BUDN QC 353 .N556 1721



OPTICKS: OR. A TREATISE OFTHE Reflections, Refractions; Inflections and Colours OF LIGHT. The Third Edition, Corrected. By Sir Isaac Newton, Knt. L O N D O N: Printed for WILLIAM and JOHN INNYS at the Weft End of St. Paul's. 1721.



Advertisement I.



ART of the enfuing Difcourse about Light was written at the defire of

Some Gentlemen of the Royal Society, in the Year 1675, and then sent to their Secretary, and read at their Meetings, and the rest was added about twelve Years after to complete the Theory; except the third Book, and the last Proposition of the Second, which were since put together out of scatter'd Papers. To avoid being engaged in Disputes about A 2 these

Advertisement.

these Matters, I have bitherto 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 Confent.

The Crowns of Colours, which fometimes appear about the Sun and Moon, I have endeavoured to give an Account of; but for want

Advertisement.

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 fome of those which I did try, until I had fatisfied my felf about all their Circumstances. To communicate what I have tried, and leave the reft to others for farther Enquiry, is all my Design in publishing thefe Papers.

In a Letter written to Mr. Leibnitz in the Year 1679, and publissed by Dr. Wallis, I mention d a Method by which I had found some general Theorems about squaring Curvilinear Figures, or

Advertisement,

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 fuch Theorems, and having since met with some Things copied out of it, I have on this Occasion made it publick, prefixing to it an Introduction, and subjoining a Scholium concerning that Method. And I have joined with it another small Tract concerning the Curvilinear Figures of the Second Kind, which was also written many Years ago, and made known to some Friends, who have solicited the making it publick.

I. P

Aptil 1. 1704.

ADVERTISEMENT II.



N 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 Effential Property of Bodies, I have added one Que-Stion concerning its Cause, chu-Jing to propose it by way of a Question, because I am not yet fatisfied about it for want of Experiments.

July 16, 1717.

T.N.

ERRATA.

Pap. 342. lin. 6. for feven, read feven and a half. Ib. lin. 8. for 14, read 15. Ib. lin. 10. for 21, 28 or 35, read $22\frac{1}{2}$, 30 or 38. Ib. lin. 12. for 70, 140, 210. read 76, 152, 228. Pag. 366. L 22. for height read diffance.



I

THE

FIRST BOOK ÓF



PART I.

෧ඁ෧෧෮෨෪෨෪෨෪෨෪෨෪෨෪෨෪෨෪෨෪෨෪෨෪෨෪෨෪෨ඁ෦ඁ෦෩ඁ



Y Defign in this Book is not to ex-plain the Properties of Light by Hy-pothefes, but to propole and prove them by Reafon and Experiments: In order to which I shall premise the following Definitions and Axioms.

DEFI-

[2]

DEFINITIONS.

DEFIN. I.

D' the Rays of Light I understand its least Parts, and those as well Successive in the Jame lines as Contemporary in several lines. For it is manifest that Light confists 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 prefently 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 propagated alone, or do or suffer any thing alone which the rest of the Light doth not or suffers not, I call a Ray of Light.

DEFIN. II.

Refrangibility of the Rays of Light, is their Disposition to be refracted or turned out of their Way in passing out of one transparent Body or Medium into another. And a greater or less Refrangibility of Rays, is their Disposition to be turned more or less out of their Way in like Incidences on the same Medium. Mathematicians usually confider 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 pailing out of one Medium into another. And thus may Rays and Refractions be confidered, if Light be propagated in an inflant. But by an Argument taken from the Æquations of the times of the Eclipfes of *Jupiter's* Satellites it feems that Light is propagated in time, fpending in its paflage from the Sun to us about feven Minutes of time: And therefore I have chofen to define Rays and Refractions in fuch general terms as may agree to Light in both cafes.

DEFIN. III.

Reflexibility of Rays, is their Diffection to be reflected or turned back into the fame Medium from any other Medium upon whafe Surface they fall. And Rays are more or lefs reflexible, which are turned back more or lefs eafily. As if Light pafs out of Glafs into Air, and by being inclined more and more to the common Surface of the Glafs and Air, begins at length to be totally reflected by that Surface; those forts of Rays which at like Incidences are reflected most copioufly, or by inclining the Rays begin fooneft to be totally reflected, are most reflexible.

DEFIN.IV.

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

[3]

[4]

DEFIN.V.

The Angle of Reflexion or Refraction, is the Angle which the line defcribed 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 Refration, are the Sines of the Angles of Incidence, Reflexion, and Refraction.

DEFIN. VII.

The Light whofe Rays are all alike Refrangible, I call Simple, Homogeneal and Similar; and that whofe Rays are fome more Refrangible than others, I call compound, Heterogeneal and Diffimilar. 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.

[5]

AXIOMS.

A X. I.

HE Angles of Reflexion, and Refraction, lie in one and the fame 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.

A X. 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 cafes of Incidence on the fame refracting Body may be determined. Thus if the B 3 RefraRefraction 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 Glafs, the Sines are as 17 to 11. In Light of other Colours the Sines have other Proportions: but the difference is fo little that it need feldom be confidered.

Suppose therefore, that RS [in Fig. 1.] repre-fents the Surface of flagnating Water, and that C is the point of Incidence in which any Ray coming in the Air from A in the Line A C is reflected or refracted, and I would know whither this Ray fhall go after Reflexion or Refraction: I crect upon the Surface of the Water from the point of Incidence the Perpendicular C P 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 defired, I produce AD to B fo 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 e-qual to the Angle and Sine of Incidence, as they ought to be by the fecond Axiom. But if the refracted Ray be defired, I produce AD to H, fo that D H may be to A D 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 defcribing a Circle A BE, 1 draw Parallel to the Perpendicular CPQ, the Line HE cutting the CircumCircumference in E, and joyning CE, this Line C E shall be the Line of the refracted Ray. For if E F be let fall perpendicularly on the Line PQ, this Line E F shall be the Sine of Re-fraction of the Ray CE, the Angle of Refraction being E CQ; and this Sine E F is equal to D H, and confequently in Proportion to the Sine of Insidence A D as a to the Incidence AD as 3 to 4.

In like manner, if there be a Prism of Glass (that is a Glafs 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 crois this Prism be defired : Let ACB [in Fig. 2.] represent a Plane cutting this Prifm tranverily to its three Parallel lines or edges there where the Light paffeth through it, and let DE be the Ray inci-dent upon the first fide of the Prifm AC where the Light goes into the Glafs; and by putting the Proportion of the Sine of Incidence to the Sine of Refraction as 17 to 11 find E F the first refracted Ray. Then taking this Ray for the Incident Ray upon the fecond fide 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. B 4

Much

Much after the fame manner, if ACBD [in Fig. 3.] reprefent a Glafs fpherically Convex on both fides (ufually called a Lens, fuch as is a Burning-glafs, or Spectacle glafs, or an Object glafs of a Telefcope) and it be required to know how Light falling upon it from any lucid point Q fhall be refracted, let Q M reprefent a Ray falling upon any point M of its first fpherical Surface ACB, and by creeting a Perpendicular to the Glafs at the point M, find the first refracted Ray M N by the Proportion of the Sines 17 to 11. Let that Ray in going out of the Glafs be incident upon N, and then find the fecond refracted Ray N q by the Proportion of the Sines 11 to 17. And after the fame manner may the Refraction be found when the Lens is Convex on one fide and Plane or Concave on the other, or Concave on both fides.

AX. VI.

Homogeneal-Rays which flow from feveral 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. Caf. 1. Let ACB [in Fig. 4.] be a reflecting or refracting Plane, and Q the Focus of the incident Rays, and Q q C a perpendicular to that Plane. And if this perpendicular be produced to q, fo that q C be equal to Q C, the point q, fhall be the Focus of the reflected Rays. Or if q C be taken on the fame fide of the Plane with Q C and in Propertion to Q C as the Sine of QC and in Proportion to QC as the Sine of Incidence to the Sine of Refraction, the point qshall be the Focus of the refracted Rays.

Caf. 2. Let ACB [in Fig. 5.] be the reflecting Surface of any Sphere whole Center is E. Bi-fect any Radius thereof (fuppole E C) in T, and if in that Radius on the fame fide the point T you take the Points Q and q, fo that TQ, TE, and Tq, be continual Proportionals, and the point Q be the Focus of the incident Rays, the point q fhall be the Focus of the reflected ones.

Caf. 3. Let ACB [in Fig. 6.] be the refracting Surface of any Sphere whole Center is E. In any Radius thereof E C produced both ways take ET and Ct equal to one another and fe-verally in fuch Proportion to that Radius as the leffer of the Sines of Incidence and Refraction hath to the difference of those Sines. And then if in the fame Line you find any two Points Q and q, fo that TQ be to ET as $E \neq$ to tq, taking tq the contrary way from t which TQ lieth from T, and if the Point Q be the Focus of any incident Rays, the Point q shall be the Focus of the refracted ones.

And

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

Caf. 4. Let ACBD [in Fig. 7.] be any refrac-ting Lens, fpherically Convex or Concave or Plane on either fide, and let CD be its Axis (that is the Line which cuts both its Surfaces perpendicularly, and paffes 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 fides the Lens are Parallel to the fame Axis; and upon the Diameter F f bifected in E, deferibe a Circle. Suppofe now that any Point Q be the Focus of any incident Rays. Draw Q E cutting the faid Circle in T and t, and therein take t q in fuch Proportion to t E as t E or T E hath to T Q. Let t q lye the contrary way from t which T Q doth from T and r and r full has the Focus of the doth from T, and q fhall be the Focus of the refracted Rays without any fenfible Error, provided the Point Q be not fo remote from the Axis, nor the Lens fo 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 pleafe.

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 fhall 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 feveral points Q, the reflected or refracted Rays shall flow from or towards fo many other Points qfound by the fame Rules. Whether the reflected and refracted Rays flow from or towards the Point q is easily known by the fituation of that Point. For if that Point be on the fame fide of the reflecting or refracting Surface or Lens with the Point Q, and the incident Rays flow from the Point Q, the reflected the 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 fide of that Surface.

A X. 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.] reprefent any Object without Doors, and AB be a Lens placed at a hole in the Window-flut 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 flape and Colours

[I2]

lours. For as the Light which comes from the Point Q goes to the Point q, fo the Light which comes from other Points P and R of the Object, comes from other Points P and K of the Object, will go to fo many other correspondent Points p and r (as is manifest by the fixth Axiom;) fo that every Point of the Object shall illuminate a correspondent Point of the Picture, and there-by 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 calting the Species of Ob-jects 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 feveral Points of the Object is fo refracted the leveral Points of the Object is to 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 hu-mour A B which is beyond the Pupil m k) as to converge and meet again at fo many Points in the bottom of the Eye, and there to paint the Picture of the Object upon that skin (called the *Tunica Pating*) with which the bottom of the Tunica Retina) with which the bottom of the Eye is covered. For Anatomifts when they have taken off from the bottom of the Eye that out-ward and most thick Coat called the Dura Mater, can then fee through the thinner Coats, the Pictures of Objects lively painted there-on. And these Pictures propagated by Mo-tion along the Fibres of the Optick Nerves in-to the Brain, are the cause of Vision. For ac-cordingly as these Pictures are perfect or im-perfect the Object is feen perfectly or imperfect perfect, the Object is feen perfectly or imperfect. ly,

[13] ly. If the Eye be tinged with any colour (as iff the Difeafe of the *Jaundife*) fo as to tinge the Pictures in the bottom of the Eye with that Colour, then all Objects appear tinged with the fame Colour. If the humours of the Eye by old Age decay, fo as by fhrinking to make the *Cornea* and Coat of the *Cryfalline humour* grow flatter than before, the Light will not be re-fracted enough, and for want of a fufficient Re-fraction will not converge to the bottom of the Eye but to fome place beyond it, and by con-fequence paint in the bottom of the Eye a con-fuled Picture, and according to the indiffinet-nefs of this Picture the Object will appear con-fufed. This is the reafon of the decay of fight in old Men, and fhews why their Sight is mend-ed by Spectacles. For thole Convex glaffes fup-ply the defect of plumpnefs in the Eye, and by encreafing the Refraction make the Rays con-verge fooner fo as to convene diffinctly at the bottom of the Eye if the Glafs have a due de-gree of convexity. And the contrary happens in fhort-fighted Men whofe 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 Vifion caufed thereby will not be diffinct, unlefs the Object be brought fo near the Eye as that the place where the converging Rays convene may be removed to the bottom, or that the plumpplace where the converging Rays convene may be removed to the bottom, or that the plump-nefs of the Eye be taken off and the Refracti-ons diminished by a Concave-glass of a due de-gree of Concavity, or lastly that by Age the Eve

Eye grow flatter till it come to a due Figure: For fhort-fighted Men fee remote Objects beft in Old Age, and therefore they are accounted to have the most lasting Eyes.

A X. VIII.

An Object feen 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 feen by Reflexion of a Looking-glafs *m n*, it thall appear, not in its proper place A, but behind the Glafs at *a*, from whence any Rays AB, AC, AD, which flow from one and the fame Point of the Object, do after their Reflexion made in the Points B, C, D, diverge in going from the Glafs to E, F, G, where they are incident on the Spectator's Eyes. For thefe Rays do make the fame Picture in the bottom of the Eyes as if they had come from the Object really placed at *a* without the interpofition of the Looking glafs; and all Vilion is made according to the place and fhape of that Picture.

In like manner the Object D [in Fig. 2.] feen through a Prifm, appears not in its proper place D, but is thence translated to fome other place d fituated in the laft refracted Ray F G drawn backward from F to d.

And fo the Object Q [in Fig. 10.] feen through the Lens AB, appears at the place g from whence the Rays diverge in paffing from the Lens to the Eye. Now it is to be noted, that the Image of the the Object at q is fo much bigger or leffer than the Object it felf at Q, as the diffance of the Image at q from the Lens A B is bigger or lefs than the diffance of the Object at Q from the fame Lens. And if the Object be feen through two or more fuch Convex or Concave-glaffes, every Glafs fhall make a new Image, and the Object fhall appear in the place and of the bignefs of the laft Image. Which confideration unfolds the Theory of Microfeopes and Telefeopes. For that Theory confifts in almost nothing elfe than the deferibing fuch Glaffes as fhall make the laft Image of any Object as diffinct and large and luminous as it can conveniently be made.

[I5]

I have now given in Axioms and their Explications the fumm of what hath hitherto been treated of in Opticks. For what hath been generally agreed on I content my felf to affume under the notion of Principles, in order to what I have farther to write. And this may fuffice for an Introduction to Readers of quick Wit and good Understanding not yet verfed in Opticks: Although those who are already acquainted with this Science, and have handled Glass, will more readily apprehend what followeth.

[16]

CONTRACTOR OF CONTRACTOR OF

PROPOSITIONS.

PROP. I. THEOR. I.

IGHTS which differ in Colours differ alfo in Degrees of Refrangibility:

The Proof by Experiments.

Exper. I. I took a black oblong fliff Paper terminated by Parallel Sides, and with a Perpendicular right Line drawn crofs 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 intenfe and thickly laid on, that the Phænomenon might be more confpicuous. This Paper I view'd through a Prifm of folid Glafs, whofe two Sides through which the Light paffed to the Eye were plane and well polished, and contained an Angle of about fixty degrees: which Angle I call the refracting Angle of the Prifm. And whilft I view'd it, I held it and the Prifm before a Window in fuch manner that the Sides of the Paper were parallel to the Prifm, and both those Sides and the Prifm were parallel to the Horizon, and the crofs Line was alfo 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 fame Paper

Paper by the Light reflected from it to the Eye. Beyond the Prifm was the Wall of the Chamber under the Window covered over with black Cloth, and the Cloth was involved in Darknefs that no Light might be reflected from thence, which in paffing by the edges of the Paper to the Eye, might mingle it felf with the Light of the Paper, and obfcure the Phænomenon thereof. Thefe things being thus ordered, I found that if the refracting Angle of the Prifm be turned upwards, fo that the Paper may feem 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 Prifm be turned downward, fo that the Paper may feem to be carried lower by the Refraction, its blue half will be carried fomething lower thereby than its red half. Wherefore in both cafes the Light which comes from the blue half of the Paper through the Prifm to the Eye, does in like Circumftances fuffer a greater Refraction than the Light which comes from the red half, and by confequence 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 diffinguished into two halfs, the one DG of an intenfely blue Colour, the other FE of an intenfely red. And BACcab represents the Prism whose refracting Planes ABba and ACca meet in the edge of the refracting Angle Aa. This edge Aa being upward, is parallel both to the

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 feen 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

I 18]

the Paper will be refracted downward, fuppofe to $\delta \varepsilon$, and the blue half will be refracted lower to δ_{2} than the red half is to $\varphi \varepsilon$.

Exper 2. About the aforefaid Paper, whofe two halfs were painted over with red and blue, and which was fliff like thin Paftboard, I lapped feveral times a flender thred of very black Silk, in fuch manner that the feveral parts of the thred might appear upon the Colours like fo many black Lines drawn over them, or like long and flender dark Shadows caft upon them. I might have drawn black Lines with a Pen, but the threds were fmaller and better defined. This Paper thus coloured and lined I fet againft a Wall perpendicularly to the Horizon, fo that one of the Colours might fland to the right hand, and the other to the left. Clofe before the Paper at the confine of the Colours below I placed a Candle to illuminate the Paper ftrongly: 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 diffance of fix Feet and one or two Inches from the Paper upon the Floor I crected a glafs Lens four Inches and a quarter broad, which

which might collect the Rays coming from the feveral Points of the Paper, and make them converge towards fo many other Points at the fame diffance of fix Feet and one or two Inches on the other fide of the Lens, and fo form the Image of the coloured Paper upon a white Paper placed there, after the fame manner that a Lens at a hole in a Window cafts the Images of Objects abroad upon a Sheet of white Paper in a dark Room. The aforefaid white Paper, erected perpendicular to the Horizon and to the Rays which fell upon it from the Lens, I moved fometimes towards the Lens, fometimes from it, to find the places where the Images of the blue and red parts of the coloured Paper appear-ed 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 flender Lines (which by reafon of their blacknefs were like Shadows on the Colours) were confused and fcarce visible, unlefs when the Colours on either fide 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 di-flinct, I found that where the red half of the Paper appeared diffinct, the blue half appeared confused, fo that the black Lines drawn upon it could fcarce be feen; 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 C 2 diffinct

[i9]

diffinct there was the diffance of an Inch and a half: the diffance of the white Paper from the Lens, when the Image of the red half of the coloured Paper appeared most diffinct, being greater by an Inch and an half than the diffance of the fame white Paper from the Lens, when the Image of the blue half appeared most diftinct. In like Incidences therefore of the blue and red upon the Lens, the blue was refracted more by the Lens than the red, fo as to converge fooner by an Inch and a half, and therefore is more refrangible.

Illustration. In the twelfth Figure, DE fignifies the coloured Paper, DG the blue half, FE the red half, MN the Lens, HJ the white Paper in that place where the red half with its black Lines appeared diffinct, and bi the fame Paper in that place where the blue half appeared diffinct. The place bi was nearer to the Lens MN than the place HJ by an Inch and an half.

Scholium. The fame things fucceed, notwithflanding that fome of the Circumflances be varied: as in the first Experiment when the Prifm and Paper are any ways inclined to the Horizon, and in both when coloured Lines are drawn upon very black Paper. But in the Defeription of these Experiments, I have fet down fuch Circumflances by which either the Phænomenon might be render'd more confpicuous, or a Novice might more eafily try them, or by which I did try them only. The fame thing I have often done in the following Experiments: Concerning all which this one Admonition may fuffice.

fuffice. Now from thefe 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, fo that in the red there are fome Rays not lefs Refrangible than those of the blue, and in the blue there are fome Rays not more Refrangible than those of the red: But these Rays in proportion to the whole Light are but few, and ferve to diminish the Event of the Expe-riment, but are not able to destroy it. For if the red and blue Colours were more dilute and weak, the diffance of the Images would be lefs than an Inch and a half; and if they were more intenfe and full, that diffance would be greater, as will appear hereafter. Thefe Experiments may fulfice for the Colours of Natural Bodies. For in the Colours made by the Refraction of Drifting this Departments Prifms this Propofition will appear by the Ex-periments which are now to follow in the next Proposition.

PROP. H. THEOR. H.

The Light of the Sun confifts of Rays differently Refrangible.

The Proof by Experiments.

Exper. 3. N a very dark Chamber at a round hole about one third part of an Inch broad, made in the Shut of a Window 1 placed a Glafs Prifm, whereby the Beam of the Sun's Light which came in at that hole might C 3 be 22

be refracted upwards toward the oppofite Wall of the Chamber, and there form a colour'd Image of the Sun. The Axis of the Prifm (that is the Line passing through the middle of the Prifm from one end of it to the other end parallel to the edge of the Refracting Angle) was in this and the following Experiments perpen-dicular to the incident Rays. About this Axis I turned the Prifm flowly, and faw the refra-cted Light on the Wall or coloured Image of the Sun first to defcend, and then to afcend. Between the Defcent and Afcent when the Image feemed Stationary, I flopp'd the Prifm, and fix'd it in that poflure, that it fhould be moved no more. For in that poflure the Re-fractions of the Light at the two fides of the refracting Angle, that is at the entrance of the Rays into the Prifm, and at their going out of it, were equal to one another. So alfo in other Experiments, as often as I would have the Re-fractions on both fides the Prifm to be equal to one another, I noted the place where the Image of the Sun formed by the refracted Light flood ftill between its two contrary Motions, in the common Period of its progrefs and regrefs; and when the Image fell upon that place, I made faft the Prifm. And in this Pofture, as the moft convenient, it is to be underflood that all the Prifms are placed in the following Francisco Prifins are placed in the following Experiments, unlefs where fome other pofture is defcribed. The Prifin therefore being placed in this po-fture, I let the refracted Light fall perpendicu-larly upon a Sheet of white Paper at the oppo-fite Wall of the Chamber, and obferved the Figure

φ...

gure and Dimensions of the Solar Image form-ed 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 diffinctly, but on its Ends very confufedly and indiffinctly, 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 diltant from the Prifm, and at this diffance that breadth if diminished by the Diameter of the hole in the Window shut, that is by a quarter of an Inch, fubtended an Angle at the Prifm 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 Re-Atilinear Sides about eight Inches; and the refracting Angle of the Prifm whereby fo great a length was made, was 64 degrees. With a lefs Angle the length of the Image was lefs, the breadth remaining the fame. If the Prifm was turned about its Axis that way which made the Rays emerge more obliquely out of the fecond refracting Surface of the Prifm, the Image foon became an Inch or two longer, or more; and if the Prifm was turned about the contrary way, fo as to make the Rays fall more oblique-ly on the first refracting Surface, the Image soon became an Inch or two fhorter. And there-fore in trying this Experiment, I was as curi-ous as I could be in placing the Prifm by the C_4 above-

above mention'd Rule exactly in fuch a pofture that the Refractions of the Rays at their emergence out of the Prifm might be equal to that at their incidence on it. This Pritin had fome Veins running along within the Glafs from one end to the other, which fcattered fome of the Sun's Light irregularly, but had no fenfible effect in increasing the length of the coloured Spectrum. For I tried the fame Experiment with other Prifms with the fame Success. And particularly with a Prifm which feemed free from fuch Veins, and whofe refracting Angle was 62 - Degrees, I found the length of the Image $9 \stackrel{1}{\Rightarrow}$ or 10 Inches at the diffance of $18 \stackrel{1}{\Rightarrow}$ Feet from the Prifm, the breadth of the hole in the Window-fhut being ± of an Inch, as beforc. And becaufe it is eafy to commit a mistake in placing the Prifm in its due posture, I repeated the Experiment four or five times, and always found the length of the Image that which is fet down above. With another Prifm of clearer Glafs and better Polifh, which feemed free from Veins, and whole refracting Angle was 63 - Degrees, the length of this Image at the fame diffance of 18 - Feet was also about 10 Inches, or 10%. Beyond these Measures for about a $\frac{1}{2}$ or $\frac{1}{2}$ of an Inch at either end of the Spectrum the Light of the Clouds feemed to be a little tinged with red and violet, but fo very faintly, that I fufpected 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 Glafs, and therefore I did not include it in thefe

thefe Meafures. Now the different Magnitude of the hole in the Window thut, and different thicknefs of the Prifin where the Rays paffed through it, and different inclinations of the Prifm to the Horizon, made no fentible changes in the length of the Image. Neither did the different matter of the Prifins make any: for in a Veilel made of polithed Plates of Glafs cemented together in the fhape of a Prifm and filled with Water, there is the like Succefs 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 Prifm to the Image, and therefore at their very going out of the Prifin 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 re-ceived, they could not pollibly be formuch inclined to one another. For let EG [in Eg. (3.) reprefent the Window-thut, 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 Prifm is feigned to be cut transverily through the middle of the Light. Or if you pleafe, let A BC reprefent the Prifm it felf, 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 caft, and P'I' the Image it felf whole fides towards w and w are Rectilinear and Parallel, and ends towards P and T Semicircular. YKHP and

and X L J T 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 fides the Prifm 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, fo 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 fame 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 fo 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 fubtend an Angle of half a Degree at the Prifm, and by confequence be equal to the breadth v w; and therefore the Image would be round. Thus it would be were the two Rays XLJT and YKHP, and all the reft which form the Image $P \approx T v$, alike refrangible. And therefore feeing 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 fuffer the greateft

[27]

greateft Refraction, must be more refrangible than those which go to the lower end T, un-less the inequality of Refraction be cafual. This Image or Spectrum P T was coloured, being red at its least refracted end T, and vio-let 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 Refrangibility. The length of the Image in the foregoing Experiments I meafured from the faintest and outmost red at one end, to the fainteft and outmost blue at the other end, excepting only a little Penumbra, whofe breadth fearce exceeded a quarter of an Inch, as was faid above.

Exper. 4. In the Sun's beam which was propagated into the Room through the hole in the Window-flut, at the diffance of fome Feet from the hole, I held the Prifm in fuch a po-flure that its Axis might be perpendicular to that beam. Then I looked through the Prifm upon the hole, and turning the Prifm to and fro about its Axis to make the Image of the hole afcend and defcend, when between its two contrary Motions it feemed Stationary, I flopp'd the Prifm that the Refractions of both fides of the refracting Angle might be equal to each other, as in the former Experiment. In this Situation of the Prifm viewing through it the faid hole, I obferved the length of its refracted Image to be many times greater than its breadth, and that the most refracted part thereof appeared violet, the leaft refracted red, the
[28]

the middle parts blue green and yellow in order. The fame thing happen'd when I removed the Prifin out of the Sun's Light, and looked through it upon the hole fhining 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 fuppofed, the refracted Image ought to have appeared round.

round. So then, by thefe two Experiments it appears that in equal Incidences there is a confiderable inequality of Refractions. But whence this inequality arifes, whether it be that fome of the incident Rays are refracted more and otherslefs, conftantly, or by chance, or that one and the fame Ray is by Refraction diffurbed, fhatter'd, dilated, and as it were fplit and fpread into many diverging Rays, as *Grimaldo* fuppofes, does not yet appear by thefe Experiments, but will appear by thofe that follow. *Exper.* 5. Confidering therefore, that if in

will appear by those that follow. Exper. 5. Confidering 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 cafual inequality of the Refractions, the fame oblong Image would by a fecond Refraction made sideways be drawn out as much in breadth by the like Dilatation of the Rays, or other cafual inequality of the Refractions sideways, I tried what would be the effects of such a fecond Refraction. For this end I ordered all things as in the third Experiment, and then placed a fecond Prifin immediately after the first [29]

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 fideways. 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 suffered and blue, did 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 paffing through the first Prifm alone when the fecond Prism is taken away, and p t the Image made by the cross Refractions of both Prisms together. Now if the Rays which tend towards the feveral Points of the round Image Y were dilated and fpread by the Refraction of the first Prism, so that they should not any longer go in fingle Lines to fingle Points, but that every Ray being fplit, fhattered, and changed from a Linear Ray to a Superficies of Rays di-verging from the Point of Refraction, and ly-ing in the Plane of the Angles of Incidence and Refraction, they should go in those Planes to fo many Lines reaching almost from one end of the Image PT to the other, and if that Image fhould

3

[30]

L 30 J fhould thence become oblong: thole Rays and their feveral parts tending towards the feveral Points of the Image P T ought to be again di-lated and fpread fideways by the transverfe Refraction of the fecond Prifm, fo as to com-pofe a four fquare Image, fuch as is reprefent-ed at π ?. For the better understanding of which, let the Image P T be diffinguished into five e-qual parts PQK, KQRL, LRSM, MSVN, NVT. And by the fame irregularity that the orbicular Light Y is by the Refraction of the first Prifm dilated and drawn out into a long Image P T, the Light PQK which takes up a space of the fame length and breadth with the Light Y ought to be by the Refraction of the fecond Prifm dilated and drawn out into the long Image $\pi q k p$, and the Light KQRL inlong Image $\pi q k p$, and the Light KQRL in-to the long Image k q r l, and the Lights LRSM, MSVN, NVT, into fo many other long I-mages lr sm, m svn, nvt7; and all these long Images would compose the four square Image π ?. 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 of Refraction. For the lecond Refraction would fpread the Rays one way as much as the firft doth another, and fo dilate the Image in breadth as much as the firft doth in length. And the fame thing ought to happen, were fome Rays cafually refracted more than others. But the Event is otherwife. The Image P T was not made broader by the Refraction of the fecond Prifm, but only became oblique, as 'tis reprefented at p t, its upper end P being by the the

the Refraction translated to a greater diffance 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 first Prifm translated farther from the place Y to which it tended before Refraction; and therefore fuffered as well in the first Prifm as in the fecond a greater Refraction than the rest of the Light, and by confequence was more refrangible than the rest, even before its incidence on the first 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 first Prifm were alfo more refracted in all the reft, and that without any Dilatation of the Image fideways: and therefore those Rays for their constancy of a greater Refraction are deservedly 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 Difque of the Sun, would illuminate and paint upon the opposite Wall if they were a-lone; E.L. the Circle which all the least refrangible Rays would in like manner illuminate and paint if they were alone; B H, C J, D K, the Circles which fo many intermediate forts of Rays would fucceflively paint upon the Wall, if they were fingly propagated from the Sun in fucceflive order, the reft being always intercepted; and conceive that there are other intermediate Circles without number, which innumerable other intermediate forts of Rays innumerable other intermediate forts of Rays would fucceflively paint upon the Wall if the Sun fhould fucceflively emit every fort apart. And feeing the Sun emits all thefe forts at once, they must all together illuminate and paint in-numerable equal Circles, of all which, being according to their degrees of Refrangibility placed in order in a continual Series, that ob-long Spectrum PT is composed which I de-fcribed 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 fingle Rays, or by any other irregularity in the Refraction of the first other irregularity in the Refraction of the first Prifm, converted into the oblong Spectrum, PT: then ought every Circle AG, BH, CJ, Cc. in that Spectrum, by the crofs Refraction of the fecond Prifm again dilating or otherwife fcattering the Rays as before, to be in like man-ner drawn out and transformed into an oblong Figure, and thereby the breadth of the Image PT

 \mathbf{PT}

P T would be now as much augmented as the length of the Image Y was before by the Refra-Ction of the first Prism; and thus by the Refractions of both Prifms together would be formed a four fquare Figure p = t7, as I described a-bove. Wherefore fince the breadth of the Spectrum PT is not increased by the Refraction fideways, it is certain that the Rays are not fplit or dilated, or otherways irregularly fcatter'd by that Refraction, but that every Circle is by a regular and uniform Refraction tranflated entire into another place, as the Circle A G by the greatest Refraction into the place a g, the Circle B H by a lefs Refraction into the place b b, the Circle C J by a Refraction still place bb, the Circle CJ by a Reflaction function the lefs into the place ci, and to of the reft; 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 fame bigness with the former, because the breadths of all the Spectrums Y, PT and pt at equal distances from the Prifms are equal.

I confidered 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 P T and pt. I placed therefore at that hole a Lens or Object-glafs of a Telefcope which might caft the Image of the Sun diffinctly on Y without any Penumbra at all, and found that the Penumbra of the rectilinear Sides of the oblong Spectrums P T and pt was D

alfo thereby taken away, fo that those Sides appeared as diffinely defined as did the Circum-ference of the first Image Y. Thus it happens if the Glass of the Prims be free from Veins, and their Sides be accurately plane and well polished without those numberless Waves or Curles which ufually arife from Sand-holes a little fmoothed in polifhing with Putty. If the Glafs be only well polifhed and free from Veins and the Sides not accurately plane but a little Convex or Concave, as it frequently happens; yet may the three Spectrums Y, PT and ptwant Penumbras, but not in equal diffances from the Prifms. Now from this want of Penumbras, I knew more certainly that every one of the Circles was refracted according to fome 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 Cir-cles in the Spectrum P T do touch, could not by that Refraction be translated into the Lines a e and g l as diffinct and flraight as they were before, but there would arife in those translated Lines fome Penumbra or Crookedness or Undulation, or other fenfible Perturbation contrary to what is found by Experience. What-foever Penumbra or Perturbation flould be made in the Circles by the crofs Refraction of the fecond Prifin, all that Penumbra or Perturbation would be confpicuous in the right Lines a e and g l which touch those Circles. And therefore fince there is no fuch Penumbra or Perturbation in those right Lines there must be none in the Circles. Since the diffance between thofe

34

[35]

those Tangents or breadth of the Spectrum is not increased by the Refractions, the Diameters of the Circles are not increafed thereby. Since those Tangents continue to be right Lines, every Circle which in the first Prifm is more or lefs refracted, is exactly in the fame proportion more or lefs refracted in the fecond. And feeing all these things continue to fucceed after the fame manner when the Rays are again in a third Prism, and again in a fourth refracted fideways, it is evident that the Rays of one and the fame Circle, as to their degree of Refrangibility continue always uniform and homogeneal to one another, and that those of feveral Circles do differ in degree of Refrangibility, and that in fome certain and conftant proportion. Which is the thing I was to prove.

There is yet another Circumftance or two of this Experiment by which it becomes ftill more plain and convincing. Let the fecond Prifm D H [in Fig 16.] be placed not immediately after the first, but at fome diffance from it; fuppofe in the mid-way between it and the Wall on which the oblong Spectrum P T is cast, fo that the Light from the first Prifm may fall upon it in the form of an oblong Spectrum π ? parallel to this fecond Prifm, and be refracted fideways 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 Prifm forms alone without the fecond; the blue ends P and p being farther diftant from one another than the red ones T and t, and by confequence D 2 F 36 T

that the Rays which go to the blue end π of the Image π ? and which therefore fuffer the greatest **Refraction** in the first Prism, are again in the second Prism more refracted than the rest.

reit. The fame thing I try'd alfo by letting the Sun's Light into a dark Room through two lit-tle round holes F and φ [in *Fig.* 17.] made in the Window, and with two parallel Prifms A BC 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 man-ner that the two colour'd Images P T and MN which they there painted were joined and to which they there painted were joined end to end and lay in one ftraight 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 Prifm DH placed crofs to the two first, refracted sideways, and the Spectrums thereby translated to fome 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 ftraight 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 tranflated farther from its former place MT, than the red end t of the other Image pt from the fame place M T; which puts the Proposition pass dispute. And this happens whether the third Prism D H be placed immediately after the two first, or at a great distance from them, fo that the Light refracted in the two firft

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

37

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 Prifm behind the Shut in that beam to refract it towards the opposite Wall, and close behind the Prifm I fixed one of the Boards, in fuch manner that the middle of the refracted Light might pass through the hole made in it, and the reft be intercepted by the Board. Then at the diffance of about twelve Feet from the first Board I fixed the other Board in fuch manner that the middle of the refracted Light which came through the hole in the first Board and fell upon the oppofite Wall might pass through the hole in this other Board, and the reft being intercepted by the Board might paint upon it the coloured Spectrum of the Sun. And close behind this Board I fixed another Prifm to refract the Light which came through the hole. Then I returned speedily to the first Prism, and by turning it flowly to and fro about its Axis, I caufed the Image which fell upon the fecond Board to move up and down upon that Board, that all its parts might fucceflively pafs through the hole in that Board and fall upon the Prilm behind it. And in the mean time, I noted the places on the opposite Wall to which that Light after its Refraction in the fecond Prism did pass; and by the difference of the places I found that the Light which being most refracted in the D 3 firft

first Prism did go to the blue end of the Image, was again more refracted in the fecond Prism than the Light which went to the red end of that Image, which proves as well the first Proposition as the fecond. 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.

Horizon in any given Angles. *Illustration.* Let F [in *Fig.* 18.] be the wide hole in the Window shut, through which the Sun fhines 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 fecond Board d e and there paint fuch an oblong coloured Image of the Sun as was defcribed in the third Experiment. By turning the Prifm A BC flowly 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 parts fucceffively through the hole g which is made in the mid-dle of that Board. In the mean while another Prifm a b c is to be fixed next after that hole gto refract the trajected Light a fecond 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 whilft the two Boards and fecond Prifm remained unmoved, those places by turning the first Prism about its Axis were changed perpetually. For when the lower part of the Light which

which fell upon the fecond Board d e was eaft through the hole g it went to a lower place Mon the Wall, and when the higher part of that Light was caft through the fame hole g, it went to a higher place N on the Wall, and when any intermediate part of the Light was caft through that hole it went to fome place on the Wall between M and N. The unchanged Po-fition of the Holes in the Boards, made the Incidence of the Rays upon the fecond Prifm to be the fame in all cafes. And yet in that common Incidence fome of the Rays were more refracted and others lefs. And those were more refracted in this Prifin which by a greater Refraction in the first Prifm were more turned out of the way, and therefore for their conflancy of being more refracted are defervedly called more refrangible.

Exper. 7. At two holes made near one ano-ther in my Window thut I placed two Prifms, one at each, which might cafl upon the oppo-fite Wall (after the manner of the third Experiment) two oblong coloured Images of the Sun. And at a little diffance from the Wall I placed a long flender Paper with flraight and parallel edges, and ordered the Prifms and Paper fo, 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 fame Paper; fo that the Pa-per appeared of two Colours, red and violet, much after the manner of the painted Paper in the first and fecond Experiments. Then with a black Cloth I covered the Wall behind the

D .4

[40]

the Paper; that no Light might be reflected from it to diffurb the Experiment, and viewing the Paper through a third Prifm held parallel to it, I faw that half of it which was illuminated by the violet Light to be divided from the other half by a greater Refraction, efpecially 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 feemed contiguous at one of their Angles like the painted Paper in the first Experiment. Which alfo happened when the Paper was too broad. Sometimes instead of the Paper I used a white

Thred, and this appeared through the Prifm divided into two parallel Threds as is repre-fented in the nineteenth Figure, where D G denotes the Thred illuminated with violet Light from D to E and with red Light from F to G, and e d f g are the parts of the Thred feen by Refraction. If one half of the Thred be con-flantly illuminated with red, and the other half be illuminated with all the Colours fucceffively, (which may be done by caufing one of the Prisms to be turned about its Axis whilst the other remains unmoved) this other half in viewing the Thred through the Prifm, 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 fartheft when when with deep violet. Which plainly fhews, that the Lights of feveral Colours are more and more refrangible one than another, in this order of their Colours, red, orange, yellow, green, blue, indigo, deep violet; and fo proves as well the first Proposition as the fecond.

41

I caufed alfo the coloured Spectrums P T [in Fig. 17.] and M N made in a dark Chamber by the Refractions of two Prifms to lye in a right Line end to end, as was defcribed above in the fifth Experiment, and viewing them through a third Prifm held parallel to their length, they appeared no longer in a right Line, but became broken from one another, as they are reprefented at p t and mn, the violet end mof the Spectrum mn being by a greater Refraction tranflated farther from its former place M T than the red end t of the other Spectrum p t.

I farther caufed those two Spectrums PT [in Fig. 20.] and M N to become co-incident in an inverted order of their Colours, the red end of each falling on the violet end of the other, as they are represented in the oblong Figure PTMN; and then viewing them through a Prism DH held parallel to their length, they appeared not co-incident as when view'd with the naked Eye, but in the form of two diffinct Spectrums p t and mn 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 PN and MT, being parted from one another by a greater Refraction of the violet to p and mthan $\begin{bmatrix} 42 \end{bmatrix}$

then of the red to u and t, do differ in degrees of Refrangibility.

I illuminated alfo a little circular piece of white Paper all over with the Lights of both Prifus intermixed, and when it was illuminarinns intermixed, and when it was illumina-ted with the red of one Spectrum and deep violet of the other, fo as by the mixture of those Colours to appear all over purple, I view-ed the Paper, first at a lefs distance, and then at a greater, through a third Prism; and as I went from the Paper, the refracted Image there-of became more and more divided by the une-qual Refraction of the two mixed Colours, and at length parted into two diffinst Images. a red at length parted into two diftinct Images, a red one and a violet one, whereof the violet was farthest from the Paper, and therefore fuffered the greatest Refraction. And when that Prism at the Window which caft the violet on the Paper was taken away, the violet Image difap-peared; but when the other Prifm 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 Prifm through which the Paper was view'd. This alfo was obfervable, that if one of the Prifms at the Window, fuppofe that which caft 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 fucceffively on the Paper from that Prifm, the violet Image changed Colour accordingly, turning fucceffively to indigo, blue, green, yelĺow

low and red, and in changing Colour came nearer and nearer to the red image made by the other Prifm, until when it was also red both

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 Prifu, 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 diffurbed by any Light coming from thence. Thefe Circles thus illuminated, I viewed through a Prifu 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 flill 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 firongeft, I placed a Prifm at the hole of the Window-flut, 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 diffance of fix Feet and two Inches behind the Lens, and there paint the Species of the Book upon a fleet of white Paper much after the manner of the fecond Experiment. The Book and Lensbeing made faft, I no[44]

I noted the place where the Paper was, when the Letters of the Book, illuminated by the fulleft red Light of the folar Image falling up-on it, did caft their Species on that Paper moft diffinely: And then I flay'd till by the Motion of the Sun and confequent Motion of his Image on the Book, all the Colours from that red to the middle of the blue pafs'd over those Let-ters; and when those Letters were illuminated by that blue I noted again the place of the Pa ters; and when those Letters were illuminated by that blue, I noted again the place of the Pa-per when they caft their Species most diffinctly 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 fooner 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 weak. it. For if these Colours be diluted and weakned by the mixture of any adventitious Light, the diffance between the Places of the Paper will not be fo great. This diffance in the fe-cond Experiment where the Colours of natural Bodies were made use of, was but an Inch and an half, by reafon of the imperfection of those Colours. Here in the Colours of the Prism, which are manifeftly more full, intenfe, and live-ly 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 confiderably greater. For the coloured Light of the Prism, by the inter-fering of the Circles described in the fecond Figure

Figure of the fifth Experiment, and alfo by the Light of the very bright Clouds next the Sun's Body intermixing with thefe Colours, and by the Light fcattered by the inequalities in the Polifh of the Prifm, was fo very much compounded, that the Species which those faint and dark Colours, the indigo and violet, caft upon the Paper were not diffinct enough to be well observed.

Exper. 9. A Prifm, whofe two Angles at its Bafe 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-fhut as in the third Experiment. And turning the Prifm flowly 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 Bafe, at which till then it went out of the Glafs, I obferved that those Rays which had fuffered the greateft Refraction were fooner reflected than the reft. 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 reft, and that afterwards the reft alfo, by a total Reflexion, became as copious as thefe. To try this, I made the reflected Light pass through another Prifm, and being refracted by it to fall afterwards upon a sheet of white Paper placed at fome diffance behind it, and there by that Refraction to paint the ufual Colours of the Prifm. And then caufing the first Prifm to be turned about its Axis as above, I observed that when

3

[46]

when those Rays which in this Prism had fuffered the greatest Refraction and appeared of a blue and violet Colour began to be totally reflected, the blue and violet Light on the Paper which was most refracted in the second Prism received a fensible increase above that of the red and yellow, which was leaft refracted; and afterwards when the reft 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 Bafe of the Prifm, being augmented first by the more refrangible Rays and afterwards by the lefs refrangible ones, is compounded of Rays differently refrangible. And that all fuch reflected Light is of the fame nature with the Sun's Light before its Incidence on the Bafe of the Prifm, no Man ever doubted: it being generally allowed, that Light by fuch Reflexions fuffers no alteration in its Modifications and Properties. I do not here take notice of any Refractions made in the fides of the first Prism, because the Light enters it perpendicularly at the first fide, and goes out perpendicularly at the fecond fide, and therefore fuffers none. So then, the Sun's incident Light being of the fame Temper and Conflitution 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 Bafe, 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 Bafe of the Prifin, MG a lefs refracted Ray, MH a more refracted Ray, MN the beam of Light reflected from the Bafe, VXY the fecond Prifm by which this beam in paffing through it is refracted, N t the lefs refracted Light of this beam, and N p the more refracted part thereof. When the first Prifin ABC is turned about its Axis according to the order of the Letters ABC, the Rays MH emerge more and more obliquely out of that Prifm, 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 Prifm, the Rays M G are also reflected to N and increase the number of the Rays Nt. And therefore the Light MN admits into its Composition, first the more refrangible Rays, and then the lefs refrangible Rays, and yet af-ter this Composition is of the fame nature with the Sun's immediate Light FM, the Reflexion of the fpecular Bafe B C caufing no alteration therein.

[47]

Exper. 10. Two Prifms, which were alike in fhape, I tied fo together, that their Axes and oppofite Sides being parallel, they composed a Parallelopiped. And, the Sun fhining into my dark Chamber through a little hole in the Window-fhut, I placed that Parallelopiped in his beam at fome diffance from the hole, in fuch a pofture

3

pofture that the Axes of the Prifms might be perpendicular to the incident Rays, and that thole Rays being incident upon the first Side of one Prifm, might go on through the two contiguous Sides of both Prifms, and emerge out of the last Side of the fecond Prifm. This Side being parallel to the first Side of the first Prifm, caufed the emerging Light to be paral-lel to the incident. Then, beyond thefe two Prifins I placed a third, which might refract that emergent Light, and by that Refraction caft the utual Colours of the Prifin upon the opposite Wall, or upon a sheet of white Paper held at a convenient distance behind the Prifin 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 Prifms became fo 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 reft remaining and on the Paper painting their Colours of green, yel-low, orange, and red as before; and afterwards by continuing the Motion of the two Prifms, by continuing the Motion of the two Prinns, the reft of the Rays alfo by a total Reflexion vanished in order, according to their degrees of Refrangibility. The Light therefore which emerged out of the two Prisms is compound-ed of Rays differently refrangible, feeing the more refrangible Rays may be taken out of it while the lefs refrangible remain. But this Light

Light being trajected only through the parallel Superficies of the two Prifms, if it fuffer'd any change by the Refraction of one Superficies it loft that impression by the contrary Refraction of the other Superficies, and so being restor'd 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 fecond Figure

[49]

ABC and BCD are the two Prifms 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 Prifm, by which the Sun's Light propagated through the hole F into the dark Chamber, and there paffing through those fides of the Prifms AB, BC, CB and CD, is refracted at O to the white Depen DT filling theory much the white Paper PT, falling there partly upon P by a greater Refraction, partly upon T by a lefs 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 B C and C B become fufficiently oblique to the Rays F M, which are incident upon them at M, there will vanish totally out of the refracted Light OPT, first of all the most refracted Rays O P, (the reft O R and O T remaining as be-fore) then the Rays O R and other intermedi-ate ones, and laftly, the leaft refracted Rays OT. For when the Plane B C becomes fufficiently E oblique

~ y.

oblique to the Rays incident upon it, those Rays will begin to be totally reflected by it towards \mathbb{N} ; and first the most refrangible Rays wards \mathbb{N} ; and first the most retrangible Rays will be totally reflected (as was explained in the preceding Experiment) and by confequence 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 fusfer the greateft Refraction, may be taken out of the Light MO whilft the reft of the Rays remain in it, and therefore that Light MO is compounded of Rays differently refrangi-ble. And becaufe the Planes A B and C D are parallel, and therefore by equal and con-trary Refractions deftroy one anothers Ef-fects, the incident Light F M must be of the fame kind and nature with the emergent Light M O, and therefore doth allo confift of Rays differently refrangible. Thefe two Lights F M and MO, before the most refrangible Rays are feparated out of the emergent Light M O, a-gree in colour, and in all other properties fo far as my observation reaches, and therefore are defervedly reputed of the same nature and conflitution, and by confequence the one is compounded as well as the other. But after compounded as well as the other. But and the most refrangible Rays begin to be totally reflected, and thereby separated out of the e-mergent Light MO, that Light changes its co-lour from white to a dilute and faint yellow, a pretty good orange, a very full sed succes-fively and then totally vanishes. For after the most refrangible Rays which paint the Paper at P with

P with

P with a purple Colour, are by a total Refle-xion taken out of the beam of Light MO, the reft of the Colours which appear on the Paper at R and T being mix'd 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 reft which appear between R and T (that is the yellow, orange, red and a little green) being mix-ed in the beam MO compound there an orange; and when all the Rays are by Reflexion taken out of the beam M O, except the least refrangible, which at T appear of a full red, their Colour is the fame in that beam MO as afterwards at T, the Refraction of the Prifm HJK ferving only to feparate the differently refran-gible 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 fecond.

