Draft of the 'Discourse Concerning Light and Colors'

Author: Isaac Newton

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Sir

I suppose you understand that all transparent substances (as Glass water, Air &c) when made very thin by being blown into bubbles or otherwise formed into plates, doe exhibit various colours according to their various thinnesse, although at a greater thicknesse they appeare very cleare & colourlesse. In my former discourse about the constitution of light, I ommited these colours, because they seemed of a more difficult consideration, & were not necessary for establishment of the Doctrine which I propounded. But because they may conduce to further discoveries for completing that Theory, especially as to the constitution of the parts of naturall bodies on which their colours or transparency depend, I have now sent you an account of them. To render this discourse short & distinct, I have first described the principal of my Observations, & then considered & made use of them. The Observations are these:

Obs: 1. Compressing two Prisms hard together that their sides (which by chance were a very little convex) might somewhere touch one another, I found the place in which they touched to become absolutely transparent as if they had there been one continued piece of Glasse. For when the light fell so obliquely on the Air which in other places was between them, as to be all reflected; it seemed in that place of contact to be wholly transmitted: in so much that when looked upon it appeared like a black or dark spot by reason that little or no sensible light was reflected from thence as from other places; & when looked through it seemed (as it were,) a hole in that Air which was formed into a thin plate by being compressed between the glasses. And through this hole Objects that were beyond might be seen distinctly which could not at all be seen through other parts of the glasses where the Air was interjacent. Although the glasses were a little convex yet this transparent spot was of a considerable breadth, which breadth seemed principally to proceed from the yeilding inwards of the parts of the glasses by reason of their mutuall pressure For by pressing them very hard together it would become much broader then otherwise.

Obs: 2. When the plate of Air, by turning the Prisms about their common Axis became so little inclined by the incident rays, that some of them began to be transmitted, there arose in it many slender arcs of colours which at first were shaped almost like a Conchoid as you see them here delineated. And by continuing the motion of the Prisms, these arcs increased & bended more & more about the said transparent spot, till they were completed into circles or rings incompassing it, & afterwards continually <501v> grew more & more contracted.

Fig: 1.

These arcs at their first appearance were of a violet & blew colour, & between them were white arcs of circles which presently (by continuing the motion of the Prisms) became a little tinged in their inward limbs with red & yellow, & to their outward limbs the blew was adjacent. So that the order of these colours from the centrall dark spot, was at that time White, Blew, Violet; Black ; Red, Orange, Yellow, White, Blew, Violet; &c. But the Yellow & Red were much fainter then the Blew & Violet.

The motion of the Prisms about their Axis being continued these colours contracted more & more, shrinking towards the whitenesse on either side of it untill they totally vanished into it. And then the circles in those parts appeared black & white without any other colours intermixed. But by further moving the Prisms about, the colours again emerged out of the whitenesse, the violet & blew at its —– inward limb, & at its outward limb the red & yellow. So that now their order from the centrall spot was White, Yellow, Red; Black; Violet, Blew, White, Yellow, Red, &c. contrary to what it was before.

Obs: 3 When the rings or some parts of them appeared only black & white, they were very distinct & well defined, & the blacknesse seemed as intense as that of the centrall spot. Also in the borders of the rings where the colours began to emerge out of the whitenesse, they were pretty distinct, which made them visible to a very great multitude. I have sometimes numbered above thirty successions (recconing every black & white ring for one succession,) & seen more of them which by reason of their smallnesse I could not number. But in other positions of the Prisms at which the rings appeared of many colours, I could not distinguish above 8 or 9 of them, & the exteriour of those were very confused & dilute.

In these two Observations to see the rings distinct, & without any other colour but black & white, I found it necessary to hold my eye at a good distance from them. For by approaching nearer, although in the same inclination of my eye to the plane of the rings, yet there emerged a blewish colour out of the white, which by dilating it selfe more & more into the black rendered the circles lesse distinct, & left the white a little tinged with red & yellow. I found also that by looking through a slit or oblong hole which was narrower then the pupill of my eye & held close to it parallel to the Prisms, I could see the circles much distincter & visible to a far greater number then otherwise.

