractions growing ſtronger within the ſame quantity of attracting Surface. The Attraction therefore within the ſame quantity of attracting Surface, is reciprocally as the diſtance between the Glaſſes. And therefore where the diſtance is exceeding ſmall, the Attraction muſt be exceeding great. By the Table in the ſecond Part of the ſecond Book, wherein the thickneſſes of colour'd Plates of Water between two Glaſſes are ſet down, the thickneſs of the Plate where it appears very black, is three eighths of the ten hundred thouſandth part of an Inch. And where the Oil of Oranges between the Glaſſes is of this thickneſs, the Attraction collected by the foregoing Rule, ſeems to be ſo ſtrong, as within a Circle of an Inch in diameter, to ſuffice to hold up a Weight equal to that of a Cylinder of Water of an Inch in diameter, and two or three Furlongs in length. And where it is of a leſs thickneſs the Attraction may be proportionally greater, and continue to increaſe, until the thickneſs do not exceed that of a ſingle Particle of the Oil. There are, therefore Agents in Nature able to make the Particles of Bodies ſtick together by very ſtrong Attractions. And it is the Buſineſs of experimental Philoſophy to find them out.

Now the ſmalleſt Particles of Matter may cohere by the ſtrongeſt Attractions, and compoſe bigger Particles of weaker Virtue; and many of theſe may cohere and compoſe bigger Particles whoſe Virtue is ſtill weaker, and ſo on for divers Succeſſions, until the Progreſſion end in the biggeſt Particles on which the Operations in Chymiſtry, and the Colours of natural Bodies depend, and which by cohering compoſe Bodies of a ſenſible Magnitude. If the Body is compact, and bends or yields inward to Preſſion without any ſliding of its Parts, it is hard and elaſtick, returning to its Figure with a Force ariſing from the mutual Attraction of its Parts. If the Parts ſlide upon one another, the Body is malleable or ſoft. If they ſlip eaſily, and are of a fit ſize to be agitated by Heat, and the Heat is big enough to keep them in Agitation, the Body is fluid; and if it be apt to ſtick to things, it is humid; and the Drops of every Fluid affect a round Figure by the mutual Attraction of their Parts, as the Globe of the Earth and Sea affects a round Figure by the mutual Attraction of its Parts by Gravity.

Since Metals diſſolved in Acids attract but a ſmall quantity of the Acid, their attractive Force can reach but to a ſmall diſtance from them. And as in Algebra, where affirmative Quantities vaniſh and ceaſe, there negative ones begin; ſo in Mechanicks, where Attraction ceaſes, there a repulſive Virtue ought to ſucceed. And that there is ſuch a Virtue, ſeems to follow from the Reflexions and Inflexions of the

Rays

Rays of Light. For the Rays are repelled by Bodies in both these Cases, without the immediate Contact of the reflecting or inflecting Body. It seems also to follow from the Emission of Light; the Ray so soon as it is shaken off from a shining Body by the vibrating Motion of the Parts of the Body, and gets beyond the reach of Attraction, being driven away with exceeding great Velocity. For that Force which is sufficient to turn it back in Reflexion, may be sufficient to emit it. It seems also to follow from the Production of Air and Vapour. The Particles when they are shaken off from Bodies by Heat or Fermentation, so soon as they are beyond the reach of the Attraction of the Body, receding from it, and also from one another with great Strength, and keeping at a distance, so as sometimes to take up above a million of times more space than they did before in the form of a dense Body. Which vast Contraction and Expansion seems unintelligible, by feigning the Particles of Air to be springy and ramous, or rolled up like Hoops, or by any other means than a repulsive Power. The Particles of Fluids which do not cohere too strongly, and are of such a smallness as renders them most susceptible of those Agitations which keep Liquors in a Fluor, are most easily separated and rarified into Vapour; and in the Language of the Chymists, they are volatile, rarifying with an easy Heat, and condensing with Cold. But those which are grosser, and so less susceptible of Agitation, or cohere by a stronger Attraction, are not separated without a stronger Heat, or perhaps not without Fermentation. And these last are the Bodies which Chymists call fix'd, and being rarified by Fermentation, become true permanent Air: those Particles receding from one another with the greatest Force, and being most difficultly brought together, which upon Contact cohere most strongly. And because the Particles of permanent Air are grosser, and arise from denser Substances than those of Vapours, thence it is that true Air is more ponderous than Vapour, and that a moist Atmosphere is lighter than a dry one, quantity for quantity. From the same repelling Power it seems to be that Flies walk upon the Water without wetting their Feet; and that the Object-glasses of long Telescopes lie upon one another without touching; and that dry Powders are difficultly made to touch one another so as to stick together, unless by melting them, or wetting them with Water, which by exhaling may bring them together; and that two polish'd Marbles, which by immediate Contact stick together, are difficultly brought so close together as to stick.