Scholium. If this Experiment and the former be conjoined and made one by applying a fourth Prifm VXY [in Fig. 22.] to refract the reflected beam MN towards t p, the conclusion will be clearer. For then the Light N p which in the fourth Prifm is more refracted, will become fuller and ftronger when the Light O P, which in the third Prifm H J K is more refracted, vanishes at P; and afterwards when the lefs refracted Light O T vanishes at T, the lefs refracted Light N t will become encreased whilft 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 E 2

51

to refult from the mixture of the Colours which fall upon the Paper P T, fo is the reflected beam MN always of fuch a Colour as ought to refult from the mixture of the Colours which fall upon the Paper pt. For when the moft refrangible Rays are by a total Reflexion taken out of the beam MO, and leave that beam of an orange Colour, the Excefs of those Rays in the reflected Light, does not only make the violet, indigo and blue at p more full, but alfo 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, fo foon as all the reflected.

Now feeing that in all this variety of Expe-riments,' whether the Trial be made in Light reflected, and that either from natural Bodies, as in the first and fecond Experiment, or fpe-cular, as in the ninth; or in Light refracted, and that either before the unequally refracted Rays are by diverging feparated from one an-other, and lofing their whitenefs which they have altogether, appear feverally of feveral Co-lours, as in the fifth Experiment; or after they are feparated from one another, and appear co-lours'd as in the firth foresthe and eight? are leparated from one another, and appear co-lour'd as in the fixth, feventh, and eighth Ex-periments; or in Light trajected through paral-lel Superficies, deftroying each others Effects, as in the tenth Experiment; there are always found Rays, which at equal Incidences on 'the fame Medium fuffer unequal Refractions, and that without any fplitting or dilating of fingle Rays, or contingence in the inequality of the Befra-Refra[53]

Refractions, as is proved in the fifth and fixth Experiments. And feeing the Rays which dif-fer in Refrangibility may be parted and forted from one another, and that either by Refraction as in the third Experiment, or by Reflexion as in the tenth, and then the feveral forts apart at equal Incidences fuffer unequal Refractions, and those forts are more refracted. than others after feparation, which were more refracted before it, as in the fixth and following Experiments, and if the Sun's Light be trajected through three or more crofs Prifins fucceffively, those Rays which in the first Prism are refracted more than others, are in all the following Prifms refracted more than others in the fame rate and proportion, as appears by the fifth Experiment; it's manifest that the Sun's Light is an heterogeneous mixture of Rays, fome of which are conftantly more refrangible than others, as was proposed.

෪ඁ෨෪ඁ෨෪෨෪෨෪෨෪෨෪෨෪෨෪෨෪෨෪෨෪෨෪෨෪෨෪෨෪෨෪෨ඁ

PROP. III. THEOR. III.

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

HIS 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 E 3 reflected 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.

$\mathcal{P} R O \mathcal{P}$. IV. **Prob.** I.

To feparate from one another the heterogeneous Rays of compound Light.

HE heterogeneous Rays are in fome mea-fure feparated from con-Retraction of the Prifm in the third Experiment, and in the fifth Experiment by taking away the Penumbra from the rectilinear fides of the coloured Image, that feparation in those very rectilinear fides or ftraight edges of the Image becomes perfect. But in all places between those rectilinear edges, those innumerable Circles there defcribed, which are feverally illuminated by homogeneal Rays, by interfering with one another, and being every where commix'd, do render the Light fufficiently compound. But if these Circles, whilst their centers keep their diffances and positions, could be made lefs in diameter, their interfering one with another and by confequence the mixture of the heterogeneous Rays would be propor-tionally diminish'd. In the twenty third Figure let A G, B H, C J, D K, E L, F M be the Cir-cles which so many forts of Rays flowing from the

the fame difque of the Sun, do in the third' Experiment illuminate; of all which and in-numerable 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 composid as was explained in the fifth Experiment. And let ag, bh, ci, dk, el, fm be for many lefs Circles lying in a like continual Series between two parallel right Lines a f and g m with the fame diffances between their centers, and illuminated by the fame forts of Rays, that is the Circle a g with the fame fort by which the corresponding Cir-cle A G was illuminated, and the Circle b hwith the fame fort by which the corresponding Circle BH was illuminated, and the rest of the Circles c i, d k, e l, f m refpectively, with the Arcles c 1, d k, e 1, f m respectively, with the fame forts of Rays by which the feveral corre-sponding Circles C J, D K, E L, F M were il-luminated. In the Figure P T composed of the greater Circles, three of those Circles A G, B H, C J, are so expanded into one another, that the three forts of Rays by which those Circles are illuminated, together with other innumerable forts of intermediate Rays, are mixed at Q R in the middle of the Circle B H. And the like mixture happened through the whole mixture happens throughout almost the whole length of the Figure P T. But in the Figure p t composed of the lefs Circles, the three lefs Circles ag, bb, ci, which answer to those three greater, do not extend into one another; nor are there any where mingled fo much as any two of the three forts of Rays by which those E 4 Circles

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

T 56]

Now he that shall thus confider it, will eafily understand that the mixture is diminished in the fame proportion with the Diameters of the Circles. If the Diameters of the Circles whilft their Centers remain the fame, be made three times lefs than before, the mixture will be alfo three times lefs; if ten times lefs, the mixture will be ten times lefs, and fo of other proportions. That is, the mixture of the Rays in the greater Figure PT will be to their mixture in the lefs p t, as the Latitude of the greater Figure is to the Latitude of the lefs. For the Latitudes of these Figures are equal to the Diameters of their Circles. And hence it eafily follows, that the mixture of the Rays in the re-fracted Spectrum p t 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 fame 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 lefs than it is, or (which comes to the fame purpose) if without doors, at a great diffance from the Prifm towards the Sun, fome opake Body were placed, with a round hole in the middle of it, to intercept all the Sun's Light, excepting fo much as coming from the middle of his Body could pass through

that

that hole to the Prifm. For fo the Circles A G, BH and the reft, would not any longer answer to the whole Difque of the Sun, but only to that part of it which could be seen from the Prifm through that hole, that it is to the appa-rent magnitude of that hole view'd from the rent magnitude of that hole view'd from the Prifm. But that these Circles may answer more distinctly to that hole, a Lens is to be placed by the Prifm to cass the Image of the hole, (that is, every one of the Circles A G, B H, Gc.) di-flinctly upon the Paper at P T, after such a manner as by a Lens placed at a Window the Species of Objects abroad are cass distinctly up-on a Paper within the Room, and the rectili-near Sides of the oblong folar Image in the fifth Experiment became distinct without any Pen-umbra. If this be done it will not be necessary ry 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.

follows. Exper. 11. In the Sun's Light let into my darkned Chamber through a finall round hole in my Window-fhut, at about ten or twelve Feet from the Window, I placed a Lens, by which the Image of the hole might be diffinetly caft upon a Sheet of white Paper, placed at the diffance of fix, eight, ten or twelve Feet from the Lens. For according to the difference of the Lenfes I ufed various diffances, which I think not worth the while to defcribe. Then immediately after the Lens I placed a Prifm, by which the trajected Light might be refracted either upwards or fideways, and thereby

by the round Image which the Lens alone did caft upon the Paper might be drawn out into a long one with parallel Sides, as in the third Ex-periment. This oblong Image I let fall upon another Paper at about the fame diffance from the Prifm as before, moving the Paper either towards the Prifm or from it, until I found the towards the Prinn or from it, until i found the juft diffance where the rectilinear Sides of the Image became most diffinct. For in this cafe the circular Images of the hole which compose that Image after the fame manner that the Cir-cles a g, b b, c i, &c. do the Figure pt [in Fig. 23.] were terminated most diffinctly without any Penumbra, and therefore extended into one another the least that they could, and by one another the leaft that they could, and by confequence the mixture of the heterogeneous Rays was now the leaft of all. By this means I used to form an oblong Image (such as is p t) [in Fig. 23, and 24.] of circular Images of the hole (such as are ag, bb, ci, &c.) and by u-fing a greater or lefs hole in the Window-shut, I made the circular Images ag, bb, ci, &c. of which it was formed, to become greater or lefs at pleasure, and thereby the mixture of the Rays in the Image pt to be as much or as little as I defired as I defired.

F 58 7

Illustration. In the twenty fourth Figure, F reprefents the circular hole in the Windowfhut, MN the Lens whereby the Image or Species of that hole is caft diffinctly upon a Paper at J, ABC the Prifm whereby the Rays are at their emerging out of the Lens refracted from J towards another Paper at p t, and the round Image at J is turned into an oblong Image p tfalling

falling on that other Paper. This Image pt confifts of Circles placed one after another in a rectilinear order, as was fufficiently explained in the fifth Experiment; and these Circles are equal to the Circle J, and confequently 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 fometimes fixty or feventy times lefs than its length. As for inftance, if the breadth of the hole F be one tenth of an Inch, and MF the diffance of the Lensfrom the hole be 12 Feet; and if p B or p M the diflance of the Image p t from the Prilm or Lens ' be 10 Feet, and the refracting Angle of the Prifm be 62 Degrees, the breadth of the Image p t will be one twelfth of an Inch and the length about fix Inches, and therefore the length to the breadth as 72 to 1, and by confequence the Light of this Image 71 times lefs compound than the Sun's direct Light. And Light thus far fimple and homogeneal, is fuffi-cient for trying all the Experiments in this Book about fimple Light. For the composition of heterogeneal Rays is in this Light fo little that it is fcarce to be difcovered and perceiv'd by Senfe, except perhaps in the indigo and vio-let. For these being dark Colours, do eafily fuffer a fenfible allay by that little fcattering Light which uses to be refracted irregularly by

the inequalities of the Prifm. Yet inflead of the circular hole F, 'tis better to fubilitute an oblong hole fhaped like a long Paral[60]

Parallelogram with its length parallel to the Prifin 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 p t will be as fimple as before, or fimpler, and the Image will become much broader, and therefore more fit to have Experiments tried in its Light than before.

Inftead of this parallelogram hole may be fub-flituted a triangular one of equal Sides, whole Bafe for inftance 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 form'd of equi-crural Triangles *a g, b h, c i, d k, e l, f m,* &c. and innumerable other intermediate ones anfwering to the triangular hole in fhape and bignefs, and lying one after another in a continual Series between two parallel Lines a f and g m. These Triangles are a little intermingled at their Bases but not at their Vertices, and therefore the Light on the brighter fide af of the Image where the Bafes of the Triangles are, is a little compounded, but on the darker fide g m is altogether uncompounded, and in all places between the fides the Composition is proportio-nal to the diffances of the places from that ob-fcurer fide g m. And having a Spectrum p tof fuch a Composition, we may try Experiments either in its flronger and lefs fimple Light near the fide a f, or in its weaker and fimpler Light near the other fide g m, as it fhall feem most convenient convenient.

[61]

But in making Experiments of this kind the Chamber ought to be made as dark as can be, left any foreign Light mingle it felf with the Light of the Spectrum pt, and render it com-pound; efpecially if we would try Experiments in the more fimple Light next the fide g m of the Spectrum; which being fainter, will have a lefs proportion to the foreign Light, and fo by the mixture of that Light be more troubled and made more compound. The Lens alfo ought to be good, fuch as may ferve for optical uses, and the Prifm 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 ufually happens, but truly plane, and its Polish elaborate, as in working Optick-glaffes, and not fuch as is usually wrought with Putty, whereby the edges of the Sandholes being worn away, there are left all over the Glass a numberless company of very little convex polite Rifings like Waves, The edges also of the Prifm and Lens to 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 Pa-per or other black Obflacles. For otherwife the ufelefs Light being reflected every way in the Chamber, will mix with the oblong Spe-ctrum and help to diffurb it. In trying thefe things fo much diligence is not altogether ne-ceflary, but it will promote the fuccefs of the Expe-

ĩ

Experiments, and by a very forupulous Examiner of things deferves to be applied. It's difficult to get Glafs Prifms fit for this purpofe, and therefore I ufed fometimes prifmatick Veffels made with pieces of broken Looking-glaffes, and filled with Rain Water. And to increase the Refraction, I fometimes impregnated the Water flrongly with Saccharum Saturni.

$\mathcal{P} R O \mathcal{P}$. 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.

HE 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 fixth part of an Inch in diameter. Upon this Paper I caufed the Spectrum of homogeneal Light defcribed in the former Proposition, fo to fall, that fome part of the Light might pass through the hole of the Paper. This transmitted part of the Light I refracted with a Prifm placed behind the Paper, and letting this refracted Light fall perpendicularly upon a white Paper two or three Feet diftant from the Prifm, 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 (fo far as I could judge by my Eye) perfectly circular, the length being no greater than the breadth. Which flows 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 fame bignefs. And going from the Papers to the diffance of fome Feet, 1 viewed both Circles through a Prifm. 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 diffinetly defined as when 'tis view'd with the naked Fye. Which proves the whole Proposition.

Exper. 14. In the homogeneal Light I placed Flies and fuch like minute Objects, and viewing them through a Prifm, I faw their parts as diffinely defined as if I had viewed them with the naked Eye. The fame Objects placed in the Sun's unrefracted heterogeneal Light which was white I viewed alfo through a Prifm, and faw them most confusedly defined, fo that I could not diffinguish their fmaller parts from one another. I placed alfo the Letters of a fmall print one while in the homogeneal Light and then in the heterogeneal, and viewing them through
64]

through a Prifun, they appeared in the latter cafe fo confused and indistinct that I could not read them; but in the former they appeared fo diffinct that I could read readily, and thought I faw them as diffinct as when I view'd them with my naked Eye. In both cafes I view'd the fame Objects through the fame Prifun at the fame diffance from me and in the fame fituation. There was no difference but in the Light by which the Objects were illuminated, and which in one cafe was fimple and in the other compound, and therefore the diffinct Vision in the former cafe and confused in the latter could arife from nothing elfe than from that difference of the Lights. Which proves the whole **Pro**position.

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

$\mathcal{P} R O \mathcal{P}$. VI. Theor. V.

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

HAT every Ray confider'd apart is conflant to it felf in fome degree of Refrangibility, is fufficiently manifest out of what has been faid. Those Rays which in the first Refraction are at equal Incidences most refracted, are also in the following Refractions at equal Inci-

[65]

Incidences moft refracted; and fo of the leaft refrangible, and the reft which have any mean degree of Refrangibility, as is manifeft by the fifth, fixth, feventh, 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 feparated 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 show.

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 to the Sines of Refraction, as was explained in the fifth Axiom: and fome by Inftruments fit-ted for measuring of Refractions, or otherwife experimentally examining this Proportion, do acquaint us that they have found it accurate. But whils they, not understanding the diffe-rent Refrangibility of feveral Rays, conceived them all to be refracted according to one and the fame Proportion, 'tis to be prefumed that they adapted their measures only to the middle of the refracted Light; fo that from their mea-fures 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 there-fore we are now to shew that the like given Pro-F

[66]

Proportions obtain in all the reft. That it fhould be fo is very reafonable, Nature being ever conformable to her felf: but an experimental Proof is defired. And fuch a Proof will be had if we can fhew 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 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 alfo 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.

ther. Exper. 15. The Sun fhining into a dark Chamber through a little round hole in the Window-fhut, let S [in Fig. 26.] reprefent his round white Image painted on the oppofite Wall by his direct Light, P T his oblong coloured Image made by refracting that Light with a Prifm placed at the Window; and pt, or 2p 2 t, or 3p 3 t, his oblong colour'd Image made by refracting again the fame Light fideways with a fecond Prifm placed immediately after the first in a crofs position to it, as was explained in the fifth Experiment: that is to fay, pt when the Refraction of the fecond. Prifm is finall, 2p 2 t when its Refraction is greater, and 3p 3 t when it is greatest. For fuch

fuch will be the diversity of the Refractions if the refracting Angle of the fecond Prifm be of various magnitudes; fuppole of fifteen or twen-ty Degrees to make the Image p t, of thirty or forty to make the Image 2p 2t, and of fixty to make the Image 3p 3t. But for want of folid Glafs Prifms with Angles of convenient big-neffes, there may be Veffels made of polifhed Plates of Glafs cemented together in the form of Prifms and filled with Water. Thefe things being thus ordered, I obferved that all the fo-lar Images or coloured Spectrums PT, p t, 2pbeing thus ordered, I observed that all the fo-lar Images or coloured Spectrums P T, p t, 2p2t, 3p 3t 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 Prifms were taken away. The Axis of the Spectrum P T, that is the Line drawn through the middle of it parallel to its rectilinear Sides, did when produced pafs exactly through the middle of that white round Image S. And when the Refraction of the first, the refracting Anto the Refraction of the first, the refracting An-gles of them both being about 60 Degrees, the 'Axis of the Spectrum $3 \not p \ 3 \not \epsilon$ made by that Re-fraction, did when produced pass allo through the middle of the fame white round Image S. But when the Refraction of the fecond Prifm but when the Refraction of the fecond Prilm was lefs 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 T P in the points m and n, a lit-tle beyond the center of that white round I-mage S. Whence the proportion of the Line 3 t T to the Line 3 p P was a little greater than F 2. the

67

[68]

the Proportion of 2t T to 2pP, and this Proportion a little greater than that of t T to pP. Now when the Light of the Spectrum P T falls Now when the Light of the Spectrum P T falls perpendicularly upon the Wall, those Lines 3 t T, 3 p P, and 2 t T, 2 p P and t T, p P, are the Tangents of the Refractions, and therefore by this Experiment the Proportions of the Tan-gents of the Refractions are obtained, from whence the Proportions of the Sines being de-rived, they come out equal, fo far as by view-ing the Spectrums and using fome mathemati-cal Reasoning I could estimate. For I did not make an accurate Computation. So then the Proposition holds true in every Ray apart, fo far as appears by Experiment. And that it is accurately true, may be demonstrated upon this Supposition. That Bodies refract Light by act-Supposition. That Bodies refract Light by acting upon its Rays in Lines perpendicular to their Surfaces. But in order to this Demonftration, I must distinguish the Motion of every

firation, I muft diffinguish 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 whatfoever be incident with any velocity on any broad and thin space terminated on both fides 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, space and ways equal to the space Root of the fum of the the fquare of the perpendicular velocity of that Motion or Thing at its Incidence on that fpace; and of the fquare 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 fame Propolition holds true of any Motion or Thing perpendicularly retarded in its paffage through that fpace, if inftead of the fum of the two Squares you take their difference. The demonstration Mathematicians will eafily find out, and therefore I shall not trouble the Reader with it.

Suppose now that a Ray coming most oblique-ly in the Line M C [in *Fig.* 1.] be refracted at C by the Plane R S into the Line C M, and if it be required to find the Line CE, into which any other Ray AC shall be refracted; let MC, A D, be the Sines of Incidence of the two Rays, and NG, E F, their Sines of Refraction, and let the equal Motions of the incident Rays be reprefented by the equal Lines MC and AC, and the Motion MC being confidered as parallel to the refracting Plane, let the other Motion A C be diffinguished into two Motions A D and DC, one of which A D is parallel, and the other DC perpendicular to the refracting Sur-face. In like manner, let the Motions of the emerging Rays be diftinguish'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 fide, and ends at a certain diffance from it on the other F fide 3,

[70]

fide, 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 diffances 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 fuffer 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 C N you write $\frac{MC}{NG}$ C G as above, then the perpendicular velocity of any other emerging Ray C E which was $\frac{AD}{EF}$ CF, will be equal to the fquare

Root of $CDq + \frac{MCq}{NGq}CGq$. And by fquaring these Equals, and adding to them the Equals ADq and MCq - CDq, and dividing the Sums by the Equals CFq + EFq and CGq + 1NGq, you will have $\frac{ADq}{EFq}$ 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 affuming 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 fort of Rays be found found in any one cafe, 'tis given in all cafes; and this may be readily found by the method in the following Proposition.

$\mathcal{P} R O \mathcal{P}$. VII. Theor. VI.

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

HE Imperfection of Telescopes is vulgarly attributed to the fpherical Figures of the Glasses, and therefore Mathematicians have propounded to figure them by the conical Sections. To shew that they are mistaken, I have inferted this Proposition; the truth of which will appear by the measures of the Refractions of the feveral forts of Rays; and thefe measures I thus determine.

In the third Experiment of the first Book, where the refracting Angle of the Prifm was 62- 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 Prifm was parallel to the Horizon, and the Refraction of the Rays at their Incidence on this Prifm 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

4

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. Thefe are the Sines of Incidence and Refraction of the mean refrangible Rays, and their proportion in round numbers is 20 to 31. This Glafs was of a colour inclining to green. The laft of the Prifms mentioned in the third Experiment was of clear white Glafs. Its refracting Angle 63: 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 fum of the Angles 8157. And their proportion in round numbers 20 to 31, as before.

From the length of the Image, which was about $9\frac{1}{7}$ or 10 Inches, fubduct its breadth, which was $2\frac{1}{7}$ Inches, and the remainder $7\frac{1}{7}$ Inches would be the length of the Image were the Sun but a point, and therefore fubtends the Angle which the moft and leaft refrangible Rays, when incident on the Prifm in the fame Lines, do contain with one another after their Emergence. Whence this Angle is 2 deg. 0'. 7''. For the diftance between the Image and the Prifm where this Angle is made, was $18\frac{1}{7}$ Feet, and at that diftance the Chord $7\frac{1}{7}$ Inches fubtends an Angle of 2 deg. 0'. 7''. Now half this Angle is the Angle which thefe 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 fame emergent mean refrangible Rays, were Were they co-incident to them within the Glafs and fuffered no other Refraction than that at their Emergence. For if two equal Refractions, the one at the Incidence of the Rays on the Prifm, the other at their Emergence, make half the Angle 2 deg. o'. 7". then one of those Refractions will make about a quarter of that Angle, and this quarter added to and fubducted 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 fubduct the common Sine of Incidence 50 from the Sines of Refraction 77 and 78, the remainders 27 and 28 flow that in fmall 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[±]th part of the whole Refraction of the mean refrangible Rays.

Whence they that are skilled in Opticks will eafily understand, that the breadth of the least circular space into which Object glasses of Telescopes can collect all forts of parallel Rays, is about the 27-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[±]/₇th part of the distance between the Object-glass and the Focus of the mean refrangible ones.

And if Rays of all forts, 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[±]th part of the distance of the Focus of the mean refrangible Rays from the Lens as the diflance 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 fame point fuffer in the Object-glasses of Telescopes and fuch like Glasses, be fo great as is here described, I contrived the following Experiment.

Exper. 16. The Lens which I used in the fecond and eighth Experiments, being placed fix Feet and an Inch distant from any Object, collected the Species of that Object by the mean refrangible Rays at the distance of fix Feet and an Inch from the Lens on the other fide. And therefore by the foregoing Rule it ought to collect the Species of that Object by the least refrangible Rays at the distance of fix Feet and $3\frac{1}{5}$ Inches from the Lens, and by the most refrangible frangible ones at the diffance of five Feet and $10\frac{1}{7}$ Inches from it: So that between the two places where these least and most refrangible Rays collect the Species, there may be the di-stance of about 5% Inches. For by that Rule, as fix Feet and an Inch (the diffance of the Lens from the lucid Object) is to twelve Feet and two Inches (the diffance of the lucid Object from the Focus of the mean refrangible Rays) that is, as one is to two, fo is the 27/th part of fix Feet and an Inch (the diffance between the Lens and the fame Focus) to the diffance between the Focus of the most refrangible Rays and the Focus of the leaft refrangible ones, which is therefore 5+7 Inches, that is very near-ly 5+7 Inches. Now to know whether this mea-fure was true, I repeated the fecond and eighth Experiment with coloured Light, which was lefs compounded than that I there made ufe fets compounded that that I there made the of: For I now feparated the heterogeneous Rays from one another by the method I de-fcribed in the eleventh Experiment, fo as to make a coloured Spectrum about twelve or fif-teen times longer than broad. This Spectrum I caft on a printed Book, and placing the above-mentioned Lens at the diffance of fix Feet and an Inch from this Spectrum to collect the Spe-cies of the illuminated Letters at the fame diflance on the other fide, 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 illumi-nated with indigo and violet appeared fo confufed

75

[76]

fufed and indiffinct, that I could not read them: Whereupon viewing the Prifm, I found it was full of Veins running from one end of the Glafs to the other; fo that the Refraction could not be regular. I took another Prifm therefore which was free from Veins, and inftead of the Letters I used two or three parallel black Lines a little broader than the stroaks of the Letters, and caffing the Colours upon these Lines in fuch 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 call the Species of the black Lines most diffinctly, 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 diffinct-ly. The violet was so faint and dark, that I could not difcern the Species of the Lines diflinctly by that Colour; and therefore confi-dering that the Prifm was made of a dark coloured Glafs inclining to green, I took another Prifm of clear white Glafs; but the Spectrum of Colours which this Prifm made had long white ftreams of faint Light fhooting out from both ends of the Colours, which made me conclude that fomething was amifs; and viewing the Prifm, 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 fuch bubbles, the Spectrum of Colours became free from those irregular Streams of Light, and was

[77]

7.5

was now fuch as I defired. But still I found the violet fo dark and faint, that I could fcarce fee 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 suffected therefore that this faint and dark Colour might be allayed by that fcattering Light which was refracted, and reflected irregularly, partly by fome very fmall bubbles in the Glaffes, and partly by the inequalities of their Polifh: which Light, tho' it was but little, yet it being of a white Colour, might fuffice to affect the Senfe fo ftrongly as to diffurb 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 confift of a fenfible mixture of heterogeneous Rays, but found it did not. Nor did the Refractions caufe any other fenfible Colour than violet to emerge out of this Light, as they would have done out of white Light, and by confequence out of this violet Light had it been fenfibly compounded with white Light. And therefore I concluded, that the reason why I could not fee the Species of the Lines diffinctly by this Colour, was only the darknefs of this Colour and thinnefs 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 di-Hances of the Colours in the Spectrum from one another, and noted the diffances of the Lens from the Foci of fuch Colours as caft the Species of the Lines diffinctly, and then confifidered

3

dered whether the difference of those diffances bear such proportion to $5\frac{1}{5}$ Inches, the greatest difference of the diffances which the Foci of the deepest red and violet ought to have from the Lens, as the diffance of the observed Colours from one another in the Spectrum bear to the greatest diffance of the deepest red and violet measured in the rectilinear fides 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 fenfible red, and the Colour in the Confine of green and blue, which at the rectilinear Sides of the Spectrum was diffant from it half the length of those Sides, the Focus where the Confine of green and blue caft the Species of the Lines diffinctly on the Paper, was nearer to the Lens than the Focus where the red caft those Lines diffinctly on it by about $2\frac{1}{2}$ or $2\frac{3}{4}$ Inches. For fometimes the Measures were a little greater, fometimes a little less, but feldom varied from one another above $\frac{1}{2}$ of an Inch. For it was very difficult to define the places of the Foci, without fome little Errors. Now if the Colours diffant half the length of the Image, (meafured at its rectilinear Sides) give $2\frac{1}{2}$ or $2\frac{3}{4}$ difference of the diffances of their Foci from the Lens, then the Colours diffant the whole length ought to give 5 or 5[±] Inches difference of those distances.

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

but

[79]

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, fo completing the femicircu-lar Ends into Circles when sides of the sh lar Ends into Circles, when either of the obferved Colours fell within those Circles, I meafured the diffance of that Colour from the femicircular end of the Spectrum, and fubducting half this diffance from the meafured difance of the two Colours, I took the remain-der for their corrected diffance; and in thefe Obfervations fet down this corrected diffance for the difference of the diffances 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 flewed) that Spectrum confifts contracted and reduced to phyfical Points, fo in that cafe this corrected diffance would be the real diffance of the two obferved Colours.

When therefore I farther observed the deepeff fensible red, and that blue whose corrected distance from it was π^2_{π} parts of the length of the rectilinear Sides of the Spectrum, the difference of the distances of their Foci from the Lens was about $3\frac{1}{2}$ Inches, and as 7 to 12 fo is $3\frac{1}{2}$ to $5\frac{1}{2}$.

When

80 7

When I observed the deepest feasible red, and that indigo whose corrected distance was $\frac{3}{7^{\frac{5}{2}}}$ 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 fo is $3^{\frac{2}{3}}$ to $5^{\frac{1}{2}}$.

When I observed the deepest fensible red, and that deep indigo whose corrected distance from one another was $\frac{1}{72}$ 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 fo is 4 to $5\frac{1}{7}$.

When I observed the deepest fensible red, and that part of the violet next the indigo, whose corrected distance from the red was $\frac{1}{2}$. or 5 of the length of the rectilinear Sides of the Spectrum, the difference of the diffances of their Foci from the Lens was about 4^{1/2} Inches, and as 5 to 6, fo is 4-2 to 53. For fometimes when the Lens was advantagioufly placed, fo that its Axis refpected the blue, and all things elfe were well ordered, and the Sun fhone clear, and I held my Eye very near to the Paper on which the Lens caft the Species of the Lines, I could fee pretty diffinctly the Species of those Lines by that part of the violet which was next the indigo; and fometimes I could fee 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 fee their Species diffinctly; and then the red appeared

peared much lefs diffinct than before. Wherefore I contrived to make the Spectrum of Colours fhorter than before, fo that both its ends might be hearer to the Axis of the Lens. And now its length was about 2⁺/₂ Inches and breadth about ⁺/₃ or ⁺/₂ of an Inch. Alfo inftead of the black Lines on which the Spectrum was caft, I made one black Line broader than thofe, that I might fee its Species more cafily; and this Line I divided by fhort crofs Lines into equal parts, for meafuring the diffances of the obferved Colours. And now I could fometimes fee the Species of this Line with its divifions almoft as far as the center of the femicircular violet end of the Spectrum, and made thefe farther Obfervations.

When I observed the deepest fensible red, and that part of the violet whole corrected distance from it was about $\frac{3}{7}$ parts of the rectilinear fides 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 $4\frac{2}{3}$ Inches, and as 8 to 9, fo are $4\frac{2}{3}$, $4\frac{3}{4}$, $4\frac{2}{3}$, to $5\frac{1}{4}$, $5\frac{1}{3\frac{3}{2}}$ respectively.

When I observed the deepest feasible red, and deepest feasible violet, (the corrected distance of which Colours when all things were ordered to the best advantage, and the Sun scheme very clear, was about $\frac{1}{12}$ or $\frac{1}{12}$ 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 formetimes $4\frac{3}{4}$ fometimes $5\frac{1}{4}$, and for the most part 5 In-G 82

ches or thereabouts: and as II to 12 or 15 to

cnes or thereabouts, and as if to iz or if to 16, fo is 5 Inches to $5\frac{1}{2}$ or $5\frac{1}{3}$ Inches. And by this progreffion of Experiments I fa-tisfied my felf, that had the Light at the very ends of the Spectrum been flrong enough to make the Species of the black Lines appear plainly on the Paper, the Focus of the deepeft 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 feveral forts of Rays, hold the fame proportion to one another in the fmalleft Refractions which they do in the greatest.

My progrefs in making this nice and trouble-fome Experiment I have fet down more at large, that they that shall try it after me may be aware of the circumfpection requifite to make it fucceed well. And if they cannot make it fucceed fo well as I did, they may notwithftand-ing collect by the proportion of the diftance of the Colours of the Spectrum, to the difference of the diffances of their Foci from the Lens, what would be the fuccefs in the more diftant Colours by a better trial. And yet if they use a broader Lens than I did, and fix it to a long Itraight Staff by means of which it may be rea-dily and truly directed to the Colour whofe Fo-cus is defired, I queflion not but the Experi-ment will fucceed 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, caft their Species lefs diffinctly on

2

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

83

Now by what has been faid, it's certain that the Rays which differ in Refrangibility do not converge to the fame Focus, but if they flow from a lucid point, as far from the Lens on one fide as their Foci are on the other, the Focus of the most refrangible Rays shall be nearer to the Lens than that of the leaft refrangible, by above the fourteenth part of the whole diffance: and if they flow from a lucid point, fo 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 diftance from it. And the diameter of the Circle in the middle fpace between those two Foci which they illuminate when they fall there on any Plane, perpendicular to the Axis (which Circle is the leaft into which they can all be ga-Circle is the leaft into which they can all be ga-thered) is about the 55th part of the diameter of the Aperture of the Glafs. So that 'tis a won-der that Telefcopes reprefent Objects fo diflinct as they do. But were all the Rays of Light equally refrangible, the Error arifing only from the fphericalnefs of the Figures of Glaffes would be many hundred times lefs. For if the Object-glafs of a Telefcope be Plano-convex, and the Plane fide be turned towards the Object, and the diameter of the Sphere whereof this Glafs is a fegment be called D, and the femidiame-ter of the Aperture of the Glafs be called S, and the Sine of Incidence out of Glafs into Air, G_2 be G 2 be

[84]

be to the Sine of Refraction as I to R: the Rays which come parallel to the Axis of the Glafs, fhall in the place where the Image of the Object is most distinctly made, be feattered all over a little Circle whose diameter is $\frac{R q}{1q} \times \frac{S cab}{D q uad}$, 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 inconfiderable. As for inflance, 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 fide of the Glafs is ground, be 100 Feet or 1200 Inches, and S the femidiameter of the little Circle (that is $\frac{Ra \times S cab}{1q \times D q uad}$ will

be $\frac{31 \times 31 \times 8}{20 \times 20 \times 1200 \times 1200}$ (or $\frac{661}{7200000}$ 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 $\frac{961}{7200000}$ to $\frac{4}{55}$ that is as I to 5449: and therefore being in comparison fo very little, deferves not to be confidered.

But you will fay, if the Errors cauled by the different Refrangibility be fo very great, how comes it to pais that Objects appear through Telefcopes fo diffinct as they do? I anfwer, 'tis becaufe

becaufe the erring Rays are not fcattered uni-formly over all that circular fpace, but collect-ed infinitely more denfely 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, fo as at the circumference to become infinitely rare; and by reafon of their rarity are not firong 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 A C, and let BF G be a finaller Circle concentrick to the former, cutting with its circumference the Diameter A C in B, and bifect AC in N, and by my reckoning the Denfity of the Light in any place B will be to its Denfity in N, as AB to BC; and the whole Light with-in the leffer Circle BFG, will be to the whole Light within the greater A E D, as the Excels of the Square of A C above the Square of A B, is to the Square of A C. As if BC be the fifth part of AC, the Light will be four times den-fer in B than in N, and the whole Light within the lefs Circle, will be to the whole Light within the greater, as nine to twenty five. Whence it's evident that the Light within the lefs Cir-cle, mult firike the Senfe much more ftrongly, 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 prifmatick Colours are the yellow and orange. These affect the Senses more strongly than all the rest together, and next to G_3 these 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, fo that these compared with the stronger Colours are little to be regarded. The Images of Objects are therefore to be pla-ced, 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 brighteft 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 Glafs and Cryflal for optical Uses is to be measured. Let us therefore place the Image of the Object in the Focus of thefe Rays, and all the yellow and orange will fall within a Circle, whole diameter is about the 250th part of the diameter of the Aperture of the Glafs. 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 thefe two Colours will fall within the fame Circle, and two fifth parts will fall without it round about; and that which falls without will be fpread through almost as much more fpace as that which falls within, and fo in the grofs 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

[87]

three quarters without, and that which falls without will be fpread through about four or five times more fpace than that which falls with-in; and fo in the grofs 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 ra-rer, becaufe the deep red in the end of the Spectrum of Colours made by a Prifm is very thin and rare, and the willow green is fomething rarer than the orange and yellow. The Light of these Colours therefore being to very much rarer than that within the Circle, will fcarce affect the Senfe, especially fince the deep red and willow green of this Light, are much darker Colours than the reft. And for the fame reafon the blue and violet being much darker Colours than thefe, and much more rarified, may be neglected. For the denfe and bright Light of the Circle, will obfcure the rare and weak Light of thefe dark Colours round about it, and render them almost infensible. The fenfible Image of a lucid point is therefore fcarce broader than a Circle whofe diameter is the 250th part of the diameter of the Aperture of the Object-glafs of a good Telefcope, or not much broader, if you except a faint and dark mif-ty Light round about it, which a Spectator will fcarce regard. And therefore in a Telefcope whole 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 fearce above. And this answers well to G 4 expe-

[88]

experience: For fome Aftronomers have found the Diameters of the fix'd Stars, in Telefcopes of between 20 and 60 Feet in length, to be about 5" or 6", or at molt 8" or 10" in diameter. But if the Eye-Glafs be tincted faintly with the fmoke of a Lamp or Torch, to obfcure the Light of the Star, the fainter Light in the circumference of the Star ceafes to be vifible, and the Star (if the Glafs be fufficiently foiled with fmoke) appears fomething more like a mathematical Point. And for the fame reafon, the enormous part of the Light in the circumference of every lucid Point ought to be lefs differnible in fhorter Telefcopes than in longer, becaufe the fhorter transmit lefs Light to the Eye.

Now that the fix'd Stars, by reafon of their immenfe diffance, appear like Points, unlefs fo far as their Light is dilated by Refraction, may appear from hence; that when the Moon paffes over them and eclipfes them, their Light vanishes, not gradually like that of the Planets, but all at once; and in the end of the Eclipfe it returns into Sight all at once, or certainly in lefs time than the fecond 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.

lels time than the lecond 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 fensible 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,

[89]

Rays, its breadth in an 100 Foot Telefcope whofe aperture is 4 Inches would be but $\frac{961}{72000000}$ parts of an Inch, as is manifelt by the foregoing computation. And therefore in this cafe the greateft Errors arifing from the fpherical Figure of the Glafs, would be to the greateft fenfible Errors arifing from the different Refrangibility of the Rays as $\frac{961}{72000000}$ to $\frac{4}{250}$ at moft, that is only as 1 to 1200. And this fufficiently flews that it is not the fpherical Figures of Glaffes but the different Refrangibility of the Rays which hinders the perfection of Telefcopes.

There is another Argument by which it may appear that the different Refrangibility of Rays, is the true caule of the imperfection of Tele-fcopes. For the Errors of the Rays arifing from the fpherical Figures of Object-glaffes, are as the Cubes of the Apertures of Object-gianes, are glaffes; and thence to make Telescopes of va-rious lengths, magnify with equal diffinctness, the Apertures of the Object-glaffes, 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 arifing from the different Refrangibilty, are as the Apertures of the Object-glaffes, and thence to make Telescopes of various lengths, magnify with equal diffinctnefs, their Apertures and Charges ought to be as the fquare Roots of their lengths; and this answers to experience, as is well known. For inflance, a Telescope of 64 Feet in length, with an Aperture

ture of $2\frac{1}{7}$ Inches, magnifies about 120 times, with as much diffinctness as one of a Foot in length, with $\frac{1}{7}$ of an Inch aperture, magnifies 15 times.

Now were it not for this different Refrangi-bility 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 outfides AGD and CHF, and alike concave on the infides 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 con-fequence out of Glass into Water, as I to K: and let the diameter of the Sphere to which the convex fides AGD and CHF are ground be D, and the diameter of the Sphere to which the concave fides 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 fides of the Glaffes, will very much correct the Errors of the Refractions on the convex fides, fo far as they arife from the fphericalnefs of the Figure. And by this means might Telescopes be brought to sufficient per-fection, were it not for the different Refrangi-bility of feveral forts of Rays. But by reason of this different Refrangibility, I do not yet fee any other means of improving Telescopes by Refractions alone than that of increasing their lengths, for which end the late Contrivance of Hugenius

Hugenius feems well accommodated. For very long Tubes are cumberfome, and fearce to be readily managed, and by reafon of their length are very apt to bend, and flake by bending fo as to caufe a continual trembling in the Objects, whereby it becomes difficult to fee them diffinctly: whereas by his contrivance the Glaffes are readily manageable, and the Objectglafs being fix'd upon a ftrong upright Pole becomes more fleady.

Seeing therefore the Improvement of Tele-fcopes of given lengths by Refractions is defperate; I contrived heretofore a Perfpective 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 confequence the length of the Inftrument about fix Inches and a quarter. The Eye-glafs was Plano-con-vex, and the diameter of the Sphere to which the convex fide was ground was about 1 of an Inch, or a little lefs, and by confequence it magnified between 30 and 40 times. By ano-ther 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 Eyeglafs and the Eye, and perforated in the mid-dle with a little round hole for the Rays to pafs through to the Eye. For this Circle by being placed here, flopp'd much of the erroneous Light, which otherwife would have diffurbed the

the Vifion. By comparing it with a pretty good Perfpective of four Feet in length, made with a concave Eye-glafs, I could read at a greater diftance with my own Inftrument than with the Glafs. Yet Objects appeared much darker in it than in the Glafs, and that partly becaufe more Light was loft by Reflexion in the Metal, than by Refraction in the Glafs, and partly be-caufe my Inftrument was overcharged. Had it caufe my Instrument was overcharged. Had it magnified but 30 or 25 times it would have made the Object appear more brisk and plea-fant. 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 to good as at the first. For the concave has been divers times tarnished and cleared again, by rubbing it with very foft Leather. When I made thefe, an Artift in London undertook to imitate it; but using another way of polishing them than I did, he fell much fhort of what I had attained to, as I afterwards underftood by difcourfing the under Workman he had em-ployed. The Polifh I ufed was in this man-ner. I had two round Copper Plates each fix Inches in diameter, the one convex the o-ther concave, ground very true to one another. On the convex I ground the Object-Metal or Concave which was to be polifh'd, till it had taken the Figure of the Convex and was ready for a Polifh. Then I pitched over the convex very thinly, by dropping melted Pitch upon it and warming it to keep the Pitch foft, whilft I ground it with the concave Copper wetted to make it fpread 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 1 could. Then I took Putty which I had made very fine by wafhing it from all its groffer 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 noife; 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 frefh Putty upon the Pitch and ground it again till it dad done making a noife, and afterwards ground the Object-Metal upon it as before. And this the Object-Metal upon it as before. And this Work I repeated till the Metal was polifhed, grinding it the last time with all my firength for a good while together, and frequently breathing upon the Pitch to keep it moist with-out laying on any more fresh Putty. The Ob-ject-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 beft, and ground the other again to fee if I could make it better than that which I kept. And make it better than that which I kept. And thus by many Trials I learn'd the way of po-lifhing, till I made those two reflecting Perspe-ctives I spake of above. For this Art of po-lishing will be better learn'd by repeated Pra-ctice 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 Parti-cles of the Putty were not by this means made 10

94

to flick 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 becaufe Metal is more difficult to polifh than Glafs, and is afterwards very apt to be fpoiled by tarnifhing and reflects not fo much Light as Glafs quick-filver'd over does: I would propound to use instead of the Metal, a Glass ground concave on the forefide, and as much convex on the back fide, and quick filver'd over on the convex fide. The Glafs must be every where of the fame thickness exactly. Otherwife it will make Objects look colour'd and indiffinct. By fuch a Glafs I tried about five or fix Years ago to make a reflecting Telescope of four Feet in length to magnify about 150 times, and I fatisfied my felf that there wants nothing but a good Artist to bring the Defign to perfection. For the Glass being wrought by one of our London Artists after such a manner as they grind Glasses for Telescopes, the' it seemed as well wrought as the object-glaffes use to be, yet when it was quick-filver'd, the Reflexion dif-covered innumerable Inequalities all over the covered innumerable Inequalities all over the Glafs. And by reafon of thefe Inequalities, Ob-jects appeared indiffinct in this Inftrument. For the Errors of reflected Rays caufed by any In-equality of the Glafs, are about fix times great-er than the Errors of refracted Rays caufed by the like Inequalities. Yet by this Experiment I fatisfied my felf that the Reflexion on the concave fide of the Glafs, which I feared would diffurb the Vifion, did no fenfible prejudice to it, and by confequence that nothing is wanting ťO

[95]

to perfect these Telescopes, but good Work-men who can grind and polish Glasses truly spherical. An Object-glass of a fourteen Foor Telescope, made by an Artificer at London, I once mended confiderably, by grinding it on Pitch with Putty, and leaning very easily on it in the grinding, left the Putty should for atch it. Whether this way may not do well enough for polishing these reflecting Glasses, I have not yet triad. But he that shall try cither this on any tried. But he that shall try either this or any other way of polifhing which he may think bet-ter, may do well to make his Glaffes ready for polifhing by grinding them without that vio-lence, wherewith our London Workmen prefs their Glaffes in grinding. For by fuch violent preffure, Glaffes are apt to bend a little in the grinding, and fuch bending will certainly fpoil their Figure. To recommend therefore the confideration of thefe reflecting Glaffes, to fuch Artifts as are curious in figuring Glaffes, I fhall defcribe this optical Inflrument in the following Proposition.

$\mathcal{P} R O \mathcal{P}$. VIII. PROB. II.

To Shorten Telefcopes.

ETABDC [in Fig. 29.] reprefent a Glafs fpherically concave on the forefide AB, and as much convex on the backfide CD, fo that it be every where of an equal thicknefs. Let it not be thicker on one fide than on the other, left it make Objects appear colour'd and indi[96]

indiffinct, and let it be very truly wrought and quick filver'd over on the back fide; and fet in the Tube VXYZ which must be very black within. Let EFG 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 Brafs or Iron F G K, to the end of which made flat it is cemented. Let this Prifm be rectangular at E, and let the other two Angles at F and G be accurately equal to each other, and by confequence equal to half right ones, and let the plane fides FE and GE be fquare, and by confequence the third fide FG a re-Atangular Parallelogram, whose length is to its Etangular Parallelogram, whole length is to its breadth in a fubduplicate proportion of two to one. Let it be fo placed in the Tube, that the Axis of the Speculum may pass through the middle of the fquare fide E F perpendicularly, and by confequence through the middle of the fide FG at an Angle of 45 Degrees, and let the fide EF be turned towards the Speculum, and the diffance of this Prifm from the Speculum be fuch that the Rays of the Light PQ, RS, Sc. which are incident upon the Speculum in Lines parallel to the Axis thereof, may enter the Prifm parallel to the Axis thereof, may enter the Prifm at the fide EF, and be reflected by the fide FG, and thence go out of it through the fide GE, to the point T which muft be the com-mon Focus of the Speculum ABDC, and of a Plano-convex Eye-glafs H, through which those Rays must pass to the Eye. And let the Rays at their coming out of the Glais pais through a fmall round hole, or aperture made in a little plate of Lead, Brafs or Silver, wherewith the

the Glass is to be covered, which hole must be no bigger than is neceffary for Light enough to pais through. For fo it will render the Ob-ject diffinct, the Plate in which 'tis made intercepting all the erroneous part of the Light which comes from the verges of the Speculum AB. Such an Inftrument well made, if it be fix Foot long, (reckoning the length from the Speculum to the Prifm, and thence to the Fo-cus T) will bear an aperture of fix 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 Inftrument be made longer or fhorter, the aper-ture muft be in proportion as the Cube of the Iquare-fquare Root of the length, and the mag-nifying 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 Prifm EFG mult be no bigger than is neceffary, and its back fide F G must not be quick-filver'd over. For without quickfilver it will reflect all the Light incident on it from the Speculum.