Obs: 4. To observe more nicely the order of the colours which arose out of the white circles as the rays became lesse & lesse inclined to the plate of Air; I took two object glasses the one a plano-convex for a fourteen foot Telescope, & the other a large double convex for one of about fifty foot, & upon this laying the other with its plane side downwards, I pressed them slowly together to make the colours succes <502r> sively emerge in the middle of the circles & then slowly lifted the upper glasse from the lower to make them successively vanish again in the same place, where being of a considerable breadth, I could more easily discerne them. And by this means I observed their succession & quantity to be as followeth.

Next to the pellucid centrall spot made by the contact of the glasses, succeeded , Blew, White, Yellow, & Red. The Blew was so very little in quantity that I could not discerne it in the circles made by the Prisms, nor could I well distinguish any violet in it,, but the Yellow & Red were pretty copious & seemed about as much in extent as the white, & foure or five times more then the Blew . The next circuit or order of colours immediately incompassing these was Violet Blew, Green, Yellow, & Red. And these were all of them copious & vivid excepting the green which was very little in quantity & seemed much more faint & dilute then the other colours. Of the other four the Violet was least & the blew lesse then the yellow or red. The third circuit or order was also Purple, Blew, Green, Yellow, & Red in which the purple seemed more reddish then the Violet in the former circuit, & the Green was much more conspicuous, being as brisque & copious as any of the other colours except the Yellow, but the Red began to be a little faded inclining very much to purple. After these succeeded in the fourth circuit Green & Red. The Green was very copious & lively, inclining on one side to blew & on the other to yellow. But in this 4th circuit there was neither violet blew nor yellow, & the Red was very imperfect & dirty. Also the succeeding colours became more & more imperfect & dilute till after three or four more revolutions they ended in perfect whitenesse.

Obs: 5. To determin the intervall of the glasses or thicknesse of the interjacent Air by which each colour was produced, I measured the diameters of the first six rings at the most lucid part of their Orbits, & squaring them I found their squares to be in Arithmeticall progression of the odd numbers 1, 3, 5, 7, 9, 11. And since one of the glasses was plane & the other sphericall, their intervalls at those rings must be in the same progression. I measured also the diameters of the dark or faint rings between the more lucid colours & found their squares to be in Arithmeticall progression of the eaven numbers 2, 4, 6, 8, 10, 12. And it being very nice & difficult to take these measures exactly I repeated them divers times at divers parts of the glasses, that by their agreement I might be confirmed in them. And the same Method I used in determining some others of the following Observations.

Obs: 6. The diameter of the sixt ring at the most lucid part of its orbit was $\frac{58}{100}$ parts of an inch, & the diameter of the Sphere <502v> on which the double convex object glass was ground was 102 foot, as I found by measuring it; & consequently the thicknesse of the Air, or Aereall intervall of the glasses at that ring was $\frac{1}{14554}$ of an inch. For as the diameter of the said sphere (102 foot or 1224 inches) is to the semidiameter of the ring $\frac{29}{100}$ so very nearely is that semi-diameter to $\frac{1}{14554}$ the said intervall of the glasses. Now by the preceedent Observation the eleventh part of this intervall ($\frac{1}{160094}$) is the thicknesse of the Air at that part of the first ring where most lucid of the colours the citrine Yellow would be most vivid were it nor mixed with other colours in the white of this ring, & this doubled gives the difference of its thicknesses at the citrine Yellow in all the other rings. viz $\frac{1}{80047}$ or to use a round number, the eighty thousandth part of an inch.