And thus Nature will be very conformable to her self and very simple, performing all the great Motions of the heavenly Bodies by the Attraction of Gravity which intercedes those Bodies, and almost all the small ones of their Particles by some other attractive and repelling Powers which intercede the Particles. The *Vis inertiæ* is a passive Principle by which Bodies

dies persist in their Motion or Rest, receive Motion in proportion to the Force impressing it, and resist as much as they are resisted. By this Principle alone there never could have been any Motion in the World. Some other Principle was necessary for putting Bodies into Motion; and now they are in Motion, some other Principle is necessary for conserving the Motion. For from the various Composition of two Motions, 'tis very certain that there is not always the same quantity of Motion in the World. For if two Globes joined by a slender Rod, revolve about their common Center of Gravity with an uniform Motion, while that Center moves on uniformly in a right Line drawn in the Plane of their circular Motion; the Sum of the Motions of the two Globes, as often as the Globes are in the right Line described by their common Center of Gravity, will be bigger than the Sum of their Motions, when they are in a Line perpendicular to that right Line. By this Instance it appears that Motion may be got or lost. But by reason of the Tenacity of Fluids, and Attrition of their Parts, and the Weakness of Elasticity in Solids, Motion is much more apt to be lost than got, and is always upon the Decay. For Bodies which are either absolutely hard, or so soft as to be void of Elasticity, will not rebound from one another. Impenetrability makes them only stop. If two equal Bodies meet directly *in vacuo*, they will by the Laws of Motion stop where they meet, and lose all their Motion, and remain in rest, unless they be elaſtick, and receive new Motion from their Spring. If they have ſo much Elaſticity as ſuffices to make them rebound with a quarter, or half, or three quarters of the Force with which they come together, they will loſe three quarters, or half, or a quarter of their Motion. And this may be tried, by letting two equal Pendulums fall againſt one another from equal heights. If the Pendulums be of Lead or ſoft Clay, they will loſe all or almoſt all their Motions: If of elaſtick Bodies they will loſe all but what they recover from their Elaſticity. If it be ſaid, that they can loſe no Motion but what they communicate to other Bodies, the conſequence is, that *in vacuo* they can loſe no Motion, but when they meet they muſt go on and penetrate one anothers Dimenſions. If three equal round Veſſels be filled, the one with Water, the other with Oil, the third with molten Pitch, and the Liquors be ſtirred about alike to give them a vortical Motion; the Pitch by its Tenacity will loſe its Motion quickly, the Oil being leſs tenacious will keep it longer, and the Water being leſs tenacious will keep it longeſt, but yet will loſe it in a ſhort time. Whence it is eaſy to underſtand, that if many contiguous Vortices of molten Pitch were each of them as large as thoſe which ſome ſuppoſe to revolve about the Sun and fix'd Stars, yet theſe and all their Parts would, by their tenacity and ſtiffneſs, communicate their Motion to one another till they all reſted among themſelves. Vortices of Oil or Water, or ſome fluider Matter, might con-

continue longer in Motion; but unleſs the Matter were void of all Tenacity and Attrition of Parts, and Communication of Motion, (which is not to be ſuppoſed) the Motion would conſtantly decay. Seeing therefore the variety of Motion which we find in the World is always decreaſing, there is a neceſſity of conſerving and recruiting it by active Principles, ſuch as are the cauſe of Gravity, by which Planets and Comets keep their Motions in their Orbs, and Bodies acquire great Motion in falling; and the cauſe of Fermentation, by which the Heart and Blood of Animals are kept in perpetual Motion and Heat; the inward Parts of the Earth are conſtantly warm'd, and in ſome places grow very hot; Bodies burn and ſhine, Mountains take Fire, the Caverns of the Earth are blown up, and the Sun continues violently hot and lucid, and warms all things by his Light. For we meet with very little Motion in the World, beſides what is owing to theſe active Principles. And if it were not for theſe Principles the Bodies of the Earth, Planets, Comets, Sun, and all things in them would grow cold and freeze, and become inactive Maſſes; and all Putrefaction, Generation, Vegetation and Life would ceaſe, and the Planets and Comets would not remain in their Orbs.