97

In this Inftrument the Object will be inverted, but may be erected by making the fquare fides EF and EG of the Prifm EFG not plane but fpherically convex, that the Rays may crofs as well before they come at it as afterwards between it and the Eye glafs. If it be defired that the Inftrument bear a larger aperture, that H may may be also done by composing the Speculum of two Glasses with Water between them.

If the Theory of making Telefcopes could at length be fully brought into practice, yet there would be certain Bounds beyond which Telefcopes could not perform. For the Air through which we look upon the Stars, is in a perpe-tual Tremor; as may be feen by the tremulous Motion of Shadows call from high Towers, and by the twinkling of the fix'd Stars. But thefe Stars do not twinkle when view'd through Telescopes which have large apertures. For the Rays of Light which pais through divers parts of the aperture, tremble each of them a-part, and by means of their various and fome-times contrary Tremors, fall at one and the fame time upon different points in the bottom of the Eye, and their trembling Motions are too quick and confused to be perceived feverally. And all these illuminated Points conflictute one broad lucid Point, composed of those many trembling Points confusedly and intenfibly mixed with one another by very fhort and fwift Tremors, and thereby caufe 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 thort ones can do, but they cannot be fo formed as to take away that confusion of the Rays which arifes from the Tremors of the Atmosphere. The only remedy is a most ferene and quiet Air, fuch as may perhaps be found on the tops of the higheft Mountains above the groffer Clouds.

THE












FIRST BOOK O F

THE



粂瘚欦蚖蓙龗嫾籊籡籡薞薞薞嫾嫾嫙嫾嫾嫾嫾嫾嫾嫾嫾嫾

PART II.

ゲテティングンジンがない、「「」」

PROP. I. THEOR. I.

The Phænomena of Colours in refracted or refletted 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. I.



R if the Sun fline into a very dark Chamber through an oblong hole F, [in Fig. 1.] whole breadth is the fixth or

eigth part of an Inch, or fomething lefs; and his beam F H do afterwards pass sirst through a H 2 very

[IOO]

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 G I, and placed at the diffance 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 transmitted through the hole H, fall afterwards upon a white Paper pt, placed after that hole H, at the diffance 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, whole 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, whilf 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 outmost in the Confine of the Shadow towards p, and any one of them as well as red may become outmost in the Confine of the Shadow towards t, and any one of them may also bor-der upon the Shadow made within the Colours by the Obstacle R intercepting fome intermediate part of the Light; and, lastly, 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 fucceed; provided the Light be not so far diminiss. To procure a Prism of folid 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 falt 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, paffed first through the Prifm A B C placed at the hole, and then through a Lens P T fomething more than four Inches broad, and about eight Feet distant from the Prifm, 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 reprefented 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 Prifin, became very much inclined to the Light as 'tis reprefented in the Pofitions de and $\delta_{\rm E}$; the fame Light in the one cafe appeared yellow and red, in the other blue. H 3 Here one and the fame part of the Light in one and the fame place, according to the various Inclinations of the Paper, appeared in one cafe white, in another yellow or red, in a third blue, whilft the Confine of Light and Shadow, and the Refractions of the Prifm in all these cafes remained the fame.

Exper. 3. Such another Experiment may be more eafily tried as follows. Let a broad beam of the Sun's Light coming into a dark Cham-ber through a hole in the Window-fhut be re-fracted by a large Prifm A B C, [in Fig. 3.] whole refracting Angle C is more than 60 Degrees, and fo foon as it comes out of the Prifm let it fall upon the white Paper DE glewed upon a fliff Plane; and this Light, when the Paper is perpendicular to it, as 'tis reprefented in DE, will appear perfectly white upon the Paper, but when the Paper is very much inclin'd to it in fuch a manner as to keep always parallel to the Axis of the Prifm, the whitenefs 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 pofture de, or into blue and violet, as in the pofture $\delta \epsilon$. And if the Light before it fall upon the Paper be twice refracted the fame way by two parallel Prifms, thefe 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 fame 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 Caufe? I anfwer, That the Paper in the pofture de, being more oblique to the more refrangible Rays than to the lefs refrangible ones, is more firongly illuminated by the latter than by the former, and therefore the lefs refrangible Rays are predominant in the reflected Light. And whereever they are predominant in any Light they tinge it with red or yellow, as may in fome meafure appear by the first Proposition of the first Book, and will more fully appear hereafter. And the contrary happens in the pofture of the Paper δe , 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 varioufly, without any refpect to any Confine of Shadow. If fuch a Bubble be cover'd with a concave Glafs, to keep it from being agitated by any Wind or Motion of the Air, the Colours will flowly and regularly change their Situation, even whilft the Eye, and the Bubble, and all Bodies which emit any Light, or caft any Shadow, remain unmoved. And therefore their Colours arife from fome regular H a [104]

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

To thefe 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 Prifms tied together in the form of a Parallelopipede, became totally of one uniform yellow or red Colour, at its emerging out of the Prifms. Here, in the production of these Colours, the Confine of Shadow can have nothing to de Confine of Shadow can have nothing to do. For the Light changes from white to yellow, orange and red fucceflively, without any alte-ration of the Confine of Shadow : And at both edges of the emerging Light where the con-trary Confines of Shadow ought to produce different Effects, the Colour is one and the fame, 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 fame 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 perpetual-ly without any change of Colour, fuch as the Confine of Shadow is vulgarly fuppofed to work in refracted Light after its Emergence. Nei-ther can these Colours arise from any new Modifications of the Light by Refractions, because they change fucceflively from white to yellow, orange and red, while the Refractions remain the fame, and also because the Refractions are made contrary ways by parallel Superficies which deftroy

[105]

deftroy one anothers Effects. They arife not therefore from any Modifications of Light made by Refractions and Shadows, but have fome other Caufe. What that Caufe is we fhewed above in this tenth Experiment, and need not here repeat it.

There is yet another material circumftance of this Experiment. For this emerging Light be-ing by a third Prifm HIK [in *Fig.* 22. *Part* 1.] refracted towards the Paper PT, and there paint-ing the ufual Colours of the Prifm, red, yellow, green, blue, violet: If thefe Colours arole from the Refractions of that Prifm modifying the Light, they would not be in the Light before its Incidence on that Prifm. And yet in that Experiment we found that when by turning the two first Prifms 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 fame red Co-lour before its Incidence on the third Prifm. And in general we find by other Experiments that when the Rays which differ in Refrangibility are feparated from one another, and any one fort of them is confidered 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 no-thing elfe than Modifications of Light caufed by Refractions, and Reflexions, and Shadows. This unchangeablenefs of Colour I am now to defcribe in the following Proposition.

 $\mathcal{P} R O \mathcal{P}.$

[106]

PROP.II. THEOR.II.

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

N 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 Successfion perpetually varying. So that there appeared as many degrees of Colours, as there were forts of Rays differing in Refrangibility.

Exper. 5. Now that these Colours could not be changed by Refraction, I knew by refracting with a Prism fometimes one very little part of this Light, fometimes 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 rcd Light was refracted, it remained totally of the fame 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 fame red entirely as at firft. The like conflancy and immutability I found alfo in the blue, green, and other Colours. So alfo if I looked through a Prifm upon any Body illu-minated with any part of this homogeneal Light, as in the fourteenth Experiment of the firft Book is deferibed; I could not perceive any new Co-lour generated this way. All Bodies illumina-ted with compound Light appear through Prifms confufed (as was faid above) and tinged with various new Colours, but thofe illuminated with homogeneal Light appeared through Prifms neither lefs diffinct, nor otherwife colour'd, than when viewed with the naked Eves. Their than when viewed with the naked Eyes. Their than when viewed with the naked Eyes. Their Colours were not in the leaft changed by the Refraction of the interpofed Prifm. I fpeak here of a fenfible change of Colour: For the Light which I here call homogeneal, being not abfolutely homogeneal, there ought to arife fome little change of Colour from its hetero-geneity. But if that heterogeneity was fo lit-tle as it might be made by the faid Experiments of the fourth Proposition, that change was not fenfible, and therefore in Experiments, where Senfe is Judge, ought to be accounted none at all at all.

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, Asses, red Lead, Orpiment, Indigo, Bife, Gold, Silver, Copper, Grass, blue Flowers, Violets, Bubbles of Water tinged with various Colours, Peacock's Feathers, the Tincture of Lignum Nepbri[108]

Nephriticum, and fuch like, in red homogeneal Light appeared totally red, in blue Light totally blue, in green Light totally green, and fo of other Colours. In the homogeneal Light of any Colour they all appeared totally of that fame Colour, with this only difference, that fome of them reflected that Light more ftrongly, others more faintly. I never yet found any Body which by reflecting homogeneal Light could fenfibly change its Colour.

From all which it is manifelt, that if the Sun's Light confifted of but one fort of Rays, there would be but one Colour in the whole World, nor would it be poffible to produce any new Colour by Reflexions and Refractions, and by confequence that the variety of Colours depends upon the composition of Light.

$\mathcal{D} E F I N I T I O N.$

H E homogeneal Light and Rays which appear red, or rather make Objects appear fo, I call Rubrific or Red-making; thofe which make Objects appear yellow, green, blue and violet, I call Yellow-making, Green-making, Blue-making, Violet-making, and fo of the reft. And if at any time I fpeak of Light and Rays as coloured or endued with Colours, I would be underftood to fpeak not philofophically and properly, but groffly, and accordingly to fuch Conceptions as vulgar People in feeing all thefe Experiments would be apt to frame. For the Rays to fpeak properly are not coloured. In them there is nothing elfe than a certain certain power and difpolition to flir up a Senfation of this or that Colour. For as Sound in a Bell or mufical String or other founding Body, is nothing but a trembling Motion, and in the Air nothing but that Motion propagated from the Object, and in the Senforium 'tis a Senfe of that Motion under the form of Sound; fo Colours in the Object are nothing but a Difpolition to reflect this or that fort of Rays more copioully than the reft; in the Rays they are nothing but their Difpolitions to propagate this or that Motion into the Senforium, and in the Senforium they are Senfations of those Motions under the forms of Colours.

EXPRESSION CONCERNESSION (CONCERNESSION)

$\mathcal{P} R O \mathcal{P}$. III. Prob. I.

To define the Refrangibility of the feveral forts of homogeneal Light answering to the several Colours.

OR determining this Problem I made the following Experiment. *Exper.* 7. When I had caufed the rectili-

Exper. 7. When I had caufed the rectilinear fides AF, GM, [in Fig. 4.] of the Spectrum of Colours made by the Prifm to be diffinctly defined, as in the fifth Experiment of the first Part is described, there were found in it all the homogeneal Colours in the fame order and fituation one among another as in the Spectrum of fimple Light, described in the fourth Proposition of that Part. For the Circles of which the Spectrum of compound Light **PT**

4

[IIO]

PT is composed, and which in the middle parts of the Spectrum interfere and are intermixed with one another, are not intermixed in their outmost parts where they touch those rectilinear fides A F and G M. And therefore in those rectilinear fides when diffinctly defined, there is no new Colour generated by Refraetion. I observed also, that if any where be-tween the two outmost Circles T M F and **P**GA a right Line, as γ δ , was cross to the Spectrum, fo as at both ends to fall perpendicularly upon its rectilinear fides, there appeared one and the fame Colour and degree of Co-lour 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 fo that the Spectrum might fall upon this delineated Figure, and agree with it exactly, whillt an Affiftant whole Eyes for diftinguishing Colours were more critical than mine, did by right Lines $\alpha \beta$, $\gamma \delta$, $\varepsilon \zeta$, $\Im c$. drawn crofs 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 indigo $\iota \lambda \mu \kappa$, and of the violet λ G A μ . And this Operation being divers times repeated both in the fame and in feveral Papers, I found that the Observations agreed well enough with one another, and that the rectilinear fides MG and FA were by the faid crofs Lines divided after the manner of a mufical Chord. Let G M be produced to X, that M X may be equal to G M, and conceive GX, 8

GX, λX , iX, ηX , ϵX , γX , αX , M X, to be in proportion to one another, as the numbers, **i**, $\frac{s}{2}$, $\frac{1}{3}$, \frac

Now these Intervals or Spaces subtending the differences of the Refractions of the Rays going to the limits of those Colours, that is, to the Points M, α , γ , ε , η , ι , λ , G, may without any fenfible Error be accounted proportional to the differences of the Sines of Refraction of those Rays having one common Sine of Incidence, and therefore fince the common Sine of Incidence of the most and least refrangible Rays out of Glass into Air was (by a method deferibed 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 G M is divided by those Inter-Rays out of Glafs 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 lefs than 50 to 77, but they varied from one another according to all intermediate proportions. And the Sines of the Incidences of the greenmaking

making Rays were to the Sines of their Refractions in all proportions from that of 50 to $77\frac{1}{37}$ unto that of 50 to $77\frac{1}{37}$. And by the like limits abovementioned were the Refractions of the Rays belonging to the reft of the Colours defined, the Sines of the red-making Rays extending from 77 to $77\frac{1}{3}$, those of the orange-making from $77\frac{1}{3}$ to $77\frac{1}{3}$, those of the yellow-making from $77\frac{1}{3}$ to $77\frac{1}{3}$, those of the green making from $77\frac{1}{3}$ to $77\frac{1}{3}$, those of the blue making from $77\frac{1}{3}$ to $77\frac{1}{3}$, those of the indigo-making from $77\frac{1}{3}$ to $77\frac{1}{3}$, and those of the violet from $77\frac{1}{3}$ 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 feveral contiguous refracting Mediums as through Water and Glafs, 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 fo corrected, that it emergeth in Lines parallel to thole in which it was incident, continues ever after to be white. But if the emergent Rays be inclined to the incident, the whitenefs of the emerging Light will by degrees in paffing on from the place of Emergence, become tinged in its edges with Colours. This I tryed by refracting Light with Prifms of Glafs placed within a prifmatick Veffel of Water. Now those Colours argue a diverging

verging and feparation 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 whitenefs argues, that in like Incidences of the Rays there is no fuch feparation of the emerging Rays, and by confequence no inequality of their whole Refractions. Whence I feem to gather the two following Theorems.

1. The Exceffes of the Sines of Refraction of feveral forts of Rays above their common Sine of Incidence when the Refractions are made out of divers denfer Mediums immediately into one and the fame rarer Medium, fuppofe 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 fame fort 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 fecond Medium.

By the first Theorem the Refractions of the Rays of every fort made out of any Medium into Air are known by having the Refraction of the Rays of any one fort. As for instance, if the Refractions of the Rays of every fort out of Rain-water into Air be defired, let the common Sine of Incidence out of Glass into Air be I subducted

II4

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 Glafs into Air be to its Sine of Refraction as 20 to 31, and the Sine of Incidence of the fame 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 Glafs 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

by Refractions. For to do this, there is nothing elfe requifite 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 deferibed in these Books, beside fome others less necessary to the Argument; and by the fuccess 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 fufficient 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 assistant and proportion.

ÅLELAKKKELEKKKKKKKKE

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 I 2. fcries

feries of unmixed prifmatick Colours lies be-tween 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 Prifm, remains un-changed, that of the other is changed and re-folved into its component Colours red and yel-low. And after the fame manner other neigh-houring homogeneal Colours may compound bouring homogeneal Colours may compound new Colours, like the intermediate homogeneal ones, as yellow and green, the Colour be-tween them both, and afterwards, if blue be added, there will be made a green the middle 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 intermedi-ate green equally towards themfelves in Com-position, 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 middle Colour. To this mix'd green there may be farther added fome red and violet, and yet the green will not prefently ceafe 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 over-come and turned into whiteness, or fome other Colour. So if to the Colour of any homoge-neal Light, the Sun's white Light composed of all forts 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

[117]

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

$\mathcal{P}RO\mathcal{P}$. V. Theor. IV.

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

The Proof by Experiments.

Exper. 9. HE Sun fhining into a dark Chamber through a little round hole in the Window-fhut, and his Light being there refracted by a Prifin to caft his coloured Image PT [in *Fig. 5.*] upon the oppofite Wall: I held a white Paper V to that Image in fuch 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 paffage from the Prifm to the Spectrum. And I found that when the Paper was held nearer to any Colour than to the reft, it appeared of that Colour to which it approached neareft; but when it was equally or almost equally diftant from all the Colours, fo that it might be equally illuminated by them all it appeared white. And in this laft fituation of the Paper, if fome 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 Pa-per 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; fo that if it had been either alone (the reft of the Light being intercepted) or if it had a-bounded 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 reft 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, whilft they are propagated from thence through the Air, do perpetually retain their proper Co-lours, becaule wherever they fall upon the Eyes of any Spectator, they make the feveral parts of the Spectrum to appear under their proper Co-lours. They retain therefore their proper Co-lours when they fall upon the Paper V, and fo by the confusion and perfect mixture of those Colours compound the whiteness of the Light reflected from thence reflected from thence.

Exper. 10. Let that Spectrum or folar Image PT. [in Fig. 6.] fall now upon the Lens MN above four Inches broad, and about fix Feet diitant from the Prifm ABC, and to figured that it may caufe the coloured Light which divergeth from the Prifm to converge and meet again

at

at its Focus G, about fix or eight Feet diffant from the Lens, and there to fall perpendicular-ly upon a white Paper D E. And if you move this Paper to and fro, you will perceive that near the Lens, as at de, the whole folar Image (fuppofe at p t) will appear upon it intenfely coloured after the manner above explained, and that by receding from the Lens there Coloured that by receding from the Lens thole Coloursthat by receding from the Lens thole 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 white-nefs, the whole Light appearing now upon the Paper like a little white Circle. And after-wards by receding farther from the Lens, the Rays which before converged will now crofs one another in the Focus G, and diverge from thence, and thereby make the Colours to ap-pear again, but yet in a contrary order; fup-pofe at $\delta \epsilon$, where the red t is now above which before was below, and the violet p is below before was below, and the violet p is below which before was above.

Let us now flop the Paper at the Focus G where the Light appears totally white and circular, and let us confider its whitenefs. I fay, 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 I 4 reffore reftore the whitenefs. 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 pafs they will fall upon this compounded orange, and together with it decompound a white. So alfo 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 pafs will fall upon this green, and together with it decompound a white. And that in this Composition of white the feveral Rays do not fuffer 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 thefe Arguments.

farther appear by these Arguments. If the Paper be placed beyond the Focus G, suppose at δ_{ϵ} , 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 feveral forts 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 Prifm HIK, and by the Refraction of that Prifm be translated to the place rv, 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 ftopp'd and let pais by turns, the red at r will accordingly difappear and return as often, but the violet at v will not thereby fuffer any Change. And fo by ftopping and letting pais alternately the blue at the Lens, the blue at r will accordingly difappear and return, without any change made in the red at r. The red therefore depends on one fort of Rays, and the blue on another fort, which in the Focus G where they are commix'd do not act on one another. And there is the fame reafon of the other Colours.

I confidered 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 fort of them more copioufly than the other fort, and by that means the reflected Light would be tinged in that Focus with the Colour of the pre-dominant 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 feverally endued there with a difpolition to ftrike the Senfe with the perception of white, then they could never lofe their whitenefs by fuch Reflexions. I in-clined therefore the Paper to the Rays very ob-liquely, as in the fecond Experiment of this Book, that the most refrangible Rays might be more copiously reflected than the rest, and the whiteness at length changed fucceflively into blue, indigo and violet. Then I inclined it 05.2 the

the contrary way, that the leaft refrangible Rays might be more copious in the reflected Light than the reft, and the whiteness turned fucceffively to yellow, orange and red. Laftly, I made an Infirument X Y in fashion

of a Comb, whole Teeth being in number fixteen were about an Inch and an half broad, and the Intervals of the Teeth about two Inches wide. Then by interposing fucceflively the Teeth of this Inftrument near the Lens, I intercepted part of the Colours by the interpofed Tooth, whill the reft of them went on through the interval of the Teeth to the Paper DE, and there painted a round folar Image. But the Paper I had first placed fo, that the Image might appear white as often as the Comb was taken away; and then the Comb being as was faid interpofed, that whiteness by reason of the inter-cepted 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 fo, that in the paffing of every Tooth over the Lens all thefe Colours, red, yellow, green, blue and purple, did always fucceed one another. I caufed therefore all the Teeth to pass fucceflively over the Lens, and when the Motion was flow, there appeared a perpetual fucceffion of the Colours upon the Paper: But if I fo much accelerated the Motion, that the Colours by reafon of their quick fucceffion could not be diffinguished from one another, the appearance of the fingle Colours ceafed. There was no red, no yellow, no green,

green, no blue, nor purple to be feen any lon-ger, but from a confusion of them all there a-rofe one uniform white Colour. Of the Light which now by the mixture of all the Colours ap-peared 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 re-tains its proper Colour till it thrike the Senfori-um. If the Impression follow one another um. If the Impressions follow one another flowly, fo that they may be feverally perceived, there is made a diffinct Senfation of all the Colours one after another in a continual fucceffion. But if the Impreflions follow one another fo quickly that they cannot be feverally perceived, there arifeth out of them all one common Senfation, which is neither of this Colour alone nor of that alone, but hath it felf indifferently to 'em all, and this is a Senfation of whiteness. By the quickness of the Succes-tions the Impressions of the feveral Colours are confounded in the Senforium, and out of that confusion arifeth 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 reafon of which is, that the Senfation of the Coal in the feveral places of that Circle remains imprefs'd on the Senforium, until the Coal return again to the fame place. And fo in a quick confecution of the Colours the Impression of every Colour remains in the Senforium, until a revolution of all the Colours be compleated, and that first Colour return again. The Impressions therefore of all the fucceflive Colours are at once in the

the Senforium, and jointly flir up a Senfation of them all; and fo it is manifelt 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

I24

of all the Colours.

And if the Comb be now taken away, that all the Colours may at once pais from the Lens to the Paper, and be there intermixed, and to-gether reflected thence to the Spectators Eyes; their Imprefions on the Senforium being now more fubtilly and perfectly commixed there, ought much more to ftir up a Senfation of whitenefs.

You may inftead 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 fee re-prefented in the feventh 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 Cham-ber, as in the third Experiment of the first Book, and let the fame be viewed through a Prifm abc, held parallel to the Prifm ABC, by whofe Refraction that Image was made, and let it now appear lower than before, fuppofe in the place S over against the red Colour T. And if you go near to the Image P T, the Spectrum S will appear oblong and coloured like the Image P T; but if you recede from it, the Colours of the Spectrum S will be contracted more and more, and

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 ap-pears white in that cafe when the Rays of ic-veral forts which converge from the feveral parts of the Image P T, to the Prism *abc*, are to refracted unequally by it, that in their paf-fage from the Prism to the Eye, they may di-verge from one and the fame point of the Spe-ctrum S, and fo fall afterwards upon one and the fame point in the bottom of the Eye, and there be mingled. there be mingled,

And farther, if the Comb be here made ufe

And farther, if the Comb be here made ufe of, by whole Teeth the Colours at the Image PT may be fucceffively intercepted; the Spe-ctrum S when the Comb is moved flowly will be perpetually tinged with fucceffive Colours: But when by accelerating the motion of the Comb, the fucceffion of the Colours is fo quick that they cannot be feverally feen, that Spe-ctrum S, by a confufed and mix'd Senfation of them all, will appear white. *Exper.* 12. The Sun flining through a large Prifin A BC [in Fig. 9.] upon a Comb X Y, placed immediately behind the Prifin, his Light which paffed through the Interflices of the Teeth fell upon a white Paper D E. The breadths of the Teeth were equal to their In-terflices, and feven Teeth together with their Interflices took up an Inch in breadth. Now when the Paper was about two or three Inches diftant from the Comb, the Light which paf-fed through its feveral Interflices painted fo fed through its feveral Interflices painted fo many

I 126]

many ranges of Colours, kl, mn, op, qr, &c. which were parallel to one another and contiguous, and without any mixture of white. And thefe ranges of Colours, if the Comb was moved continually up and down with a receiprocal motion, afcended and defcended in the Paper, and when the motion of the Comb was fo quick, that the Colours could not be diffinguished from one another, the whole Paper by their confusion and mixture in the Senforium appeared white.

Let the Comb now reft, and let the Paper be removed farther from the Prifm, and the feveral 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 diffance of the Paper from the Comb is about a Foot, or a little more (fuppofe in the place 2D 2E) they will fo far dilute one another as to become white.

With any obftacle let all the Light be now flopp'd which paffes through any one interval of the Teeth, fo that the range of Colours which comes from thence may be taken away, and you will fee the Light of the reft of the ranges to be expanded into the place of the range taken away, and there to be coloured. Let the intercepted range pafs on as before, and its Colours falling upon the Colours of the other ranges, and mixing with them, will reftore the whitenefs.

Let the Paper 2 D 2 E be now very much inclined to the Rays, fo that the most refrangible Rays Rays may be more copioufly reflected than the reft, and the white Colour of the Paper through the Excefs 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 copioufly reflected than the reft, and by their Excess the whiteness will be changed into yellow and red. The feveral Rays therefore in that white Light do retain their colorific qualities, by which those of any fort, when-ever they become more copious than the reft, do by their Excess and Predominance cause their proper Colour to appear.

And by the fame 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 feveral intervals of the Teeth of the Comb do the office of fo many Prifms, every interval producing the Phænomenon of one Prifm. Whence inftead of those intervals using feveral Prifms, I try'd to compound whiteness by mixing their Colours, and did it by using only three Prifms, as also by using only two as follows. Let two Prifms A BC and abc, [in Fig. 10.] whose refracting Angles B and b are equal, be fo placed parallel to one another, that the refracting Angles CB and cb, at which the Rays emerge, may lie in Directum.

rectum. Then let the Light trajected through them fall upon the Paper MN, diftant about 8 or 12 Inches from the Prifms. And the Colours generated by the interior limits B and cof the two Prifms, will be mingled at PT, and there compound white. For if either Prifm be taken away, the Colours made by the other will appear in that place PT, and when the Prifm is reftored to its place again, fo that its Colours may there fall upon the Colours of the other, the mixture of them both will reftore the whitenefs.

the whitenefs. This Experiment fucceeds alfo, as I have tri-ed, when the Angle b of the lower Prifm, is a little greater than the Angle B of the upper, and between the interior Angles B and c, there intercedes fome fpace Bc, as is reprefented in the Figure, and the refracting Planes B C and bc, are neither in directum nor parallel to one another. For there is nothing more requifite to the fuccels of this Experiment, than that the Rays of all forts may be uniformly mixed upon the Paper in the place P T. If the most refrangible Rays coming from the fuperior Prifm take up all the fpace from M to P, the Rays of the fame fort which come from the in-ferior Prifm ought to begin at P, and take up all the reft of the fpace from thence towards N. If the least refrangible Rays coming from the fuperior Prifm take up the fpace MT, the Rays of the fame kind which come from the other Prifm ought to begin at T, and take up other Prifm ought to begin at T, and take up the remaining space TN. If one fort of the Rays which have intermediate degrees of Refrangibility,

frangibility, and come from the fuperior Prifm be extended through the fpace MQ, and another fort of those Rays through the space MR, and a third fort of them through the space MS, the fame forts of Rays coming from the lower Prifm, ought to illuminate the remaining spaces Q N, R N, S N, respectively. And the same is to be understood of all the other forts of Rays. For thus the Rays of every fort will be fcattered uniformly and eavenly thro' the whole Ipace M N, and fo being every where mix'd in the fame proportion, they mult every where produce the fame Colours. And therefore fince by this mixture they produce white in the exterior fpaces MP and TN, they must also pro-duce white in the interior space PT. This is the reafon of the composition by which white-nefs was produced in this Experiment, and by what other way foever I made the like composi-tion the refult was whitenefs.

Lattly, If with the Teeth of a Comb of a due fize, the colour'd Lights of the two Prifms which fall upon the fpace P T be alternately intercepted, that fpace P T, when the motion of the Comb is flow, will always appear coloured, but by accelerating the motion of the Comb fo much, that the fucceffive Colours cannot be diftinguish'd from one another, it will appear white

Exper. 14. Hitherto I have produced whitenefs by mixing the Colours of Prifms. If now the Colours of natural Bodies are to be mingled, let Water a little thicken'd with Soap be agitated to raife a Froth, and after that Froth K has has flood a little, there will appear to one that fhall view it intently various Colours every where in the Surfaces of the feveral Bubbles; but to one that fhall go fo far off that he cannot diflinguish the Colours from one another, the whole Froth will grow white with a perfect whitenes.

Exper. 15. Laftly, in attempting to compound a white by mixing the coloured Powders which Painters use, I confider'd that all colour'd Powders do fupprefs and ftop in them a very confiderable part of the Light by which they are illuminated. For they become colour'd by reflecting the Light of their own Colours more copioufly, and that of all other Colours more fparingly, and yet they do not reflect the Light of their own Colours fo copioufly as white Bodies do. If red Lead, for inflance, 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 Prifm, as is defcribed 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 copioufly than red Lead doth. And if they be held in the Light of any other Colour, the Light reflected by the Paper will ex-ceed the Light reflected by the red Lead in a much greater proportion. And the like hap-pens in Powders of other Colours. And there-fore by mixing fuch Powders we are not to ex-pect a ftrong and full white, fuch as is that of Paper, but fome dusky obfcure one, fuch as might arife from a mixture of light and darknefs.
nefs, or from white and black, that is, a grey, or dun, or ruffet brown, fuch as are the Colours of a Man's Nail, of a Moufe, 'of Ashes, of ordinary Stones, of Mortar, of Dust and Dirt in High ways, and the like. And fuch 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, compofed a dun Colour like that of a Moufe. For thefe two Colours were feverally fo compounded of others, that in both together were mix-ture of all Colours; and there was lefs red Lead used than Viride Æris, because of the fulness of its Colour. Again, one part of red Lead, and four parts of blue Bife, composed a dun Colour verging a little to purple, and by ad-ding 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 fucceeded best with-out Minium thus. To Orpiment I added by little and little a certain full bright purple, which Painters use until the Orpiment ceased to be vellow, and became of a pale and to be yellow, and became of a pale red. Then, I diluted that red by adding a little Viride Æ-ris, and a little more blue Bife than Viride Æris, until it became of fuch 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. K 2 To

To affign the Proportions accurately may be difficult, by reafon of the different goodnefs of Powders of the fame kind. Accordingly as the Colour of any Powder is more or lefs full and luminous, it ought to be used in a lefs or greater proportion.

proportion. Now confidering that thefe grey and dun Co-lours may be also produced by mixing whites and blacks, and by confequence differ from perfect whites not in species of Colours but on-ly in degree of Luminous fields, 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 increa-fing their Light they can be brought to perfect fing their Light they can be brought to perfect whitenefs, it will thence also follow, that they are of the fame fpecies of Colour with the beft whites, and differ from them only in the quan-tity of Light. And this I tried as follows. I took the third of the abovemention'd grey Mixtures (that which was compounded of Orpiment, Pur-ple, Bife, and *Viride* \mathcal{A} *ris*) and rubbed it thick-ly upon the Floor of my Chamber, where the Sum fhone upon it through the opened Cafe-ment; and by it, in the fhadow, I laid a piece of white Paper of the fame bignefs. Then going from them to the diffance of 12 or 18 Feet, fo that I could not difcern the uncavenness of the Surface of the Powder, nor the little shadows let fall from the gritty Particles thereof; the Powder appeared intenfely white, fo as to tranfcend even the Paper it felf in whitenefs, 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 fuch a grey Colour as the Powder had done before. But by laying the Paper where the Sun fhines thro' the Glafs of the Window, or by flutting the Window that the Sun might fhine through the Glafs upon the Powder, and by fuch other fit means of increasing or decreasing the Lights wherewith the Powder and Paper were illumi-nated, the Light wherewith the Powder is illu-minated may be made fluoreer in fuch a data minated may be made flronger in fuch a due proportion than the Light wherewith the Paper is illuminated, that they fhall both appear ex-actly alike in whitenefs. For when I was try-ing this, a Friend coming to vifit me, I flopp'd him at the Door, and before I told him what the Colours were, or what I was doing; I ask-ed him, Which of the two Whites were the beft, and wherein they differed? And after he had at that diffance viewed them well, he an-fwer'd, That they were both good Whites, and that he could not fay which was beft, nor wherein their Colours differed. Now if you confider, that this white of the Powder in the Sun-fhine was compounded of the Colours which the component Powders (Orpiment, Purple, Bife, and *Viride Æris*) have in the fame Sunfhine, you must acknowledge by this Experi-ment, as well as by the former, that perfect whitenefs may be compounded of Colours. From what has been faid it is alfo evident,

From what has been faid it is alfo evident, that the whitenefs of the Sun's Light is compounded of all the Colours wherewith the feveral forts of Rays whereof that Light confifts, when by their feveral Refrangibilities they are K_3 fepaseparated 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 fame 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.

VITH the Center O [in Fig. 11.] and Ra-dius O D defcribe a Circle ADF, and diffinguish its circumference into feven parts DE, EF, FG, GA, AB, BC, CD, propor-tional to the feven musical Tones or Intervals of the eight Sounds, Sol, la, fa, fol, la, mi, fa, fol, contained in an eight, that is, proportional to the number 1, 10, 10, 10, 10, 10, 10. Let the first part DE represent a red Colour, the fecond EF orange, the third F G yellow, the fourth CA green, the fifth A B blue, the fixth BC indigo, and the feventh CD violet. And conceive that these are all the Colours of uncompounded Light gradually paffing into one another, as they do when made by Prifms; the circumference DEFGABCD, reprefenting the whole feries of Colours from one end of the Sun's colour'd Image to the other, fo that from D to E be all degrees of red, at E the mean Colour between red and orange, from E toF

[135]

to F all degrees of orange, at F the mean between orange and yellow, from F to G all degrees of yellow, and fo on. Let p be the cen-ter of gravity of the Arch D E, and q, r, s, t, u, x, the centers of gravity of the Arches E F, FG, GA, A B, BC and CD refpectively, and about those centers of gravity let Circles proportional to the number of Rays of each Cofour in the given Mixture be defcrib'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-ma-king Rays in the Mixture, and fo of the reft. Find the common center of gravity of all those Circles p, q, r, s, t, n, ∞ . 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 O'Z shall be proportional to the fulness or intensenties of the Colour, that is, to its diffance from whitenefs. 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 fhall be intenfe and florid in the highest degree; if it fall in the mid way between the circumference and center, it shall be but half to intenfe, that is, it shall be such a Colour as would be made by diluting the intenfeft yellow K 4 with

[136]

with an equal quantity of whitenefs; and if it fall upon the center O, the Colour shall have loft all its intenfenefs, and become a white. But tott all its intemenels, and become a white. But it is to be noted, That if the point Z fall in or near the line O D, the main ingredients being the red and violet, the Colour compounded fhall not be any of the prifmatick Colours, but a purple, inclining to red or violet, according-ly as the point Z lieth on the fide of the line D O towards E or towards C, and in general the compounded violet is more bright and more fiery than the uncompounded. Allo if only two of the primary Colours which in the circle are opposite to one another be mixed in the circle are proportion, the point Z shall fall upon the cen-ter 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 pro-duce a perfect white. Whether it may be com-pounded of a mixture of three taken at equal diffances in the circumference I do not know, but of four or five I do not much queflion but it may. But thefe are Curiofities of little or no moment to the underflanding the Phænomena of Nature. For in all whites produced by Na-ture, there uses to be a mixture of all forts of Rays, and by confequence a composition of all Colours.

To give an inftance of this Rule; fuppofe 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 fix parts, and of red ten [137]

ten parts. Proportional to thefe parts defcribe the Circles x, v, t, s, r, q, p, refpectively, that is, fo that if the Circle x be one, the Circle vmay be one, the Circle t two, the Circle s three, and the Circles r, q and p, five, fix and ten. Then I find Z the common center of gravity of Then I find Z the common center of gravity of thefe Circles, and through Z drawing the Line O Y, the Point Y falls upon the circumference between E and F, fome thing nearer to E than to F, and thence I conclude, that the Colour compounded of thefe Ingredients will be an o-range, verging a little more to red than to yel-low. Alfo I find that O Z is a little lefs than one half of O Y and thence I conclude that low. Alfo I find that O Z is a little lefs than one half of O Y, and thence I conclude, that this orange hath a little lefs than half the ful-nefs or intenfenefs of an uncompounded o-range; that is to fay, that it is fuch an orange as may be made by mixing an homogeneal o-range with a good white in the proportion of the Line O Z to the Line Z Y, 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:

This Rule I conceive accurate enough for practice, though not mathematically accurate; and the truth of it may be fufficiently proved to Senfe, by ftopping any of the Colours at the Lens in the tenth Experiment of this Book. For the reft of the Colours which are not ftopp'd, but pafs on to the Focus of the Lens, will there compound either accurately or very nearly fuch a Colour as by this Rule ought to refult from their mixture.

PROP.

[138]

$\mathcal{P} R O \mathcal{P}$. 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 Re-fractions do not arife from any new Modifications of the Rays imprefs'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 feveral Colours of the homogeneal Rays do conftantly anfwer 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 confequence that those their Colours are likewife immuta-It has also been proved directly by refrable. cting and reflecting homogeneal Lights apart, that their Colours cannot be changed, (Prop. 2. Part 2.) It has been proved also, that when the feveral forts of Rays are mixed, and in croffing pass through the same space, they do not act on one another fo as to change each others colorific qualities. (Exper. 10. Part 2.) but by mixing their Actions in the Senforium beget a Senfation differing from what either would do apart, that is a Senfation of a mean Colour between

139

tween their proper Colours; and particularly when by the concourfe and mixtures of all forts 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 lofe or alter their feveral colorific qualities, but by all their various kinds of Actions mix'd in the Senforium, beget a Senfation of a middling Colour between all their Colours, which is whitenefs. For whitenefs is a mean between all Colours, having it felf indifferently to them all, fo 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 prefently lofe its Colour, but a white Powder mix'd with any Colour is prefently 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 forts of Rays, fo its whitenefs is a mixture of the Colours of all forts of Rays; those Rays having from the beginning their feveral colorific qua-lities as well as their feveral Refrangibilities, and retaining them perpetually unchanged not-withstanding any Refractions or Reflexions they may at any time fuffer, and that whenever any fort 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) fepa-rated from the reft, they then manifest their proper Colours. These things have been provid, and the fum of all this amounts to the Press. and the fum of all this amounts to the Propofition here to be proved. For if the Sun's Light

15

[140]

is mix'd of feveral forts of Rays, each of which have originally their feveral Refrangibilities and colorific Qualities, and notwithstanding their Refractions and Reflexions, and their various Separations or Mixtures, keep those their original Properties perpetually the fame 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 confift by which those Colours And therefore if the reafon of any are feen. Colour whatever be required, we have nothing elfe to do than to confider how the Rays in the Sun's Light have by Reflexions or Refractions, or other caufes been parted from one another, or mixed together; or otherwife to find our what forts of Rays are in the Light by which that Colour is made, and in what proportion; and then by the laft Problem to learn the Colour which ought to arife by mixing those Rays (or their Colours) in that proportion. I fpeak here of Colours 10 far as they arife from Light. For they appear fometimes by other Caufes, as when by the power of Phantaly we fee Colours in a dream, or a mad Man fees things before him which are not there; or when we fee Fire by ftriking the Eye, or fee Colours like the Eye of a Peacock's Feather, by prefling our Eyes in either corner whilft we look the other way. Where these and fuch like Causes interpose not, the Colour always answers to the fort or forts of the Rays whereof the Light confifts, as I have conflantly 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.

ŧŧŧŧŧŧŧŧŧŧŧŧŧŧŧŧŧŧŧŧŧŧ

PROP. VIII. PROB. III.

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

ET ABC [in Fig. 12.] represent a Prism refracting the Light of the Sun, which comes into a dark Chamber through a hole $F \varphi$ comes into a dark Chamber through a hole $f \phi$ almost as broad as the Prifm, and let MN re-prefent 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 T7, the middle fort between the indigo making and blue-ma-king Rays upon the space Ω is the middle fort king Rays upon the Space Q_{\varkappa} , the middle fort of the green-making Rays upon the fpace R_{ϱ} , the middle fort between the yellow-making and the middle fort between the yellow-making and orange-making Rays upon the fpace $S\sigma$, and o-ther intermediate forts upon intermediate Spa-ces. For fo the Spaces upon which the feveral forts adequately fall will by reafon of the dif-ferent Refrangibility of those forts be one lower than another. Now if the Paper MN be fo near the Prism that the Spaces PT and π ? do not interfere with one another, the distance be-tween them T π will be illuminated by all the forts of P are in that proportion to one another forts of Rays in that proportion to one another which they have at their very first coming out of

л. Д of the Prism, and confequently be white. But the Spaces PT and π 7 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 in-digo and blue. At S where all the Rays are mixed except the red-making and orange-making, their Colours ought by the fame 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 whitenefs.

I42

So again, on the other fide of the white at τ , where the leaft refrangible or utmost red-making Rays are alone, the Colour must be the deepest red. At σ the mixture of red and orange will compound a red inclining to orange. At e the mixture of red, orange, yellow, and one half of the green must compound a middle Colour between orange and yellow. At χ 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 χ to π , where by a mixture of all forts of Rays it will become white. Thefe Colours ought to appear were the Sun's Light perfectly white: But becaufe it inclines to yellow, the Excels of the yellow-making Rays whereby 'tis tinged with that Colour, be-ing mixed with the faint blue between S and T, will draw it to a faint green. And fo the Co-lours in order from P to τ ought to be violet, indigo, blue, very faint green, white, faint yel-low, orange, red. Thus it is by the computa-tion: And they that pleafe to view the Colours made by a Prifm will find it fo in Nature. Thefe are the Colours on both fides the white when the Paper is held between the Prifm, and

when the Paper is held between the Prifm, and when the Paper is held between the Prifm, 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. Al-fo the yellow and blue will now become less compounded, and by consequence more intense than before. And this also agrees with expe-rience rience.

And if one look through a Prifm upon a white Object encompafied with blacknefs or darknefs, the reafon of the Colours arifing on the edges is much the fame, as will appear to one that fhall a little confider it. If a black Ob-ject be encompafied with a white one, the Colours which appear through the Prifin are to be derived from the Light of the white one, fpread-

ing 4 [144]

ing into the Regions of the black, and there: fore they appear in a contrary order to that; when a white Object is furrounded with black. And the fame is to be underftood when an Object is viewed, whofe parts are fome of them lefs luminous than others. For in the borders of the more and lefs luminous parts, Colours ought always by the fame Principles to arife from the Excefs of the Light of the more luminous, and to be of the fame kind as if the darker parts were black, but yet to be more faint and dilute.

What is faid of Colours made by Prifins may be eafily applied to Colours made by the Glaffes of Telefcopes or Microfcopes, or by the Humours of the Eye. For if the Object-glafs of a Telefcope be thicker on one fide than on the other, or if one half of the Glafs, or one half of the Pupil of the Eye be cover'd with any opake fubitance: the Object-glafs, or that part of it or of the Eye which is not cover'd, may be confider'd as a Wedge with crooked Sides, and every Wedge of Glafs or other pellucid Subftance has the effect of a Prifm in refracting the Light which paffes 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 faid. 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, fuffices only to bring that yellow to a pale white inclining to blue, and not to tinge it with a manifestly feftly blue Colour. To obtain therefore a better blue, I ufed inflead 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.] repre-

fent a Prifm in the open Air, and S the Eye of the Spectator, viewing the Clouds by their Light coming into the Prifm at the plane fide FIGK, and reflected in it by its base HEIG, and thence going out through its plane fide HEFK to the Eye. And when the Prifm and Eye are conveniently placed, fo that the Angles of Incidence and Reflexion at the Bafe may be about 40 Degrees, the Spectator will fee a Bow MN of a blue Colour, running from one end of the Bafe to the other, with the Concave fide towards him, and the part of the Bafe IMNG beyond this Bow will be brighter than the other part EMNH on the other fide of it. This blue Colour MN being made by nothing elfe than by reflexion of a fpecular Superficies, feems fo odd a Phænomenon, and fo difficult to be explained by the vulgar Hypothesis of Philosophers, that I could not but think it deferved to be taken notice of. Now for understanding the rea-Ken notice of. Now for understanding the rea-fon of it, fuppole the Plane A B C to cut the plane Sides and Bafe of the Prifm perpendicu-larly. From the Eye to the Line B C, where-in that Plane cuts the Bafe, draw the Lines S pand S t, in the Angles S p c 50 degr. $\frac{1}{2}$, and S t c49 degr. $\frac{1}{28}$, and the Point p will be the limit beyond which none of the most refragible Rays can pass through the Bafe of the Prifm, and be refracted, whole Incidence is such that and be refracted, whose Incidence is fuch that thev

· 2 世 唐 明 的 節 順

145

they may be reflected to the Eye; and the Point t will be the like limit for the least re-frangible Rays, that is, beyond which none of them can pass through the Base, whose Incidence is fuch 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 up. on the Bafe beyond t, that is, between t and B, and can come from thence to the Eye will be reflected thither: But on this fide r, 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 Bafe 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 Bafe and be refracted; and the fame is to be understood of the meanly refrangible Rays on either fide of the Point r. Whence it follows, that the Bafe of the Prifm must every where between t and B, by a total reflexion of all forts of Rays to the Eye, look white and bright. And every where between p and C, by reafon of the transmission of many Rays of every fort, look more pale, obfcure 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 lefs refrangible are tranf-mitted, the Excess of the most refrangible in the reflected Light will tinge that Light with their Colour, which is violet and blue. And

this

T 147 T

this happens by taking the Line C pr t B any where between the ends of the Prifm H G and EI.

PROP. IX. PROB. IV.

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

HIS Bow never appears but where it rains in the Sun-fhine, and may be made artificially by fpouting up Water which may break aloft, and fcatter into drops, and fall down like Rain. For the Sun fhining upon thefe drops certainly caufes the Bow to appear to a Spectator flanding 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 that this Bow is made by refraction of the Sun's Light in drops of falling Rain. This was underftood by fome of the Ancients, and of late more fully difcover'd and explain'd by the famous Antonius de Dominis Archbishop of Spa-lato, in his Book De Radiis Vissas & 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 Refra-tions of the Sun's Light, and one Reflexion between them, and the exterior by two Refra-tions and two forts 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 Glafs filled with

L 2

[148]

with Water, and placed in the Sun to make the Colours of the two Bows appear in them. The fame Explication Des-Cartes hath purfued in his Meteors, and mended that of the exterior But whilft they underftood not the true Bow. origin of Colour's, it's necessary to purfue it here a little farther. For understanding therefore how the Bow is made, let a drop of Rain or any other fpherical transparent Body be reprefented by the Sphere BNFG, [in Fig. 14] de. fcribed with the center C, and femi-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 perpen-diculars C D and CE, and produce C D till it fall upon the circumference at L. Parallel to the incident Ray A N 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 A N and G R contain; and the Arch Q F and Angle A X R will be biggeft when ND is to CN as $\sqrt{11-RR}$ to $\sqrt{3}$ RR, in which cafe NE will be to ND as 2 R to I. Alfo 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 $\sqrt{8}$ RR, in which case NE will be to ND as 3 R to I. And fo 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 $\sqrt{15}$ RR, 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 $\sqrt{24}$ RR, in which case NE will be to ND as 5 R to I; and fo on infinitely, the numbers 3, 8, 15, 24, Sc. being gather'd by continual addition of the terms of the arithmetical Progression 3, 5, 7, 9, Sc. The truth of all this Mathematicians will easily examine.