Obs: 7. These dimensions were taken when my eye was placed perpendicularly over the glasses in or neare the axis of the Rings But when I viewed them obliquely they became bigger, continually swelling as I removed my eye further from their Axis. And partly by measuring the diameter of the same circle at severall obliquities of my eye, partly by other meanes, as also by making use of the two Prisms for very great obliquities, I found its diameter, & consequently the thicknesse of the Air at its perimeter in all those obliquities to be very nearly in the proportions expressed in this Table

Angle of Incidence on the Air.	Angle of Refraction into the Air.	Diameter of the Ring.	Thicknesse of the Air.
$00^{gr}. 00^{min}$	$00^{gr}. 00^{g\ min}.$	10.	10.
6. 26.	10. 00.	$10\frac{1}{13}$.	$10\frac{2}{15}$.
12. 45.	20. 00.	$10\frac{1}{3}$.	$10\frac{2}{3}$.
18. 49.	30. 00.	$10\frac{3}{4}$.	$11\frac{1}{2}$.
24. 30.	40. 00.	$11\frac{2}{5}$.	13.
29. 37.	50. 00.	$12\frac{1}{2}$.	$15\frac{1}{2}$.
33. 58.	60. 00.	14.	20.
35. 47.	65. 00.	$15\frac{1}{4}$.	$23\frac{1}{4}$.
37. 19.	70. 00.	$16\frac{4}{5}$.	$28\frac{1}{4}$.
38. 33.	75. 00.	$19\frac{1}{4}$.	37.
39. 27	80. 00.	$22\frac{6}{7}$.	$52\frac{1}{4}$.
40. 0	85. 00.	29.	$84\frac{1}{10}$.
40. 11	90. 00.	35.	$122\frac{1}{2}$.

In the two first Columns are expressed the obliquities of the incident & emergent rays to the Plate of Air, that is their angles of incidence & refraction. In the third Column the diameter of any coloured Ring at those obliquities is exprest in parts of which ten constitute th at diameter when the rays are perpendicular. And in the 4^{th} Column the thicknesse of the Air at the circumference of that Ring is exprest in parts of which also 10 constitute that thicknesse when the rays are perpendicular.

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Obs: 8. The dark spot in the middle of the Rings increased also by the obliquation of the eye; although almost insensibly. But if instead of the Object-glasses the Prisms were made use of, its increase was more manifest when viewed so obliquely that no colours appeared about it. It was least when the rays were incident most obliquely on the interjacent Air, & as the obliquity decreased it increased more & more untill the coloured rings appeared, & then decreased again, but not so much as it increased before. And hence it is evident that the transparency was not onely at the absolute contact of the glasses but also where they had some little intervall. I have sometimes observed the diameter of that spot to be between half & two fift parts of the diameter of the exterior circumference of the Red in the first circuit or revolution of colours when viewed almost perpendicularly; whereas when viewed obliquely it hath wholly vanished & become opake & white like the other parts of the glasse. Whence it may be collected that the glasses did then scarcely or not at all touch one another, & that their intervall at the perimeter of that spot when viewed perpendicularly was about a 5^{t} or a 6^{t} part of their intervall at the circumference of the said Red

Obs: 9. By looking through the two contiguous Object-glasses, I found that the interjacent Air exhibited Rings of colours as well by transmitting light as by reflecting it. The centrall spot was now white, & from it the order of the colours were Yellowish Red; Black; Violet, Blew, White, Yellow, Red; Violet, Blew, Green, Yellow, Red, &c But these colours were very faint & dilute unlesse when the light was trajected very obliquely through the glasses. For by that meanes they became pretty vivid. Onely the first Yellowish Red, like the blew in the 4^{th} Observation was so little & faint as scarcely to be discerned. Compareing the coloured Rings made by reflexion, with these made by transmission of the light; I found that White was opposite to Black, Red to Blew, Yellow to Violet, & Green to a compound of Red & Violet. That is, those parts of the glasse were black when looked at through which when looked upon appeared white, & on the contrary. And so those which in one case exhibited blew did in the other case exhibit Red. And the like of the other colours.