All theſe things being conſider'd, it ſeems probable to me, that God in the Beginning form'd Matter in ſolid, maſſy, hard, impenetrable, moveable Particles, of ſuch Sizes and Figures, and with ſuch other Properties, and in ſuch Proportion to Space, as most conduced to the End for which he form'd them; and that these primitive Particles being Solids, are incomparably harder than any porous Bodies compounded of them; even so very hard, as never to wear or break in pieces: No ordinary Power being able to divide what God himself made one in the first Creation. While the Particles continue entire, they may compose Bodies of one and the same Nature and Texture in all Ages: But should they wear away, or break in pieces, the Nature of Things depending on them, would be changed. Water and Earth composed of old worn Particles and Fragments of Particles, would not be of the same Nature and Texture now, with Water and Earth composed of entire Particles, in the Beginning. And therefore that Nature may be lasting, the Changes of corporeal Things are to be placed only in the various Separations and new Associations and Motions of these permanent Particles; compound Bodies being apt to break, not in the midst of solid Particles, but where those Particles are laid together, and only touch in a few Points.

It seems to me farther, that these Particles have not only a *Vis inertiæ*, accompanied with such passive Laws of Motion as naturally result from that Force, but also that they are moved by certain active Principles, such as is that of Gravity, and that which causes Fermentation, and the Cohesion of Bodies. These Principles I consider not as occult Qualities, supposed to result from the specifick Forms of Things, but as general Laws of Nature, by which the Things themſelves are form'd: their Truth appearing to us by Phænomena, though their Cauſes be not yet diſcover'd. For theſe are manifeſt Qualities, and their Cauſes only are occult. And the *Ariſtotelians* gave the Name of occult Qualities not to manifeſt Qualities, but to ſuch Qualities only as they ſuppoſed to lie hid in Bodies, and to be the unknown Cauſes of manifeſt Effects: Such as would be the Cauſes of Gravity, and of magnetick and electrick Attractions, and of Fermentations, if we ſhould ſuppoſe that theſe Forces or Actions aroſe from Qualities unknown to us, and uncapable of being diſcovered and made manifeſt. Such occult Qualities put a ſtop to the Improvement of natural Philoſophy, and therefore of late Years have been rejected. To tell us that every Species of Things is endow'd with an occult ſpecifick Quality by which it acts and produces manifeſt Effects, is to tell us nothing: But to derive two or three general Principles of Motion from Phænomena, and afterwards to tell us how the Properties and Actions of all corporeal Things follow from thoſe manifeſt Principles, would be a very great ſtep in Philoſophy, though the Cauſes of thoſe Principles were not yet diſcover'd: And therefore I ſcruple not to propoſe the Principles of Motion above mention'd, they being of very general Extent, and leave their Cauſes to be found out.

Now by the help of theſe Principles, all material Things ſeem to have been compoſed of the

the hard and solid Particles above mention'd, variously associated in the first Creation by the Counsel of an intelligent Agent. For it became him who created them to set them in order. And if he did so, it's unphilosophical to seek for any other Origin of the World, or to pretend that it might arise out of a Chaos by the mere Laws of Nature; though being once form'd, it may continue by those Laws for many Ages. For while Comets move in very excentrick Orbs in all manner of Positions, blind Fate could never make all the Planets move one and the same way in Orbs concentrick, some inconsiderable Irregularities excepted which may have risen from the mutual Actions of Comets and Planets upon one another, and which will be apt to increase, till this System wants a Reformation. Such a wonderful Uniformity in the Planetary System must be allowed the Effect of Choice. And so must the Uniformity in the Bodies of Animals, they having generally a right and a left side shaped alike, and on either side of their Bodies two Legs behind, and either two Arms, or two Legs, or two Wings before upon their Shoulders, and between their Shoulders a Neck running down into a Back-bone, and a Head upon it; and in the Head two Ears, two Eyes, a Nose, a Mouth and a Tongue, alike situated. Also the first Contrivance of those very artificial Parts of Animals, the Eyes, Ears, Brain, Muscles, Heart, Lungs, Midriff, Glands, Larynx, Hands, Wings, Swimming Bladders, natural