Now it is to be obferved, that as when the Sun comes to his Tropicks, Days increafe and decreafe but a very little for a great while together; fo when by increafing the diffance CD, thefe Angels come to their limits, they vary their quantity but very little for fome time together, and therefore a far greater number of the Rays which fall upon all the Points N in the Quadrant B L, fhall emerge in the limits of thefe Angles, than in any other Inclinations. And farther it is to be obferved, that the Rays which differ in Refrangibility will have different limits of their Angles of Emergence, and by confequence according to their different degrees of Refrangibility emerge most copioully L 3 in

2

[150]

in different Angles, and being feparated from one another appear each in their proper Colours. And what those Angles are may be eafily gather'd from the foregoing Theorem by computation.

For in the leaft refrangible Rays the Sines I and R (as was found above) are 108 and 81, and thence by computation the greateft Angle AXR will be found 42 Degrees and 2 Minutes and the leaft Angle AYS, 50 Degrees and 57 Minutes. And in the most refrangible Rays the Sines I and R are 109 and 181, and thence by computation the greatest Angle AXR 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 Spe-ctator'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. refpectively, and thefe Angels turned about their common Side OP, shall with their other Sides OE, OF; OG, OH, defcribe the Verges of two Rain bows AF BE and CH DG. For if E, F, G, H, be drops placed any where in the conical Superficies defcribed 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 Deg. 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 fend the most refrangible Rays most copiously to the Eye, and thereby ffrike

I I SI]

ftrike the Senfes with the deepeft 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 Senfes with the deepest red Colour in that Region. And by the same Argument, the Bays which And by the fame Argument, the Rays which have intermediate degrees of Refrangiblity 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 progrefs from E to F, or from the infide of the Bow to the outfide 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 SG O being equal to the Angle POG, or 50 Gr. 51 Min. fhall be the leaft Angle in which the leaft refrangible Rays can

Again, the Angle SGO being equal to the Angle POG, or 50 Gr. 51 Min. fhall be the leaft Angle in which the leaft refrangible Rays can after two Reflexions emerge out of the drops, and therefore the leaft refrangible Rays fhall come most copioufly to the Eye from the drops in the Line OG, and ftrike the Senfe 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 Senfes L 4 with with the deepeft violet in that Region. And by the fame Argument, the drops in the Regions between G and H fhall ftrike the Senfe with the intermediate Colours in the order which their degrees of Refrangibility require, that is, in the progrefs from G to H, or from the infide of the Bow to the outfide in this order, red, orange, yellow, green, blue, indigo, violet. And fince thefe four Lines OE, OF, OG, OH, may be fituated any where in the abovemention'd conical Superficies, what is faid of the Drops and Colours in thefe Lines is to be underflood of the Drops and Colours every where in those Superficies.

Thus shall there be made two Bows of Colours, an interior and ftronger, 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 G F which is between the Bows. The breadth of the interior Bow EOF meafured crofs the Colours shall be I Degr. 45 Min. and the breadth of the exterior GOH shall be 3 Degr. 10 Min. and the diftance between them GOF fhall be 8 Gr. 15 Min. the greatest Semi-diameter of the inner-most, 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 breadth of the Bows will be increafed and their diffance decreafed by half a Degree, Degree, and fo the breadth of the interior Iris will be 2 Degr. 15 Min. that of the exterior 3 Degr. 40 Min. their diffance 8 Degr. 25 Min. the greateft Semi-diameter of the interior Bow 42 Degr. 17 Min. and the least of the exterior 50 Degr. 42 Min. And fuch 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, and the breadth of the red, yellow and green in that Iris 63 or 64 Minutes, besides the outmost faint red ob-fcured by the brightness of the Clouds, for foured 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 befides the violet, which was fo much obfcured 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 $2\frac{1}{3}$ Degrees, as above. The leaft distance between this Iris and the exterior Iris was about 8 Degrees and 30 Minutes. The exterior Iris was broader than the interior, but fo faint, especi-ally on the blue fide, that I could not measure its breadth diffinctly. At another time when both Bows appeared more diffinct, 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 fame Colours in the interior as 3 to 2.

This

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-fhine a Glafs Globe filled with Water, and viewing it in fuch a pofture 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 (fuppofe at O) fhall fee a full red Colour in that fide of the Globe oppofed to the Sun as 'tis reprefented at F, and if that An-gle become lefs (fuppofe by depreffing the Globe to E) there will appear other Colours, yellow, green and blue fucceffively in the fame fide of the Globe. But if the Angle be made about 50 Degrees (fuppofe by lifting up the Globe to G) there will appear a red Colour in that fide of the Globe towards the Sun, and if the An-gle be made greater (fuppofe by lifting up the ther confirmed by the known Experiment (made gle be made greater (fuppofe by lifting up the Globe to H) the red will turn fucceflively to the other Colours, yellow, green and blue. The fame thing I have tried by letting a Globe reft, and raifing or depreffing the Eye, or o-therwife moving it to make the Angle of a just magnitude.

Thave heard it reprefented, that if the Light of a Candle be refracted by a Prifin to the Eye; when the blue Colour falls upon the Eye the Spectator fhall fee red in the Prifin, and when the red falls upon the Eye he fhall fee 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 miftake feems to arife from the difficulty of difcerning what Colours fall on the Eye. For, on the contrary, I have fomtimes had occafion to obferve in the Sun's Light refracted by a Prifm, that the Spectator always fees that Colour in the Prifm which falls upon his Eye. And the fame I have found true alfo in Candle-light. For when the Prifm is moved flowly from the Line which is drawn directly from the Candle to the Eye, the red appears first in the Prifm and then the blue, and therefore each of them is feen 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 a-bout 26. Degrees from the Sun, and to decay gradually both ways as the diffance from him increafes and decreafes. And the fame is to be understood of Light transmitted through fpherical Hail-stones. And if the Hail be a little flatted, as it often is, the Light transmitted may grow fo ftrong at a little lefs diftance than that of 26 Degrees, as to form a Halo about the Sun or Moon; which Halo, as often as the Hail-ftones 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 *Hu-genius* has observ'd) and make the infide there-of more distinctly defined than it would other wife

wife be. For fuch Hail-flones, though fpherical, by terminating the Light by the Snow, may make a Halo red within and colourlefs without, and darker in the red than without, as Halos ufe 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 directes Lines.

[156]

The Light which paffes through a drop of Rain after two Refractions, and three or more Reflexions, is fcarce ftrong enough to caufe a fenfible Bow; but in those Cylinders of Ice by which *Hugenius* explains the *Parhelia*, it may perhaps be fenfible.

$\mathcal{P} R O \mathcal{P}$. X. Prob. V.

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

HESE Colours arife from hence, that fome natural Bodies reflect fome forts of Rays, others other forts more copioufly than the reft. Minium reflects the leaft refrangible or red making Rays most copioufly, and thence appears red. Violets reflect the most refrangible, most copioufly, and thence have their Colour, and fo of other Bodies. Every Body reflects the Rays of its own Colour more copioufly than the reft, and from their excefs and predominance in the reflected Light has its Colour. *Exper.* *Exper.* 17. For if in the homogeneal Lights obtained by the folution of the Problem proposed in the fourth Proposition of the first Part you place Bodies of feveral Colours, you will find, as I have done, that every Body looks most fplendid and luminous in the Light of its own Colour. Cinnaber in the homogeneal red own Colour. Cinnaber in the homogeneal red Light is moft refplendent, in the green Light it is manifeftly lefs refplendent, and in the blue Light ftill lefs. Indigo in the violet blue Light is moft refplendent, and its fplendor is gradu-ally diminifh'd as it is removed thence by de-grees 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 ftrongly reflected than the other Co-lours red and violet, and fo of the reft. But to make thefe Experiments the more manifeft, fuch Bodies ought to be chofen as have the fulleft and moft vivid Colours, and two of those Bodies most vivid Colours, and two of those Bodies are to be compared together. Thus, for in-stance, if Cinnaber and *ultra*-marine blue, or fome other full blue be held together in the red homogeneal Light, they will both appear red, but the Cinnaber will appear of a ftrongly lu-minous and resplendent red, and the *ultra*-ma-rine 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 ftrongly luminous and resplendent blue, and the Cinnaber of a faint and dark blue. Which puts it out of dispute, that the Cinnaber resplects the red Light much more copiously than the *ultra*-marine doth, and the most vivid Colours, and two of those Bodies the

4

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

And as the reafon of the Colours of natural Bodies is evident by these Experiments, fo it is farther confirmed and put pass differed by the two first Experiments of the first Part, whereby 'twas proved in fuch Bodies that the reflected Lights which differ in Colours do differ also in degrees of Refrangibility. For thence it's certain, that fome Bodies reflect the more refrangible, others the less refrangible Rays more copiously.

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

For if Bodies by Reflexion cannot in the leaft change the Colour of any one fort 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 muft be had that the Light be fufficiently homogeneal. For if Bodies be illuminated by the ordinary prifmatick Colours, they will appear neither of their own Day-light Colours, nor of the Colour of the Light call on them, but of fome [159]

fome middle Colour between both, as I have found by Experience. Thus red Lead (for in-ftance) illuminated with the ordinary prifmatick 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 lefs compounded. For becaufe red Lead appears red when illuminated with white Light, wherein all forts of Rays are equally mix'd, and in the green Light all forts of Rays are not equally mix'd, the Excefs of the yellow-making, green-making and blue-making Rays in the incident green Light, will caufe those Rays to abound fo much in the reflected Light as to draw the Colour from red towards their Colour. And becaufe the red Lead reflects the red-making Rays most copioufly 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 inflance, 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 ftill thicker becomes red, and where 'tis thickest

the 4

the fed is deepeft and darkeft. For it is to be conceiv'd that fuch a Liquor ftops the indigo-making and violet-making Rays most eafily, the blue-making Rays more difficultly, the green-making Rays fill more difficultly, and the red-making most difficultly: And that if the thick-nefs of the Liquor be only fo much as fuffices to flop a competent number of the violet-making and indigo making Rays, without dimi-nifhing much the number of the reft, the reft must (by *Prop. 6. Part* 1.) compound a pale yellow. But if the Liquor be for much thicker as to flop also a great number of the blue making Rays, and fome of the green-making, the reft must compound an orange; and where it is fo thick as to ftop alfo a great number of the green-making and a confiderable number of the yellow-making, the reft must begin to compound a red, and this red must grow deeper and darker as the yellow-making and orangemaking Rays are more and more ftopp'd by in-creafing the thicknefs of the Liquor, fo that few Rays befides 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 Veffel, found in a clear Sun-fhine Day, that when he was funk many Fathoms deep into the Water, the upper part of his Hand on which the Sun fhone directly through the Water and through a fmall Glafs Window in the Veffel, appeared of a red Colour like that of a Damask Rofe, and the Water below and the under part of his Hand illuminated by Light reflected from the Water

Water 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 pais most freely and copioufly to great depths. For thereby the Sun's direct Light at all great depths, by reason of the predominating red-making Rays, must ap-pear red; and the greater the depth is, the ful-ler and intenfer must that red be. And at fuch depths as the violet-making Rays fcarce penetrate unto, the blue-making, green-making and yellow-making Rays being reflected from be-low more copioufly than the red-making ones, must compound a green.

Now if there be two Liquors of full Colours, fuppofe a red and a blue, and both of them fo thick as fuffices to make their Colours fufficiently full; though either Liquor be fufficient-ly transparent apart, yet will you not be able to fee 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 cafually with Glass Wedges filled with red and blue Liquors, and was furprized at the unex-pected event, the reafon of it being then un-known; which makes me truft the more to his Experiment, though I have not tried it my felf. But he that would repeat it must take care the Liquors be of very good and full Colours. Now whill Bodies become coloured by reflect-

ing or transmitting this or that fort of Rays more copioufly than the reft, it is to be conceived that they ftop and ftifle in themselves the Rays M which

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 maily Gold lets into its Body the blue making Rays to be reflected to and fro within it till they be stopp'd and stifled, whils it reflects the yellow-making outwards, and thereby looks yellow. And much after the fame manner that Leaf Gold is yellow by re-flected and blue by transmitted Light and met flected, and blue by transmitted Light, and maf-fy Gold is yellow in all Positions of the Eye; there are some Liquors, as the Tincture of Lignum Nephriticum, and some forts of Glass which transmit one fort of Light most copiously, and reflect another fort or Light mon copiou-ly, and reflect another fort, and thereby look of feveral Colours, according to the position of the Eye to the Light. But if these Liquors or Glasses were so thick and mass 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 Learner wet allow the Eye, though this I cannot yet affirm by experience. For all colour'd Bodies, fo far as my Obfervation reaches, may be feen through if made fufficiently thin, and therefore are in fome made luftciently thin, and therefore are in 10me measure transparent, and differ only in degrees of Transparency from tinged transparent Li-quors; 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 fame 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

then the reflected Colour will be diminished, and perhaps cease, by making the Body very thick, and pitching it on the backfide 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 fome fort of Rays, and intromit or transmit other forts, shall be faid in the next Book. In this Proposition I content my felf to have put it past dispute, that Bodies have such Properties, and thence appear colour'd.

$\mathcal{P}RO\mathcal{P}$. 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 thereim to experience the Truth of the foregoing Propositions.

ET ABC *abc* [in *Fig.* 16.] reprefent a Prifin 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 ufual 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. M 2.

[164]

Then let another Prifm DEG deg, parallel to the former, be placed at X, to refract that white Light upwards towards Y. Let the re-fracting Angles of the Prifms, and their diffances from the Lens be equal, fo that the Rays which converged from the Lens towards X, and with-out Refraction, would there have croffed and dimension of the diverged again, may by the Refraction of the fecond Prilm be reduced into Parallelism and diverge no more. For then those Rays will recompose a beam of white Light X Y. If the refracting Angle of either Prism be the bigger, that Prifm must be fo much the nearer to the Lens. You will know when the Prifms and the Lens are well fet together, by observing if the beam of Light X Y which comes out of the fe-cond Prifm be perfectly white to the very edges of the Light, and at all diftances from the Prilm continue perfectly and totally white like a beam of the Sun's Light. For till this happens, the polition of the Prisms and Lens to one another muit be corrected, and then if by the help of a long beam of Wood, as is reprefented in the Figure, or by a Tube, or fome other fuch Infrument made for that purpose, they be made failt in that fituation, you may try all the fame Experiments in this compounded beam of Light X Y, which have been made in the Sun's direct Light. For this compounded beam of Light has the fame appearance, and is endow'd with all the fame Properties with a direct beam of the Sun's Light, fo far as my Obfervation reaches. And in trying Experiments in this beam you may by stopping any of the Colours p, q, r, sand

and t, at the Lens, fee how the Colours produced in the Experiments are no other than those which the Rays had at the Lens before they enter'd the composition of this Beam: And by confequence that they arife 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 inflance, having with a Lens $4\frac{1}{7}$ Inches broad, and two Prifms on either hand $6\frac{1}{7}$ Feet

broad, and two Prifms on either hand 67 Feet distant from the Lens, made fuch a beam of compounded Light: to examin the reafon of the Colours made by Prifins, I refracted this compounded beam of Light XY with another Prifm HIK k b, and thereby caft the ufual prif-matick Colours PQRST upon the Paper LV placed behind. And then by ftopping any of the Colours p, q, r, s, t, at the Lens, I found that the fame Colour would vanish at the Paper. So if the purple p was ftopp'd at the Lens, the purple P upon the Paper would va-nifh, and the reft of the Colours would remain nifh, and the reft of the Colours would remain unalter'd, unlefs perhaps the blue, fo far as fome purple latent in it at the Lens might be feparated from it by the following Refractions. And fo by intercepting the green upon the Lens, the green R upon the Paper would vanifh, and fo of the reft; which plainly fhews, that as the white beam of Light X Y was compounded of feveral Lights varioufly colour'd at the Lens, fo the Colours which afterwards emerge out of it by new Refractions are no other than thofe of which its whitenefs was compounded. The M 3 M 3 Refira166

Refraction of the Prifm HIK k b generates the Colours PQRST upon the Paper, not by changing the colorific qualities of the Rays, but by feparating the Rays which had the very fame 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 reafon of the Co-lours of natural Bodies, I placed fuch 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 fame Colours at the Lens before they enter'd the Composition of that beam. Thus, for instance, Cinnaber illuminated by this beam appears of the fame red Colour as in Day-light; and if at the Lens you intercept the green-making and blue-making Rays, its rednefs will become more full and lively: But if you there in-tercept the red-making Rays, it will not any longer appear red, but become yellow or green, or of fome other Colour, according to the forts of Rays which you do not intercept. So Gold in this Light X Y appears of the fame 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 Nephriticum








[167]

cum (as I have alfo tried) when held in this beam of Light XY, looks blue by the reflect-ed 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 lofe its reflected blue Colour, whilft its transmitted red remains perfect and by the lofs of fome 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 lofe its transmitted red, whils its blue will re-main and become more full and perfect. Which fhews, that the Infusion does not tinge the Rays with blue and red, but only transmit those most copioufly which were red-making before, and reflects those most copiously which were blue-making before. And after the fame manner may the Reafons of other Phænomena be examined, by trying them in this artificial beam of Light XY.



$\cdot M 4$

THE

[168]



THE

SECOND BOOK

OPTICKS.

嬚榺嫾蔳漛塧溄嫾捓嫾嶶蓙蓙蓙蓙춙蔳蔳蓙蓙蓙蓙蓙蓙蓙蓙蓙蓙

PART I.

读或表示感染。在这些是不会是有意义。这些是是是是是是是是是是是

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



T has been observed by others, that transparent Substances, as Glass, Water, Air, Sc. when made very thin by being blown into Bubbles, or otherwise into Plates, do exhibit various Colours

formed into Plates, do exhibit various Colours according to their various thinnefs, although at a greater a greater thicknefs they appear very clear and colourlefs. In the former Book I forbore to treat of thefe Colours, becaufe they feemed of a more difficult Confideration, and were not neceffary for establishing the Properties of Light there discourfed of. But because they may conduce to farther Discoveries for compleating the Theory of Light, especially as to the conflitution of the parts of natural Bodies, on which their Colours or Transparency depend; I have here fet down an account of them. To render this Discourse flort and distinct, I have first deferibed the principal of my Observations, and then confider'd and made use of them. The Observations are these.

Obf. 1. Compreffing two Prifms hard together that their fides (which by chance were a very little convex) might fomewhere touch one another: I found the place in which they touched to become abfolutely transparent, as if they had there been one continued piece of Glass. For when the Light fell fo obliquely on the Air, which in other places was between them, as to be all reflected; it feemed in that place of contact to be wholly transmitted, infomuch that when look'd upon, it appeared like a black or dark fpot, by reafon that little or no fenfible Light was reflected from thence, as from other places; and when looked through it feemed (as it were) a hole in that Air which was formed into a thin Plate, by being compress'd between the Glaffes. And through this hole Objects that were beyond might be feen distinctly, which could not at all be feen through other parts of the the Glaffes where the Air was interjacent. Although the Glaffes 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 Glaffes, by reason of their mutual pressure. For they pressing them very hard together it would become much broader than otherwise.

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

Thefe Arcs at their first appearance were of a violet and blue Colour, and between them were white Arcs of Circles, which prefently 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, Sc. But the yellow and red were much fainter than the blue and violet. The Motion of the Prifms about their Axis being continued, thefe Colours contracted more and more, fhrinking towards the whitenefs on either fide 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 whitenefs, 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, Sc. contrary to what it was before.

Obf. 3. When the Rings or fome parts of them appeared only black and white, they were very diffinct and well defined, and the blacknefs feemed as intenfe as that of the central Spot. Alfo in the Borders of the Rings, where the Colours began to emerge out of the whitenefs, they were pretty diffinct, which made them vifible to a very great multitude. I have fometimes number'd above thirty Succeffions (reckoning every black and white Ring for one Succeffion) and feen more of them, which by reafon of their finalnefs I could not number. But in other Positions of the Prifms, at which the Rings appeared of many Colours, I could not diffinguish above eight or nine of them, and the Exterior of those were very confused and dilute.

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

T 171]

[172]

at a good diffance from them. For by approaching nearer, although in the fame inclination of my Eye to the Plane of the Rings, there emerged a blueifh Colour out of the white, which by dilating it felf more and more into the black, render'd the Circles lefs diffinct, and left the white a little tinged with red and yellow. I found alfo by looking through a flit or oblong hole, which was narrower than the Pupil of my Eye, and held clofe to it parallel to the Prifms, I could fee the Circles much diflincter and vifible to a far greater number than otherwife.

Obf. 4. To observe more nicely the order of the Colours which arose out of the white Circles as the Rays became less and less incli-ned to the Plate of Air; I took two Objectglaffes, 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 fide downwards, I prefied them flowly together, to make the Colours fucceflively emerge in the middle of the Circles, and then flowly lifted the upper Glafs from the lower to make them fucceflively 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 encompaffing that new Colour. And by comcompreffing the Glaffes 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 laft: And fo on until a third; a fourth, a fifth, and other following new Colours fucceffively emerged there, and became Rings encompaffing the innermost Colour, the last of which was the black Spot. And, on the contrary, by lifting up the upper Glafs from the lower, the diameter of the Rings would decrease, and the breadth of their Orbit increase, until their Colours reached fucceffively to the center; and then they being of a confiderable breadth, I could more eafily difcern and diffinguish their Species than hefore. And by this means I observ'd their Succeffion and Quantity to be as followeth.

Next to the pellucid central Spot made by the contact of the Glaffes fucceeded blue, white, yellow, and red. The blue was fo little in quantity that I could not difcern it in the Circles made by the Prifms, nor could I well diffinguifh any violet in it, but the yellow and red were pretty copious, and feemed 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 encompaffing thefe were violet, blue, green, yellow, and red : and thefe were all of them copious and vivid, excepting the green, which was very little in quantity, and feemed much more faint and dilute than the other Colours. Of the other four, the violet was the leaft in extent, and the blue lefs than the yellow or red. The third Circuit or Order

4

[**1**74]

Order was purple, blue, green, yellow, and red; in which the purple feemed more reddiffi-than the violet in the former Circuit, and the than the violet in the former Circuit, and the green was much more confpicuous, 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. Af-ter this fucceeded the fourth Circuit of green and red. The green was very copious and live-ly, inclining on the one fide to blue, and on the other fide to yellow. But in this fourth Circuit there was neither violet, blue, nor yel-low, and the red was very imperfect and dir-ty. Alfo the fucceeding Colours became more and more imperfect and dilute, till after three and more imperfect and dilute, till after three or four revolutions they ended in perfect whitenefs. Their form, when the Glaffes were molt comprefs'd fo as to make the black Spot appear in the center, is delineated in the fe-cond Figure; where a, b, c, d, e: f, g, b, i,k: l, m, n, o, p: q, r: s, t: v, x: y, z de-note the Colours reckon'd in order from the center, black, blue, white, yellow, red: vio-let, blue, green, yellow, red: purple, blue, green, yellow, red: green, red: greenish blue, red: greenish blue, pale red: greenish blue, reddifh white.

Obf. 5. To determine the interval of the Glaffes, or thickness of the interjacent Air, by which each Colour was produced, I measured the Diameters of the first fix 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

I75]

And fince one of these Glasses was plane, and the other spherical, their Intervals at those Rings must be in the fame 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 Progresfion 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 fame method I used in determining fome others of the following Observations. Obs. 6: The Diameter of the fixth 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-glafs was ground was about 102 Feet, and hence I ga-thered the thickness of the Air or Aereal Interval of the Glaffes at that Ring. But fome time after, fuspecting that in making this Observation I had not determined the Diameter of the Sphere with fufficient accurateness, and being uncertain whether the Plano convex Glafs was truly plane, and not fomething concave or convex on that fide which I accounted plane; and whether I had not preffed the Glaffes together, as I often did, to make them touch; (For by preffing fuch Glasses together their parts easily yield inwards, and the Rings thereby become fenfibly broader than they would be, did the Glaffes keep their Figures.) I repeated the Experiment, and found the Diameter of the fixth

4.

[176]

fixth lucid Ring about $\frac{55}{100}$ parts of an Inch. 1 repeated the Experiment alfo with fuch an Ob-ject-glass of another Telescope as I had at hand. This was a double Convex ground on both fides to one and the fame Sphere, and its Fo-cus was distant from it 83[±] Inches. And thence, if the Sines of Incidence and Refraction of the bright yellow Light be affumed in proportion as II to 17, the Diameter of the Sphere to which the Glass was figured will by computation be found 182 Inches. This Glafs I laid upon a flat one, fo that the black Spot appeared in the middle of the Rings of Colours without any other Preffure than that of the weight of the Glafs. And now measuring the Diameter of the fifth dark Circle as accurately as I could, I found it the fifth part of an Inch pre-cifely. This measure was taken with the points of a pair of Compasses on the upper Surface on the upper Glafs, and my Eye was about eight or nine Inches diffant from the Glafs, almost perpendicularly over it, and the Glass was $\frac{1}{2}$ of an Inch thick, and thence it is eafy to collect that the true Diameter of the Ring between the Glaffes was greater than its measur'd Diameter above the Glaffes in the Proportion of 80 to 79, or thereabouts, and by confequence equal to $\frac{16}{79}$ part of an Inch, and its true Semi-diameter equal to $\frac{8}{79}$ parts. Now as the Dia-meter of the Sphere (182 Inches) is to the Se-mi-diameter of this fifth dark Ring ($\frac{8}{79}$ parts of an Inch) fo is this Semi-diameter to the thicknefs of the Air at this fifth dark Ring; which is there-

[177]

therefore $\frac{32}{5^{5}793^{1}}$ or $\frac{100}{17747^{5}4}$ 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 fame Experiment I repeated with another double convex Object-glais ground on both fides to one and the fame Sphere. Its Focus was diltant from it 1681 Inches, and therefore the Diameter of that Sphere was 184 Inches. The Glass being laid upon the fame plain Glass, the Diameter of the fifth of the dark Rings, when the black Spot in their center appear'd plainly without preffing the Glaffes, was by the measure of the Compasses upon the upper Glass $\frac{121}{600}$ parts of an Inch, and by confequence between the Glaffes it was $\frac{1222}{6000}$. For the upper Glass was $\frac{1}{2}$ of an Inch thick, and my Eye was diftant 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 thicknefs 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 fame thing by laying these Object-glasses upon flat pieces of a broken Looking-glass, and found the fame Measures of the Rings: Which makes me rely upon them till N they

[178]

they can be determin'd more accurately by Glasses ground to larger Spheres, though in fuch 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 diffant from the Glass; fo that the Rays were inclined to the Glafs in an Angle of about four Degrees. Whence by the following Obfervation you will understand, that had the Rays been perpendicular to the Glaffes, the thicknefs of the Air at these Rings would have been lefs in the proportion of the Radius to the Secant of four Degrees, that is of 10000 to 10024. Let the thickneffes found be therefore diminish'd in this Proportion, and they will become $\frac{r}{86052}$ and $\frac{r}{89063}$, or (to use the nearest round number) the $\frac{1}{80000}$ 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, Sc. gives the thicknesses of the Air at the most luminous parts of all the brighteft Rings, viz. 178000 $\frac{3}{178000}$, $\frac{5}{178000}$, $\frac{7}{178000}$, $\mathbb{S}c$. their arithmetical Means $\frac{2}{178000}$, $\frac{4}{178000}$, $\frac{6}{178000}$, $\mathfrak{S}c$. being its thickneffes at the darkeft parts of all the dark ones.

Obf.

Obf. 7. The Rings were leaft when my Eye was placed perpendicularly over the Glassies in the Axis of the Rings: And when I view'd them obliquely they became bigger, continually fwelling as I removed my Eye farther from the Axis. And partly by measuring the Diameter of the fame Circle at feveral 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 confequently 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 In-	Angle of Re-	Diameter	Thickne fs
cidence on	fraction in-	of the	of the
the Air.	to the Air.	Ring.	Air.
Degr. Min.			
<u>o</u> o oo	00 00	IO	ro
06 2.6	10 00	1013	1073
12 45	20 00	IC ^r	$10\frac{2}{3}$
18 49	30 00	$10\frac{1}{4}$	1 I - <u>†</u>
24 30	40 00	117	13
29 37	50 00	12-	$15\frac{1}{2}$
33 58	60 00	I4	20
35 47	65 00	15‡	234
37 19	70 00	16‡	28 <u>+</u>
38 33	75 00	194	37
39 27	80 00	224	524
40 00	85 00	29	8473
40 II	90 00	35	122-1

N 2

[180]

· 12

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 conflitute 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 conflitute its thickness when the Rays are perpendicular.

And from thefe Meafures I feem to gather this Rule: That the thicknefs of the Air is proportional to the fecant of an Angle, whofe Sine is a certain mean Proportional between the Sines of Incidence and Refraction. And that mean Proportional, fo far as by thefe Meafures I can determine it, is the first of an hundred and fix 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 Glafs into the Plate of Air, or from the Sine of Incidence when the Refraction is made out of the Plate of Air into the Glafs.

Obj. 8. The dark Spot in the middle of the Rings increased also by the Obliquation of the Eye, although almost infensibly. 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 the obliquity decreafed it increafed more and more until the colour'd Rings appear'd, and then decreafed again, but not fo much as it increafed 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 fearcely, 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 fixth part of their Interval at the circumference of the faid red.

Obf. 9. By looking through the two contiguous Object glaffes, 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, $\Im c$. But these Colours were very faint and dilute, unless when the Light was trajected very obliquely through the Glaffes: For by that means they became pretty vivid. Only the first yellowish red, like the blue in the fourth Observation, was fo little and faint as fcarcely to be difcern'd. Comparing N 3 182

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 Glafs were black when looked through, which when looked upon appear'd white, and on the contrary. And fo those which in one cafe exhibited blue, did in the other cafe exhibit red. And the like of the other Colours. The manner you have reprefented in the third Figure, where AB, CD, are the Surfaces of the Glaffes contiguous at E, and the black Lines between them are their Diftances in arithmetical Progreffion, and the Colours written above are feen by reflected Light, and those below by Light transmitted.

Obf. 10. Wetting the Object glasses a little at their edges, the Water crept in flowly between them, and the Circles thereby became lefs and the Colours more faint: Infomuch 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 lefs By meafuring them I found the Pro-Room. portions of their Diameters to the Diameters of the like Circles made by Air to be about feven to eight, and confequently the Intervals of the Glaffes at like Circles, caufed 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 lefs denfe than Water be comprefs'd between the Glaffes, their Intervals at the Rings caufed thereby will be to their Intervals [183]

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

Obj. 11. When the Water was between the Glaffes, if I prefied the upper Glafs varioufly 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 prefently vanifh. Its appearance was fuch as interjacent Air would have caufed, and it exhibited the fame Colours. But it was not Air, for where any Bubbles of Air were in the Water they would not vanifh. The Reflexion muft have rather been caufed by a fubtiler Medium, which could recede through the Glaffes at the creeping in of the Water.

Obf. 12. These Observations were made in the open Air. But farther to examine the Effects of colour'd Light falling on the Glass, 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 difcern above eight or nine.

Obf. 13. Appointing an Affiftant to move the Prifm to and fro about its Axis, that all the Colours might fucceffively fall on that part of the Paper which I faw by Reflexion from that N 4 part Part of the Glaffes, where the Circles appear'd, fo that all the Colours might be fucceffively reflected from the Circles to my Eye whilit I held it immoveable, I found the Circles which the red Light made to be manifeftly bigger than those which were made by the blue and violet, And it was very pleafant to fee them gradually swell or contract accordingly as the Colour of the Light was changed. The Interval of the Glaffes at any of the Rings, when they were made by the utmost red Light, was to their Interval at the fame Ring when made by the utmost violet, greater than as 3 to 2, and lefs than as 13 to 8. By the most of my Observations it was as 14 to 9. And this Proportion feem'd very nearly the fame in all Obliquities of my Eye; unless when two Prisms were made use of inftead of the Object-glaffes. For then at a certain great obliquity of my Eye, the Rings made by the feveral Colours feem'd equal, and at a greater obliquity those made by the violet would be greater than the fame Rings made by the red: the Refraction of the Prifm in this cafe caufing the most refrangible Rays to fall more obliquely on that plate of the Air than the least refrangible ones. Thus the Experiment fucceeded in the colour'd Light, which was fufficiently ftrong and copious to make the Rings fenfible. And thence it may be gather'd, that if the most refrangible and least refrangible Rays had been copious enough to make the Rings fenfible without the mixture of other Rays, the Proportion which here was 14 to 9 would have been a little greater, fuppofe 144 or 144 to 9. Obf.

[184]

I85 **]**

Obf. 14. Whill the Prifm was turn'd about its Axis with an uniform Motion, to make all the feveral Colours fall fucceffively 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 fwiftent in the red, and floweff 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; les 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 fame 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 greateft Diame-ter of the fame 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 Prifm, where the red is most contracted, the violet most expanded, and in the midst of all the Colours is the Comfine of green and blue. And hence I feem to collect that the thickneffes of the Air between the Glaffes there, where the Ring is fucceffively ly made by the limits of the five principal Co-lours (red, yellow, green, blue, violet) in or-der (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 fix lengths of a Chord which found the Notes in a fixth Major, sol, la, mi, fa, sol, la. But it agrees fomething better with the Obfervation to fay, that the thickneffes of the Air between the Glaffes there, where the Rings are fucceffively made by the limits of the feven Colours, red, orange, yellow, green, blue, indi-go, violet in order, are to one another as the Cube Roots of the Squares of the eight lengths of a Chord, which found the Notes in an eighth, *fol, la, fa, fol, la, mi, fa fol*; that is, as the Cube Roots of the Squares of the Numbers, r,

Ob/. 15. Thefe 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 fame Colour with those which were reflected, and of the bigness of their immediate Spaces. And from thence the origin 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.

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

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 fides with Air.

Obf. 17. If a Bubble be blown with Water first made tenacious by diffolving 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, fo that no accurate Observation can be made of them,) as foon as I had blown any of them **I** 188]

them I cover'd it with a clear Glafs, and by that means its Colours emerged in a very regular order, like fo many concentrick Rings encom-paffing the top of the Bubble. And as the Bub-ble grew thinner by the continual fubfiding of the Water, these Rings dilated flowly and overfpread the whole Bubble, descending in order to the bottom of it, where they vanish'd fucceffively. In the mean while, after all the Co. lours were emerged at the top, there grew in the center of the Rings a fmall round black Spot, like that in the first Observation, which continually dilated it felf till it became fometimes 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 curioufly, I faw within it feveral finaller round Spots, which appeared much blacker and darker than the reft, whereby I knew that there was fome Reflexion at the other places which were not fo dark as those Spots. And by farther Tryal I found that I could fee the Images of fome things (as of a Candle or the Sun) ve-ry faintly reflected, not only from the great black Spot, but alfo from the little darker Spots which were within in it.

Befides the aforefaid colour'd Rings there would often appear fmall Spots of Colours, afcending and defcending up and down the fides of the Bubble, by reafon of fome Inequalities in the fubfiding of the Water. And fometimes fmall black Spots generated at the fides would afcend

[189]

afcend up to the larger black Spot at the top of the Bubble, and unite with it. Obf. 18. Becaufe the Colours of these Bubbles

Obf. 18. Becaufe the Colours of thefe Bubbles were more extended and lively than those of the Air thinn'd between two Glasses, and so more easy to be diffinguish'd, I shall here give you a farther description of their order, as they were observ'd in viewing them by Restexion 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 Succeffions 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 fearce any other Colour fensible 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 fo much as the former three; after that fucceeded 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 blueisth Colour; but there fucceeded 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 fucceeded with a very bright and intense yellow, which was but little in quantity, and foon chang'd

3

[190]

chang'd to green: But that green was copious and fomething 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 lefs in quantity than the blue, and much inclin'd to red.

The fixth red was at first of a very fair and lively Scarlet, and foon 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 fomething inferior to the former blue; and the violet was intense and deep with little or no redness in it. And less in quantity than the blue.

In the laft red appeared a tincture of fcarlet next to violet, which foon changed to a brighter Colour, inclining to an orange; and the yellow which follow'd was at firft pretty good and lively, but afterwards it grew more dilute, until by degrees it ended in perfect whitenefs. And this whitenefs, if the Water was very tenacious and well temper'd, would flowly fpread and dilate it felf 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, untill it refembled the Threds of an irregular Net-work, and soon after vanish'd and left all the upper part of the Bubble of the faid dark blue Colour. And this Colour, after the aforefaid manner, dilated it felf downwards, until fometimes it hath overfpread the whole Bubble. In the mean while at the top, which was of a darker blue than the bottom, and appear'd alfo full of many round blue Spots, fomething darker than the reft, 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 themfelves until the Bubble broke.

If the Water was not very tenacious the black Spots would break forth in the white, without any fensible intervention of the blue. And fometimes they would break forth within the precedent yellow, or red, or perhaps within the blue of the fecond order, before the inter-mediate Colours had time to difplay themfelves.

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

Obf. 19. Viewing in feveral oblique Politions of my Eye the Rings of Colours emerging on the

the top of the Bubble, I found that they were fenfibly dilated by increasing the obliquity, but yet not fo much by far as those made by thinn'd Air in the feventh Observation. For there they were dilated to much as, when view'd most obliquely, to arrive at a part of the Plate more than twelve times thicker than that where they appeared when viewed perpendicularly; whereas in this case the thickness of the Water, at which they arriv'd when view'd most obliquely, was to that thickness which exhibited them by perpendicular Rays, fomething less than as 8 to 5. By the best of my Observations it was between 15 and $15\frac{1}{2}$ to 10; an increase about 24 times less than in the other case.

Sometimes the Bubble would become of an uniform thicknefs all over, except at the top of it near the black Spot, as I knew, because it would exhibit the fame appearance of Colours in all Politions of the Eye. And then the Colours which were feen 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 Obliqui-ties. Now observing how much the Colours at the fame places of the Bubble, or at divers places of equal thickness, were varied by the fe-veral Obliquities of the Rays; by the affiftance 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 fame Colour, at feveral Obliquities, to

.

[193]

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

Incide the W	nce on ⁷ ater.	Refract to the V	ion in- Vater.	Thickness of the Water.
Degr.	Min.	Degr.	Min.	2
00	00	- 00	00	to
15	00	II	ÌI	IO ^I
30	00	2.2	I	10 <u>4</u>
45	00	32	2	İI4
60	00	40	30	13
75	00	46	25	14-2
90	00	48	35	155

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 diffolution 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 exhibit-ed in those feveral Obliquities, is express'd in parts, of which ten constitute its thickness when the Rays are perpendicular. And the Rule found by the feventh Obfervation 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 fecant of an Angle whole Sine is the first of an hundred and fix arithmetical mean Proportionals [194]

nals between the Sines of Incidence and Refraction counted from the leffer Sine, that is, from the Sine of Refraction when the Refraction is made out of Air into Water, otherwife from the Sine of Incidence.

I have fometimes obferv'd, that the Colours which arife on polish'd Steel by heating it, or on Bell metal, and fome other metalline Subftances, 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 fo great and fenfible 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 fend 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 Eyes is leaft in Colours of the denfeit thin Substances.

Obj. 20. As in the ninth Obfervation, fo 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, feem'd red at its apparent circumference, if the Clouds at the fame time, or immediately after, were view'd through it, the Colour at its circumference would be blue. And, on the contrary,

[195]

Contrary, when by reflected Light it appeared blue, it would appear red by transmitted Light. Obf. 21. By wetting very thin Plates of Muf-covy Glass, whose thinness made the like Co-lours appear, the Colours became more faint and languid, especially by wetting the Plates on that fide opposite to the Eye: But I could not because any variation of their Spacies. So then perceive any variation of their Species. So then the thicknefs 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 Obfervations, may be known the thicknefs which Bubbles of Water, or Plates of Mufcovy Glafs, or other Subfances, have at any Colour produced by them.

Obf. 22. A thin transparent Body, which is denfer than its ambient Medium, exhibits more brisk and vivid Colours than that which is fo much rarer; as I have particularly observed in the Air and Glafs. For blowing Glafs 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 Glaffes.

Obf. 23. Comparing the quantity of Light reflected from the feveral 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 fironger than that reflected from those parts of the thin Medium or Plate which were without the Rings; as I could manifeltly per-ceive by viewing at a diftance the Rings made bv

by the two Object glaffes; or by comparing two Bubbles of Water blown at diftant times, in the first of which the whiteness appear'd, which fucceeded all the Colours, and in the other, the whitenefs which preceded them all.

[196]

Obf. 24. When the two Object-glaffes were lay'd upon one another, fo as to make the Rings of the Colours appear, though with my naked Eye I could not difcern above eight or nine of those Rings, yet by viewing them through a Prism I have seen a far greater multitude, infomuch that I could number more than forty, befides many others, that were fo very fmall and clofetogether, that I could not keep my Eye fleady on them feverally fo as to number them, but by their Extent I have fometimes estimated them to be more than an hundred. And I believe the Experiment may be improved to the difcovery. of far greater Numbers. For they feem to be really unlimited, though visible only fo far as they can be separated by the Refraction of this Prifm as I shall hereafter explain.

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

4

197

Prifm very diftant from the Object-glaffes, the middle part of those Arcs became also confufed, so as to difappear and conftitute an even whitenes, whilst on either fide their ends, as also the whole Arcs farthest from the center, became distincter than before, appearing in the form as you fee them design'd in the fifth Figure.

The Arcs, where they feem'd diffincteft, were only white and black fucceffively, without any other Colours intermix'd. But in other places there appeared Colours, whofe order was inverted by the Refraction in fuch manner, that if I first held the Prifm very near the Objectglaffes, and then gradually removed it farther off towards my Eye, the Colours of the 2d, 3d, 4th, and following Rings fhrunk 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 fometimes fo lay'd one Object-glafs upon the other, that to the naked Eye they have all over feem'd uniformly white, without the leaft appearance of any of the colour'd Rings; and yet by viewing them through a Prifm, great multitudes of those Rings have discover'd themfelves. And in like manner Plates of Muscovy Glass, and Bubbles of Glass blown at a Lamp Furnace, which were not fo 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 O 3 the

[198]

the form of Waves. And fo Bubbles of Water, before they began to exhibit their Colours to the naked Eye of a By-flander, have appeared through a Prifm, girded about with many parallel and horizontal Rings; to produce which Effect, it was neceffary to hold the Prifm parallel, or very nearly parallel to the Horizon, and to difpofe it fo that the Rays might be refracted upwards.


[199]



ТНЕ SECOND BOOK O F OPTICKS.

PART II.

Remarks upon the foregoing Observations.



A VING 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 fimplest of them, fuch as are the 2d, 3d, 4th, 9th, 12th, 18th, 20th, and 24th, I first explain plain the more compounded. And first to shew how the Colours in the fourth and eighteenth Obfervations are produced, let there be taken in any right Line from the Point Y, [in Fig. 6.] the lengths Y A, Y B, Y C, Y D, Y E, Y F, Y G, YH, in proportion to one another, as the Cube Roots of the Squares of the Numbers, $\frac{1}{2}$, $\frac{2}{37}$, $\frac{1}{37}$, $\frac{2}{3}, \frac{3}{4}, \frac{1}{6}, \frac{5}{7}, 1$, whereby the lengths of a mufical Chord to found 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 a, B B, Sc. be erected, by whole Intervals the Extent of the feveral Colours fet underneath against them, is to be reprefented. Then divide the Line A a in fuch proportion as the Numbers 1, 2, 3, 5, 6, 7, 9, 10, 11, Sc. fet 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, Gc.

200

Now if A 2 be fuppoled to reprefent the thicknels 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, H K will represent its thicknels, at which the utmost red is most copiously reflected in the same Series. Also by the 5th and 16th Observations, A 6 and H N will denote the thicknels at which those extreme Colours are most copiously reflected in the series, and A 10 and H Q the thicknels, at which they are most copiously reflected in the third Series, and fo on. And the thicknels 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 A H from the intermediate parts of the Lines 2 K, 6 N, 10 Q, Gc. 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 defign the leaft thicknefs, and A 3 the greatest thicknefs, at which the extreme violet in the firft Series is reflected, and let H I, and H L, defign 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 fo on: But yet with this caution, that the Reflexions be fuppofed ftrongeft at the intermediate Spaces, 2 K, 6 N, 10 Q, Sc. and from thence to decrease gradually towards these limits, I, 3 L, 5 M, 7 O, &c. on either fide; where you must not conceive them to be precifely limited, but to decay indefinitely. And whereas I have affign'd the fame Latitude to every Series; I did it, because although the Colours in the first Series seem to be a little broader than the reft, by reafon of a stronger Reflexion there, yet that inequality is fo infenfible as fcarcely to be determin'd by Obfervation.

Now according to this Defcription, conceiving that the Rays originally of feveral Colours are by turns reflected at the Spaces 1 I L 3, 5 M O 7, 9 P R 11, Sc. and transmitted at the Spaces AHI 1, 3 L M 5, 7 O P 9, Sc. 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 A H, at that distance from it by which the thickness of the Body is represented the alternate Spaces IIL 3, 5 MO7, Sc. 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 defired, apply the Ruler as you see at $\pi \rho \sigma \phi$, and by its pafsing through some of the blue at π and yellow at σ , as well as through the green at ρ , 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 fome blue and yellow.

By this means you may know how the Colours from the center of the Rings outward ought to fucceed in order as they were defcribed in the 4th and 18th Obfervations. For if you move the Ruler gradually from A H through all diftances, having paſs'd over the firft Space which denotes little or no Reflexion to be made by thinneft Subſtances, it will firft arrive at I 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 fuccefſive deficience of its component Colours, turns firft to compound yellow, and then to red, and laſt of all

all the red ceafeth at L. Then begin the Co. lours of the fecond Series, which fucceed in order during the transit of the edge of the Ruler from 5 to O, and are more lively than before, becaufe more expanded and fevered. And for the fame 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 fucceed in order; first, the violet, which a little interferes with the red of the fecond order, and is thereby inclined to a reddifh purple; then the blue and green, which are lefs mixed with other Colours, and confequently more lively than be-fore, especially the green: Then follows the yellow, some of which towards the green is diflinct and good, but that part of it towards the fucceeding 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 fucceeds a green. And this at first is much inclined to blue, but foon becomes a good green, the on-ly unmix'd and lively Colour in this fourth Se-ries. For as it verges towards the yellow, it begins to interfere with the Colours of the fifth Series, by whofe mixture the fucceeding yellow and red are very much diluted and made dirty, especially the yellow, which being the weaker Colour is fcarce able to shew it felf. After

After this the feveral 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 forts of Colours are in all places pretty equally blended, and compound an even whitenefs.

[204]

And fince by the 15th Obfervation the Rays endued with one Colour are transmitted, where those of another Colour are reflected, the reafon 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 thefe Colours, but alfo the precife thicknefs of the Plate, or thin Body at which they are exhibited, be defired in parts of an Inch, that may be alfo obtained by affiftance of the 6th or 16th Obfervation. For according to those Obfervations the thicknefs of the thinned Air, which between two Glaffes exhibited the most luminous parts of the first fix Rings were $\frac{1}{178000}, \frac{3}{178000}, \frac{5}{178000}, \frac{7}{178000}, \frac{9}{178000}$ parts of an Inch. Suppose the Light reflected most copiously at these thickneffes be the bright citrine yellow, or confine of yellow and orange, and these thickneffes will be $F \lambda$, $F \mu$, $F \xi$, $F \sigma$, F 7. And this being known, it is easy to determine what thickneffs of Air is represented by $G \varphi$, or by any other diffance of the Ruler from A H.