Obs: 10. Wetting the Object glasses a little at their edges, the water crept in slowly between them, & the circles thereby became lesse & the colours more faint: in so much that as the water crept along one half of them at which it first arrived would appeare broken of from the other half & contracted into a lesse Room. By measuring them I found the proportion of their diameters to the diameters of the like circles made by Air to be about seven to eight, & consequently the intervalls of the glasses at like circles caused by these two Mediums water & air are as about three to four. Perhaps it may **{**be**}** <503v> a generall Rule that if any other Medium more or lesses dense y^{n} water be compressed between the glasses, their intervall at the Rings caused thereby will be to their intervall caused by the interjacent Air, as the sines are which measure the refraction made out of that Medium into Air

Obs: 11. When the water was between the glasses if I pressed the upper glasse variously at its edges to make the Rings move nimbly from one place to another, a little bright spot would —— immediately follow the center of them, which upon creeping in of the ambient water into that place would presently vanish. It's appearance was such as interjacent Air would have caused, & it exhibited the same colours. But it was not Air, for where any aereall bubbles were in the water they would not vanish. The reflexion must rather have been caused by a subtiler Medium which could recede through the Glasse at the creeping in of the water.

Obs: 12. These Observations were made in the open Air. But further to examin the effects of coloured light falling on the Glasses, I darkened the Room & viewed 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 coloured paper by reflexion in the glasses as in a looking glass.. And by this meanes the Rings became distincter & visible to a far greater number then in the open Air. I have sometimes seen more then 20 of them, whereas in the open Air I could not discerne above 8 or 9.

Obs: 13. Appointing an Assistant to move the Prism to & fro about its Axis, that all the colours might successively fall on that plart of the paper which I saw by reflexion from that part of the glasses where the circles appeared so that all the colours might be successively reflected from the circles to my eye whilst I held it immoveable; I found the circles which the Red light made to be manifestly biger then those which were made by the Blew & Violet. And it was very pleasant to see them gradually swell or contract accordingly as the colour of the light was changed. The interval of the Glasses at any of the rings when they were made by the utmost red light was to their intervall at the same Ring when made by the utmost Violet, greater then 3 to 2 & lesse then 13 to 8. By the most of my Observations it was as 14 to 9. And this proportion seemed very nearely the same in all obliquities of my eye; unlesse when two Prisms were made use of instead of the Object-glasses. For then at a certain great obliquity of my eye the Rings made by the severall colours seemed equall, & at a greater obliquity those made by the Violet would be greater then the same Rings made by the Red.

Obs 14. While the Prism was turned about its axis with an eaven motion The Contraction or dilatation of a Ring made by all the severall colours of the Prism successively reflected from the Object-Glasses, was swiftest in the Red, slowest in the Violet, & in intermediate colours it had intermediate degrees of celerity. Comparing the extent or breadth of the rings or variation of the Air's thickness which each colour obteined moved over & took up by this contraction or dilatation <504r> I found that the Blew was sensibly more extended then the Violet, the Yellow then the Blew, & the Red then the Yellow. And to make a juster estimation of their proportions I observed that the extent or breadth of the Red squared that is the variation of the thickness of the air where all the red by contraction & dilatation appeared was almost double to that of the Violet, & that the light was of a middle colour between Yellow & Green at that intervall of the Glasses which was an Arithmeticall mean between the two extreame intervalls where the colours began & ended: contrary to what happens in the colours made by the refraction of a Prism, where the Red is most contracted, the Violet most expanded, & in the midst of all the colours is the confine of Green & Blew.