tural Spectacles, and other Organs of Senſe and Motion; and the Inſtinct of Brutes and Inſects, can be the effect of nothing elſe than the Wiſdom and Skill of a powerful ever-living Agent, who being in all Places, is more able by his Will to move the Bodies within his boundleſs uniform Senſorium, and thereby to form and reform the Parts of the Univerſe, than we are by our Will to move the Parts of our own Bodies. And yet we are not to conſider the World as the Body of God, or the ſeveral Parts thereof, as the Parts of God. He is an uniform Being, void of Organs, Members or Parts, and they are his Creatures ſubordinate to him, and ſubſervient to his Will; and he is no more the Soul of them, than the Soul of a Man is the Soul of the Species of Things carried through the Organs of Senſe into the place of its Senſation, where it perceives them by means of its immediate Preſence, without the Intervention of any third thing. The Organs of Senſe are not for enabling the Soul to perceive the Species of Things in its Senſorium, but only for conveying them thither; and God has no need of ſuch Organs, he being every where preſent to the Things themſelves. And ſince Space is diviſible *in infinitum*, and Matter is not neceſſarily in all places, it may be alſo allow'd that God is able to create Particles of Matter of ſeveral Sizes and Figures, and in ſeveral Proportions to Space, and perhaps of different Denſities and Forces, and thereby to vary the Laws of Nature, and make Worlds of ſeveral ſorts in

ſeveral

ſeveral Parts of the Univerſe. At leaſt, I ſee nothing of Contradiction in all this.

As in Mathematicks, ſo in Natural Philoſophy, the Inveſtigation of difficult Things by the Method of Analyſis, ought ever to precede the Method of Compoſition. This Analyſis conſiſts in making Experiments and Obſervations, and in drawing general Concluſions from them by Induction, and admitting of no Objections againſt the Concluſions, but ſuch as are taken from Experiments, or other certain Truths. For Hypotheſes are not to be regarded in experimental Philoſophy. And although the arguing from Experiments and Obſervations by Induction be no Demonſtration of general Concluſions; yet it is the beſt way of arguing which the Nature of Things admits of, and may be looked upon as ſo much the ſtronger, by how much the Induction is more general. And if no Exception occur from Phænomena, the Concluſion may be pronounced generally. But if at any time afterwards any Exception ſhall occur from Experiments, it may then begin to be pronounced with ſuch Exceptions as occur. By this way of Analyſis we may proceed from Compounds to Ingredients, and from Motions to the Forces producing them; and in general, from Effects to their Cauſes, and from particular Cauſes to more general ones, till the Argument end in the moſt general. This is the Method of Analyſis: And the Syntheſis conſiſts in aſſuming the Cauſes diſcover'd, and eſtabliſh'd as Principles, and by them explaining the Phæ-

nomena

nomena proceeding from them, and proving the Explanations.