But farther, fince by the 10th Obfervation the thickness of Air was to the thickness of Water, which [205]

which between the fame Glaffes exhibited the fame Colour, as 4 to 3, and by the 21ft Obfer-vation the Colours of thin Bodies are not varied by varying the ambient Medium; the thick-nefs of a Bubble of Water, exhibiting any Co-lour, will be $\frac{1}{4}$ of the thicknefs of Air produ-cing the fame Colour. And fo according to the fame 10th and 21ft Obfervations the thickthe fame 10th and 21ft Obfervations the thick-nels of a Plate of Glafs, whole Refraction of the mean refrangible Ray, is measured by the proportion of the Sines 31 to 20, may be $\frac{2}{3^{\circ}}$ of the thicknels of Air producing the fame Co-lours; 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 forts of Rays have other Proportions. But the differences of thole Proportions are fo little that I do not here confider them. On thefe Grounds I have composed the following Ta-Grounds I have composed the following Ta-ble, 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.

[206]

The thickness of colour'd Plates and Particles of

A second se				-
		Air,	Water	Glafs.
na an an an Araba (Araba) Ar an Araba (Araba) Ar Araba Marina	Very black Black	I I	nix ni4	1 [
with the second second	Beginning of	ž	II	17
Their Colours of th	Blue	2 =	14	111
first Order,	White	经	37	37
and the second second	Orange	83	6	47
	Red	9	63	54
	/ Violet		83	-1
	Indigo	125	95	$8\frac{1}{11}$
	Green	14 17-1		9
Of the fecand Order,	Yellow	1)8 10 2	12	97 IO7
	Orange Bright red	17 ²	13	115
	Scarlet	183 103	134	112
	Churple	21 $22\frac{1}{22}$	164	1310
	Blue	2.3 -	$17\frac{1}{2^{\circ}}$	157-
Of the third Order,	Green	255	18-2	10-
	Red	29	213	185
	Bluifh'red	32	24	203
	S Bluifh green	24	251	22
Of the fourth Order,	Schlowich green	355	2.6 <u>+</u>	$22\frac{3}{2}$
	ZRed	30 40 - 7	301	20
Of the fifth Order	Greenish blue	46	341	20-
Of the mill Order,	Z Red	522	393	34
Of the firth Order	SGreenish blue	587	44	38
Of the fixth Order,	ZRed	65	484	42
Of the feventh Or-	SGreenish blue	7 I	537	453
der,	Ruddy white	77	577	493
· · · ·		•		

Now

Now if this Table be compared with the 6th Scheme, you will there fee the conflictution of each Colour, as to its Ingredients, or the original Colours of which it is compounded, and thence be enabled to judge of its Intenfeneis or Imperfection; which may fuffice in explication of the 4th and 18th Observations, unless it be farther defired to delineate the manner how the Colours appear, when the two Object-glaffes are laid upon one another. To do which, let there be defcribed a large Arc of a Circle, and a ftreigth Line which may touch that Arc, and parallel to that Tangent feveral occult Lines, at fuch diffances from it, as the Numbers fet 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 flow at what diffances from the center, or Point of contract, each Colour is reflected.

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

a very

4

^[207]

208

* 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 43, to which add 9, the thickness exhibiting blue of the fecond Order, and the Sum will be 133; which is the thickness exhibiting the purple of the third Order.

To explain, in the next place, the circum-flances of the 2d and 3d Observations; that is, how the Ring's of the Colours may (by turning the Prifms 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 Glaffes, and that according to the Table in the 7th Obfervation, 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 faid Air than those of red, are thereby made more oblique to the fecond Superficies, at which they are reflected to produce the colour'd Rings, and confequently the yellow Circle in each Ring will be more dilated than the red; and the Excess of its Dilatation will be fo 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 fame Ring. And for the fame reafon the green, blue and violet, will be alfo fo much dilated by the ſŧill

fill greater obliquity of their Rays, as to become all very nearly of equal extent with the red, that is, equally diffant from the center of the Rings. And then all the Colours of the fame Ring muft be coincident, and by their mixture exhibit a white Ring. And thefe white Rings muft have black and dark Rings between them, becaufe they do not fpread and interfere with one another as before. And for that reafon alfo they muft become diffincter and vifible to far greater numbers. But yet the violet being obliqueft will be fomething more dilated in proportion to its extent than the other Colours, and fo 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 fenfibly dilated than the red and yellow, and fo being farther removed from the center of the Rings, the Colours muft 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 reafon of the greateft obliquity of its Rays, being in proportion most of all expanded, will foonest appear at the exterior Limb of each white Ring, and become more confpicuous than the rest. And the feveral Series of Colours belonging to the feveral Rings, will by their unfolding and spreading, begin again to interfere, and thereby render the Rings lefs diffinct, and not visible to fo great numbers.

If

If inflead of the Prifms the Object-glaffes be made use of, the Rings which they exhibit become not white and diffinct by the obliquity of the Eye, by reason that the Rays in their passage through that Air which intercedes the Glaffes are very nearly parallel to those Lines in which they were first incident on the Glaffes, and confequently the Rays endued with feveral Colours are not inclined one more than another to that Air, as it happens in the Prifms.

There is yet another circumstance of these Experiments to be confider'd, and that is why the black and white Rings which when view'd at a diftance appear diftinct, 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 reafon is, that the Rays which enter the Eye at feveral parts of the Pupil, have feveral Obliquities to the Glaffes, and those which are most oblique, if confider'd apart, would reprefent 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 leaft oblique. And this Expansion is to much the greater by how much the greater is the difference of the Obli-quity; 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 fecond, or farther Superficies of the thinn'd Air at which they are reflected, and have also the greatest varia. variation of Obliquity, which makes that Colour fooneft emerge out of the edges of the white. And as the breadth of every Ring is thus augmented, the dark Intervals muft be diminifh'd, until the neighbouring Rings become continuous, and are blended; the exterior first, and then those nearer the center, fo that they can no longer be dillinguish'd apart, but seem to conflitute an even and uniform whiteness.

Among all the Observations there is none accompanied with fo odd circumstances as the twenty fourth. Of those the principal are, that in thin Plates, which to the naked Eye feem of an even and uniform transparent whiteness, without any terminations of Shadows, the Refraction of a Prifm fhould make Rings of Colours appear, whereas it ufually 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 diffinct and white, although it ufually renders Objects confused and coloured. The Caufe of these things you will underftand by confidering, that all the Rings of Co-lours are really in the Plate, when view'd with the naked Eye, although by reason of the great breadth of their Circumferences they fo much interfere and are blended together, that they feem to constitute an uniform whiteness. But when the Rays pais through the Prifm to the Eye; the Orbits of the feveral Colours in every Ring are refracted, fome more than others, according to their degrees of Refrangibility: By which means the Colours on one fide of the P_2 Ring [212]

Ring (that is in the Circumference on one fide of its center) become more unfolded and dilated, and those on the other fide more complicated and contracted. And where by a due Refraction they are fo much contracted, that the several Rings become narrower than to interfere with one another, they must appear diffinct, and also white, if the constituent Colours be fo much contracted as to be wholly coincident. But, on the other fide, 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 diffinct.

To explain this a little farther, fuppofe the concentrick Circles A V, and B X, [in Fig. 7.] represent the red and violet of any Order, which, together with the intermediate Colours, conflitute any one of thefe Rings. Now thefe being view'd through a Prifm, the violet Circle B X, will by a greater Refraction be farther tranflated from its place than the red A V, and fo approach nearer to it on that fide of the Circles, towards which the Refractions are made. For inflance, if the red be translated to av, the violet may be translated to bx, fo as to approach nearer to it at x than before, and if the red be farther tranflated to a v, the violet may be fo much farther translated to bx as to convene with it at x, and if the red be yet farther translated to $\alpha \Upsilon$, the violet may be still fo much farther translated to $\beta \xi$ as to pass beyond it at ξ , and convene with it at e and f. And this being underflood not only of the red and violet, but of all the other intermediate Colours, and and alfo of every revolution of those Colours, you will easily perceive how those of the fame revolution or order, by their nearness at x vand $\Upsilon \xi$, and their coincidence at x v, e and f, ought to conflict pretty diffined Arcs of Cir-cles, 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 feveral at $\Upsilon \xi$, but yet in a contrary order to that which they had before, and still retain beyond e and f. But, on the other fide, at a b, a b, or a β , these Colours must become much more coufused by being dilated and spread fo, as to interfere with those of other Orders. And the fame confusion will happen at $\Upsilon \xi$ be-tween e and f, if the Refraction be very great, or the Prifm very diftant from the Object-glaffes: In which cafe no parts of the Rings will be feen, fave only two little Arcs at e and f, whose diffance from one another, will be augmented by removing the Prifm still farther from the Object-glaffes: And these little Arcs must be distinctest and whitest at their middle, and at their ends, where they begin to grow con-fufed they must be coloured. 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 $\Upsilon \xi$, will be red and yellow on that fide next the center, and blue and violet on the other fide. But their other ends which verge from $\Upsilon \xi$ will on the contrary be blue and violet on that fide to-P 3 wards wards the center, and on the other fide red and yellow.

214

Now as all thefe things follow from the properties of Light by a mathematical way of reafoning, fo the truth of them may be manifelled by Experiments. For in a dark Room, by viewing thefe Rings through a Prifm, by reflexion of the feveral prifmatick Colours, which an affiftant caufes to move to and fro upon a Wall or Paper from whence they are reflected, whilf the Spectator's Eye, the Prifm and the Objectglaffes (as in the 13th Obfervation) are placed fleady: the Pofition of the Circles made fucceflively by the feveral Colours, will be found fuch, in refpect of one another, as I have defcribed in the Figures $a \ b \ x \ v$, or $a \ b \ x \ v$, or $a\beta\xi \Upsilon$. And by the fame method the truth of the Explications of other Obfervations may be examined.

By what hath been faid, the like Phænomena of Water, and thin Plates of Glafs may be underftood. But in fmall fragments of thole Plates, there is this farther obfervable, that where they lye flat upon a Table and are turned about their centers whill they are viewed through a Prifm, they will in fome pollures exhibit Waves of various Colours, and fome of them exhibit thefe Waves in one or two Pofitions only, but the most of them do in all Politions exhibit them, and make them for the most part appear almost all over the Plates. The reason is, that the Superficies of fuch Plates are not even, but have many Cavities and Swellings, which how thallow foever do a little vary the thickness of the Plate. For at the feveral fides of those Cavities, for the Reasons newly described, there ought to be produced Waves in feveral poflures of the Prifm. Now though it be but some very small, and narrower parts of the Glass, by which these Waves for the most part are caufed, yet they may feem 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 for many several Waves, as there were divers orders of Colours promiscuously reflected from that part of the Glass.

Thefe are the principal Phænomena of thin Plates or Bubbles, whole Explications depend on the properties of Light, which I have heretofore deliver'd. And these you see do necef-farily follow from them, and agree with them, even to their very least circumstances; and not only fo, but do very much tend to their proof. Thus, by the 24th Obfervation, it appears, that the Rays of feveral Colours made as well by thin Plates or Bubbles, as by Refractions of a Prifm, have feveral degrees of Refrangibility, where-by 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 affociated together fo as to become visible by themselves like Arcs of Circles. For if the Rays were all alike refrangible, 'tis impossible that the whiteness, which P 4 to - to the naked Senfe 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; fuch 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 fuch irregularities, it would be impossible for Refractions to render those Rings so very diffinct, and well defined, as they do in the 24th Observation. It is necessive therefore that every Ray have its proper and constant degree of Refraction is ever justly and regularly perform'd, and that feveral Rays have several of those degrees.

And what is faid of their Refrangibility may be also understood of their Reflexibility, that is of their Dispositions to be reflected fome at a greater, and others at a lefs 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 alfo, that whiteness is a diffimilar mixture of all Colours, and that Light is a mixture of Rays endued with all those Colours. For confidering the multitude of the Rings of Colours, in the 3d, 12th and 24th Observations, it is manifeft. feft, that although in the 4th and 18th Obfervations 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 whitenes. 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 conftant 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 Obfervations; compared with the 4th or 18th, there appears to be the fame conflant relation between Colour and Reflexibility, the violet being in like circumflances reflected at leaft thickneffes of any thin Plate or Bubble, the red at greatest thicknesses, and the intermediate Colours at intermediate thickneffes. Whence it follows, that the colorifick Dispositions of Rays are also connate with them and immutable, and by confequence that all the Productions and Appearances of Colours in the World are derived not from any phyfical Change caufed in Light by Refraction or Reflexion, but only from the various Mixtures or Separations of Rays, by virtue of their different Refrangibility

or

or Reflexibility. And in this refpect the Science of Colours becomes a Speculation as truly mathematical as any other part of Opticks. I mean fo far as they depend on the Nature of Light, and are not produced or alter'd by the Power of Imagination, or by ftriking or prefling the Eye.



[219]



ТНЕ

SECOND BOOK

O F

OPTICKS.

籡嶶嶶蓙∽孆籡蓤覾嶶礛闣濸峾蔳蔳巤薞蔳蔳遻蔳蔳蔳蔳蔳蔳蔳蔳蔳蔳蔳

PART III.

鏲瘚嫙枩娦獤嫾鹷摡嶶籡鵋嫾迱嫾譥燓慦冹冹嫾嫾嫾瘚峾赺**蓙**嫾嫾**礉**憗滶繎 笍**艞**

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



A M now come to another part of this Defign, which is to confider how the Phænomena of thin transparent Plates fland related to those of all o-

ther natural Bodies. Of these Bodies I have already told you that they appear of divers Co-

lours,

lours, accordingly as they are difpofed to reflect most copiously the Rays originally endued with those Colours. But their Conflictutions, whereby they reflect fome Rays more copiously than others, remain to be difcover'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.

HE Analogy between Reflexion and Re-fraction will appear by confidering, that when Light paffeth obliquely out of one Medi. um into another which refracts from the perpendicular, the greater is the difference of their refractive Denfity, the lefs Obliquity of Incidence is requisite to cause a total Reflexion. For as the Sines are which measure the Refration, fo is the Sine of Incidence at which the total Reflexion begins, to the Radius of the Circle, and confequently that Angle of Incidence is least where there is the greatest difference of the Sincs. Thus in the paffing 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 Anglo of Incidence is about 48 Degrees 35 Minutes. In In paffing out of Glafs 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 fo in paffing 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 in-terceding two transparent Mediums, (such as are Air, Water, Oil, common Glass, Crystal, me-talline Glasses, Island Glasses, white transparent Arfenick, Diamonds, Sc.) the Reflexion is stronger or weaker accordingly, as the Super-ficies bath a greater or less refracting Power ficies hath a greater or lefs refracting Power. For in the Confine of Air and Sal-gem 'tis ftronger than in the Confine of Air and Water, and Itill ftronger in the Confine of Air and common Glafs or Crystal, and stronger in the Con-fine 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 slill weaker if they be immerged in the more firongly refracting Liquors of well rectified Oil of Vitriol or Spirit of Tur-pentine. If Water be diffinguish'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 fomething greater, in

4

in that of Water and Sal-gem still greater, and in that of Water and Glass, or Crystal, or other denfer Substances still greater, accordingly as those Mediums differ more or less in their re-fracting Powers. Hence in the Confine of common Glafs 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 Glaffes of equal denfity, there is not any fenfible Reflexion, as was shewh in the first Observation. And the same may be understood of the Superficies interceding two Crystals, or two Liquors, or any other Sub. stances in which no Refraction is caufed. So then the reason why uniform pellucid Mediums, (fuch as Water, Glafs, or Cryftal) have no fen. fible 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 fame degree of denfity.

222

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.

HAT this is fo has been obferved by others, and will eafily be granted by them that have been converfant with Microlcopes. And it may be alfo tried by applying any fubflance ftance to a hole through which fome Light is immitted into a dark Room. For how opake foever that Subftance may feem in the open Air, it will by that means appear very manifeftly transparent, if it be of a fufficient thinnes. Only white metalline Bodies must be excepted, which by reason of their excessive density feem 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 Corpuscies 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.

HE truth of this is evinced by the two precedent Propositions: For by the fecond 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 fuch Interstices between them, because Reflexions are caused only in Superficies, which intercede Mediums of a differing density by *Prop.* 1.

But

224

But farther, that this difcontinuity of parts is the principal Caufe of the opacity of Bodies, will appear by confidering, that opake Subilances become transparent by filling their Pores with any Subflance of equal or almost equal den. fity 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 and many other Substances foaked in fuch Liquors as will intimately pervade their little Pores, become by that means more transparent than otherwife; fo, on the contrary, the most transparent Substances may by evacuating their Pores, or separating their parts, be render'd fufficiently opake, or Salts or wet Paper, or the *Oculus Mundi* Stone by being dried, Horn by being foraped, Glass by being reduced to Pow. der, or otherwise flawed, Turpentine by being flirred about with Water till they mix imper-fectly, and Water by being form'd into many fmall Bubbles, either alone in the form of Froth, or by shaking it together with Oil of Turpen-tine, or Oil Olive, or with fome other conve-nient Liquor, with which it will not perfectly incorporate, And to the increase of the opaci-ty of these Bodies it conduces fomething, that by the 23d Observation the Reflexions of very thin transparent Substances are considerably flronger than those made by the fame Substances of a greater thickness. quors as will intimately pervade their little of a greater thicknefs.

[225]

PROP. IV.

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

OR the opakeft Bodies, if their parts be fubtily divided, (as Metals by being diffolved in acid Menftruums, $\mathfrak{Gc.}$) become perfectly transparent. And you may also remember, that in the eighth Observation there was no fensible 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 thinness almost infensible, fo 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 Confiderations, 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.

[226]

PROB. 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.

OR if a thinn'd or plated Body, which being of an even thicknefs, appears all over of one uniform Colour, fhould be flit into Threds, or broken into Fragments, of the fame thicknefs with the Plate; I fee no reafon why every Thred or Fragment fhould not keep its Colour, and by confequence why a heap of those Threds or Fragments fhould not conflitute a Mass or Powder of the fame Colour, which the Plate exhibited before it was broken. And the parts of all natural Bodies being like fo many Fragments of a Plate, must on the fame grounds exhibit the fame Colours.

Now that they do fo, will appear by the affinity of their Properties. The finely colourd Feathers of fome Birds, and particularly thofe of Peacocks Tails, do in the very fame part of the Feather appear of feveral Colours in feveral Positions of the Eye, after the very fame manner that thin Plates were found to do in the 7th and 19th Observations, and therefore their Colours arise from the thinnels of the transparent parts of the Feathers; that is, from the flendernels of the very fine Hairs, or Capillamenta, which grow out of the fides of the groffer 227

Stoffer lateral Branches or Fibres of those Feathers. And to the fame purpole it is, that the Webs of fome Spiders by being fpun very fine have appeared colour'd, as fome have observ'd, and that the colour'd Fibres of fome Silks by Varying the Polition of the Eye do vary their Colour. Alfo 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, fome forts of painted Glafs, the Infufion of Lignum Nephriticum, and fome other Substances reflect one Colour, and transmit another, like thin Bodies in the 9th and 20th Obfervations. And fome 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 juftly pretended for those changes, befides the breaking of their parts into lefs parts by that contrition after the fame manner that the Colour of a thin Plate is changed by varying its thicknefs. For which reafon alfo it is that the colour'd Flowers of Plants and Vegetables by being bruifed utually become more transparent than before, or at least in fome degree or other change their Colours. Nor is it much lefs to my purpole, that by mixing divers Liquors very odd and remarkable Productions and Changes of Colours may be effected, of which no caufe can be more obvious and rational than that 2

[228]

the faline Corpufcles of one Liquor do vari-oufly act upon or unite with the tinging Cor-puicles of another, to as to make them fwell, or fhrink (whereby not only their bulk but their denfity alfo may be changed) or to divide them into fimaller Corputcles, (whereby a colour'd Liquor may become transparent) or to make many of them affociate into one clufter, where. by two transparent Liquors may compose a co-lour'd one. For we see how apt those faline Menstruums are to penetrate and diffolve Subflances to which they are applied, and fome of them to percipitate what others diffolve. In like manner, if we confider the various Phanomena 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 fmall to caufe any Reflexion in their Superficies. But when in order to compose Drops of Rain they begin to coalesce and conflitute Globules of all intermediate fizes, those Globules when they become of a convenient fize to reflect fome Colours and transmit others, may conflitute Clouds of various Colours according to their fizes. And I fee not what can be rationally conceived in fo transparent a Subflance as Water for the production of these Colours, besides the various fizes of its fluid and globular Parcels.

[229]

PROP. VI.

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

HIS will appear by confidering, 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 Obfervation, a very little variation of obliquity will change the reflected Colour where the thin Body or fmall Particle is rarer than the ambient Medium, infomuch that fuch a fmall Particle will at diverfly oblique Incidences reflect of all forts of Colours, in fo great a variety that the Colour refulting from them all, confuledly reflected from a heap of fuch Particles, mult 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 fmall Particle be much denfer than the ambient Medium, the Colours according to the 19th Observation are fo little changed by the variation of obliquity, that the Rays which are reflected least obliquely may predominate over the rest fo much as to cause a heap of such Particles to appear very intenfely of their Colour.

It conduces also fomething 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 O_3 brisk

[230]

brisk than those exhibited by the rarer within the denser.

PROP. VII.

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

OR fince the parts of thefe Bodies by *Prop.* 5. do most probably exhibit the fame Colours with a Plate of equal thickness, provided they have the fame refractive density; and fince their parts feem for the most part to have much the fame density with Water or Glass, as by many circumstances is obvious to collect; to determine the fizes 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 defired to know the diameter of a Corpuscle, which being of equal density with Glass thall reflect green of the third Order; the Number 16⁺ shews it to be $\frac{16\frac{1}{4}}{1000000}$ 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 intenfe are most probably of the fecond 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 [23I]

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

mixture of violet and blue. There may be good greens of the fourth order, but the pureft are of the third. And of this order the green of all Vegetables feem to be, partly by reafon of the intenfenefs of their Colours, and partly becaufe when they wither fome of them turn to a greenifh yellow, and others to a more perfect yellow or orange, or perhaps to red, paffing first through all the aforefaid intermediate Colours. Which Changes feem to be effected by the exhaling of the moiflure which may leave the tinging Corpufcles more denfe, and fomething augmented by the accretion of the oily and earthy part of that moifture. Now the green without doubt is of the fame 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 fecond or third order, but the beft are of the third. Thus the Colour of violets feems to be of that order, becaufe their Syrup by acid Liquors turns red, and by urinous and alcalizate turns green. For fince it is of the nature of Acids to diffolve or attenuate, and of Alcalies to precipitate or incraffate, if the purple Colour of the Syrup was of the fecond order, an acid Liquor by attenuating its tinging Corpufcles would change it to a red of the first order, and an Alcali by incraffating them would change it to a green of the fecond order; Q 4 which which red and green, especially the green, feem too imperfect to be the Colours produced by these Changes. But if the faid purple be fup. posed 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 lefs reddifh purple than that of the violets, its Colour most probably is of the fecond order. But yet there being no Body commonly known whole 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 poffibly be the Colour of fome Substances; and particularly the azure Colour of the Skies feems to be of this order. For all Vapours when they begin to condenfe and coalefce into fmall parcels, become first of that bignefs whereby fuch an Azure must be reflected before they can conflitute Clouds of other Colours. And fo 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 großnefs requisite to reflect other Colours, as we find it is by experience.

Whitenefs, 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 233

Metals to be. For whilft the denfeft of Metals, Gold, if foliated, is transparent, and all Metals become transparent if diffolved in Menftruums or vitrified, the opacity of white Metals arifeth not from their denfity alone. They being lefs denfe than Gold would be more tranfparent than it, did not fome other Caufe concur with their denfity to make them opake. And this cause I take to be fuch a bigness of their Particles as fits them to reflect the white of the first order. For if they be of other thickneffes they may reflect other Colours, as is manifest by the Colours which appear upon hot Steel in tempering it, and fometimes upon the Surface of melted Metals in the Skin or Scoria which arifes upon them in their cooling. And as the white of the first order is the strongest which can be made by Plates of transparent Subftances, fo it ought to be ftronger in the denfer Substances of Metals than in the rarer of Air, Water and Glafs. Nor do I fee but that metallic Subflances of fuch a thickness as may fit them to reflect the white of the first order, may, by reafon of their great denfity (according to the tenour of the first of these Propolitions) reflect all the Light incident upon them, and fo be as opake and fplendent as it's poffible for any Body to be. Gold, or Copper mix'd with lefs 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 fo are finaller, than those of Gold and Copper, and

8

[234]

and alfo that they are fo opake as not to fuffer the Particles of Gold or Copper to fhine through them. Now it is fcarce to be doubted, but that the Colours of Gold and Copper are of the fecond 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 Mer. cury argues that they are not much bigger, nor may they be much lefs, left they lofe 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 finaller, 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 fmaller, 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 compu-tation) would be to the Sine of its Refraction, as 71 to 200 or 7 to 200 And therefore the 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 lefs than the thickness of the Skin of those Bubbles in the proportion of 2 to 7. Whence it's poffible that the Particles of Mercury may be as little as the Particles of fome
235

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

Laftly, for the production of black, the Corpufcles must be less than any of those which exhibit Colours. For at all greater fizes there is too much Light reflected to conflitute this Colour. But if they be supposed a little less than is requifite to reflect the white and very faint blue of the first order, they will, according to the 4th, 8th, 17th and 18th Observations, reflect fo very little Light as to appear intenfly black, and yet may perhaps varioully refract it to and fro within themfelves fo long, until it happen to be flifled and loft, by which means they will appear black in all politions of the Eye without any transparency. And from hence may be underflood why Fire, and the more fubtle diffolver Putrefaction, by dividing the Particles of Substances, turn them to black, why finall quantities of black Substances impart their Colour very freely and intenfly to other Subflances to which they are applied; the minute Particles of these, by reafon of their very great number, eafily o-verfpreading the grofs Particles of others; why Glais ground very elaborately with Sand on a Copper Plate, 'till it be well polifi'd, makes the Sand, together with what is worn off from the Glafs and Copper, become very black: why black Subftances do fooneft 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 fo very imall Cor-pufcles;) and why blacks are usually a little inclined

clined 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 Microfcopes may at length be improved to the difcovery of the Particles of Bodies on which their Colours depend, if they are not already in fome meafure arrived to that degree of perfection. For if those Instruments are or can be fo far improved as with fufficient diffinctness to represent Objects five or fix hundred times bigger than at a Foot diffance they appear to our naked Eyes, I should hope that we might be able to difcover fome of the greatest of those Corpufcles. And by one that would magnify three or four thousand times perhaps they might all be discover'd, but those which produce blacknefs. In the mean while I fee nothing material in this Difcourfe that may rationally be doubted of, excepting this Polition. That transparent Corpufcles of the fame thickness and denfity with a Plate, do exhibit the fame Colour. And this I would have underftood not without fome Latitude, as well becaufe those Corpufcles may be of irregular Figures, and many Rays must be obliquely incident on them, and to have a fhorter way through them than the length of their Diameters, as because the **f**traitnefs

[237]

ftraitnefs of the Medium pent in on all fides within fuch Corpufcles may a little alter its Motions or other qualities on which the Reflexion depends. But yet I cannot much fufpect the laft, becaufe I have obferved of fome fmall Plates of Mufcovy Glafs which were of an even thicknefs, that through a Microfcope they have appeared of the fame 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 Satiffaction, if those Corpufcles can be discover'd with Microfcopes; which if we shall at length attain to, I fear it will be the utmoss impossible to fee the more fecret and noble Works of Nature within the Corpufcles by reason of their transparency.

PROP. VIII.

The Caufe of Reflexion is not the impinging of Light on the folid or impervious parts of Bodies, as is commonly believed.

THIS will appear by the following Confiderations. 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 strongly reflecting parts than Water or Glass. But if that should possibly be suppofed, yet it will avail nothing; for the Reflexion is as strong or stronger when the Air is drawn away away from the Glafs, (fuppofe in the Air-Pump invented by Otto Gueric, and improved and made useful 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 lefs obliquely it is in great meafure 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 confidering 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 If any Man fuppofe that it is not reflected it. by the Air, but by the outmost superficial parts of the Glafs, there is still the fame difficulty: Besides, that such a Supposition is unintelligible, and will alfo appear to be falfe by applying Water behind fome part of the Glafs inftead of Air. For fo in a convenient obliquity of the Rays, fuppole of 45 or 46 Degrees, at which they are all reflected where the Air is adjacent to the Glafs, 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 Wa-ter behind the Glass, and not on the striking of the Rays upon the parts of the Glafs. Third-ly, If the Colours made by a Prifm placed at the entrance of a Beam of Light into a darken'd Room be fucceflively caft on a fecond Prifm placed [239]

placed at a greater diffance from the former, in fuch manner that they are all alike incident upon it, the fecond Prifm may be fo inclined to the incident Rays, that thole which are of a blue Colour shall be all reflected by it, and yet those of a red Colour pretty copiously transmit-ted. Now if the Reflexion be caused by the parts of Air or Glais, I would ask, why at the same Obliquity of Incidence the blue should wholly impinge on those parts fo as to be all reflected, and yet the red find Pores enough to be in a great measure transmitted. Fourth-ly, Where two Glasses to uch one another, there is no fensible Reflexion as was declared in the furth Observation; and yet I fee no reason why is no fensible 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 Obser-vation) by the continual fubsiding and exha-ling of the Water grew very thin, there was such a little and almost infensible quantity of Light reflected from it, that it appeared in-tensity black; whereas round about that black Spot, where the Water was thicker, the Refle-xion was so fitrong as to make the Water seem very white. Nor is it only at the least thick-ness of thin Plates or Bubbles, that there is no manifest Reflexion, but at many other thick-ness continually greater and greater. For in the 15th Observation the Rays of the same Co-lour were by turns transmitted at one thickness, and reflected at another thickness, for an in-determinate number of Successions. And yet determinate number of Successions. And yet in

4

[240]

in the Superficies of the thinned Body, where it is of one thickness; there are as many it is of 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 Bub-bles at one and the same place to reflect the Rays of one Colour and transmit those of ano-ther, as they do according to the 13th and 15th Observations. For it is not to be imagined that at one place the Bays which for inflance that at one place the Rays which for inflance exhibit a blue Colour, fhould have the fortune to dafh upon the parts, and thole which exhi-bit 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 fhould hit upon its pores, and the red upon its parts. Laftly, were the Rays of Light reflected by impinging on the folid parts of Bodion, their Boffariers for the folid parts of Bodies, their Reflexions from polifh'd Bodies could not be fo regular as they are. For in polifhing Glafs with Sand, Putty or Tripoly, it is not to be imagined that those Subitances can by grating and fretting the Glass bring all its least Particles to an accurate Polish; fo that all their Surfaces shall be truly plain or truly fpherical, and look all the fame way, fo as together to compose one even Surface. The fmaller the Particles of those Substances are, the fmaller will be the Scratches by which they continually fret and wear away the Glafs until it be polifh'd, but be they never fo fmall they can wear away the Glafs no otherwife than by grating and feratching it, and breaking the **Protu**

ļ

Protuberances, and therefore polifh it no otherwife than by bringing its roughness to a ve-ry fine Grain, fo that the Scratches and Frettings of the Surface become too finall to be visible. And therefore if Light were reflected by impinging upon the folid parts of the Glafs, it would be featter'd as much by the most polish'd Glass as by the roughest. So then it remains a Problem, how Glafs polifh'd by fretting Substances can reflect Light fo regularly as it does. And this Problem is fcarce otherwife to be folved than by faying, that the Reflexion of a Ray is effected, not by a fingle point of the reflecting Body, but by fome 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 diffance shall be shewn hereafter.

Now if Light be reflected not by impinging on the folid parts of Bodies, but by fome other principle; it's probable that as many of its Rays as impinge on the folid parts of Bodies are not reflected but stifled and lost in the Bodies. For otherwife we must allow two forts of Refle-Should all the Rays be reflected which xions. impinge on the internal parts of clear Water or Crystal, those Substances would rather have a cloudy Colour than a clear Transparency. make Bodies look black, it's necessary that many Rays be ftopp'd, retained and loft in them, and it feems not probable that any Rays can be flopp'd and stifled in them which do not impinge on their parts. 美ですが

And

And hence we may understand that Bodies are much more rare and porous than is com. monly believed. Water is nineteen times light. er, and by confequence nineteen times rater than Gold, and Gold is fo rare as very readily and without the least opposition to transmit the and without the real oppointion to training the magnetic Effluvia, and eafily to admit Quick-filver into its Pores, and to let Water país through it. For a concave Sphere of Gold fil-led with Water, and foder'd up, has upon pref-fing the Sphere with great force, let the Water fqueeze through it, and ftand all over its out. fide in multitudes of small Drops, like Dew, without burfting or cracking the Body of the Gold, as I have been inform'd by an Eye witnefs. From all which we may conclude, that Gold has more Pores than folid parts, and by confequence that Water has above forty times more Pores than 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 pleafes, fo that Light may find a ready paffage through transparent Subflances.

The Magnet acts upon Iron through all denfe Bodies not magnetick nor red hot, without any diminution of its virtue; as for inflance, through Gold, Silver, Lead, Glafs, Water. The gravitating Power of the Sun is transmitted through the vaft Bodies of the Planets withcut any diminution, fo as to act upon all their parts to their very centers with the fame Force and [243]

and according to the fame Laws as if the part upon which it acts were not furrounded with the Body of the Planet. The Rays of Light whether they be very fmall Bodies projected, or only Motion or Force propagated, are mo-ved in right Lines; and whenever a Ray of Light is by any Obftacle turned out of its recti-linear way, it will never return into the fame rectilinear way, unlefs perhaps by very great ac-cident. And yet Light is transmitted through pellucid folid Bodies in right Lines to very great diffances. How Bodies can have a fulficient quantity of Pores for producing the Effects is quantity of Pores for producing these Effects is very difficult to conceive, but perhaps not al-together impossible. For the Colours of Bodies arife 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 fmaller, which have as much empty Space between them as equals all the Magnitudes of these fmaller Particles: And that in like manner these smaller Particles are again composed of others much fmaller, all which together are equal to all the Pores or empty Spaces between them; and fo on perpetually till you come to folid Particles, fuch as have no Pores or empty Spaces within them: And if in any groß Body there be, for inftance, three fuch degrees of Particles, the lock of which are failed which Po Particles, the least of which are folid; this Body will have feven times more Pores than folid R 2/ Parts

Parts. But if there be four fuch degrees of Particles, the leaft of which are folid, the Body will have fifteen times more Pores than folid Parts. If there be five degrees, the Body will Parts. If there be not degrees, the Body will have one and thirty times more Pores than folid Parts. If fix degrees, the Body will have fixty and three times more Pores than folid Parts. And fo on perpetually. And there are other ways of conceiving how Bodies may be exceed-ing 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 fame power variously exercised in various Circumstances.

HIS appears by feveral Confiderations. First, Because when Light goes out of Glais 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 Glafs after it has refracted the Light as ob-liquely as is poffible if the Incidence be ftill made more oblique, becomes too flrong to let any of its Rays go through, and by confequence caufes total Reflexions. Secondly, Becaufe Light is alternately reflected and transmitted by thin Plates of Glass for many Successions ac-cordingly as the thickness of the Plate increafes in an arithmetical Progression. For here the thickness of the Glass determines whether that Power by which Glass acts upon Light fhall caufe it to be reflected, or fuffer it to be tranf-

2

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

PROP. X.

If Light be fwifter 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 uncluous and sulphureous Bodies refract more than others of this same density.

ET AB reprefent the refracting plane Surface of any Body, and IC a Ray incident very obliquely upon the Body in C, fo that the



Angle A C I may be infinitely little, and let C R be the refracted Ray. From a given Point B perpendicular to the refracting Surface erect BR meeting with the refracted Ray C R in R, and if C R represent the Motion of the refracted Ray, and this Motion be diftinguish'd into two Motions C B and B R, whereof C B is paral-R 3 lef lel to the refracting Plane, and B R perpendicular to it: C B shall represent the Motion of the incident Ray, and B R the Motion generated by the Refraction, as Opticians have of late explain'd.

[246]

Now if any Body or thing, in moving through any Space of a given breadth terminated on both fides by two parallel Planes, be urged forward in all parts of that Space by Forces tending directly forwards towards the laft 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 feveral diffances be bigger or lefs in any given Propor-tion, the Motion generated by the Forces in the whole paffage 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 confider'd as fuch a Space, the Motion of the Ray generated by the retracting Force of the Body, during its paffage through that Space, that is the Motion B R, mult be in a fubduplicate Proportion of that refracting Force. I fay therefore that the Square of the Line BR, and by confequence the refracting Force of the Body is very nearly as the denfity of the fame Body. For this will appear by the following Ta-ble, wherein the Proportion of the Sines which measure the Refractions of feveral Bodies, the Square of BR fuppofing CB an unite, the Denfities

[247]

fities 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 Bo- dies.	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 proportion- ate.	the ack- fity and fpecifick gravity f the Bo- ly.	the re frastive Power of the Body in espect of its density.
A Pfeudo- l'opazius, being a natural, pellucid, brittle, hairy Stone, of a yellow Colour.	23 to 1.	τ'699	4'27	3979
Air.	3201 to 3200	5'000625	0'0012	5208
Gials of Antimony.		12 500	5 20	4004
Glafe vulgar.	31 to 20	1 1025	2'58	5436
Cryftal of the Rock.	25 to 10	1'445	2'65	\$450
Ifland Cryftal.	sto 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	LISII	1'714	6716
Niter.	32 to 2	1345	1'9	7079
Dantzick Vitriol.	303 to 200	295	1'715	755.1
Oil of Vitriol.	10 to	1041	1 7	6124
Rain Water.	529 to 390	507845	1.1	75+5
Gum Arabick.	31 to 2	11179	1 375	8574
Spirit of Wine well rectified.	Ico to 7	30'8765	0'866	10121
Camphire.	3 to 3	2 1 2.5	0'996	12551
Oil Olive.	22 10 1	SUISIE	0'913	12007
Linseed Oil.	40 to 2	7111948	0.932	12819
Spirit of Tupentine.	25 to I	7 1 1020	0 874	13222
Ambar.	14 to	91 42	1 04	13054
A Diamond.	1 100 to 4	14 949	134	1 14550

The Refraction of the Air in this Table is determin'd by that of the Atmosphere observed $\mathbf{R} \mathbf{4}$ by by Aftronomers. For if Light pafs through many refracting Substances or Mediums gradu. ally denfer and denfer, and terminated with parallel Surfaces, the fum of all the Refractions will be equal to the fingle Refraction which it would have fuffer'd in paffing immediately out of the first Medium into the last. And this holds true, though the number of the refracting Subflances be increased to infinity, and the distances from one another as much decreafed, fo 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 paffing 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 fuf-fer in passing at like obliquity out of a Vacuum immediately into Air of equal denfity with that in the loweft part of the Atmosphere.

[248]

Now although a Pfeudo Topaz, a Selenitis, Rock Cryftal, Ifland Cryftal, Vulgar Glafs, (that is, Sand melted together) and Glafs of Antimony, which are terreftrial ftony alcalizate Concretes, and Air which probably arifes from fuch Subftances by Fermentation, be Subftances very differing from one another in denfity, yet by this Table, they have their refractive Powers almost in the fame proportion to one another as their denfities are, excepting that the Refraction of that ftrange Subftance Ifland Cryftal is a little bigger than the reft. And particularly Air, which is 3500 times rarer than the Pfeudo-Topaz, and 4400 times rarer than Glafs [249]

Glass of Antimony, and 2000 times rarer than the Selenitis, Glass vulgar, or Crystal of the Rock, has notwithstanding its rarity the fame 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, Linfeed Oil, Spirit of Turpentine and Ambar, which are fat fulphureous unctuous Bodies, and a Diamond, which probably is an unctuous Subflance coagulated, have their refractive Powers in proportion to one another as their denfities without any confiderable variation. But the refractive Powers of these unctuous Subflances are two or three times greater in respect of their densities than the refractive Powers of the former Subflances in respect of theirs.

Water has a refractive Power in a middle degree between those two forts of Substances, and probably is of a middle nature. For out of it grow all vegetable and animal Substances, which confist as well of fulphureous 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 Subfances and Water, and accordingly are composed of those two forts 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 feems to be composed of both, united by Fermentation; the Water, by means of fome faline Spirits with which 'tis impregnated, diffolving the Oil, and volatizing it by the action. For Spirit of Wine is inflamable by means of its oily parts, and be-ing diftilled often from Salt of Tartar, grows by every distillation more and more aqueous and phlegmatick. And Chymifts obferve, that Vegetables (as Lavender, Rue, Marjoram, Sc.) distilled per se, before fermentation yield Oils without any burning Spirits, but after fermen-tation yield ardent Spirits without Oils: Which fhews, that their Oil is by fermentation con-verted into Spirit. They find alfo, that if Oils be poured in fmall quantity upon fermentating Vegetables, they dillil over after fermentation in the form of Spirits.

So then, by the foregoing Table, all Bodies feem to have their refractive Powers proportional to their denfities, (or very nearly;) excepting fo far as they partake more or lefs of fulphureous oily Particles, and thereby have their refractive Power made greater or lefs. Whence it feems rational to attribute the refractive Power of all Bodies chiefly, if not wholly, to the fulphureous parts with which they abound. For it's probable that all Bodies abound more or lefs with Sulphurs. And as Light congregated by a Burning-glafs acts moft upon fulphureous Bodies, to turn them into Fire and Flame; fo, fince all action is mutual, Sulphurs ought to act mot most upon Light. For that the action between Light and Bodies is mutual, may appear from this Confideration; 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 feveral thickneffes and denfities, reflect feveral forts of Rays, and thereby appear of feveral Colours, and by confequence that nothing more is requisite for producing all the Colours of natural Bodies than the feveral fizes and denfities of their transparent Particles. But whence it is that these Plates, Fibres and Particles do, according to their feveral thickneffes and denfities, reflect feveral forts of Rays, I have not yet explain'd. To give fome infight into this matter, and make way for underfland-ing the next part of this Book, I fhall 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 underflood before the reason of their actions upon one' another can be known. And becaufe the last Proposition depended upon the velocity of Light, I will begin with a Proposition of that kind.

PROP.

[252]

Рков. 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.

HIS was observed first by Roemer, and and then by others, by means of the E-clipse of the Satellites of Jupiter. For these Eclipfes, when the Earth is between the Sun and *Jupiter*, happen about feven or eight Minutes fooner than they ought to do by the Tables, and when the Earth is beyond the Sun they happen about feven 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 cafe than in the former by the Diameter of the Earth's Orbit. Some inequalities of time may arife from the Excentricities of the Orbs of the Satellites; but those cannot answer in all the Satellites, and at all times to the pofition and distance of the Earth from the Sun. The mean motions of Jupiter's Satellites is also fwifter in his defcent from his Aphelium to his Perihelium, than in his afcent in the other half of his Orb: But this inequality has no respect to the polition of the Earth, and in the three interior Satellites is infenfible, as I find by computation from the Theory of their gravity.

PROP.

[253]

PROP. XII.

Every Ray of Light in its passage through any refracting Surface is put into a certain transent 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 Obfervations it appears, that one and the fame fort of Rays at equal Angles of Incidence on any thin transparent Plate, is alternately reflect-ed and transmitted for many Succeffions accordingly as the thickness of the Plate increases in arithmetical Progression of the Numbers, o, 1, 2, 3, 4, 5, 6, 7, 8, Gc. fo 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 thickness o, 2, 4, 6, 8, 10, 12, Gc. 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, Sc. and thereby make the Rings which appear by Reflexion. And this alternate Re-flexion and Transmission, as I gather by the 24th Observation, continues for above an hundred viciffitudes, and by the Obfervations in the next part of this Book, for many thousands, being propagated from one Surface of a Glafs Plate to the 254

the other, though the thickness of the Plate be a quarter of an Inch or above: So that this alternation feems 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, becaufe it depends on their diffance. By the 21ft Obfervation, if either Surface of a thin Plate of Mufcovy Glafs be wetted, the Colours caufed by the alternate Reflexion and Refraction grow faint, and therefore it depends on them both.

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

It is also influenced by fome action or difpofition, propagated from the first to the second, becaufe otherwife at the fecond it would not depend on the first. And this action or dispofition, in its propagation, intermits and returns by equal Intervals, becaufe in all its progrefs it inclines the Ray at one distance from the first Surface to be reflected by the fecond, at another to be transmitted by it, and that by equal Intervals for innumerable viciffitudes. And becaufe the Ray is difpofed to Reflexion at the distances 1, 3, 5, 7, 9, Sc. and to Transmission at the diftances 0, 2, 4, 6, 8, 10, Sc. (for its transmission through the first Surface, is at the distance o, and it is transmitted through both together, if their diffance be infinitely little or much lefs than 1) the disposition to be transmitted [255]

mitted at the diffances 2, 4, 6, 8, 10, &c. is to be accounted a return of the fame difposition 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; What kind of action or disposition this is; Whether it confifts in a circulating or a vibra-ting motion of the Ray, or of the Medium, or fomething elfe, I do not here enquire. Those that are averse from affenting to any new Dif-coveries, but such as they can explain by an Hypothes, may for the prefent suppose, that as Stones by falling upon Water put the Water into an undulating Notion, and all Bodies by percussion excite vibrations in the Air; fo the Rays of Light, by impinging on any refracting or reflecting Surface, excite vibrations in the refracting or reflecting Medium or Subfance, and by exciting them agitate the folid parts of and by exciting them agitate the folid parts of the refracting or reflecting Body, and by agita-ting them caufe the Body to grow warm or hot; that the vibrations thus excited are pro-pagated in the refracting or reflecting Medium or Subflance, much after the manner that vibrations are propagated in the Air for caufing Sound, and move fafter than the Rays fo as to overtake them; and that when any Ray is in that part of the vibration which confpires with its Motion, it eafily breaks through a refracting Surface, but when it is in the contrary part of the vibration which impedes its Motion, it is eafily reflected; and, by confequence, that e-very Ray is fucceffively difpofed to be eafily re-flected, or eafily transmitted, by every vibration

4

tion which overtakes it. But whether this Hypothefis be true or falfe I do not here confider. I content my felf with the bare Difcovery, that the Rays of Light are by fome caufe or other alternately difpofed to be reflected or refracted for many viciflitudes.

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.

HIS may be gather'd from the 24th Obfervation, where the Light reflected by thin Plates of Air and Glafs, which to the naked Eye appear'd evenly white all over the Plate, did through a Prifm appear waved with many Succeffions of Light and Darknefs made by alternate Fits of easy Reflexion and easy Tranfmission, the Prifm fevering and distinguishing the Waves of which the white reflected Light was composed, as was explain'd above. 257

And hence Light is in Fits of eafy Reflexion and eafy 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 Restron do reflect it most easily.

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

Light by one and the fame Power varioufly exercised in various circumstances, and in Prop. I. 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 fort 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.

HIS is manifest by the 7th and 19th Obfervations.

PROF.

[259]

PROP. XVI.

In feveral forts of Rays emerging in equal Augles out of any refracting Surface into the fame Medium, the Intervals of the following Fits of eafy Reflexion and eafy Transmission are either accurately, or very nearly, as the Cube-Roots of the Squares of the lengths of a Chord, which found the Notes of an Eight, fol, la, fa, fol, la, mi, fa, fol, with all their intermediate degrees answering to the Colours of those Rays, according to the Analogy deferibed in the seventh Experiment of the fecond Part of the first Book.

HIS is manifest by the 13th and 14th Obfervations.

PROP. XVII.

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

This is manifest by the 10th Observation.

PROP.

[260]

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 Restexion are the $\frac{1}{89000}$ th part of an Inch. And of the same length are the Intervals of their Fits of easy Transmission.

HIS 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 fort 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 fet down. And for the same reason I add the two following Propositions.

[261]

PROP. XIX.

If any fort of Rays falling on the polite Surface of any pellucid Medium be reflected back, the Fits of eafy 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 eafy Transmission.

OR fince the Fits of eafy Reflexion and eafy 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 eafy Reflexion, the progression of the distances of these Fits from that point mult begin from 0, and fo be of the Numbers 0, 2, 4, 6, 8, Gc. And therefore the progression of the distances of the intermediate Fits of eafy Transmission reckon'd from the fame point, must be in the progression of the odd Numbers 1, 3, 5, 7, 9, Gc. contrary to what happens when the fits are propagated from points of Refraction.

PROP.

S 3

[262]

Р R о р. XX. -

The Intervals of the Fits of eafy Reflexion and eafy 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.

OR when Light is reflected by the fecond Surface of thin Plates, it goes out afterwards freely at the first Surface to make the Rings of Colours which appear by Reflection, and by the freedom of its egreis, makes the Colours of these Rings more vivid and strong than those which appear on the other fide of the Plates by the transmitted Light. The reflected Rays are therefore in Fits of eafy Tranfmiffion at their egrefs; 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 alfo the Proportions fet 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 fecond Surface, before and after Reflexion, be equal; the diffances of the Fits of eafy Tranfinisiion from either Surface, must be in the fame progression after Reflexion as before; that is, from the first Surface which transmitted them, in the progression of the even Numbers bers 0, 2, 4, 6, $\overline{8}$, $\mathfrak{C}c$. and from the fecond which reflected them, in that of the odd Numbers 1, 3, 5, 7, $\mathfrak{C}c$. But thefe two Propofitions will become much more evident by the Obfervations in the following part of this Book.



54

[264]



ТНЕ

SECOND BOOK



PART IV.

茪ӽ枩濲촜瘷[⋇]⋍⋍⋍⋇⋇[⋇]⋇⋇⋇⋇⋇⋇⋇⋇⋇⋇⋇⋇⋇⋇⋇

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



HERE is no Glafs or Speculum how well foever polifh'd, but, befides the Light which it refracts or reflects re-

a faint Light, by means of which the polifh'd Surface, when illuminated in a dark room by a beam beam of the Sun's Light, may be eafily feen in all politions of the Eye. There are certain Phænomena of this fcatter'd Light, which when I first observed them, feem'd very strange and furprising 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 Glafs Speculum ground concave on one fide and convex on the other, to a Sphere of five Feet and eleven Inches Radius, and quick-filver'd over on the convex fide. 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 diffance of about five Feet and eleven Inches from the Speculum, in fuch manner, that the beam of Light might pass through a little hole made in the middle of the Chart to the Specu-lum, and thence be reflected back to the fame hole: I observed upon the Chart four or five concentric Irifes or Rings of Colours, like Rainbows, encompaffing the hole much after the manner that those, which in the fourth and following Obfervations of the first part of this third Book appear'd between the Object glaffes, en-compafied the black Spot, but yet larger and fainter than those. These Rings as they grew larger and larger became diluter and fainter, fo that the fifth was fcarce visible. Yet fometimes, when the Sun shone very clear, there appear'd faint Lineaments of a fixth and seventh. If the diffance of the Chart from the SpecuSpeculum was much greater or much lefs than that of fix Feet, the Rings became dilute and vanish'd. And if the distance of the Speculum from the Window was much greater than that of fix Feet, the reflected beam of Light would be fo broad at the distance of fix Feet from the Speculum where the Rings appear'd, as to obfcure one or two of the innermost Rings. And therefore I usually placed the Speculum at about fix Feet from the Window; fo 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 exprefs'd.

Obf. 2. The Colours of thefe Rain-bows fucceeded one another from the center outwards, in the fame 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 Objectglasses. 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 encompaffed with a dark grey or ruffet, and that dark grey with the Colours of the first Iris; which Colours on the infide next the dark grey were a little violet and indigo, and next to that a blue, which on the outfide grew pale, and then fucceeded 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 fecond, whose Colours were in order from the infide 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 feem'd of a bluish green within, and red without, but fo faintly that it was difficult to difcern the Colours.

Obf. 3. Measuring the Diameters of thefe Rings upon the Chart as accurately as I could, I found them alfo in the fame proportion to one another with the Rings made by Light transmitted through the two Object-glass. 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 $1\frac{1}{12}$, $2\frac{3}{8}$, $2\frac{1}{12}$, $3\frac{3}{8}$ Inches, whole 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 feems 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 \circ , 1, 2, 3, 4, $\Im c$. I measured also the Diameters of the dark Circles between these luminous ones, and found their Squares in the progression of the numbers bers $\frac{1}{2}$, $\mathbf{1}_{1}^{1}$, $2\frac{1}{2}$, $3\frac{1}{2}$, $4\frac{3}{2}$ Inches. If speculum, being $\mathbf{1}_{1}\frac{1}{2}$, $2\frac{1}{2}\frac{1}{2}$, $4\frac{3}{2}\frac{1}{2}$ Inches. If the diffance of the Chart from the Speculum was increased or diminished, the Diameters of the Circles were increased or diminished proportionally.

Obf. 4. By the analogy between thefe 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 spreate 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.

Obf. 5. Placing a Prifm at the Window to refract the intromitted beam of Light, and caft 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 pafs through to the Speculum, whilf the reft were intercepted by the Paper. And now I found Rings of that Colour only which fell upon the Speculum. If the [269]

the Speculum was illuminated with red, the Rings were totally red with dark Intervals, if with blue they were totally blue, and fo of the other Colours. And when they were illumi-nated 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 1/2, 1-2, 2¹/₂, 3¹/₂. 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 feveral intermediate bigneffes anfwering 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 outfide 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 fpread into the Colours of the neighbouring Rings on either fide, after the manner explain'd in the first and second Part of this Book, and by mixing diluted one another fo that they could not be diffinguish'd, unless near the center where they were least mix'd. For in this Observation I could fee the Rings more diffinctly, and to a greater number than before, being able in the yellow Light to number eight or nine of them, be-fides a faint fhadow of a tenth. To fatisfy my felf how much the Colours of the feveral Rings fpread 2

fpread into one another, I measured the Dia. meters of the fecond and third Rings, and found them when made by the Confine of the red and orange to be to the fame 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. Alfo the Circles made fucceffively by the red, yellow and green, differ'd more from one another than those made fucceffively by the green, blue and indigo. For the Circle made by the violet was too dark to be feen. To carry on the computation, let us therefore suppose that the differences of the Diameters of the Circles made by the utmost 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 in-digo and violet, and outmost violet, are in pro-portion as the differences of the lengths of a Monochord which found the Tones in an Eight; foil, la, fa, fol, la, mi, fa, fol, that is, as the numbers 2, 78, 72, 73, 27, 27, 13. 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 $\frac{1}{78} + \frac{1}{72} + \frac{1}{72} + \frac{1}{77}$ to $\frac{1}{7}$, that is as $\frac{1}{77}$ to $\frac{1}{7}$, 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 $r_{2} + r_{2} + r_{2} + r_{3}^{2} + r_{7}^{2} + r_{7}^{2}$, that is, as $r_{7}^{6} to r_{7}^{2}$

or
271

or as 16 to 5. And therefore these differences will be $\frac{3}{4}$ 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.

Object values of the line tart of this book. Object values of the line tart of this book. appear'd plaineft, I faw 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 Pofitions of the Eye, fwelling and fhrinking 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 diffant 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 poftures of my Eye their center had other politions. They appear'd by the Light of the Clouds propagated to the Speculum through the hole in the Win-dow, and when the Sun fhone through that hole upon the Speculum, his Light upon it was was of the Colour of the Ring whereon it fell, but by its fplendor obfcured the Rings made by the Light of the Clouds, unlefs when the Speculum was removed to a great diffance from the Window, fo that his Light upon it might be broad and faint. By varying the polition 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 conftantly varied upon the Speculum, as it did upon my Eye, the fame Colour always appearing to a By-ftander 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 thefe reflected Colours propagated thither from the Speculum in feveral Angles, and that their production depended not upon the termination of Light and Shadow.

Obf. 7. By the Analogy of all thefe Phænomena with thole of the like Rings of Colours defcribed in the first Part of this Book, it feemed 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-filver were rubb'd off from the backfide of the Speculum, the Glass alone would cause the fame Rings of Colours, but much more faint than before; and therefore the Phænomenon depends not upon the Quick-filver, unless fo far as the Quick-filver by increasing the Reflexion of the backfide of the Glass increases the Light of the Rings of Colours. I found alfo that a Speculum of Metal without Glass made fome Years [273]

Years fince 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 Obfervations 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 flill more oblique, and fo on; fo here, in the fixth Obfervation, the Light which emerged out of the Glass in feveral Obliquities, made the Glafs appear of feveral Colours, and being propagated in those Obliquities to the Chart, there painted Rings of those Colours. And as the reafon why a thin Plate appeared of feveral Co-lours in feveral Obliquities of the Rays, was, that the Rays of one and the fame fort are re-flected by the thin Plate at one obliquity and transmitted at another, and those of other forts transmitted where these are reflected, and reflected where thefe 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 fame fort did at one Obliquity emerge out of the Glafs, at another did not emerge but were reflected back towards the Quick-filver by T

[274]

by the hither Surface of the Glafs, and according. ly as the Obliquity became greater and greater emerged and were reflected alternately for many Succeffions, and that in one and the fame Obliquity the Rays of one fort were reflected, and those of another transmitted. This is manifest by the fifth Observation of this Part of this Book. For in that Obfervation, when the Speculum was illuminated by any one of the prif-matick Colours, that Light made many Rings of the fame 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 caft on the Speculum by the Prifm was varied, the Rings became of the Colour caft on it, and varied their bignefs 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 feemed to me therefore that these Rings were of one and the fame 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 fecond Surface of the Plate after one palfage through it, but here the Rays go twice through the Plate before they are alternately re-flected and transmitted. First, they go through it from the first Surface to the Quick-filver, and then return through it from the Quick-filver to the first Surface, and there are either transmitted

mitted to the Chart or reflected back to the Quick-filver, accordingly as they are in their Fits of eafy Reflexion or Transmillion 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 fame perpendicular Lines, by reafon of the equality of thefe Angles and Lines, are of the fame length and number within the Glafs after Reflexion as before by the 19th Propofition of the third Part of this Book. And therefore fince all the Rays that enter through the first Surface are in their Fits of easy Transmiffion 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 eafy Transmission at their return to the first, and by confequence 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 reafon holds good in all forts of Rays, and therefore all forts must go out promifeu-ously 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, mult be greater after Reflexion than before by the 15th and 20th Propolitions. And thence it may happen that the Rays at their return to the first Surface, may in certain Obliquities be in Fits of eafy Reflexion, and return back to the Quick-filver, and in other interme-diate Obliquities be again in Fits of eafy Tran'-miflion, and fo go out to the Chart, and paint on it the Rings of Colours about the white Spot. T z And

[276]

And becaufe the Intervals of the Fits at equal Obliquities are greater and fewer in the lefs refrangible Rays, and lefs and more numerous in the more refrangible, therefore the lefs 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 encom-passing 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 fecond Obfervation; and thefe Colours in the fecond 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

Thefe feem to be the Reafons of thefe Rings in general; and this put me upon obferving the thicknefs of the Glafs, and confidering whether the Dimensions and Proportions of the Rings may be truly derived from it by computation.

Obf. 8. I measured therefore the thickness of this concavo convex Plate of Glass, and found it every where $\frac{1}{2}$ of an Inch precisely. Now, by the fixth 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 fame, Part 277

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 thicknefs is the $\frac{11}{1513000}$ th or $\frac{1}{137545}$ th part of an Inch, fuppofing the Sines are as 11 to 17. And if this thickness be doubled it transmits the same bright Light of the Second Ring, if tripled it transmits that of the third, and fo on, the bright vellow Light in all thefe cafes being in its Fits of Transmillion. And therefore if its thickness be multiplied 34386 times fo as to become 4 of an Inch it transmits the fame bright Light of the 34386th Ring. Suppose this be the bright yellow Light transmitted perpendicularly from the reflecting convex fide of the Glass through the concave fide to the white Spot in the center of the Rings of Colours on the Chart: And by a Rule in the 7th and 19th Obfervations 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 fame bright Light of the fame Ring in any Obliquity is to this thickness of $\frac{1}{2}$ 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 fix 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 en-compassing it, that is, in this cafe, out of Glass into Air. Now if the thickness of the Glass be Т 3 increafed

[278]

increafed by degrees, fo as to bear to its first thicknefs, (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 Glafs towards the first, fecond, third and fourth Rings of Co-lours) and if the first thickness be divided into 100000000 equal parts, the increased thickneffes will be 100002908, 100005816, 100003725 and 100011633, and the Angles of which these thickneffes are fecants will be 26' 13", 37' 5", 45' 6" and 52' 26", the Radius being 10000000; and the Sines of these Angles are 762, 1079, 1321 and 1525, and the proportional Sines of Refraction 1172, 1659, 2031 and 2345, the Ra-dius being 100000. For fince 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 II to II $\frac{6}{106}$ those Secants will be to the Sines of Refraction as II $\frac{6}{100}$ to 17, and by this Ana-

logy 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 279

to $\frac{1}{2}$ of an Inch as 34386 to 34385, 34384, 34383, 34382, refpectively. And therefore if the thicknels in all these cases be $\frac{1}{2}$ of an Inch (as it is in the Glass of which the Speculum was made) the bright Light of the 34385th Ring shall e-merge where the Sine of Refraction is 1172, and that of the 34384th, 34383th and 34382th Ring where the Sine is 1659, 2031, and 2345 respectively. And in these Angles of Restra-ction the Light of these Rings shall 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 these Rings shall subtend the Angles of Refraction made at the concave Surface of the Speculum, and by confequence their Diameters shall be to the distance of the Chart from the Speculum es those Sines of Refraction doubled are to the Radius, that is, as 1172, 1659, 2031, and 2345, doubled are to 100000. And therefore if the diffance of the Chart from the concave Surface of the Speculum be fix Feet (as it was in the third of these Observations) the Diameters of the Rings of this bright yellow Light upon the Chart shall be 1'688, 2'389, 2'925, 3'375 Inches. For these 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 those found in the third of these Observations by measuring them, viz. with 17: 23, 27: and 33 Inches, and therefore the Theory of deriving these Rings from the thick-T₄ - nefs [280]

nefs of the Plate of Glass of which the Specunefs of the Plate of Glafs of which the Specu-lum was made, and from the Obliquity of the emerging Rays agrees with the Obfervation. In this computation I have equalled the Diameters of the bright Rings made by Light of all Co-lours, to the Diameters of the Rings made by the bright yellow. For this yellow makes the brighteft part of the Rings of all Colours. If you defire 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 Dia-meters of the bright yellow ones in a fubdupli-cate 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 Diamecaufed those Fits, that is by putting the Diamecaufed thole Fits, that is by putting the Diame-ters of the Rings made by the Rays in the Ex-tremities and Limits of the feven Colours, red, orange, yellow, green, blue indigo, violet, pro-portional to the Cube-roots of the Numbers, I, $\frac{2}{2}$, $\frac{1}{2}$, $\frac{1}{3}$, \frac vations.

And thus I fatisfy'd my felf that these Rings were of the fame 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 mat-

ter

[281]

ter out of doubt, I added the following Ob-

Obf. 9. If these Rings thus depend on the thickness of the Plate of Glass, their Diameters at equal diflances from several Speculums made of such concavo-convex Plates of Glass as are ground on the fame Sphere, ought to be reciprocally in a fubduplicate proportion of the thicknesses of the Plates of Glais. 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 fides to the fame Sphere with the former Plate. Its thickness was a parts of an Inch; and the Diameters of the three first bright Rings meafured between the brighest parts of their Orbits at the diffance of fix Feet from the Glafs were 3. $4\frac{1}{7}$. $5\frac{1}{8}$. Inches. Now the thickness of the other Glass being i of an Inch was to the thickness of this Glass as to to that is as 31 to 10, or 310000000 to 10000000, 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 Obfervation by the thinner Glass, 3. 4th. 5th, to the Diameters of the fame Rings made in the third of these Obfervations by the thicker Glafs $1\frac{1}{1+\sigma}$. $2\frac{3}{s}$. $2\frac{1}{1+\sigma}$, that is, the Diameters of the Rings are reciprocally in a fubduplicate proportion of the thickneffes of the Plates of Glass.

So then in Plates of Glass which are alike con-

[282]

concave on one fide, and alike convex on the other fide, and alike quick-filver'd on the con-vex fides, and differ in nothing but their thick-n: (s, the Diameters of the Rings are recipro-cally in a fubduplicate proportion of the thick-nefies of the Plates. And this flews fufficient. ly that the Rings depend on both the Surfaces of the Glafs. They depend on the convex Sur-face becaufe they are more luminous when that Surface is quick-filver'd over than when it is without Quick filver. They depend alfo upon the concave Surface, becaufe without that Sur-face a Speculum makes them and face a Speculum makes them not. They depend on both Surfaces and on the diffances be-tween them, becaufe their bignefs is varied by varying only that diffance. And this depen-dence is of the fame kind with that which the Colours of thin Plates have on the diffance of the Surfaces of those Plates, because the bignefs of the Rings and their proportion to one another, and the variation of their bignefs ari-fing from the variation of the thicknefs of the Glafs, and the orders of their Colours, is fuch as ought to refult from the Propolitions in the end of the third Part of this Book, derived from the Phænomena of the Colours of thin Plates fet down in the first Part.

There are yet other Phænomena of these Rings of Colours but fuch as follow from the fame 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 fome of them.

Qbf.

[283]

Obf. 10. When the beam of the Sun's Light was reflected back from the Speculum not di-rectly to the hole in the Window, but to a place a little diffant 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 confequence in the center of the fpherical 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 fo alfo did the white round Spot, and new Rings of Colours emerged fucceflively out of their common center, and the white Spot became a white Ring encompating them; and the incident and reflect-ed beams of Light always fell upon the oppo-fite parts of this white Ring, illuminating its Perimeter like two mock Suns in the oppofite parts of an Iris. So then the Diameter of this Ring, measured from the middle of its Light on one fide to the middle of its Light on the other fide, was always equal to the diffance between the middle of the incident beam of Light, and the middle of the reflected beam meafured 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 confequence to their Angles of Refraction at their entrance [284]

entrance into the Glafs, but yet their Angles of Reflexion were not in the fame Planes with their Angles of Incidence.

Obf. 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 diffance of the incident and reflected beams at the Chart was a. bout 7 parts of an Inch, and then it began to . grow dark in the middle. And when that di. Itance was about $r_{T'}$ of an Inch, the white Spot was become a Ring encompating a dark round Spot which in the middle inclined to violet and indigo. And the luminous Rings encompaffing it were grown equal to those dark ones which in the four first Observations encompassed them, that is to fay, 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 17. 27. 27, 3 k, Sc. Inches.

When the diffance 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 foon after a yellow and red. And when the Colour at the center was brighteft, being between yellow and red, the bright Rings were grown equal to those Rings which in the four first Observations next encomencompafied them; that is to fay, 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 come equal to the fecond of those and so on. For the Diameters of the white Ring, and of the other luminous Rings encompassing it, were now $I_{T_c}^{+1}$, $2\frac{3}{5}$, $2\frac{1}{7}$, $3\frac{3}{5}$, 5c. or thereabouts.

When the diffance 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 fecond of the luminous Rings was grown equal to the fecond of those, and the first of those which was now become the third Ring was become equal to the third of those, and fo on. For their Diameters were $1\frac{1}{12}$, $2\frac{1}{3}$, $2\frac{1}{12}$, $3\frac{1}{3}$ Inches, the diffance of the two beams of Light, and the Diameter of the white Ring being $2\frac{3}{3}$ Inches.

When thefe two beams became more diflant 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

3

[286]

equal to the first of the bright Rings mentioned 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 be-

The Colours of the Rings in the middle began now to grow very dilute, and if the diitance between the two Beams was increafed half an Inch, or an Inch more, they vanih'd whilf the white Ring, with one or two of the Rings next it on either fide, continued fill vifible. But if the diffance of the two beams of Light was ftill more increafed, thefe alfo vanifhed: For the Light which coming from feveral parts of the hole in the Window fell upon the Speculum in feveral Angles of Incidence, made Rings of feveral bigneffes, which diluted and blotted out one another, as I knew by intercepting fome part of that Light. For if I intercepted that part which was neareft to the Axis of the Speculum the Rings would be lefs, if the other part which was remoteft from it they would be bigger.

they would be bigger. Obf. 12. When the Colours of the Prifm were caft fucceffively on the Speculum, that Ring which in the two laft Obfervations was white, was of the fame bignefs in all the Colours, but the Rings without it were greater in the green than in the blue, and ftill greater in the yellow, and greateft in the red. And, on the contrary, the Rings within that white Circle were lefs in the green than in the blue, and ftill lefs

lefs in the yellow, and leaft 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 Glafs after Reflexion are equal in length and number to the Fits of the fame Ray within the Glass before its Incidence on the reflecting Surface. And therefore fince all the Rays of all forts at their entrance into the Glafs were in a Fit of Transmillion, they were also in a Fit of Transmission at their returning to the same Surface after Reflexion; and by confequence were transmitted and went out to the white Ring on the Chart. This is the reason why that Ring was of the fame bignefs 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 leaft 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 fleps; fo that the Rings of this Colour without are greatest, and within least. And this is the reason why in the last Obfervation, 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.

Thefe are the Phænomena of thick convexoconcave Plates of Glafs, which are every where of the fame thicknefs. There are yet other Phænomena when thefe Plates are a little thicker on one fide than on the other, and others when when the Plates are more or lefs 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, fo far as I have yet observed, follow from the Propositions in the end of the third part of this Book, and fo confpire 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 profecuted. I content my felf with having profecuted this kind of Phænomena fo far as to discover their Cause, and by discovering it to ratify the Propositions in the third Part of this Book.

Obf. 13. As Light reflected by a Lens quick. filver'd on the backfide makes the Rings of Co. lours above defcribed, fo 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, fome Colours ought to be transmitted, as in the case of a Lens, and others to be reflected back to the Eye. For inftance, if the Diameter of a fmall drop or globule of Water be about the 500th part of an Inch, fo that a red-making Ray in paffing through the middle of this globule has 250 Fits of eafy Tranfmiffion within the globule, and that all the red-making Rays which are at a certain diftance from this middle Ray round about it have 249 Fits within the globule, and all the like Rays at a certain farther diffance round about it have 248 Fits, and all those at a certain farther diftance 247 Fits, and fo on; these concen289

concentrick Circles of Rays after their tranf-miflion, falling on a white Paper, will make concentrick Rings of red upon the Paper, fup-poling the Light which pafles through one fin-gle globule, flrong enough to be fenfible. And, in like manner, the Rays of other Colours will make Rings of other Colours. Suppofe now that in a fair Day the Sun fhines through a thin Cloud of fuch globules of Water or Hail, and that the globules are all of the fame bignefs; and the Sun feen through this Cloud fhall ap-pear encompafled with the like concentrick Rings of Colours, and the Diameter of the first Ring of red fhall be $7\frac{1}{4}$ Degrees, that of the fe-cond $10\frac{1}{4}$ Degrees, that of the third 12 Degrees 33 Minutes. And accordingly as the Globules Minutes. And accordingly as the Globules of Water are bigger or lefs, the Rings shall be lefs or bigger. This is the Theory, and Experience answers it. For in June 1692. I faw by reflexion in a Vessel of Hagnating 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 enclos'd one another immediately, fo that their Colours proceeded in this continual order from the Sun outward : blue, white, red; purple, blue, green, pale yellow

yellow and red; pale blue, pale red. The Di. ameter of the fecond Crown measured from the middle of the yellow and red on one fide of the Sun, to the middle of the fame Colour, on the other fide was 9; Degrees, or therea-bouts. The Diameters of the first and third I had not time to measure, but that of the first feemed to be about five or fix Degrees, and that of the third about twelve. The like Crowns appear fometimes about the Moon: for in the beginning of the Year 1664, Feb. 19th at Night, I faw two fuch Crowns about her. The Diameter of the first or innermost was about three Degrees, and that of the fecond 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 thefe Colours were blue and green on the infide of the outward Crown, and red on the outfide of it. At the fame time there appear'd a Halo about 22 Degrees 35' diffant from the center of the Moon. It was elliptical, and its long Diameter was perpendicular to the Horizon, verging below fartheft from the Moon. I am told that the Moon has fometimes three or more concentrick Crowns of Colours encompafiing 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 diffance of 22 Degrees from the

Book II Tab. I. Fig 1 2 lmnopy r and a second sec die Sing and sin hrvens/ABU Red breas Red Clean Green Blear Purple Pron Pron Red Green Green Lan Green Lan Green Blev Fiolet Zed Vellen Red 1977 2 (19-1 Veller Veller Ficher Blenih Gr Red . Blend & Gree Blineigh Gree Red Blen Red D



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



[292]



THE

THIRD BOOK O F



^C PARTI

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



RIMALDO has inform'd us, that \overline{G} if a beam of the Sun's Light be let into a dark Room through a very fmall 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, fo that they cannot be diffinguish'd. These broad Shadows and Fringes have been reckon'd by fome to proceed from the ordinary refraction of the Air, but without due examination of the Matter. For the circumstances of the Phænomenon, fo far as I have observed them, are as follows.

Obf. I. I made in a piece of Lead a fmall Hole with a Pin, whofe breadth was the 42d part of an Inch. For 2I 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, Threds, Pins, Straws, and fuch like flender Subflances placed in this beam of Light, were confiderably 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, whole breadth was but the 280th part of an Inch, being held in this Light, at the diftance of about twelve Feet from the Hole, did caft a Shadow which at the diltance of four Inches from the Hair was the fixtieth part of an Inch broad, that is, above four times broader than the Hair, and at the diftance 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 diffance of ten Feet was the eighth part of an Inch broad, that is 35 times broader. U 3 Nor Nor is it material whether the Hair be encompafied with Air, or with any other pellucid Subitance. For I wetted a polifh'd Plate of Glafs, and laid the Hair in the Water upon the Glafs, and then laying another polifh'd Plate of Glafs upon it, fo that the Water might fill up the fpace between the Glaffes, I held them in the aforefaid beam of Light, fo that the Light might pafs through them perpendicularly, and the Shadow of the Hair was at the fame diflances as big as before. The Shadows of Scratches made in polifh'd Plates of Glafs were alfo much broader than they ought to be, and the Veins in polifh'd Plates of Glafs did alfo caft the like broad Shadows. And therefore the great breadth of thefe Shadows proceeds from fome other caufe than the Refraction of the Air.

Let the Circle X [in Fig. 1.] reprefent the middle of the Hair; A D G, B E H, C F I, three Rays passing by one fide of the Hair at feveral distances; KN Q, L OR, MP S, three other Rays passing by the other fide of the Hair at the like distances; D, E, F, and N, O, P, the places where the Rays are bent in their pasfage by the Hair; G, H, I and Q, R, S, the places where the Rays fall on a Paper G Q; I S the breadth of the Shadow of the Hair cast on the Paper, and T I, V S, 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 T I and V S is bent in passing by the Hair, and turned aside from the Shadow I S, because if any part of of this Light were not bent it would fall on the Paper within the Shadow, and there illuminate the Paper, contrary to experience. And becaufe when the Paper is at a great diffance from the Hair, the Shadow is broad, and therefore the Rays TI and VS are at a great diffance from one another it follows that the Hair acts upon the Rays of Light at a good diffance in their paffing by it. But the action is ftrongeft on the Rays which pafs by at least diffances, and grows weaker and weaker accordingly as the Rays pafs by at diffances greater and greater, as is reprefented in the Scheme: For thence it comes to pafs, that the Shadow of the Hair is much broader in proportion to the diffance of the Paper from the Hair, when the Paper is nearer the Hair, than when it is at a great diflance from it.

Obf. 2. The Shadows of all Bodies (Metals, Stones, Glafs, Wood, Horn, Ice, $\mathfrak{S}c.$) 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 broadelt 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 U_4 rel

296

red without. The fecond Fringe was almost contiguous to the first, and the third to the fecond, and both were blue within and yellow and red without, but their Colours were very faint, efpecially those of the third. The Co-lours 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 floop'd off near the edges with a Diamond cut, be held in the fame beam of Light, the Light which paffes 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 fometimes appear four or five Fringes of Colours. Let A B, C D [in Fig. 2.] reprefent the parallel Planes of a Look-ing glass, and B D the Plane of the Diamondcut, making at B a very obtule Angle with the Plane A B. And let all the Light between the Rays E NI and FBM pafs directly through the parallel Planes of the Glafs, 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 paffes directly through the parallel Planes of the Glafs, and falls upon the Paper between I and M, will be border'd with three or more Fringes at M.

Sa

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

Obf. 3. When the Hair was twelve Feet diflant 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 fame Scale placed nine Feet beyond it; I measured the breadth of the Shadow and Fringes as accurately I could, and found them in parts of an Inch as follows.

[298]

At the diftance of	half a Foot	nine Feet
The breadth of the Shadow		' F
The breadth between the middles of the brigheft Light of the innermoft Fringes on either fide the Shadow	3'; or 3';	30
The breadth between the Middles of the brighteft Light of the middle moft Fringes on either fide the Sha- dow	I 2.3 ±	4. 109
The breadth between the Middles of the brighteft Light of the outmoft Fringes on either fide the Shadow	$\frac{1}{18} \text{ or } \frac{1}{18\frac{1}{2}}$	73
The diftance between the Middles of the brighteft Light of the firft and fecond Fringes	¥ <u>"I's</u> isi	• i T
The diftance between the Middles of the brighteft Light of the fe- cond and third Fringes	r T-yw	- <u>1</u> -1
The breadth of the luminous part (green, white, yellow and red) of the firft Fringe	1.4.2	: Y 772
The breadth of the darker Space be- tween the firft and fecond Fringes	*3*4'++	1
The breadth of the luminous part of the fecond Fringe	*2",9"0"	55
The breadth of the darker Space be tween the fecond and third Fringes	- 1914-191	.8.2

[299]

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

Obf. 4. When the Shadow and Fringes were caft obliquely upon a fmooth white Body, and that Body was removed farther and farther from the Hair, the first Fringe began to appear and look brighter than the reft 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 fecond Fringe began to appear at a lefs diffance from the Hair than that of the third part of an Inch. The fecond Fringe began to appear at a diftance from the Hair of lefs than half an Inch, and the Shadow between that and the third Fringe at a diftance lefs than an Inch, and the third Fringe at a diftance lefs than three Inches. At greater diffances they became much more fenfible, but kept very nearly the fame proportion of their breadths and intervals which they had at their first appearing. For the diffance between the middle of the first and the middle of the second Fringe, was to the diftance between the middle of the fecond and middle of the third Fringe, as three to two, or ten to feven. And the last of these two diffances 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 fecond Fringe as feven to four,

four, and to the dark Interval of the first and fecond Fringe as three to two, and to the like dark Interval between the fecond and third as two to one. For the breadths of the Fringes feem'd to be in the progression of the Numbers $\mathbf{I}, \sqrt{\frac{1}{3}}, \sqrt{\frac{1}{3}}, and$ their Intervals to be in the fame progression with them; that is, the Fringes and their Intervals together to be in the continual progression of the Numbers $\mathbf{I}, \sqrt{\frac{1}{3}}, \sqrt{\frac$

Obf. 5. The Sun shining into my darken'd Chamber through a Hole a quarter of an Inch broad; I placed at the diffance of two or three Feet from the Hole a Sheet of Paftboard, which was black'd all over on both fides, 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 failen'd to the Pailboard with Pitch the Blade of a fharp Knife, to intercept fome part of the Light which palled through the Hole. The Planes of the Palt-board and Blade of the Knife were parallel to one another, and perpendicular to the Rays. And when they were fo placed that none of the Sun's Light fell on the Pailboard, but all of it paffed through the Hole to the Knife, and there part of it fell upon the Blade of the Knife, and part of it paffed by its edge: I let this part of the

the Light which paffed by, fall on a white Pa-per two or three Feet beyond the Knife, and there faw two streams of faint Light shoot out both ways from the beam of Light into the shadow like the Tails of Comets. But becaufe the Sun's direct Light by its brightnefs upon the Paper obscured these faint streams, so that I could fcarce fee them, I made a little hole in the midit of the Paper for that Light to pafs through and fall on a black Cloth behind it; and then I faw the two ftreams 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 ftrong for the fpace of about a quarter of an Inch, or half an Inch, and in all its progrefs from that direct Light decreafed gradually till it became infenfible. The whole length of either of these streams measured upon the Paper at the diffance of three Feet from the Knife was about fix or eight Inches; fo that it fubtended an Angle at the edge of the Knife of about 10 or 12, or at most 14 Degrees. Yet fometimes I thought I faw it fhoot three or four Degrees farther, but with a Light fo very faint that I could fcarce perceive it, and fufpected it might (in fome measure at least) arise from fome other caufe than the two ftreams did. For placing my Eye in that Light beyond the end of that fiream which was behind the Knife, and looking towards the Knife, I could fee a line of Light upon its edge, and that not only when my Eye was in the line of the Streams, but alfo when it was without that line either towards the

í.

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 feem'd to pass between the Light of that Fringe and the edge of the Knife, and that which passed nearest the edge to the most bent, though not all of it.

Obf. 6. I placed another Knife by this, for that their edges might be parallel and look towards one another, and that the beam of Light might fall upon both the Knives, and fome part of it pass between their edges. And when the distance of their edges was about the 400th part of an Inch the fiream parted in the middle, and left a Shadow between the two parts. This Shadow was fo black and dark that all the Light which paffed between the Knives feem'd to be bent, and turn'd afide to the one hand or to the other. And as the Knives still approached one another the Shadow grew broad. er, 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 leaft bent, and goes to the inward ends of the Streams, paffes by the edges of the Knives at the greateft diffance, and this diffance when the Shadow begins to appear between the Streams is about the 800 part of an Inch. And the Light which paffes by the edges of the Knives at diffances still lefs and lefs is more and more [303]

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.

Obf. 7. In the fifth Observation the Fringes did not appear, but by reafon of the breadth of the hole in the Window became fo broad as to run into one another, and by joining, to make one continued Light in the beginning of the Streams. But in the fixth, as the Knives approached one but in the fixth, as the Knives approached one another, a little before the Shadow appear'd between the two ftreams, the Fringes began to appear on the inner ends of the Streams on either fide of the direct Light, three on one fide made by the edge of one Knife, and three on the other fide made by the edge of the o-ther Knife. They were diffincteft when the Knives were placed at the greateft diffance from the hole in the Window and ftill become more the hole in the Window, and ftill became more diffinct by making the hole lefs, infomuch that I could fometimes fee a faint Lineament of a fourth Fringe beyond the three above men-tion'd. And as the Knives_continually approach'd one another, the Fringes grew di-Hincler 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 felf on both fides into the Streams of Light deferibed 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 fo [great that the Rays which go to the innermost Fringe feem'd to be bent above twenty times more when this Fringe was ready to vanish, than when one of the Knives was taken away.

[304]

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 fecond 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 fecond, and that of the Streams of Light deforibed in the fifth and fixth Observations pasfed by the edges of the Knives at less distances than that of any of the Fringes.

Obf. 8. I caufed the edges of two Knives to be ground truly firait, and pricking their points into a Board fo that their edges might look towards one another, and meeting near their points contain a rectilinear Angle, I faften'd their Handles together with Pitch to make this Angle invariable. The diftance of the edges of the Knives from one another at the diftance 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 I Degree 54'. The Knives thus fix'd together I placed in a beam of
305]

of the Sun's Light, let into my darken'd Cham-ber through a hole the 42d part of an Inch wide at the diffance of 10 or 15 Feet from the hole, and let the Light which paffed between their edges fall very obliquely upon a fmooth white Ruler at the diffance of half an Inch, or an Inch from the Knives, and there faw the Fringes made by the two edges of the Knives 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 fensibly broader, till they met in An-gles 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 di-flance from the Knives, the Fringes where they were farther from the place of their meeting, were a little narrower, and became fomething broader and broader as they approach'd nearer broader and broader as they approach'd nearer and nearer to one another, and after they met they crofs'd one another, and then became much broader than before.

Whence I gather that the diffances at which the Fringes pafs by the Knives are not increa-fed nor alter'd by the approach of the Knives, but the Angles in which the Rays are there bent are much increafed by that approach; and that the Knife which is neareft any Ray determines which way the Ray fhall be bent, and the other Knife increafes the bent Knife increases the bent.

Obf. 9. When the Rays fell very obliquely upon the Ruler at the diffance of the third part of an Inch from the Knives, the dark line between the first and second Fringe of the Sha-Х 'dow

, dow of one Knife, and the dark line between the first and fecond Fringe of the Shadow of the other Knife met with one another, at the diffance of the fifth part of an Inch from the end of the Light which paffed between the Knives at the concourse of their edges. And therefore the diffance of the edges of the Knives at the meeting of thefe dark lines was the 160th part of an Inch. For as four Inches to the eighth part of an Inch, fo is any length of the edges of the Knives meafured from the point of their concourfe to the diffance of the edges of the Knives at the end of that length, and fo 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 paffes between the Knives where they are diffant the 160th part of an Inch, and the one half of that Light passes by the edge of one Knife at a di-flance 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 paffes by the edge of the other Knife, at a diffance 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 diffance from the Knives greater than the third part of an Inch, the dark lines above mention'd meet at a greater diflance than the fifth part of an Inch from the end of the Light which paffed between the Knives at the concourfe of their edges; and therefore the Light which falls upon the Paper where those dark lines meet passes between the Knives

[306].

8

307

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

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

Distances of thePaper from the Knives in Inches.	Diflances between the edges of the Knives in millefimal parts of an Inch.
I ¹ /2.	0'012
37.	0'020
8 <u>;</u> .	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 fame Light at all diffances of the Paper from the Knives, but when the Paper is held near the Knives, the Fringes are made by Light which paffes by the edges of the Knives at a lefs diffance, and is more bent than when the Paper is held at a greater diffance from the Knives Knives. Ob[.

X 2

[308]

Obf. 10. When the Fringes of the Shadows of the Knives fell perpendicularly upon a Paper at a great diffance from the Knives, they were in the form of Hyperbolas, and their Dimen-fions were as follows. Let C A, C B [in Fig. 3.] reprefent lines drawn upon the paper parallel to the edges of the Knives, and between which u the Light would fall if it paffed between 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 An-gles 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 is, f k t, and g l v, three hyperbolical lines reprefenting 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 fecond and third Fringes of the fame Shadow ; x ip, ykq and $\approx l r$, three other hyperbolical lines repre-fenting 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 fecond and third Fringes of the fame Shadow. And conceive that thefe three Hyperbolas are like and equal to the former three, and crofs them in the points i, k and l, and that the Shadows of the Knives are terminated and diffinguish'd from the first luminous Fringes by the lines e i s and x i p, until the meeting and croffing of the Fringes, and then those lines cross the Fringes in the form of dark lines, terminating the first luminous Fringes within fide, and diffinguishing them from another Light which begins begins to appear at *i*, and illuminates all the triangular fpace *i p* DE *s* comprehended by thefe dark lines, and the right line D E. Of thefe Hyperbolas one Afympote is the line D E, and the other Afympotes are parallel to the lines CA and C B. Let r v reprefent a line drawn any where upon the Paper parallel to the Afymptote D E, and let this line crofs the right lines A C in *m* and B C in *n*, and the fix dark hyperbolical lines in *p*, *q*, *r*; *s*, *t*, v; and by mea-furing the difference *p s*, *q t*, *r v*, and thence collecting the lengths of the Ordinates n p, n q, *n r* or *m s*, *m t*, *m v*, and doing this at feveral difference of the line *r v* from the Afymptote D D, you may find as many points of thefe Hy-D D, you may find as many points of the Hyperbolas as you pleafe, and thereby know that thefe curve lines are Hyperbolas differing little from the conical Hyperbola. And by meafuring the lines C_i , C_k , C_i , you may find other points of thefe Curves. For inflance, when the Knives were diffant

from the hole in the Window ten Feet, and the from the hole in the Window ten Feet, and the Paper from the Knives nine Feet, and the An-gle contained by the edges of the Knives to which the Angle A C B is equal, was fubtend-ed by a Chord which was to the Radius as \mathbf{I} to 32, and the diffance of the line rv from the Afymptote 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 diffances of the X 3 brighteft X 3

310

brighteft 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. Obf. 11. The Sun fhining into my darken'd Room through a fmall round hole made in a

Plate of Lead with a flender Pin as above; I placed at the hole a Prifm to refract the Light, and form on the opposite Wall the Spectrum of Colours, defcribed in the third Experiment of the first Book. And then I found that the Shadows of all Bodies held in the coloured Light between the Prifm 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 fenfible blue or violet, and in the deep blue Light they were totally blue without any fenfible red or yellow; and fo in the green Light they were totally green, excepting a little yellow and blue, which were mix'd in the green Light of the And comparing the Fringes made in Prifm. the feveral 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 bignefs. For the Fringes with which the Shadow of a Man's Hair were border'd, being meafur'd crofs the Shadow at the diffance of fix Inches from the Hair; the diffance between the middle and most luminous part of the first or innermost Fringe on one fide of the Shadow, and that of the like Fringe on the other fide of the Shadow was in the full red Light $\frac{1}{37\frac{1}{2}}$ of an Inch, and in the full violet

violet $\frac{1}{\sqrt{27}}$. And the like diffance between the middle and most luminous parts of the fecond Fringes on either fide the Shadow was in the full red Light $\frac{1}{\sqrt{27}}$, and in the violet $\frac{1}{\sqrt{27}}$ of an Inch. And thefe diffances of the Fringes held the fame proportion at all diflances from the Hair without any fenfible variation.

So then the Rays which made thefe Fringes in the red Light paffed by the Hair at a greater diftance than those did which made the like Fringes in the violet; and therefore the Hair in caufing thefe Fringes acted alike upon the red Light or least refrangible Rays at a greater diftance, and upon the violet or most refrangi-ble Rays at a less diftance, and by those actions difpofed the red Light into larger Fringes, and the violet into fmaller, and the Lights of intermediate Colours into Fringes of intermediate bigneffes without changing the Colour of any fort of Light.

When therefore the Hair in the first and fecond of these Observations was held in the white beam of the Sun's Light, and caft a Shadow which was border'd with three Fringes of dow which was border a 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 vari-ous inflexions whereby the feveral forts of Rays were feparated from one another, which before feparation by the mixture of all their Colours, composed the white beam of the Sun's Light, but whenever feparated compose Lights of the feveral Colours which they are originally diffeofeveral Colours which they are originally difpo-fed to exhibit. In this 11th Obfervation, where the

 X_4

[312]

the Colours are feparated before the Light paf. fes by the Hair, the leafl refrangible Rays, which when feparated from the reft make red, were inflected at a greater diffance from the Hair, fo as to make three red Fringes at a greater di-flance from the middle of the Shadow of the Hair; and the most refrangible Rays which when feparated make violet, were inflected at a lefs diflance from the Hair, fo as to make three violet Fringes at a lefs diffance from the middle of the Shadow of the Hair. And other Rays of intermediate degrees of Refrangibility were inflected at intermediate diffances from the Hair, fo as to make Fringes of intermediate Colours at intermediate diffances from the middle of the Shadow of the Hair. And in the fecond Obfervation, where all the Colours are mix'd on the white Light which paffes by the Hair, thefe Colours are feparated 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 infide of the Fringe next the Shadow, the red on the outfide fartheft 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 Pringe 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. Thefe are the three Fringes of colour'd

[313]

lour'd Light with which the Shadows of all Bodies are border'd in the fecond Observation.

When I made the foregoing Obfervations, I defign'd to repeat most of them with more care and exactness, and to make Tome 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 confideration. And fince I have not finish'd this part of my Defign, I shall conclude, with proposing only fome Queries in order to a farther fearch to be made by others:

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

Qu. 2. Do not the Rays which differ in Refrangibility differ alfo in Flexibility, and are they not by their different Inflexions (eparated from one another, fo as after (eparation to make the Colours in the three Fringes above deforibed? And after what manner are they inflected to make those Fringes?

Qu. 3. Are not the Rays of Light in paffing by the edges and fides of Bodies, bent leveral 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, arife from three fuch 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 fame Principle, acting varioufly in various Circumftances?

Qu. 5. Do not Bodies and Light act mutually upon one another, that is to fay, 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 confifts?

Qu. 6. Do not black Bodies conceive heat more eafily 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 flifled and lost?

Qu. 7. Is not the ftrength and vigour of the action between Light and fulphureous Bodies observed above, one reason why fulphureous 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 fhine, and is not this Emiffion perform'd by the vibrating Motions of their parts? And do not all Bodies which abound with terreftrial parts, and efpecially with fulphureous ones, emit Light as often as those parts are fufficiently agitated; whether that agitation be made by Heat, or by Friction, or Percuffion, or Putrefaction, or by any vital Motion, or any other Caufe? As for inftance; Sea Water in a raging Storm; Quickfilver 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 Wa-ters, usually call'd *Ignes Fatui*; Stacks of moist Hay or Corn growing hot by fermentation; Glow-worms and the Eyes of fome Animals by vital Motions; the vulgar *Phosphorus* agitated by the attrition of any Body, or by the acid Particles of the Airs. Ambar and fome Dia Particles of the Air; Ambar and fome Diamonds by ftriking, prefling or rubbing them; Scrapings of Steel ftruck off with a Flint; Iron hammer'd very nimbly till it become fo hot as to kindle Sulphur thrown upon it; the Axle-trees of Chariots taking fire by the rapid rotation of the Wheels; and fome Liquors mix'd with one another whofe Particles come together with an Impetus, as Oil of Vitriol diffilled from its weight of Nitre, and then mix'd with twice its weight of Oil of Annifeeds. So alfo a Globe of Glais about 8 or 10 Inches in diameter, being put into a Frame where it may be fwiftly 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 fame time a piece of white Paper or a white Cloth, or the end of ones Finger be held at the diffance 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 fuch an agitation as to emit Light, and make the white Paper, Cloth or Fin-ger, appear lucid like a Glow-worm; and in rushing out of the Glass will fometimes push againft

[316]

against the Finger fo as to be felt. And the fame 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 fo hot as to emit Light copioufly? For what elfe is a red hot Iron than Fire? And what elfe is a burning Coal than red hot Wood?

Qu. 10. Is not Flame a Vapour, Fume or Exhalation heated red hot, that is, fo 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 shi-ning 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 afcends 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 intenfe, fume copioufly, 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 copioufly, and thereby flames. All flaming Bodies, as Oil, Tallow, Wax, Wood, foffil Coals, Pitch, Sulphur, by flaming wafte and vanish into burning Smoke, which Smoke, if the Flame be put out, is very thick and visible, and fometimes fmells ftrongly, but in the Flame lofes its fmell

fmell by burning, and according to the nature of the Smoke the Flame is of feveral Colours, as that of Sulphur blue, that of Copper open'd with fublimate green, that of Tallow yellow, that of Camphire white. Smoke paffing 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 Char-coal and Sulphur eafily take fire, and fet fire to the Nitre, and the Spirit of the Nitre being thereby rarified into Vapour, rushes out with Exploiton much after the manner that the Va-pour of Water rufhes out of an Æolipile; the Sulphur alfo being volatile is converted into Vapour, and augments the Explosion. And the acid Vapour of the Sulphur (namely that which diffils under a Bell into Oil of Sulphur,) entring violently into the fix't Body of the Nitre, fets loofe the Spirit of the Nitre, and ex-cites a greater Fermentation, whereby the Heat is farther augmented, and the fix'd Body of the Nitre is alfo rarified into Fume, and the Explo-fion 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 caufe 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 arifes therefore from the violent action whereby all the Mixture being quickly and vehemently heated, is rarified and

[318]

and converted into Fume and Vapour: which Vapour, by the violence of that action, becoming fo hot as to fhine, appears in the form of Flame.