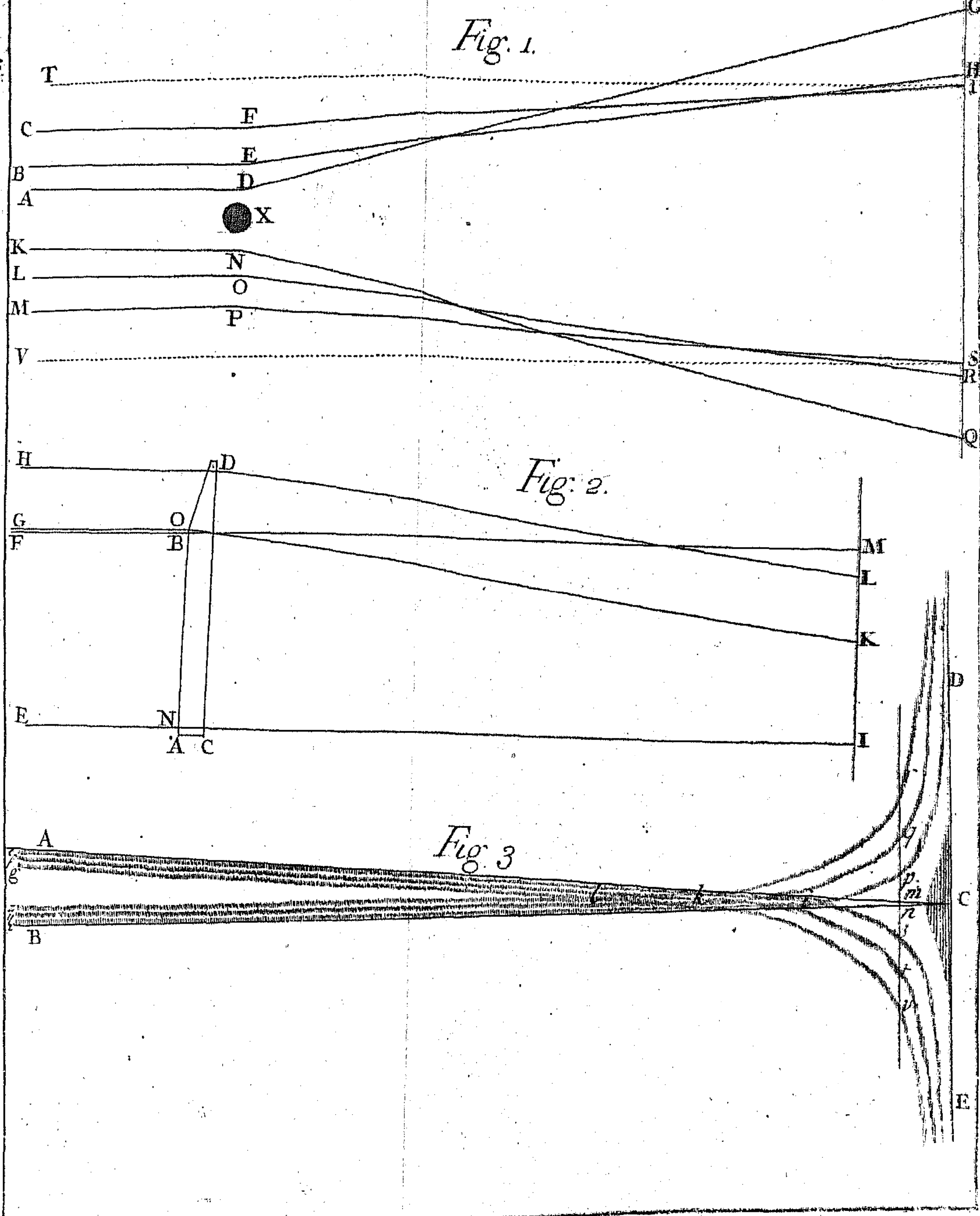
In the two first Books of these Opticks, I proceeded by this Analysis to discover and prove the original Differences of the Rays of Light in respect of Refrangibility, Reflexibility, and Colour, and their alternate Fits of easy Reflexion and easy Transmission, and the Properties of Bodies, both opake and pellucid, on which their Reflexions and Colours depend. And these Discoveries being proved, may be assumed in the Method of Composition for explaining the Phænomena arising from them: An Instance of which Method I gave in the End of the first Book. In this third Book I have only begun the Analysis of what remains to be discover'd about Light and its Effects upon the Frame of Nature, hinting several things about it, and leaving the Hints to be examin'd and improved by the farther Experiments and Observations of such as are inquisitive. And if natural Philosophy in all its Parts, by pursuing this Method, shall at length be perfected, the Bounds of moral Philosophy will be also enlarged. For so far as we can know by natural Philosophy what is the first Cause, what Power he has over us, and what Benefits we receive from him, so far our Duty towards him, as well as that towards one another, will appear to us by the Light of Nature. And no doubt, if the Worship of false Gods had not blinded the Heathen, their moral Philosophy would have gone farther than to the four Cardinal Virtues; and

instead

inſtead of teaching the Tranſmigration of Souls, and to worſhip the Sun and Moon, and dead Heroes, they would have taught us to worſhip our true Author and Benefactor.

*FINIS.*

Book III Plate I



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