Qu. 11. Do not great Bodies conferve their heat the longest, their parts heating one ano-ther, and may not great dense and fix'd Bo-dies, when heated beyond a certain degree, emit Light fo copioufly, as by the Emiflion and Re-action of its Light, and the Reflexions and Refractions of its Ray within its Pores to grow flill hotter, till it comes to a certain period of heat, fuch as is that of the Sun? And are not the Sun and fix'd Stars great Earths vehemently hot, whofe heat is conferved by the greatness of the Bodies, and the mutual Action and Reaction between them, and the Light which they emit, and whofe parts are kept from fuming a-way, not only by their fixity, but alfo by the vaft weight and denfity of the Atmospheres in-cumbent upon them, and very ftrongly com-pressing them, and condensing the Vapours and Exhalations which arife from them? For if Water be made warm in any pellucid Veffel emptied of Air, that Water in the Vacuum will bubble and boil as vehemently as it would in the open Air in a Veffel fet 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 re-quifite to make it boil in vacuo. Alfo a mixture of Tin and Lead being put upon a red hot Iron *in vacuo* emits a Fume and Flame, but the fame

L 317 J fame Mixture in the open Air, by reafon of the incumbent Atmofphere, does not fo much as e-mit any Fume which can be perceived by Sight. In like manner the great weight of the Atmo-phere which lies upon the Globe of the Sun may hinder Bodies there from rifing up and going away from the Sun in the form of Va-pours and Fumes, unlefs by means of a far greater heat than that which on the Surface of our Earth would very eafily turn them into Va-pours and Fumes. And the fame great weight may condenfe thofe Vapours and Exhalations as foon as they fhall at any time begin to afcend from the Sun, and make them prefently fall back again into him, and by that action increafe his Heat much after the manner that in our Earth the Air increafes the Heat of a culinary Earth the Air increases the Heat of a culinary Fire. And the fame weight may hinder the Globe of the Sun from being diminish'd, unless by the Emission of Light, and a very small quan-tity 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, be-ing propagated along the folid Fibres of the op-tick Nerves into the Brain, caufe the Senfe of feeing. For becaufe depts Redice caufe feeing. For becaufe denfe Bodies conferve their Heat a long time, and the denfeft Bodies con-ferve their Heat the longeft, the Vibrations of their parts are of a lafting nature, and there-fore may be propagated along folid Fibres of uniform denfe Matter to a great diffance, for conveying into the Brain the imprefions made upon all the Organs of Senfe. For that Motion which

which can continue long in one and the fame part of a Body, can be propagated a long way from one part to another, supposing the Body homogeneal, fo that the Motion may not be reflected, refracted, interrupted or diforder'd by any unevenness of the Body. Qu 13 Do not several forts of Rays make Vibrations of several bigness, which according to their bigness excite Sensations of several Colours much after the manner that the Vibra

Qu 13 Do not feveral forts of Rays make Vibrations of feveral bignefles, which according to their bignefles excite Senfations of feveral Colours much after the manner that the Vibrations of the Air, according to their feveral bignefles excite Senfations of feveral founds? And particularly do not the most refrangible Rays excite the shortest Vibrations for making a Senfation of deep violet, the least refrangible the largest for making a Senfation of deep red, and the several intermediate forts of Rays, Vibrations of several intermediate bignefles to make Senfations of the feveral intermediate Colours?

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

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

2

321

the Head, and the Fibres on the left fide of both Nerves uniting in the fame place, and af-ter union going into the Brain in the Nerve which is on the left fide of the Head, and these two Nerves meeting in the Brain in fuch a manner that their Fibres make but one entire Species or Picture, half of which on the right fide of the Senforium comes from the right fide of both Eyes through the right fide of both op-tick Nerves to the place where the Nerves meet, and from thence on the right fide of the Head into the Brain, and the other half on the left fide of the Senforium comes in like manner from the left fide of both Eyes. For the optick Nerves of fuch Animals as look the fame way with both Eyes (as of Men, Dogs, Sheep, Oxen, Gc.) meet before they come into the Brain, but the optick Nerves of fuch Animals as do not look the fame way with both Eyes (as of Fishes and of the Chameleon) do not

(as of Filles and of the Chameleon) do not meet, if I am rightly inform'd. Qu. 16. When a Man in the dark preffes either corner of his Eye with his Finger, and turns his Eye away from his Finger, he will fee 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 fuch 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 Se322

cond of Time before they ceafe? And when a Man by a firoke upon his Eye fees a flash of Light, are not the like Motions excited in the *Revina* by the firoke? 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 because the Motions excited in the bottom of the Eye by the Rays of Light are of a lasting nature, and continue till the Coal of Fire in going round returns to its former place? And confidering the lastingnels 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 flagnating 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 diflances. And the Vi-brations or Tremors excited in the Air by per-cuffion, continue a little time to move from the cuffion, continue a little time to move from the place of percuffion in concentrick Spheres to great diffances. And in like manner, when a Ray of Light falls upon the Surface of any pel-lucid 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 arife and be propagated, when they are excited in the bottom of the Eye by the Preflure or Motion of the Finger, or by the Light which comes from the Coal of Fire in the Light which comes from the Coal of Fire in the ExperiExperiments above mention'd? And are not these Vibrations propagated from the point of Incicope to great diffances? And do they not overtake the Rays of Light, and by overtaking them fucceffively, do they not put them into the Fits of easy Reflexion and easy Transmillion defcrib'd above? For if the Rays endeavour to recede from the denseft part of the Vibration, they may be alternately accelerated and retarded by the Vibrations overtaking them. *Qu.* 18. If in two large tall cylindrical Veffels of Glass inverted, two little Thermometers

be fufpended fo as not to touch the Veffels, and the Air be drawn out of one of thefe Veffels, and thefe Veffels thus prepared be carried out of a cold place into a warm one; the Thermo-meter *in vacuo* will grow warm as much, and almost as foon as the Thermometer which is not in vacuo. And when the Veffels are carried back into the cold place, the Thermometer in vacuo will grow cold almost as foon as the other Thermometer. Is not the Heat of the warm Room convey'd through the Vacuum by the Vibrations of a much fubtiler Medium than Air, which after the Air was drawn out remained in the Vacuum? And is not this Medium the fame with that Medium by which Light is re-fracted and reflected, and by whole Vibrations Light communicates Heat to Bodies, and is put into Fits of eafy Reflexion and eafy Tranf-miffion? And do not the Vibrations of this Medium in hot Bodies contribute to the intenfeneis and duration of their Heat? And do not hot Bodies communicate their Heat to contiguous cold Y 2

[324]

cold ones, by the Vibrations of this Medium propagated from them into the cold ones? And is not this Medium exceedingly more rare and tubtile than the Air, and exceedingly more elaflick and active? And doth it not readily pervade all Bodies? And is it not (by its claffick force) expanded through all the Heavens?

force) expanded through all the I-leavens? $Q_{ll.19}$. Doth not the Refraction of Light proceed from the different density of this Æthereal Medium in different places, the Light receding always from the density thereof greater in free and open Spaces void of Air and other großler 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 pafling out of Water, Glafs, Cryflal, and other compact and denfe Bodies into empty Spaces, grow denfer and denfer 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 condenfation of this Medium extend to fome diffance from the Bodies, and thereby caufe the Inflexions of the Rays of Light, which pafs by the edges of denfe Bodies, at fome diffance from the Bodies.

Qu.

[325]

Qu. 21. Is not this Medium much rarer with-in the denfe Bodies of the Sun, Stars, Planets and Comets, than in the empty celefial Spaces between them? And in paffing from them to great diffances, doth it not grow denier and denfer perpetually, and thereby caufe the gra-vity of those great Bodies towards one another, and of their parts towards the Bodies; every Body endeavouring to go from the denfer 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 fee no reafon 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 flow, yet if the elastick force of this Modium has exceeding from the great it may sufficient to Medium be exceeding great, it may fuffice to impel Bodies from the denfer parts of the Medium towards the rarer, with all that power which we call Gravity. And that the elaftick force of this Medium is exceeding great, may be gathered from the fwiftnels of its Vibrations. Sounds move about 1140 English Feet in a fe-cond Minute of Time, and in feven or eight Minutes of Time they move about one hundred English Miles. Light moves from the Sun to us in about feven or eight Minutes of Time, which diftance is about 70000000 English Miles, fupposing the horizontal Parallax of the Sun to Υż be [326]

be about 12''. And the Vibrations or Pulfes of this Medium, that they may caufe the alternate Fits of eafy Transmission and eafy 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 \times 700000 (that is, above 49000000000) 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 flronger in finall Magnets than in great ones in proportion to their bulk, and Gravity is greater in the Surfaces of finall Planets than in those of great ones in proportion to their bulk, and fmall Bodies are agita-ted much more by electric attraction than great ones; fo the fmallness of the Rays of Light may contribute very much to the power of the Agent by which they are refracted. And to if any one fhould 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 fmaller than those of Air, or even than those of Light: The exceeding fmallness 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 confequence exceedingly lefs able to refift the motions of Projectiles, and exceed[327]

exceedingly more able to press upon gross Bo-dies, by endeavouring to expand it felf.

Qu. 22. May not Planets and Comets, and all grois Bodies, perform their Motions more freely, and with lefs refiftance in this Æthereal Medium than in any Fluid, which fills all Space adequately without leaving any Pores, and by conte-quence is much denfer than Quick-filver or Gold ? And may not its refiftance be fo fmall, as to be inconfiderable? For inflance; If this Æther (for fo I will call it) should be supposed 700000 times more elaffick than our Air, and above 700000 times more rare; its refiltance would be above 600000000 times lefs than that of Water. And fo fmall a refiftance would fcarce make any fenfible alteration in the Motions of the Planets in ten thousand Years. If any one would ask how a Medium can be fo rare, let him tell me how the Air, in the upper parts of the Atmosphere, can be above an hundred thoufand thousand times rarer than Gold. Let him alfo tell me, how an electrick Body can by Friction emit an Exhalation fo rare and fubtle, and yet fo potent, as by its Emission to cause no fensible 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 Cop-per, or Leaf Gold, at the diffance of above a Foot from the electrick Body? And how the Effluvia of a Magnet can be fo rare and fubtile, as to pass though a Plate of Glass without any Resistance or Diminution of their Force, and yet fo potent as to turn a magnetick Needle beyond the Glass? 911.

Y 4

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 folid, pellucid and uniform Capillamenta of the optick Nerves into the place of Senfation? 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 folid, pellucid and uniform Capillamenta of those Nerves into the place of Senfation? And fo of the other Senfes.

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 folid, pellucid and uniform Capillamenta of the Nerves into the Muscles, for contracting and dilating them? I fuppose that the Capillamenta of the Nerves are each of them folid 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 suffaces may make the whole Nerve (composed of many Capillamenta) appear opake and white. For opacity arifes from reflecting Surfaces, such as may diflurb and interrupt the Motions of this Medium.

Qu. 25. Are there not other original Properties of the Rays of Light, befides those already defcribed? An inflance of another original Property [329]

Property we have in the Refraction of Island Crystal, defcribed first by *Erasmus Bartholine*, and afterwards more exactly by *Hugenius*, in his Book De la Lumiere. This Crystal is a pellucid fiffile Stone, clear as Water or Crystal of the Rock, and without Colour; enduring a red Heat without lofing its transparency, and in a very firong Heat calcining without Fusion. Steep'd a Day or two in Water, it loses its na-tural Polish. Being rubb'd on Cloth, it attracts pieces of Straws and other light things, like Ambar or Glafs; and with Aqua fortis it makes an Ebullition. It feems to be a fort of Talk, and is found in form of an oblique Parallelopiped, with fix parallelogram Sides and eight folid An-gles. The obtufe Angles of the Parallelograms are each of them 101 Degrees and 52 Minutes; the acute ones 78 Degrees and 8 Minutes. Two of the folid Angles opposite to one another, as C and E, are compafied each of them with three of these obtuse ing scheme. Angles, and each of the other fix 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 Sides, and not in any other Planes. It cleaves with a gloffy polite Surface not perfectly plane, but with fome little unevennefs. It is eafily fcratch'd, and by reafon of its foftnefs it takes a Polifh very difficultly. It polifhes better up-on polifh'd Looking-glafs than upon Metal, and perhaps better upon Pitch, Leather or Parch-ment. 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 tranf-parent parent

[330]

parent and polite. But for feveral Experiments, it is not neceffary to polifh it. If a piece of this cryftalline Stone be laid upon a Book, every Letter of the Book feen 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 Cryftal, it becomes divided into two beams by means of the fame double Refraction. Which beams are of the fame Colour with the incident beam of Light, and feem equal to one another in the quantity of their Light, or very nearly equal. One of thefe Refractions is perform'd by the ufual Rule of Opticks, the Sine of Incidence out of Air into this Cryftal being to the Sine of Refraction, as five to three. The other Refraction, which may be called the unufual Refraction, is perform'd by the following Rule.



Let ADBC reprefent the refracting Surface of

of the Cryftal, C the biggeft folid Angle at that Surface, GEHF the opposite Surface, and CK a perpendicular on that Surface. This perpendicular makes with the edge of the Cryftal CF, an Angle of 19 Degr. 3'. Join KF, and in it take KL, fo that the Angle KCL be 6 Degr. 40'. and the Angle LCF 12 Degr. 23'. And if ST reprefent 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 fame 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 fhall become divided, fhall 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 unufual 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 fuch 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 an unufual Refraction

In like manner Crystal of the Rock has a double

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

When the beam S T incident on Ifland Cryftal, is divided into two beams TV and T X and thefe two beams arrive at the farther Surface of the Glafs; the beam T V, which was refracted at the first Surface after the ufual manner, shall be again refracted entirely after the ufual manner at the fecond Surface; and the beam T X, which was refracted after the unufual manner in the first Surface, shall be again refracted entirely after the unufual manner in the fecond Surface; fo that both these beams shall emerge out of the fecond Surface in lines parallel to the first incident beam S T. And if two pieces of Island Crystal be placed one after another, in fuch manner that all

And if two pieces of Illand Cryital be placed one after another, in fuch 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 unufual manner in the first Surface, shall be refracted after the unufual manner in all the following Surfaces. And the fame 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 fome Rays are in this Experiment conflantly refract-

ed

[333]

ed after the ulual manner, and others confantly after the unufual manner: For if the difference be not original, but arifes from new Modifications imprefs'd on the Rays at their firft Refraction, it would be alter'd by new Modifications in the three following Refractions; whereas it fuffers no alteration, but is conflant, and has the fame effect upon the Rays in all the Refractions. The unufual 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 difcover'd.

Qu. 26. Have not the Rays of Light feveral fides, endued with feveral original Properties? For if the Planes of perpendicular Refraction of the fecond 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 unufual manner in passing through the second Crystal; and the Rays which are refracted after the unufual manner in paffing through the first Crystal, will be all of them refracted after the ufual manner in paffing through the fecond Crystal. And therefore there are not two forts of Rays differing in their nature from one ano-ther, one of which is constantly and in all Po-fitions refracted after the ufuel memory and the fitions refracted after the ufual manner, and the other constantly and in all Positions after the unufual manner. The difference between the two forts of Rays in the Experiment mention'd in the 25th Question, was only in the Politions of 334

of the Sides of the Rays to the Planes of per-pendicular Refraction. For one and the fame Ray is here refracted fometimes after the ufual. and fometimes after the unufual manner, according to the Polition which its Sides have to the Crystals. If the fides of the Ray are posited the fame way to both Crystals, it is refracted after the fame manner in them both: But if that fide of the Ray which looks towards the Coall of the unufual Refraction of the first Cryftal, be 90 Degrees from that fide of the fame Ray which looks towards the Coaft of the unufual Refraction of the fecond Cryftal, (which may be effected by varying the Polition of the fecond Crystal to the first, and by confequence 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 fecond Crystal, shall be refracted after the usual or after the unufual manner, but to turn about this Crystal, fo that the Coast of this Crystal's unufual Refraction may be on this or on that fide of the Ray. And therefore every Ray may be confider'd as having four Sides or Quarters, two of which opposite to one another incline the Ray to be refracted after the unufual manner, as often as either of them are turn'd towards the Coaft of unufual Refraction; and the other two, whenever either of them are turn'd towards the Coast of unusual Refraction, do not incline it to be otherwife refracted than after the usual manner. The two first may there-fore be call'd the Sides of unufual Refraction. And

[335]

And fince these Dispositions were in the Rays before their Incidence on the second, third and fourth Surfaces of the two Crystals, and fuffered no alteration (fo far as appears) by the Refraction of the Rays in their passage. through those Surfaces, and the Rays were refracted by the fame Laws in all the four Surfaces; it appears that those Dispositions were in the Rays originally, and fuffer'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, fome of them after the usual, and fome of them after the unufual manner, accordingly as their Sides of unufual Refraction were then turn'd towards the Coast of the unufual Refraction of that Cryftal, or fideways from it.

Évery Ray of Light has therefore two oppofite Sides, originally endued with a Property on which the unufual Refraction depends, and the other two oppofite 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 diffinguish'd from one another.

by which the oldes of the Rays differ, and are diffinguish'd from one another. In explaining the difference of the Sides of the Rays abovemention'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 unufual manner in the second Crystal, supposing the Planes of perpendicular Refraction to be at right Angles with one

4

one another, as above; and on the contrary, If the Planes of the perpendicular Refractions of the two Crystals be neither parallel nor per-pendicular 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 fecond Crystal. For in this cafe the Rays in each of the two Beams will fome of them have their Sides of unufual Refraction, and fome of them their other Sides turn'd toward the Coaft of the unufual Refraction of the fecond Cryftal.

Qu. 27. Are not all Hypotheles erroneous which have hitherto been invented for explain-ing the Phænomena of Light, by new Modifica-tions of the Rays? For thole Phænomena de-pend not upon new Modifications, as has been fuppofed, but upon the original and unchange-able Properties of the Rays.

2*u.* 28. Are not all Hypothefes erroneous, in which Light is fuppofed to confift in Pref-fion or Motion, propagated though a fluid Me-dium? For in all these Hypothefes, the Phæno-mena of Light have been hitherto explain'd by fuppofing that they arife from new Modifica-tions of the Rays; which is an erroneous Suppolition.

If Light confilled only in Preffion propaga-ted without actual Motion, it would not be a-ble to agitate and heat the Bodies which refract and reflect it. If it confilted in Motion propa-gated to all diffances in an inftant, it would require an infinite force every moment, in every thining

^[336]

[337]

fhining Particle, to generate that Motion. And if it confilted in Preflion or Motion, propagated either in an inflant or in time, it would bend into the Shadow. For Preflion or Motion cannot be propagated in a Fluid in right Lines beyond an Obltacle which stops part of the Mction, but will bend and fpread every way into the quiefcent Medium which lies beyond the Obstacle. Gravity tends downwards, but the Preffure of Water arifing from Gravity tends every way with equal force, and is propagated as readily, and with as much force, fideways as downwards, and through crooked paffages as through ftrait ones. The Waves on the Surface of flagnating Water, paffing by the fides of a broad Obftacle which ftops part of them, bend afterwards and dilate themfelves gradually into the quiet Water behind the Obftacle. The Waves, Pulfes or Vibrations of the Air, where-in Sounds confift bend manifelly though not in Sounds confift, bend manifeftly, though not fo much as the Waves of Water. For a Bell or a Canon may be heard beyond a Hill which intercepts the fight of the founding Body, and Sounds are propagated as readily through crooked Pipes as through ftreight ones. But Light is never known to follow crooked Paffages nor to bend into the Shadow. For the fix'd Stars by the Interpolition of any of the Planets ceale to be feen. And fo do the Parts of the Sun by the Interpolition 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 Z

and is perform'd only in the paffage of the Ray by the Body, and at a very fmall diffance from it. So foon as the Ray is paft the Body, it goes right on.

To explain the unufual Refraction of Island Crystal by Pression or Motion propagated, has not hitherto been attempted (to my knowledge) except by *Huygens*, who for that end fuppofed two feveral vibrating Mediums within that Cry-ftal. But when he tried the Refractions in two fucceflive pieces of that Crystal, and found them fuch as is mention'd above: He confeffed himfelf at a lofs for explaining them. For Preffions or Motions, propagated from a shining Body through an uniform Medium, must be on all fides alike; whereas by those Experiments it appears, that the Rays of Light have different Properties in their different Sides. different Properties in their uncreated duces. He fulpected that the Pulfes of *Æther* in paf-fing through the first Crystal might receive cer-tain 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.

Mais pour dire comment cela fe fait, je n'ay rien trove jufqu' ici qui me fatisfaffe. C. H. de la lumicrc. c. 5. p. 91. Polition of that Cryflal. But what Modifications thole might be he could not fay, nor think of any thing fatisfactory in that Point. And if he had

known that the unufual 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 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 thefe Hypothefes, how Rays can be alternately in Fits of eafy Reflexion and eafy Transmission; unlefs 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 fwifter, 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 confequence is reacted upon the other, and by con fequence is reacted upon, without retarding, fhattering, differing and confounding one an-others Motions, is inconceivable. And against filling the Heavens with fluid Mediums, unless they be exceeding rare, a great Objection arifes from the regular and very lafting Motions of the Planets and Comets in all manner of Courfes through the Heavens. For thence it is mani-feft, that the Heavens are void of all fenfible Refiftance, and by confequence of all fenfible Matter.

For the refifting Power of fluid Mediums arifes partly from the Attrition of the Parts of the Medium, and partly from the Vis inertia of the Matter. That part of the Refiftance of Z_2 a fphe[340]

a fpherical Body which arifes from the Attrition of the Parts of the Medium is very nearly as the Diameter, or at the most, as the Fattum of the Diameter, and the Velocity of the fpherical Body together. And that part of the Refistance which arifes from the Vis inertiæ of the Matter, is as the Square of that Fattum. And by this difference the two forts of Refiftance may be diffinguish'd from one another in any Medium; and these being diffinguish'd, it will be found that almost all the Refistance of Bodies of a competent Magnitude moving in Air, Water, Quick filver, and fuch like Fluids with a competent Velocity, arises from the Vis inertiæ of the Parts of the Fluid.

Now that part of the refifting Power of any Medium which arifes from the Tenacity, Friction or Attrition of the Parts of the Medium, may be diminish'd by dividing the Matter into fmaller Parts, and making the Parts more smooth and flippery: But that part of the Resistance which arises from the *Vis inertia*, is proportional to the Denfity of the Matter, and cannot be diminish'd by dividing the Matter into smaller Parts, nor by any other means than by decrea-fing the Denfity of the Medium. And for these Reasons the Denfity of fluid Mediums is very nearly proportional to their Refiftance. Li-quors which differ not much in Denfity, as Wa-ter, Spirit of Wine, Spirit of Turpentine, hot Oil, differ not much in Refiftance. Water is thirteen or fourteen times lighter than Quick-filver, and by confequence thirteen or fourteen times rarer, and its Refiftance is lefs than that óf
[34I]

of Quick-filver in the fame Proportion, or there-abouts, 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 confequence eight or nine hundred times rarer, and accordingly its Refi-ftance is lefs than that of Water in the fame Proportion, or thereabouts; as I have also found by Experiments made with Pendulums. And in thinner Air the refiftance is still lefs, and at length, by rarifying the Air, becomes infenfi-ble. For fmall Feathers falling in the open Air meet with great Refiltance, but in a tall Glafs well emptied of Air, they fall as fait as Lead or Gold, as I have feen tried feveral times. Whence the Resistance seems still to decrease in proportion to the denfity of the Fluid. For I do not find by any Experiments, that Bodies moving in Quick-filver, Water or Air, meet with any . other fenfible Refiftance than what arifes from the Denfity and Tenacity of those fensible Flu-ids, as they would do if the Pores of those Fluids, and all other Spaces, were filled with a denfe and fubtile Fluid. Now if the Refiltance in a Veffel well emptied of Air, was but an hundred times lefs than in the open Air, it would be about a million of times lefs than in Quick filver. But it feems to be much less in fuch a Veffel, 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-Z 3 CHIMA

cuum we can make below. For fince the Air is comprefs'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 feven 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 fixteen 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, 10000000000 or 10000000000000000000 times rarer; and fo Oh.

Heat promotes Fluidity very much, by dimi-nishing the Tenacity of Bodies. It makes ma-ny Bodies fluid which are not fluid in cold, and increases the Fluidity of tenacious Liquids, as of Oil, Balsam and Honey, and thereby de-creases their Resistance. But it decreases not the Refistance of Water confiderably, as it would do if any confiderable part of the Refistance of Water arole from the Attrition or Tenacity of its Parts. And therefore the Reliftance of Water arifes principally and almost entirely from the Vis inertia of its Matter; and by confe-quence, if the Heavens were as denfe as Water, they would not have much less Resistance than Water; if as denfe as Quick-filver, they would not have much lefs Refiftance than Quick-filver; if abfolutely denfe, or full of Matter without any *Vacuum*, let the Matter be never fo fubtile and fluid, they would have a greater Reliftance

343

Refiftance than Quick-filver. A folid Globe in fuch a Medium would lofe above half its Motion in moving three times the length of its Diameter, and a Globe not folid (fuch as are the Planets) would be retarded fooner. And therefore to make way for the regular and laft-ing Motions of the Planets and Comets, it's ne-cellary to empty the Heavens of all Matter, except perhaps fome very thin Vapours, Steams or Effluvia, arifing from the Atmospheres of the Earth, Planets and Comets, and from such an exceedingly rare Æthereal Medium as we defcribed 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 ferves only to diffurb and retard the Motions of those great Bodies, and make the Frame of Nature languish: And in the Pores of Bodies, it ferves only to stop the vibrating Motions of their Parts, wherein their Heat and Activity confifts. And as it is of no use, and hinders the Operations of Nature, and makes her languish, fo there is no evidence for its Existence, and therefore it ought to be rejected. And if it be rejected, the Hypothefes that Light confifts in Preffion or Motion propagated through fuch a Medium, are rejected with it.

And for rejecting fuch a Medium, we have the Authority of those the oldest and most celebrated Philosophers of Greece and Phænicia, who made a Vacuum and Atoms, and the Gravity of Atoms, the first Principles of their Philosophy; tacitly attributing Gravity to fome o-Z 4 ther, 344

ther Caufe than denfe Matter. Later Philofophers banish the Confideration of fuch a Caufe out of Natural Philofophy, feigning Hypothefes for explaining all things mechanically, and re-ferring other Caufes to Metaphyficks: Whereas the main Bufinefs of Natural Philofophy is to argue from Phænomena without feigning Hy-pothefes, and to deduce Caufes from Effects, till we come to the very first Cause, which cer-tainly is not mechanical; and not only to unfold the Mechanism of the World, but chiefly to refolve thefe and fuch like Queftions. What is there in places almost empty of Matter, and whence is it that the Sun and Planets gravitate towards one another, without denfe Matter between them? Whence is it that Nature doth nothing in vain; and whence arifes all that Order and Beauty which we fee in the World? To what end are Comets, and whence is it that Planets move all one and the fame 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 fo much Art, and for what ends were their feveral 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 Inflinct in Animals? Is not the Senfory of Animals that place to which the fenfitive Subftance is prefent, and into which the fenfible Species of Things are carried through the Nervesand Brain, that there they may be perceived. by

by their immediate prefence to that Subflance? And thefe things being rightly difpatch'd, does it not appear from Phænomena that there is a Being incoporeal, living, intelligent, omniprefent, who in infinite Space, as it were in his Senfory, fees the things themfelves intimately, and throughly perceives them, and comprehends them wholly by their immediate prefence to himfelf: Of which things the Images only carried through the Organs of Senfe into our little Senforiums, are there feen and beheld by that which in us perceives and thinks. And tho' every true Step made in this Philofophy brings us not immediately to the Knowledge of the firft Caufe, 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 fmall Bodies emitted from fhining Subflances? For fuch Bodies will pafs through uniform Mediums in right Lines without bending into the Shadow, which is the Nature of the Rays of Light. They will alfo be capable of feveral Properties, and be able to conferve their Properties unchanged in paffing through feveral Mediums, which is another Condition of the Rays of Light. Pellucid Subflances act upon the Rays of Light at a diffance in refracting, reflecting and inflecting them, and the Rays mutually agitate the Parts of those Subflances at a diffance for heating them; and this Action and Re action at a diffance, very much relembles an attractive Force between Bodies. If Refraction be perform'd by Attraction of the Rays, the Sines of Incidence mult be to the Sines of Refraction [346]

fraction in a given Proportion, as we fhew'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 to-wards 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 afcribed to the Refiftance of an abfolute Vacuum, but must be caused by the Power of the Glafs 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 otherwife 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 balanc'd 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 Glafs, the Attraction of the Glafs 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 very long Telescopes, the one plane the o-ther a little convex, and so compressing them that they do not fully touch, nor are too far afunder. For the Light which falls upon the farther Surface of the first Glass where the Interval between the Glaffes is not above the ten hundred

[347]

hundred thousandth part of an Inch, will go through that Surface, and through the Air or *Vacuum* between the Glasses, and enter into the fecond Glass, as was explain'd in the first, fourth and eighth Observations of the first Part of the fecond Book. But if the fecond Glass be taken away, the Light which goes out of the fecond Surface of the first Glais 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 Glafs, there being nothing elfe to turn it back. Nothing is more requisite for producing all the variety of Colours and degrees of Refrangibi-lity, 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 Sur-faces from the right Course; and the rest as they are bigger and bigger, may make the ftronger and more lucid Colours, blue, green, tronger and more lucid Colours, blue, green, yellow and red, and be more and more diffi-cultly diverted. Nothing more is requifite for putting the Rays of Light into Fits of eafy Re-flexion and eafy Transmission, than that they be fmall Bodies which by their attractive Powers, or fome other Force, flir up Vibrations in what they act upon, which Vibrations being fwifter than the Rays, overtake them fucceflively, and agitate them fo as by turns to increase and de-crease their Velocities, and thereby put them into those Fits. And lastly, the unufual Refrainto those Fits. And lastly, the unufual Refraction of Island Crystal looks very much as if it were perform'd by fome kind of attractive virtue

[348]

tue lodged in certain Sides both of the Rays, and of the Particles of the Cryftal. For were it not for fome kind of Disposition or Virtue lodged in fome 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 per-pendicularly on the Crystal, would not be re-fracted towards that Coast rather than towards any other Coast both at their Incidence and at any other Coaft, both at their Incidence and at their Emergence, fo as to emerge perpendi-cularly by a contrary Situation of the Coaft of unufual Refraction at the fecond Surface; the Crystal acting upon the Rays after they have pass'd through it, and are emerging into the Air, or, if you pease, into a *Vacuum*. And fince the Crystal by this Disposition or Virtue does not act upon the Rays, unlefs when one of their Sides of unufual Refraction looks towards that Coaft, this argues a Virtue or Dif-position in those Sides of the Rays, which an-fwers to and fympathizes with that Virtue or Disposition of the Crystal, as the Poles of two Magnets answer to one another. And as Mag-netism may be intended and remitted, and is found only in the Magnet and in Iron: So this found only in the Wagnet and in Iron: So this Virtue of refracting the perpendicular Rays is greater in Ifland Cryftal, lefs in Cryftal of the Rock, and is not yet found in other Bodies. I do not fay that this Virtue is magnetical; it feems to be of another kind: I only fay, that what ever it be, it's difficult to conceive how the Rays of Light, unlefs they be Bodies, can have a permanent Virtue in two of their Sides which

[349]

which is not in their other Sides, and this with-

which is not in their other sides, and this with-out any regard to their Polition to the Space or Medium through which they pals. What I mean in this Queffion by a Vacuum, and by the Attractions of the Rays of Light to-wards Glafs or Crystal, may be understood by what was faid in the 18th, 19th and 20th Queftions.

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 fo long as they continue fufficiently hot, and Light mutually ftops in Bodies as often as its Rays ftrike upon their Parts, as we fhew'd above. I know no Body lefs apt to fhine 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 fufficient Heat, fhines by Heat like other Bodies.

The changing of Bodies into Light, and Light into Bodies, is very conformable to the Courfe of Nature, which feems delighted with Tranfmutations. Water, which is a very fluid taftinutations. water, which is a very fluid tail-lefs Salt, fhe changes by Heat into Vapour, which is a fort of Air, and by Cold into Ice, which is a hard, pellucid, brittle, fufible Stone; and this Stone returns into Water by Heat, and Vapour returns into Water by Cold. Earth by Heat be-comes Fire, and by Cold returns into Earth: Denfe Bodies by Fermentation rarify into feve-rel forts of Air, and this Air by Fermentation ral forts of Air, and this Air by Fermentation, and fometimes without it, returns into denfe Bodies.

4

Bodies. Mercury appears fometimes in the form of a fluid Metal, fometimes in the form of a hard brittle Metal, fometimes in the form of a corrofive pellucid Salt call'd Sublimate, fometimes in the form of a taitlefs, 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 Diffillation 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 infenfible Magnitudes, and change into Animals; Tadpoles into Frogs: and Worms into Flies. All Birds, Beafts and Fishes, Infects, Trees, and other Vegetables, with their feveral parts, grow out of Wa-ter 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 flanding longer yields a Sediment and a Spirit, but before Putrefaction is fit Nourishment for Animals and Vegetables. And among fuch various and strange Transmutations, why may not Nature change Bodies into Light, and Light into Bodies?

Qu. 31. Have not the fmall Particles of Bodies certain Powers, Virtues or Forces, by which they act at a diffance, 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 one

Į,

[35I]

one upon another by the Attractions of Gravi-ty, Magnetism and Electricity; and these In-ftances 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 confonant and conformable to her felf. How these Attractions may be perform'd, I do not here confider. What I call Attraction may be perform'd by impulse, or by some other means unknown to me. I use that Word here to fignify only in general any Force by which Bodies tend towards one another, whatfoever be the Caufe. 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 Caufe by which the Attraction is perform'd. The At-tractions of Gravity, Magnetifm and Electrici-ty, reach to very fenfible diffances, and fo have been observed by vulgar Eyes, and there may be others which reach to fo fmall distances as hitherto escape Observation; and perhaps ele-ctrical Attraction may reach to such small di-

ftances, 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 fuch 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 after

after it is fatiated with Water? And whence is it but from this attractive Power that Water which alone diffils with a gentle lukewarm Heat, will not diffil 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 fatiated draws no more, and in Diffillation lets go the Water vemore, and in Difficultion lets go the water ve-ry difficultly? And when Water and Oil of Vi-triol poured fucceflively into the fame Veffel 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 coa-lefce with Violence, and by confequence ruffi towards one another with an accelerated Motion? And when Aqua fortis or Spirit of Vi-triol poured upon Filings of Iron, diffolves 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 rufh towards the Parts of the Metal with violence, and run forcibly into its Pores till they get between its outmost Particles and the main Mafs of the Metal, and furrounding those Particles loofen them from the main Mafs, and fet them at liberty to float off into the Water? And when the acid Particles which alone would diffil with an eafy Heat, will not feparate from the Particles of the Metal without a very violent

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

When Spirit of Vitriol poured upon com-mon Salt or Salt-petre makes an Ebullition with the Salt and unites with it, and in Diffillation 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 diffilled, 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 Subftances, or Oil of Turpentine thicken'd with a little Balfam of Sulphur, and the Liquors grow fo very hot in mixing, as prefently to fend up a burn-ing Flame: Does not this very great and fudden Heat argue that the two Liquors mix with vio-lence, 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 fame reason that well rectified Spirit of Wine poured on the fame compound Spi-rit flashes; and that the Pulvis fulminans, compofed of Sulphur, Nitre, and Salt of Tartar, goes off with a more fudden and violent Explofion than Gun powder, the acid Spirits of the Sulphur and Nitre rushing towards one another, and towards the Salt of Tartar, with fo great

Aa

354

great a violence, as by the flock to turn th whole at once into Vapour and Flame? When the Diffolution is flow, it makes a flow Ebulli tion and a gentle Heat; and where it is quick er, it makes a greater Ebullition with more Heat; and where it is done at once, the Ebul lition is contracted into a fudden Blaft or vio lent Explosion, with a Heat equal to that o Fire and Flame. So when a Drachm of the a bove 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 exhau-sted Receiver, which was a Glass fix Inches wide, and eight Inches deep. And even the grofs Body of Sulphur powder'd, and with an equal weight of Iron Filings, and a little Water made into Pafte, acts upon the Iron, and in five or fix 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 Corufcations, Earthquakes, hot fuffocating Exhalations, Hurricanes and Spouts; we may learn that fulphureous Steams abound in the Bowels of the Earth and ferment with Minerals, and fometimes take Fire with a fudden Corufcation and Explosion; and if pent up in fubterraneous Caverns, burft the Caverns with a great fhaking of the Earth, as in fpringing of a Mine. And then the Vapour generated by the Explosion, expiring through the Pores of the Earth.

[355]

Earth, feels hot and fuffocates, and makes Tempefts and Hurricanes, and fometimes caufes the Land to flide, or the Sea to boil, and carries up the Water thereof in Drops, which by their weight fall down again in Spouts. Alfo fome fulphureous Steams, at all times when the Earth is dry, alcending into the Air, ferment there with nitrous Acids, and fometimes taking fire caufe Lightening and Thunder, and fiery Meteors. For the Air abounds with acid Vapours fit to promote Fermentations, as appears by the rufting of Iron and Copper in it, the kindling of Fire by blowing, and the beating of the Heart by means of Refpiration. Now the above mention'd Motions are fo great and vio-lent as to fhew 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 caufes 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 firongly by the Salt of Tartar than by the Metal, and by the fironger Attraction go from the Metal to the Salt of Tartar? And fo when a Solution of Iron in Aqua fortis diffolves the Lapis Calaminaris and lets go the Iron, or a Solution of Copper diffolves Iron im-A a 2 merfed [356]

merfed in it and lets go the Copper, or a Solution of Silver diffolves Copper and lets go the Silver, or a Solution of Mercury in Aqua fortis being poured upon Iron, Copper, Tin or Lead, diffolves the Metal and lets go the Mercury, does not this argue that the acid Particles of the Aqua fortis are attracted more firongly by the Lapis Calaminaris than by Iron, and more firongly by Iron than by Copper, and more firongly by Iron, Copper, Tin and Lead, than by Mercury? And is it not for the fame reafon that Iron requires more Aqua fortis to diffolve it than Copper, and Copper more than the other Metals; and that of all Metals, Iron is diffolved moft eafily, and is moft apt to ruft; and next after Iron, Copper? When Oil of Vitriol is mix'd with a little

When Oil of Vitriol is mix'd with a little Water, or is run per deliquium, and in Diftillation the Water alcends difficultly, and brings over with it fome 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 fhew 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 clofe with the fix'd Body? And is it not for the fame reafon that the Water and acid Spirits which are mix'd together in Vinegar, Aqua fortis, and Spirit of Salt, cohere and rife together in Diftillation; but if the Menftruum be poured on Salt of Tartar, or on Lead or Iron or any fix'd Body which which it can diffolve, the Acid by a ftronger At-traction adheres to the Body, and lets go the Water? And is it not alfo from a mutual At-traction that the Spirits of Soot and Sea Salt unite and compose the Particles of Sal-armoniac, which are lefs volatile than before, becaufe groffer and freer from Water; and that the Particles of Sal-armoniac in Sublimation carry up the Particles of Antimony, which will not fublime alone; and that the Particles of Mercury uniting with the acid Particles of Micra 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 diffolved them, compose a confiftent Body; and that in fubliming Cinnaber from Salt of Tartar, or from quick Lime, the Sulphur by a ftronger Attraction of the Salt or Lime lets go the Mercury, and stays with the fix'd Body; and that when Mercury fublimate is fublimed from Antimony, or from Re-gulus of Antimony, the Spirit of Salt lets go the Mercury, and unites with the antimonial Me-tal which attracts it more ftrongly, and ftays with it till the Heat be great enough to make them both afcend together; and then carries up the Metal with it in the form of a very fu-fale Salt' called Butter of Antimony although fible 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 diffolves Silver and not Gold, and Aqua regia diffolves Gold and not A a 3 Silver,

Silver, may it not be faid that Aqua fortis is fubtile enough to penetrate Gold as well as Sil-ver, but wants the attractive Force to give it Entrance; and that Aqua regia is fubtile enough to penetrate Silver as well as Gold, but wants the attractive Force to give it Entrance? For Aqua regia is nothing elfe than Aqua fortis mix'd with fome Spirit of Salt, or with Sal-ar-moniac, and even common Salt diffolved in A moniac; and even common Salt diffolved in Aqua fortis, enables the Menstruum to diffolve Gold, though the Salt be a grofs 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 dif-folving, mixing with, and weakening the Sal-armoniac or Spirit of Salt, and its not attract-ing, or perhaps repelling the Antimony? And is it not for want of an attractive Virtue be-tween the Parts of Water and Oil, of Qüickfilver and Antimony, of Lead and Iron, that thefe Substances do not mix; and by a weak Attraction, that Quick-filver and Copper mix difficultly; and from a ftrong one, that Quickfilver and Tin, Antimony and Iron, Water and Salts, mix readily? And in general, is it not from the fame Principle that Heat congregates homegeneal Bodies, and feparates heterogeneal ones?

When Arfnick with Soap gives a Regulus, and with Mercury fublimate a volatile fufible Salt,

[358]

359

Salt, like Butter of Antimony, doth not this fhew that Arfnick, which is a Subfance totally volatile, is compounded of fix'd and volatile Parts, firongly cohering by a mutual Artraction, fo that the volatile will not afcend without car-rying up the fixed? And fo, when an equal weight of Spirit of Wine and Oil of Vitriol are digefted together, and in Diffillation yield two fragrant and volatile Spirits which will not mix with one another, and a fix'd black Earth remains behind; doth not this flow that Oil of remains behind; doth not this flew that Oil of Vitriol is compofed of volatile and fix'd Parts ftrongly united by Attraction, fo as to afcend together in form of a volatile, acid, fluid Salt, until the Spirit of Wine attracts and feparates the volatile Parts from the fixed? And therefore, fince Oil of Sulphur *per campanam* is of the fame Nature with Oil of Vitriol, may it not be inferred, that Sulphur is alfo a mixture of volatile and fix'd Parts fo ftrongly cohering by Attraction, as to afcend together in Sublima-tion. By diffolving Flowers of Sulphur in Oil of Turpentine, and diffilling 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 fo fmall a quantity as fcarce to be worth confidering. The acid Salt diffolved in Water, is the fame with Oil of Sulphur per campanam, and abounding much in the Bowels of the Earth, and particularly in Markafites, unites it felf to the other Ingredients of the Markafite, which are, Bitumen, I-Aa4 ron, [360]

ron, Copper and Earth, and with them com-pounds 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 flick together for compounding thefe Minerals, and that the Bitumen carries up the other Ingredients of the Sulphur, which without it would not fublime? And the fame Queftion 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 folid, as appears by their Analyfis; and fo are Salts and Minerals, fo far as Chymifts have been hitherto able to examine their Composition.

When Mercury fublimate is refublimed with frefh Mercury, and becomes *Mercurius dulcis*, which is a white taftlefs Earth fcarce diffolvable in Water, and *Mercurius dulcis* refublimed with Spirit of Salt returns into Mercury fublimate; and when Metals corroded with a little acid turn into Ruft, which is an Earth taftlefs and indiffolvable in Water, and this Earth imbibed with more Acid becomes a metallick Salt; and when fome Stones, as Spar of Lead, diffolved in proper *Menftruums* become Salts; do not thefe things fhew that Salts are dry Earth and watry Acid united by Attraction, and that the Earth will not become a Salt without fo much 361]

much Acid as makes it diffolvable in Water? Do not the fharp and pungent Taftes of Acids arife from the flrong Attraction whereby the acid Particles rufh upon and agitate the Parti-cles of the Tongue? And when Metals are diffolved in acid Menstruums, and the Acids in conjunction with the Metal act after a different manner, fo that the compound has a different tafte much milder than before, and fometimes a fweet one; is it not because the Acids adhere to the metallick Particles, and thereby lofe much of their Activity? And if the Acid be in too fmall a Proportion to make the Compound diffolvable in Water, will it not by adhering ftrongly to the Metal become unactive and lofe its taile, and the Compound be a taftlefs Earth? For fuch things as are not diffolvable by the Moisture of the Tongue, act not upon the Tafte.

As Gravity makes the Sea flow round the denfer and weightier Parts of the Globe of the Earth, fo the Attraction may make the watry Acid flow round the denfer and compacter Particles of Earth for composing the Particles of Salt. For otherwife the Acid would not do the office of a Medium between the Earth and common Water, for making Salts diffolvable in the Water; nor would Salt of Tartar readily draw off the Acid from diffolved Metals, nor Metals the Acid from Mercury. Now as in the great Globe of the Earth and Sea, the denfeft Bodies by their Gravity fink down in Water, and always endeavour to go towards the Center of the Globe; fo in Particles of Salt, the an denfeft [362]

denseft Matter may always endeavour to approach the Center of the Particle: So that a Particle of Salt may be compared to a Chaos: being denfe, hard, dry, and earthy in the Center; and rare, foft, moift, and watry in the Circumference. And hence it feems to be that Salts are of a lafting nature, being fcarce deftroy'd unlets by drawing away their watry Parts by violence, or by letting them foak into the Pores of the central Earth by a gentle Heat in Putrefaction, until the Earth be diffolved by the Water, and feparated into fmaller Particles, which by reafon of their finallness make the rotten Compound appear of a black Colour. Hence also it may be that the Parts of Animals and Vegetables preferve their feveral Forms, and affimilate their Nourishment; the foft and moift Nourishment eafily changing its Texture by a gentle Heat and Motion, till it becomes like the denfe, hard, dry, and durable Earth in the Center of each Particle. But when the Nourishment grows unfit to be affimilated, or the central Earth grows too feeble to affimilate it, the Motion ends in Confusion, Putrefaction and Death.

If a very small quantity of any Salt or Vitriol be diffolved in a great quantity of Water, the Particles of the Salt or Vitriol will not fink to the bottom, though they be heavier in Specie than the Water, but will evenly diffufe themfelves into all the Water, fo as to make it as faline 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 themfelves, and get as far afunder 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; fo 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 faline 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 diffances in rank and file, and by confequence that they acted upon one another by fome Power which at equal diffances is equal, at unequal diffances unequal. For by fuch a Power they will range themfelves uni-formly, and without it they will float irregularly, and come together as irregularly. And fince the Particles of Ifland Cryftal act all the fame way upon the Rays of Light for caufing the unufual Refraction, may it not be fupposed that in the Formation of this Crystal, the Particles not only ranged themselves in rank and file for concreting in regular Figures, but alfo by fome kind of polar Virtue turned their homogeneal Sides the fame way?

The Parts of all homogeneal hard Bodies which fully touch one another, flick together very [364]

very firongly. And for explaining how this may be, fome have invented hooked Atoms, which is begging the Queftion; and others tell us that Bodies are glued together by reft, that is, by an occult Quality, or rather by nothing; and others, that they flick together by confpiring Motions, that is, by relative reft amongft themfelves. I had rather infer from their Cohefion, that their Particles attract one another by fome force, which in immediate Contact is exceeding flrong, at fmall diffances performs the chymical Operations above mention'd, and reaches not far from the Particles with any fenfible Effect.

All Bodies feem to be composed of hard Particles: For otherwife 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 diffolving the Mercury and evaporating the Flegm; Spirit of Wine and Spirit of Urine, by deflegm-ing and mixing them; and Spirit of Urine and Spirit of Salt, by fubliming them together to make Sal-armoniac. Even the Rays of Light feem to be hard Bodies; for otherwife they would not retain different Properties in their different Sides. And therefore Hardnefs may be reckon'd the Property of all uncompounded Matter. At least, this feems to be as evident as the univertal Impenetrability of Matter. For all Bodies, fo far as Experience reaches, are either hard, or may be harden'd; and we have no other Evidence of univerfal Impenetrability, befides a large Experience without an experimental 365

mental Exception. Now if compound Bodies are fo very hard as we find fome of them to be, and yet are very porous, and confift of Parts which are only laid together; the fimple Particles which are void of Pores, and were never yet divided, must be much harder. For such hard Particles being heaped up together, can fcarce touch one another in more than a few Points, and therefore must be separable by much less Force than is requisite to break a folid Particle, whofe Parts touch in all the Space between them, without any Pores or Interffices to weaken their Cohefion. And how fuch very hard Particles which are only laid together and touch only in a few Points, can flick together, and that fo firmly as they do, without the affiftance of fomething which caufes them to be attracted or prefs'd towards one another, is very difficult to conceive.

The fame thing I infer also from the cohering of two polish'd Marbles in vacuo, and from the standing of Quick-filver 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, fo that its Parts be every where contiguous both to one another and to the Glass. The Atmosphere by its weight prefiles the Quick-filver into the Glass, to the height of 29 or 30 Inches. And fome other Agent raises it higher, not by preffing 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 staking the Glass. [366]

Glafs, the whole Mercury falls down to the height of 29 or 30 Inches. And of the fame kind with thefe Experi-ments are those that follow. If two plane po-lish'd Plates of Glass (suppose two pieces of a polish'd Looking glass) be laid together, so that their fides be parallel and at a very small diftance from one another, and then their lower edges be dipped into Water, the Water will rife up between them. And the lefs the diftance of the Glaffes is, the greater will be the height to which the Water will rife. If the diftance be about the hundredth part of an Inch, the Water will rife 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 diffance very nearly. For the attractive Force of the Glassies the fame, whether the diffance between them be greater or lefs; and the weight of the Water drawn up is the fame, if the height of the water drawn cally proportional to the height of the Glaffes. And in like manner, Water afcends between And in like manner, Water alcends between two Marbles polifh'd plane, when their polifh-ed fides are parallel, and at a very little diffance from one another. And if flender Pipes of Glafs be dipped at one end into flagnating Wa-ter, the Water will rife up within the Pipe, and the height to which it arifes will be reciprocally proportional to the Diameter of the Cavity of the Pipe, and will equal the height to which it rifes between two Planes of Glafs, if the Semi-diameter of the Cavity of the Pipe be equal to diameter of the Cavity of the Pipe be equal to the diffance between the Planes, or thereabouts. And

[367]

And these Experiments fucceed after the fame 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 Preffure of the Atmosphere,

And if a large Pipe of Glass be filled with fifted Ashes well pressed together in the Glass, and one end of the Pipe be dipped into stag-nating Water, the Water will rife up flowly in the Ashes, so as in the space of a Week or Fort-night to reach up within the Glass, to the height of 30 or 40 Inches above the stagnating Water. And the Water rifes 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, at-tracting or repelling it as much downwards as upwards. And therefore the Action of the Particles is very ftrong. But the Particles of the Ashes being not to dense and close together as those of Glass, their Action is not fo ftrong as that of Glass, which keeps Quick-fil-ver sufpended to the height of 60 or 70 Inches, and therefore acts with a Force which would keep Water fulpended to the height of above 60 Feet.

By the fame Principle, a Sponge fucks in Water, and the Glands in the Bodies of Animals, according to their feveral Natures and Difpofitions, fuck in various Juices from the Blood.

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

8

[368]

rizon, the other upon the first, fo as at one of their ends to touch one another, and contain an Angle of about 10 or 15 Minutes, and the fame be first moisten'd on their inward fides with a clean Cloth dipp'd into Oil of Oranges or Spirit of Turpentine, and a Drop or two of the Oil or Spirit be let fall upon the lower Glafs at the other end; fo foon as the upper Glafs is laid down upon the lower fo as to touch it at one end as above, and to touch the Drop at the other end, making with the lower Glais 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 Concourfe of the Glaffes. For the two Glaffes attract the Drop, and make it run that way to-wards 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 afcend between the Glasses, and therefore is attracted. And as you lift up the Glaffes more and more, the Drop will afcend flower and flower, and at length reft, being then carried downward by its Weight, as much as upwards by the Attra-ction. And by this means you may know the Force by which the Drop is attracted at all di-flances from the Concourfe of the Glaffes.

Now by fome Experiments of this kind, (made by Mr. *Hawkshy*) it has been found that the Attraction is almost reciprocally in a duplicate Proportion of the diffance of the middle of the Drop from the Concourse of the Glass, *viz.* [369]

wiz. reciprocally in a fimple Proportion, by reafon of the fpreading of the Drop, and its touching each Glafs in a larger Surface; and again reciprocally in a fimple Proportion, by reafon of the Attractions growing itronger within the fame quantity of attracting Sur-face. The Attraction therefore within the fame quantity of attracting Surface, is reciprocally as the diffance between the Glailes. And therefore where the dillance is exceeding fmall, the Attraction mult be exceeding great. By the Table in the fecond Part of the fecond Book, wherein the thickneffes of colour'd Plates of Water between two Glaffes are fet 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 Glaffes is of this thickness, the Attraction collected by the foregoing Rule, feems to be fo flrong, as within a Circle of an Inch in diameter, to fuffice to hold up a Weight equal to that of a Cy-linder of Water of an Inch in diameter, and under of water of an inch in diameter, and two or three Furlongs in length. And where it is of a lefs thicknefs the Attraction may be proportionally greater, and continue to increafe; until the thicknefs do not exceed that of a fin-gle Particle of the Oil. There are therefore Agents in Nature able to make the Particles of Bodies flick together by very flrong Attractions. And it is the Bufinefs of experimental Philofophy to find them out.

Novy

Now the fmalleft Particles of Matter may cohere by the flrongest Attractions, and compose bigger Particles of weaker Virtue; and many of these may cohere and compose bigger Par-ticles whose Virtue is still weaker, and so on for divers Succeffions, until the Progreffion end in the biggeft Particles on which the Operations in Chymiftry, and the Colours of natural Bodies depend, and which by cohering compose Bo-dies of a fensible Magnitude. If the Body is compact, and bends or yields inward to Pref-fion without any fliding of its Parts, it is hard and elaftick, returning to its Figure with a Force rifing from the mutual Attraction of its Parts. If the Parts flide upon one another, the Body is malleable or foft. If they flip eafily, and are of a fit fize 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 diffolved in Acids attract but a fmall quantity of the Acid, their attractive Force can reach but to a fmall diffance from them. And as in Algebra, where affirmative Quantities vanish and cease, there negative ones begin; fo in Mechanicks, where Attraction ceafes, there a repulsive Virtue ought to fucceed. And that there is fuch a Virtue, feems to follow from the Reflexions and Inflexions of the Rays

371

Rays of Light. For the Rays are repelled by Bodies in both these Cases, without the immediate Contact of the reflecting or inflecting Bo-dy. It feems also to follow from the Emission of Light; the Ray fo foon as it is flaken off from a flining Body by the vibrating Motion of the Parts of the Body, and gets beyond the reach of Attraction, being driven away with ex-ceeding great Velocity. For that Force which is fufficient to turn it back in Reflexion, may be fufficient to emit it. It feems also to follow from the Production of Air and Vapour. low from the Production of Air and Vapour. The Particles when they are flaken off from Bodies by Heat or Fermentation, fo foon as they are beyond the reach of the Attraction of the Body, receding from it, and alfo from one another with great Strength, and keeping at a diffance, fo as fometimes to take up above a million of times more fpace than they did be-fore in the form of a denfe Body. Which vaft Contraction and Expansion feems unintelligible, by feigning the Particles of Air to be springy and ramous, or rolled up like Hoops, or by a-ny other means than a repulsive Power. The Particles of Fluids which do not cohere too strongly, and are of fuch a strainers ftrongly, and are of fuch a fmallnefs as renders throngly, and are of fuch a imaline as renders them moft fufceptible of those Agitations which keep Liquors in a Fluor, are most easily fepa-rated and rarified into Vapour, and in the Lan-guage of the Chymists, they are volatile, rari-fying with an easy Heat, and condensing with Cold. But those which are grosser, and so less fusceptible of Agitation, or cohere by a strong-B b 2 er

[372]

er Attraction, are not feparated without a ftronger Heat, or perhaps not without Fermen-tation. And these laft are the Bodies which Chymifts call fix'd, and being rarified by Fer-mentation, 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 ftrongly. And because the Particles of perma-nent Air are groffer, and arise from denser Sub-ftances than those of Vapours, thence it is that true Air is more ponderous than Vapour, and that a moss the fermion of the fame re-pelling Power it feems 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 fo as to flick 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 flick together, are difficultly brought fo close together as to flick. close together as to flick.

And thus Nature will be very conformable to her felf and very fimple, performing all the great Motions of the heavenly Bodies by the Attraction of Gravity which intercedes those Bodies, and almost all the final ones of their Particles by fome other attractive and repelling Powers which intercede the Particles. The Vis insertiæ is a passive Principle by which Bodies

373

dies perfift in their Motion or Reft, receive Motion in proportion to the Force imprefling it, and refift as much as they are relified. By this Principle alone there never could have been any Motion in the World. Some other Principle was neceflary for putting Bodies into Mo-tion; and now they are in Motion, fome other Principle is necellary for conferving the Mo-tion. For from the various Composition of two Motions, 'tis very certain that there is not always the fame quantity of Motion in the World. For if two Globes joined by a flender 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 defcribed 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 Inftance it appears that Motion may be got or loft. But by reafon of the Tenacity of Fluids, and Attrition of their Parts, and the Weakness of Elasticity in Solids, Motion is much more apt to be loft than got, and is always upon the Decay. For Bodies which are either abfolutely hard, or fo foft as to be void of Elatticity, will not rebound from one another. Impenctrability makes them only ftop. If two equal Bodies meet directly *in vacuo*, they will by the Laws of Motion ftop where they meet, and lofe all their Motion, and remain in reft, unlefs B b 3 they

[374]

they be elaftick, and receive new Motion from their Spring. If they have fo much Elafticity as fuffices to make them rebound with a quarter, or half, or three quarters of the Force with which they come together, they will lofe 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 lofe all or almost all their Mo-tions: If of elastick Bodies they will lose all but what they recover from their Elasticity. If it be faid, that they can lofe no Motion but what they communicate to other Bodies, the confequence is, that *in vacuo* they can lofe no Mo-tion, but when they meet they must go on and penetrate one anothers Dimensions. If three equal round Veffels be filled, the one with Water, the other with Oil, the third with molten Pitch, and the Liquors be flirred about alike to give them a vortical Motion; the Pitch by its Tenacity will lofe its Motion quickly, the Oil being lefs tenacious will keep it longer, and the Water being lefs tenacious will keep it long-eft, but yet will lofe it in a flort time. Whence it is eafy to understand, that if many contiguous Vortices of molten Pitch were each of them as large as those which fome fuppose 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 refted among themfelves. Vortices of Oil or Water, or fome fluider Matter, might continue

375

continue longer in Motion; but unlefs the Matter were void of all Tenacity and Attrition of Parts, and Communication of Motion, (which is not to be fuppofed) the Motion would con-ftantly decay. Seeing therefore the variety of Motion which we find in the World is always decreasing, there is a necessity of conferving and recruiting it by active Principles, fuch 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 caufe of Fermentation, by which the Heart and Blood of Animals are kept in perpetual Motion and Heat; the inward Parts of the Earth are conflantly warm'd, and in fome 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, befides what is owing to thefe active Principles. And if it were not for thefe Principles the Bo-dies 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 ceafe, and the Planets and Comets would not remain in their Orbs.

All these things being confider'd, it seems probable to me, that God in the Beginning form'd Matter in folid, massly, hard, impenetrable, moveable Particles, of sizes and Figures, and with such other Properties, and in such Proportion B b 4 to

[376]

to Space, as most conduced to the End for which he form'd them; and that these primi-tive 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 fame 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 fame Nature and Texture now, with Water and Earth composed of entire Particles, in the Beginning. And therefore that Nature may be lafting, the Changes of corporeal Things are to be placed only in the various Separations and new Aflociations and Motions of thefe per-manent Particles; compound Bodies being apt to break, not in the midft of folid Particles, but where those Particles are laid together, and only touch in a few Points.

It feems to me farther, that these Particles have not only a Vis inertia, accompanied with fuch 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
[377]

as general Laws of Nature, by which the Things themfelves_are form'd: their Truth appearing to us by Phænomena, though their Caufes be not yet difcover'd. For these are manifest Qua-lities, and their Caufes 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 Caufes of manifeft Effects: Such as would be the Caufes of Gravity, and of magnetick and electrick Attractions, and of Fermentations, if we should fuppose that these Forces or Actions arose from Qualities unknown to us, and uncapable of be-Qualities unknown to us, and uncapable of be-ing difcovered and made manifeft. Such oc-cult Qualities put a ftop to the Improvement of natural Philofophy, and therefore of late Years have been rejected. To tell us that every Species of Things is endow'd with an oc-cult specifick Quality by which it acts and pro-duces manifeft Effects, is to tell us nothing: But to derive two or three general Principles of Motion from Physican of Motion from Phænomena, and afterwards to tell us how the Properties and Actions of all to tell us how the Properties and Actions of all corporeal Things follow from those manifest Principles, would be a very great step in Phi-losophy, though the Causes of those Principles were not yet discover'd: And therefore I foru-ple not to propose the Principles of Motion a-bove mention'd, they being of very general Ex-tent, and leave their Causes to be found out. Now by the help of these Principles, all ma-terial Things seem to have been composed of the

the

[378]

the hard and folid Particles abovemention'd, varioufly affociated in the first Creation by the Counfel of an intelligent Agent. For it became him who created them to fet them in order. And if he did fo, it's unphilofophical to feek And it he did to, it's unphilolophical to leek for any other Origin of the World, or to pre-tend that it might arife out of a Chaos by the mere Laws of Nature; though being once form'd, it may continue by those Laws for ma-ny Ages. For while Comets move in very ex-centrick Orbs in all manner of Positions, blind Fate could never make all the Planets move one and the fame way in Orbs concentrick, fome inconfiderable Irregularities excepted which may have rifen 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 Uniwants a Ketormation. Such a wonderful Uni-formity in the Planetary Syftem muft be allow-ed the Effect of Choice. And fo muft the Uniformity in the Bodies of Animals, they ha-ving generally a right and a left fide fhaped a-like, and on either fide of their Bodies two Legs behind, and either two Arms, or two Legs, or two Wings before upon their Shoul-ders, and between their Shoulders a Neck run-ning down into a Back bone, and a Head up-on it; and in the Head two Ears, two Eyes, a Nofe, a Mouth, and a Tongue, alike fituated Nofe, a Mouth, and a Tongue, alike fituated. Alfo the first Contrivance of those very artifi-cial Parts of Animals, the Eyes, Ears, Brain, Muscles, Heart, Lungs, Midriff, Glands, La-rynx, Hands, Wings, Swimming Bladders, natural

[379]

tural Spectacles, and other Organs of Senfe and Motion; and the Instinct of Brutes and Insects, can be the effect of nothing elfe than the Wifdom 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 boundlefs uniform Senforium, 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 confider the World as the Body of God, or the feveral Parts thereof, as the Parts of God. He is an uniform Being, void of Organs, Members or Parts, and they are his Creatures fubordinate to him, and fubfervient 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 Senfe into the place of its Sen-fation, where it perceives them by means of its immediate Prefence, without the Intervention of any third thing. The Organs of Senfe are not for enabling the Soul to perceive the Spe-cies of Things in its Senforium, but only for cies of Things in its Senforium, but only for conveying them thither; and God has no need of fuch Organs, he being every where prefent to the Things themfelves. And fince Space is divisible *in infinitum*, and Matter is not necef-farily in all places, it may be also allow'd that God is able to create Particles of Matter of feveral Sizes and Figures, and in feveral Proportions to Space, and perhaps of different Denfi-ties and Forces, and thereby to vary the Laws of Nature, and make Worlds of feveral forts in feveral [380]

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

As in Mathematicks, fo in Natural Philofophy, the Investigation of difficult Things by the Method of Analysis, ought ever to precede the Method of Composition. This Analysis confifts in making Experiments and Obfervations, 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 Hypothefes are not to be regarded in ex-perimental Philofophy. And although the ar-guing from Experiments and Obfervations by Induction be no Demonstration of general Con-Induction be no Demonstration of general Con-clusions; yet it is the belt way of arguing which the Nature of Things admits of, and may be looked upon as fo much the flronger, by how much the Induction is more general. And if no Exception occur from Phænomena, the Con-clusion may be pronounced generally. But if at any time afterwards any Exception stall oc-cur from Experiments, it may then begin to be pronounced with fuch Exceptions as occur. By this way of Analysis we may proceed from Comthis way of Analyfis we may proceed from Com-pounds to Ingredients, and from Motions to the Forces producing them; and in general, from Effects to their Caufes, and from particular Caufes to more general ones, till the Argu-ment end in the most general. This is the Method of Analyfis: And the Synthesis confists in asfuming the Caufes discover'd, and establish'd as Principles, and by them explaining the Phænomena

[381]

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 Co-lour, 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 ariting from them: An In-flance 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 dif-cover'd about Light and its Effects upon the Frame of Nature, hinting feveral things about it, and leaving the Hints to be examin'd and improv'd by the farther Experiments and Obfervations of fuch 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 enlar-ged. 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 to far our Duty towards him as well from him, fo 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 Hea-then, their moral Philosophy would have gone farther than to the four Cardinal Virtues; and inflead

1

inflead 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, as their Ancessors did under the Government of *Noab* and his Sons before they corrupted themselves.

FINIS.





BOOKS printed for WILLIAM and JOHN INNYS.

PTICE five de Reflexionibus, Refractionibus, Inflexionibus & Coloribus Lucis Libri tres. Authore Haaco Newton, Equite Aurato. Latine reddidit Samuel Clarke, S. T. P. Editio fecunda, auctior. Svo. 1719.

Philofophiæ Naturalis Principia Mathematica, Auctore Ifaaco Newton, Equ. Aur. 4to.

Phyfico-Theology: Or a Demonstration of the Being and Attributes of God, from his Works of Creation, with large Notes and many curious Observations by *W. Derbam*, Canon of *Windfor*, and F. R. S. the fifth Edit. 8vo. 1720.

Mr. Derham's Aftro-Theology: Or a Demonstration of the Being and Attributes of God from a Survey of the Heavens, with Cutts, the third Edit. 8vo. 1719.

Philofophical Letters between the late Learned Mr. Ray and feveral of his Ingenious Correspondents, Natives and Foreigners. To which are added those of *Francis Willoughby*, Efq; The whole confisting of many curious Discoveries and Improvements in the History of Quadrupeds, Birds, Fishes, Infects, Plants, Fossiles, Fountains, Gr. publish'd by Mr. Derham, 8vo. 1718.

Mr. Ray's three Phyfico-Theological Difcourfes, concerning I. The primitive Chaos, and Creation of the World. II. The general Deluge, its Caufes and Effects. III. The Diffolution of the World and future Conflagration, Ge. Illustrated with Copper Plates, the fourth Edition, with Additions, 8vo. 1721.

His Wifdom of God in the Works of the Creation. The feventh Edition, 8vo. 1717.

Mr. Ronayne's Treatife of Algebra, 8vo. 1717.

Geometria Organica: five Defcriptio Linearum Curvarum Univerfalis, Auctore Colino Mac Laurin, Math. Col. Abred. Prof. & R. S. S. 4to. 1720.

An Introduction to Natural Philosophy, or Philosophical Le-Etures read in the University of Oxford, A. D. 1700. To which are added, The Demonstrations of Mr. Haygens's Theorems, concerning Force and circular Motion. By John Keill. M.D. Sav. Prof. of Aftronomy, and F. R. S. 8vo. 1720.

Philofophical Transactions, giving some Account of the prefent Undertakings, Studies and Labours of the Ingenious, in many confiderable Parts of the World. Vol. 30. for the Years 1717, 1718 and 1719. Continued and publish'd by Dr. Edmund Halley, J. U. D. and Reg. Soc. Secr. 410.

The Lives of the French, Italian and German Philosophers, late Members of the Royal Academy of Sciences in Paris. Together with Abstracts of the choicess Communicated by them to that Illustrious Society. To which is added, the Preface of the Ingenious Monsieur Fontenelle, Secretary and Author of the History of the faid Academy, 8vo. 1717.

Leonardi

3

Leon ardi Plukenetii. M.D. Opera omnia Botanica in fex Tomos divifa, viz. I. II. III. Phytographiæ. IV. Almageftum Botanicum. V. Almagefti Botanici Mantiffa, VI Amaltheum Botanicum in quibus Stirpes illuftriores minus cognitæ, exoticæ, Rariorefque noviffime detectæ ad plures Chiliadas defcribuntur. Tum Iconibus (Tabulis Æneis CCCCL1V. fumma cura depictis Figurantur.

Methodus Incrementorum directa & universa. Auctore Brook Taylor L. L. D. & Reg. Soc. Secr. 410. 1717.

The Pofthumous Works of Dr. Robert Hooke; in which, I. The prefent Deficiency of natural Philotophy is difcourfed of, with the Methods of rendring it more certain and beneficial. II. Of the Nature, Motion and Effects of Light, particularly that of the Sun and Comets. III. An hypothetical Explication of Memory 3 how the Organs made use of by the Mind in its Operation may be mechanically underftood. IV. An Hypothesis and Explication of the Cause of Gravity, or Gravitation, Magnetism, ere. V. Difcourses of Earthquakes, their Causes and Effects, and Histories of feveral: To which are annex'd, Physical Explications of feveral of the Fables in Ovid's Metamorphosis, very different from other Mythologick Interpreters. VI. Lectures for improving Navigation and Aftronomy, with the Defcriptions of feveral new and useful Inffruments, illustrated with Sculptures. To these Difcourses is prefix'd the Author's Life. By Richard Waller, R. S. Secr. Folio.

A Treatife of Algebra, both Hiftorical and Practical; with fome additional Treatifes. I. Of the Cono-Cuneus. II. Of angular Sections and Trigonometry. III. Of the Angle of Contact, with other things appertaining to the Composition of Magnitudes, the Inceptives of Magnitudes, and the Composition of Motions, with the Refults thereof. IV. Of Combinations, Alterations, and aliquot Parts. By John Wallis, D. D. Folio.

New Experiments Phyfico-Mechanical, touching the Air, and its Effects, made, for the most part, in a new Pneumatical Engine. The third Edition. Whereunto is added, A Defence of the Author's Explication of the Experiments against the Objections of *Francifcus Linus*, and *Tho. Hobbes*; with Cuts. By the Honourg able Robert Boyle, Efq: 4to.

(i)

BOOKS printed for WILLIAM and JOHN INNYS, at the Prince's Arms at the Weft End of St. Pauls, 1724.

Lbins Natural Hiftory of English Infects, with 100 Copper Pintes colour'd by the Author, to which are added large Notes, and many Curious Objervations by W. Derham, F. R. S. 4to. Adam's Sermons publish'd by Dr. Sacheverel, Svo. Athenagoras's Apologeticks, Eng. by Mr. Humphreys, 8vo. Antwer to Fonunel's Hiftory of Oracles, 2 Vols. 820. Antwer to Fonunel's Hiftory of Oracles, 2 Vols. 820. St. Athanafus's Oracions, Eng. by Mr. Parker, 2 Vols. 820. Anfwer to the Layman's Plea for Separation, 800. Antiquities of Palmyra by Mr. Seller, 820. Altieri's Italian and Englith Dictionary, in the Prefs, in 2 Vols. 412. Allen of the Calybeat Waters of England, 820. Antonici Iter Britan. cum Comment. T. & R. Gale, 410. Allen Synophis Medicina Practica, 8vo. Appendix ad Epistolam de Cotefii Inventis, 410. Art of Thinking, 12mo. Atlas Manuale, or Sett of fmall Maps by H. Moll. B Iffe's Beauty of Holinefs in the Common Prayer, 820. - - Sermon on Cathedral Worthip or Choir Service, 820. - - Decency and Order in publick Worship, 820. Lufus Poetici olim conferipti, 820. Bennet's Difcourfe of Schifm, 8vo. - - Directions for fludying Divinity, 8vo. Bragg, on the Miracles of our Bleffed Saviour, 2 Vols. 8vo. on the Parables, 2 Volls. 8vo. Burkitt, on the New Teftament, Folio. Berkley's Dialogues againft Scepticks and Atheifts, 8vo. Brett's Divine Right of Epifcopacy, 8vo. - - - of Tradition. - - - Anfwer to Delaune's Plea for the Nonconformills. - - of the Independency of the Church. Bacon's Effays, 8vo. Bollus Treatile of Epick Poetty, 2 Vols. 12mp Boyer's French and English Dictionary, 810. - - - French Grammar, 8vo. Duke of Buckingham's Works, 2 Vols. 4to. Bibliotheca Literaria, 420, publift'd monthly. Baynard of hot and cold Baths, 5th Edit. 820. Boyle's Philosophical Works abridg'd, 2 Vols. 410. in the Prefs. - Medicinal Experiments, 6th Edit. 12mo. Boerhaave's Practical Aphorifms, 8vo. - - - Prefcriptions to his Aphorifms, 12mo. Boulton's Syftem of Rational and Practical Surgery, 8vo. Bibliotheca Biblica, or a Commentary on the Bible, publish'd monthly, Bellinger of the Nutrition of the Fœus, 8vo. Belloft's Hofpital Surgeon, 12mo. Blair's Botanick Effays with Cuts, 8vo. Bailey's Sermons, 2 Vols. 8vo. Bennet of Confimptions, 8vo. Bellini's Mechanical Accounts of Fevers, 820. Beveridge's Private Thoughts. - - - Thelaarus Theologicus, 4 Vols. Sto. - - - of Prayer and frequent Communico. Barrow's Works, 2 Vols. Felie. Baglivi's

(2) Buglivi's Practice of Phylick, 800. Bradley of Gardening, 820, wRollinge of the Great Duty of Prayer, 8va. Charity, 8to. Chriffian Elognence in Theory and Practice, by Mr. D'Oyley, 8co. Chillingworth Works Felle. St. Cyprians Works, Engl. by Dr. Marfhall, Follo, Bp. Couns's Devotions, 12mo. Chriftian Panera by Tho. a Kempit, Engl. by Dr. Sanhope, Rec. the fame in a Pocket Volume, ramo. Clementis EpittoLe, cum Noris Hen, Wotton, 8vo. Cafes against the Diffenters, in 3 Vols. 820, A lip. of Cambray's Pious Thoughts, Sza, Clergyman's Companion for villing the Sick, 850, Caffelii Lexicon Deptadonton, 2 Vols. Folio. Clergyman's Vademeenin per J. Johnfon, 2 Vols. 12mo. Chrithan's belt Guide, 820. Grafo Thefasrus Medicamentoram, 12me. Cockharn of a Gonnorthway li 20. - - - - of Fluxes, #vo. Confii Harmonia Meufuratum, 470. Cowper's Myotomia Reformana, Folio, 1724. Campbell of the Middle Scates Folio, Cafar ex Recentione Job. Davidi, 410. - in Ulim Delphini, 8w-. Chronicon Saxonicium ex MSS. Cod. edid. Edm. Gibfons 4ta. Cheusaa's True French Matters Beo. Cardie's Lite and Adventures, 2 Vols. Clerk's Vade Meenin, or Clerkthip improv'd, 12ma. Catalogue Librorum M88, in Bibl. Coll. Corp. Chr. in Cant. Folio. Cains de Ephemera Britannica, Rea. Creeche's Hota es 12mo. Lat Clarendon's Haffory of the Rebellion, G Vols, 840, Circionis Obtiones in Ulim Delphini, Svo. m n n m n feledar, 19.000. Callillo de Curiali live Aulico ex Receuf. Sam. Drake, 820. Cellus de Vua & Rehus Gellis Julii Caelario, 12mo. Ho, of Cork of drinking its Memory of the Deads Bro. of Healths in General, Spa- of Healths in Gener,
o - Charity Sermon, Spo. Cowley's Works, 2 Vols. 12ms. Compleas Geographer, Folie, Clementia Alexandrini Opera, per Potter, 2 Vols, Fulia. D Ionyfus de Situ Orbia, per Wella, 920. Dotwell's Works abridg'd with his Lite, 2 Vola, 820. Se. John Denham's Philms, 220. Dahe's Amoniy, a Volt. Spy. Deidier de Mortós Venereiro 820, 1724. Devision Levison Moye Tellamenti, Bro. Dile Pharmacompia, 2 Vols, 12ma-

- S. Supplementation depending. Davelout Memoirs of the Garter, Itza.

Dicknessered Death, Law

Distigray against the Analosputter rame.

Diake (Gaine) Conchy ad Chemma Stan

Digitably Monath on conglications Engl. Falls.

- Bop lemen by morens, 9 Vida India.

Denna's Civil Law, Engl. with phones by Dr. Straham, 2 Vuls, Police

Du Ends Method of fluidying Decenity.

Derham's

(3)

Derham's Phylico Theology, 8:0. - - - - Aftro-Theology, 820. Decerpta ex Ovidio in Ulum Scholz Etonenfis, Sco. Dryden's Plays, 6 Vols. 12ma. - - - - Milcellanies, 6 Vols. 12mo. - - - - - Virgil, 3 Vols. - - - - Juvenal, 12mo. Dugdale's Antiquities of Warwickthire, Felle, in the Prefs. Epillola ad Amicum de Cotefii Inventis, 4re. Electa Majora ex Ovidio in Ulum Schola: Eton. - - - Minora ex Ovidio, &c. 820. Episteri Enchiridion Lar. Verf. adumbr. per Edv. Ivie, Sto. Echard's Hiftery of England. - - - Roman Hiftory, 5 Vols. 820. - - - - Gazetteer in two Parts, 12ms. - - - Ecclefiaffical Hiftory, 2 Vols. Eve. Epistolæ Obscurorum Virorum, 12me. Epigrammatum Delectus ex Poetis Latinis, 12mo. Ecton's Liber Valorum & Decimarum, Svo. 1723. Edwards against Popery, Sco. 1724. Epigrammanım Gracorum Delectus Opera Th. Johnfon. F Ruit Walls improv'd by D. N. Fatio, F. R. S. 410. Franklyn Orthotonia, five de Græcz Linguz Tonis, 12me. Farnaby's Rhetorick. Fiddes's General Treatife of Morality, 8ve. Friend Emmenologia. - - - de Febribus. - - - de Purgantibus in Variolis-Fuller Pharmacopœia Extemporanea, 12mo. - - - the fame in English. - - - Pharmacopœia Domestica. - - - Pharm. Bateana. Floyer's Treatife of the Afthma. ---- Hiftory of Cold Bathing. Florus in Ufum Delphini, 820. Aftrell's Chriftian Inflitutes. G Antren & Cornuan Annuaces. ---- Certainty and Necessity of Religion in Ceneral, & Sermons at Boyle's Lectures, 800. Grabe's Spicilegium Patrum, 2 Vols. 820. - - - - two Tracts against Mr. Whiston. Gentleman Inftructed, 8vo. Gregorii Nomenclatura in Ufum Schol. 8vo. Greenfield's Treatife of the Stone and Gravel with Cuts, Sto. Goodman's Penitent pardoned, 8vo. - - - Winter Evening Conference, Svo. - Old Religion, 12mo. God's Judgment against the Apostate Church, 800. Giblon's Parochial Visitations, 800. God's Mercies, an Abstract from Scripture, Seo. Geddes's Hiftory of the Church of Malabar, 8ve, Gravefande's Mathem. Elements of Nat. Philosophy, 2 Vols. Suo. - - - Eflay on Perspective, 8vo. 1724. Garretfon's English Exercises, 12mo. Gordon's Geographical Grammar, 820. Guardians, 2 Vols. 12mo. H Ooker's Ecclefiaftical Polity, &c. Folio, 1724. Hool's Addrefs to Parents, on Education, 800.

L'Holpital's Analytick Treatile of Conick Sections, 410-Hatton's Platter, 15th Edition, 12mo. 1724.

A 2

(4) Hiftory of Herodotus Engl. by Littlebury, 2 Vols. 840. Horneck's Crucified Jefus, 8vo. ---- Great Law of Confideration, 8vo. Horn's Microtechne, or Introduction to Surgery, 12ma. Human Prudence, 12mo. Hudibras, with Cutts, 12mo. Hatton's Comes Commercii, 8vo. - - Merchant's Magazine, 4to. Howell's Hiftory of the Bible with Cutts, 3 Vols, 8vo. Howard's Cookery, 8vo. Horatius in Ulum Delphini, Sue. Homeri Iliados Liber primus Gr. Lat. Silvani, 8ve. Hickes's Devotions, 12mo. Hutchinfon's Tracts of the publick Debts, &c. Hook's Polthumous Works with Cutts, Folio. Hiftory of England, 3 Vols. Folio. - of Majorca, Minerca, &c. 8vo. Historiæ Britan. Saxon. Anglo-Danicæ Scriptores XV. per Tho. Gale. Folio. Hippocrates de Morbis Popularibus cum Comment. Joh. Friend: M. D. Harris de Morbis Acutis Infantum. - - - de Pefte & Inoculat, Variolarum, 8vo. Helvetius of the Animal OEconomy and Small Pox, 8vo. Heifter's Compendium of Anatomy, 8vo. Hopkins's Works, Folio. Hart's Bulwark florm'd in Anfwer to Delaune's Plea, 8vo. Hilfory of Genghizcan the Great, 800, - - of Thucidides Engl. by Tho. Hobbes, 2 Vols. 800, - - of Timur-Bec, commonly call'd Tamerlain, 2 Vols. 800, Historiarum Fabellarumque Delectus, 8vo. T Effery of Monmonth's British Hiltory, Engl. 8vo. Jenkin of the Christian Religion, 2 Vols. 800. Ben. Johnfon's Works with Cutts, 6 Vols. 8ve. Inferiptio Sigea cum Comment, Edm. Chilhull, Folio. Johnfon's Grammatical Commentaries, 8vo. - - Noctes Nottinghamicz, 8vo. Ignatii Epiftolæ per Th. Smith, 4to. Jultinus in Ulum Delpnin, avo. Sr. Leoline Jenkins's Life and Letters, 2 Vols. Folio. 1724. Juftinus in Ufum Delphini, 8vo. Jurin's Letter of Inoculating the Small Pox, 8vo. Juvenal cum Notis Farnabil, 820. Justini Martyris Dialogus cum Tryphone, per Sam. Jebb, 820. Juvenal in Ufum Delphini, 8vo. Ettlewell's Works, with his Life, 2 Vols. Folio. - - his Life, feperate.
- - Meafures of Christian Obedience, 8vo. - - - of the Sacrament. -* - - of Profulenels." - - - - Death made comfortable, 12mo. Keill (Joh.) Introductio ad Veram Phylicam, 8vo. - - - Introduction to Natural Philolophy, 8ve. - (Jac.) Tentamina Medico-Phyli de Olcon. Anim. 300. - - Effays of Animal Olconomy, 800. King's Mifcellanies, 8vo. Kennet's Roman Antiquities, 8vo. King's Heathen Gods, 12mo. Keay's Practical Measurer's Pocket Companion, 8vo, Ucas's Enquiry after Happinels, 2 Vols. 8vo. - - - Practical Chriftianity; 8vo. Lucas's a part of the second
Lucas's Dury of Servants, 12ma. - - - Influence of Conversation, 12ma. - - Plain Man's Guide to Heaven. Lowth's Commentary on the Prophet Ifaiah, 412, - - - - on Jeremiah, 420. - - on Ezckiel, 410.
- - two Sermons at the Affizes at Winchefter, 8co. Lay Baptifm Invalid, with the reft of the Author's Works, 2 Vols. 8-10-- - Sacerdotal Powers. - - Diffenters Baptifin null and void, 820. - Second Part of Lay Baptifm Invalid, 820. - - Supplement to the first and fecond Parts, Sve. Lawrence's Christian Morals, 820. Law's three Letters to the Bp. of Bangor, 8cc. - Remarks on the Fable of the Bees, 870. Life of Archbifhop Whitgift by Mr. Strype, Folio. - - and Negotiations of Sr. Leoline Jenkins, 2 Vols. Fella. - of Mr. Dodwell with an Abridgment of his Works, 2 Vois. 8ve. - - of Mr. Kettlewell, Svo. - of Mr. Sage, Author of the Cyprianick Age, 8ve. - - of Dr. Feild by Mr. Le Neve, Suo. - of Mr. J. Mills, Svo. Lock's Works, 3 Vols. Folio. - - of Human Understanding, 2 Vols. 800. Littleton's Dictionary, 4tc. L'Effrange's Ælop, 2 Vols. 8vo. Lemery's Chymiltry, 800. Lady's Library, 3 Vols. 12mo. Lives of the English Bithops, by Mr. Le Neves, 2 Vols. See. Lady's Travels into Spain, 2 Vols. Lowthorp's Abridgement of the Philof. Tranf. ; Vols. 4to. Le Neve's Succeilion of the Bifhops and Dignitaries, Folio. Luciani Dialogi Selectra, Gr. Lat. Lucretius cum Interpretatione & Notis Tho. Creech, Svo. Leland de Scriptoribus Britannicis, 2 Vols. 800. Leufdeni Compendium Gracum Novi Teltamenti, Svo. Lommius de Curandis Febribus continuis, 820. Lancafter's Chronological Effay on Daviel, 410. Letter of Influction Thewing the Way to Christian Perfection, 12mm. Laws of Liberty and Property, 12mo. M Angey's Difcourfes on the Lord's Prayer, 820. - - Defense of the Bp. of London's Letter to his Clergy, Ste. Anfwer to Toland's Nazarenus, 8vo. - - - five fingle Sermons, Sve. Mead of the Ule of Maps and Globes, 8ve. Mantaire's English Grammar, 8ve. - - Graca Lingua Dialecta, Svo. Mead de Pelte, Svo. Maclaurin Geometria Organica, 410. Motray's Travels, 2 Vols. Folie. Mufæ Anglicanæ, 2 Vols. 12mo. Countels of Morton's Devotions, 24me. Medulla Hiltoria Anglincana, 820. Marshall's Translation of St. Cyprian's Works, Falia. Mauger's French Grammar, 820. Montaigne's Ellays, 3 Vols. 8vo. Morland's Vade Mecum. Motteux's Don Quixote, 4 Vols. 12mo. Marfhal Tabula Chronologica, Folio. Morton of Confumptions, 800. Mayernæ Praxis Medica, 2 Vols. 840.

(6)

Moli's Compleat Geographer, Folio. Martin's Genuinenels of the Text, there are three in Heaven, 8ve. two Critical Differtations, 8vo. Examination of Emlyn's Anfwer, 8vo. * - - Difcourfe of Natural Religion, 8vo. Memoirs of the Academy of Sciences at Paris, 8vo. Sr. Macarius's Spiritual Homilies, 8 vo. Meraphylica Compendium, 8vo. 1723. N Arbrough's Voyages, 8ve. Sr. Ifaac Newton's Opticks. the fame in Latin by Dr. Clarke, 8vo. - -Principia Philosophiæ Mathematica, 4ro. In the Prefs. - -- Algebra, in English by Mr. Raphfon. - - Analyfis per Quantitatim Series, &c. 4to. Nicols de Literis Inventis, 8vo. Notarum ad Inferiptionem Sigeam Appendicula, Felio. Noticia Anglicana, or the Arms of the Nobility, 2 Vols. 8vo. Newcome's Ordination Sermon, 8vo. Nelfon's Feafts and Fafts of the Church, 8vo. - on the Sacraments 12mo. Ckley's Account of Barbary, 8vo. JOvidii Metamorph. in Ulum Delphini, 820. - Epiftolæ in Ufum Delphini, 8vo. Triftium in Ulum Delphini, 8vo. - Fastorum cum Notis Variorum, 8ve. Axton's Effays on the Knowledge and Cure of Difeafes, 8ve, - - - Directory for young Phylicians, 8ve. Patrick's Devout Chriftian, 12mo. - - - Chriftian Sacrifices 12mo. - - Advice to a Friend, 12mo. Help to young Beginners, 12we.
Pfalms, 12me. Plutarch's Morals Engl. 5 Vols. 12mo. - - - - Lives, Engl. Potter's Greek Antiquities, 2 Vois. 8vo. - - of Church Government, Svo. Principles of Deifm truly reprefented, 8vo. Pafchal Cycle, and other Tables ufed by the Church, 8vs. Pfalter in Welfh. Plukenetii Opera Omnia Botanica, 6 Vol. Falia. Perrault's Architecture Engl. by James, Fallo. Pratt Grammatica Linguz Latinz, 8vo & 12mo. Palladio's Architecture, 470. - Ditto by Leoni, 2 Vols. Folio. Pearfon on the Creed, Folio. Pozzo's Architecture in Perfpective, Folio. Puffendorf's Law of Nature, Folio. - Ditto abridg'd with Notes by Spavan, 2 Vols. 8vo.
- Introduction to the Hiftory of Europe, 8vo. Prideaux's Connexion of the Hiftory of the Old and New Tellament, 3 Vols. Svo. - - Life of Mahomet, 820. Pope's Homer with Cuts, 6 Vols. 12mo. Mifcellanies, 2 Vols. 12mo. Philosophical Transactions Compleat, from the Year 1665 to 1724 in 32 Vols. or molt of the Numbers leparate. - - the fame abridg'd to the Year 1720 by Mr. Lowthorp and Mr. Motte in 5 Vols. 4to, Planus in Ulum Delphini, 8vo. Pharmacopœia Collegii Regalis Medicorum Londinenfis, 12mo, 1724. Ditto, per Shipton, 12mo.

Phar-

(7) Pharmacopteia Bateana, Ed. nova, per Tho. Fuller, 12mo. Pye's Obfervations on the various Methods of Lithotomy, 4to. 1724. Pitcairne's Elements of Phylick, 8vo. Poete minores, Gr. Lat. 8vo. Prior's Poems, 2 Vols. 12mo. Phædrus, per Johnfon, in utum Scholæ Etonentis, 8vo. Plinii Paneg. in usum Delphini, 8vo. Uinctilian de Inft. Orat, cum Notis Edm. Gibson, 800. Quincy's Prelectiones Pharmaceutice, 4to. College Difpenfatory in English, with Notes, 8vo. Pharm. Officinalis, 8vo. Lexicon Medicum, 8vo. Quarles's Divine Emblems, 12mo. Ay's Philosophical Letters, with Mr. Willoughby, &c. 8vo. - Wildom of God in the Creation, 8th Edit. 8vo. Phylico Theological Difcourfes, 4th Edit. 8vo. Perfualive to a holy Life, 8vo. Hiftoria Plantarum, 3 Vols. Fol. - - Supplementum, vel Tom. 3. feperatim. Synopfis Methodica Stirpium Brit. Stirpium Europ. extra Britan. nafcentium Sylloge, 800: Synophs Methodica Avium & Pifcium, cum hg. 820. Hiftoria Infectorum, 4to. Synopfis Methodica Animalium Quadr. 8vo. Methodus Infectorum, 8vo. Stirpium Orientalium Catalogi tres, 8vo. Methodus Plantarum, 8vo. - - De Variis Plantatum Methodis, 8vo. Robertioni Lexicon Hebraicum, 410. Reflections on Reafon, Svo. Rogers's Farewell-Sermon, 8vo. Rufnworth's Hiftorical Collections, 8 Vols. Fol. Rolcommon and Duke's Poems. Religious Philosopher, 2 Vols. 4to. with Cuts. Ronayne's Algebra, 8vo Robertson's Diffenters Self-condemn'd, 410. Robinson of the Stone and Gravel, 800. and Barris States Riverius's Practice of Phylick, Svo. Ratcliff's Difpenfatory, 8vo. Ramazini of Tradefmens Difeafes, 820. STebbing of the Operations of the Holy Spirit, 820. - - Trafts againft the Bp. of Bangor, 820. Sanderfoni Pralectiones de Confcientia, 820. Sacheverell's Sermons, 8vo. Suztonius in usum Delphini, 8vo. Spectators, 8 Vols. 120. Stevens's Supplement to Dugdale's Monasticon, 2 Vols. Fol. Stanhope's Tho. à Kempis's Christian Pattern, 820. and 120. St. Auftin's Meditations, 8vo. Epictetus's Morals, 8vo. Sydenham's Works, 8vo. - - - Practice of Phylick, Svo. Seneca's Morals, by Sir R. L' Effrange, 8vo. Strauchius's Chronology, 8ve. Sherlock of Death, 8vo. - - - of Judgment, 8vo. Smith's Poems, 8vo. Salluftius cum Notis Var. per Jof. Walle, 410. Schrevelii Lexicon, Gr. Lat. 800.

Sophoclis Trag. Antig. & Trachinia, Gr. Lat. per T. Johnfon, 8vo. Synophis Communium Locorum ex Poetis Latinis, 12mo. Sckickardi Horologium Hebraicum. 8vo. Selden's Works, 3 Vols. Fol. in the Prefs. Sanctorius de Medicina Statica, cum Comment. M. Lifter, 12mo. Sydenhami Proceflis Integri & Tract. de Phthifi. 12mo. Salmon on Bates's Difpenfatory, 8vo. - - - on Sydenham's Practice of Phylick, 8vo. Shaw's Fundamental Doctrines of the Church of Engl. 2 Vols. 8vo. State of Ruilia, 2 Vols. 8vo. Squire's Anfwer to the Independent Whig, 8vo. St. John Concio ad Clerum, 8vo. - - Sermon before the Sons of the Clergy, 8vo; Saurin's Differtations on the Bible, Fol. Stillingfleet's Origines Sacræ, the 8th Edit. Fol. 1724. Salluftius in ufum Delphini, 8vo. TAylor (Brook) Methodus Incrementorum, 410. Trapp Prælectiones Poetica, Tom. 3 800. Tafwell Physica in usum Juvent. Acad. 8vo. Trial of the Regicides, 8vo. 1724. Tatlers, 4 Vols. 12mo. Telemachus, Engl. with Cuts, 2. Vols. 12mo. Terence Engl. by Echard, &c. 12mo. Terentius in ufum Delph. 8vo. Turner's Siphillis, 8vo. - - of the Difeafes of the Skin, Svo. 7 Ocabularium Anglo-Saxonicum, 8vo. Voffii Elementa Rhetorica, 8vo. Vidæ Poemata. Vertor's Revolutions in the Roman Republick, 2 Vols. 8vo. - - - in Sweden, 8vo. - - - in Portugal, 8vo. - - Hiftory of the Establishment of the Bretons, z Vols. 8vo-Virgilius cum Notis Binaldi, 12mo. in ulum Delphini, 8vo. Vitruvius Britannicus, or British Architect, by C. Campbell, 2 Vols. Fol. T Illymot's English Particles, 8vo. Nouns and Verbs, 8vo. - Shorter Examples, 12mo. Wainwright of Non-Naturals, 8ve. Willoughby Hiftoria Pifcium. recogn. Jo. Raius cum fig. Fol. Whithy Ethices Compendium, in ulum Juvent. Acad. 8vo. 1724. White's new and exact Obfervations on Fevers, 800. Waterland's 8 Sermons at Lady Moyer's Lecture, 8vo. Vindication of Chrift's Divinity, 8vo. ----- Second Vindication of Chrift's Divinity, 8vo. - Farther, Vindication of Chrift's Divinity, 8vo. Crit. Hiftory of the Athanafian Creed. 4. Single Sermons, 8ve. Welfted de Ætate vergente, 8vo. Week's Preparation, 120. Wifeman's Surgery, 2 Vols. 8vo. Waller's Poems, 12mo. Wilkins of Natural Religion. Wingate's Arithmetick, 8vo. VOung's Sermons, 2 Vols. 8vo.

(-8)

FINIS.