Obs: 15. These Rings were not of various colours like those in the open Air but appeared all over of that Prismatique colour onely with which they were illuminated. And by projecting the Prismatique colours immediately upon the glasses, I found that the light which fell on the dark spaces which were between the coloured Rings, was transmitted through the Glasses without any variation of colour. For on a white paper placed behind, it would paint Rings of the same colour with those which were reflected, & of the bignesse of their intermediate spaces. And from hence the origine of these Rings is manifest, namely that the aereall intervall of the glasses, according to its various thicknesse, is disposed in some places to reflect, & in others to transmit the light of any colour, & in the same place to reflect one colour where it transmits another.

Obs: 16. The squares of the diameters of these Rings made by any Prismatique colour were in Arithmeticall Progression as in the 5^{t} Observation. And the diameter of the sixt circle when made by the citrine Yellow & viewed almost perpendicularly, was about $\frac{58}{100}$ parts of an inch, agreable to the 6^{t} Observation.

The precedent Observations were made with a rarer thin Medium terminated by a denser, such as was Air or water —— comprest 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 Moscovy Glasse, Bubbles of Water, & some other thin substances terminated as all sides with Air

Obs: 17. If a Bubble be blown with water, first made tenacious by dissolving a little soape in it, tis a common observation that after a while it will appeare tinged with a great variety of colours. To defend these bubbles from being agitated by the externall Air (whereby their colours are irregularly moved one among another, so that no accurate observation can be made of them,) as soon as I had blown any of them I covered it with a cleare glasse, & by that meanes its colours emerged in a very regular order like so many concentrick rings incompassing the top of the Bubble. And <504v> as the bubble grew thinner by the continuall subsiding of the water these rings dilated slowly & overspread the whole bubble descending in order to the bottom of it where they vanished successively. In the meane while after all the colours were emerged at the top, there grew in the center of the Rings a small round black spot like that in the first Observation which continually dilated it selfe till it became sometimes more then $\frac{1}{2}$ or $\frac{3}{4}$ of an inch in breadth before the Bubble brake. At first I thought there had been no light reflected from the water in that place, but observing it more curiously I saw within it severall smaller round spots which appeared much blacker & darker then the rest, whereby I knew that there was some reflexion at the other places which were not so dark as those spots. And by further tryall I found that I could see the images of some things (as of a candle or the Sun) very faintly reflected not onely from the great black spot but also from the little darker spots which were within it.

Besides the afforesaid coloured Rings there would often appeare small spots of colours ascending & descending up & down the sides of the Bubble, by reason of some inequalities in the subsiding of the water. And sometimes small black spots generated at the sides would ascend up to the larger black spot at the top of the Bubble & unite with it.

Obs: 18. Because the colours of these Bubbles were more extended & lively then those of Air thind between two Glasses, & so more easy to be distinguished: I shall here give you a further description of their order as they were observed in viewing them by reflexion of the Skies when of a white colour, whilst a black substance was placed behind the bubble. And they were these; Red, Blew; Red, Blew; Red, Blew; Red, Green; Red, Yellow, Green, Blew, Purple; Red, Yellow, Green, Blew, Violet; Red, Yellow, White, Blew, Black.

The three first successions of Red & Blew were very dilute & dirty, especially the first where the Red seemed in a manner to be white Amongst these there was scarcely any other colour sensible, onely the Blews (& principally the second blew) inclined a little to Green.

The fourth Red was also dilute & dirty but not so much as the former three; After that succeeded little or no Yellow, but a copious Green which at first inclined a little to yellow, & then became a pretty brisque & good Willow Green, & afterwards changed to a blewish colour; but there succeeded neither Blew nor violet.

The fift Red at first inclined very much to purple & afterwards became more bright & brisque but yet not very pure. This was succeeded with a very bright & intense Yellow, which was but little in quantity, & soon changed to Green: But that Green was **{**copious**}** & something more pure deep & lively then the former Green. After <505r> that followed an excellent Blew of a bright Sky colour, & then a Purple which was lesse in quantity then the Blew & much inclined to Red.

The sixt Red was at first of a very faire & lively Scarlet, & soon after of a brighter colour being very pure & brisque & the best of all the Reds. Then after a lively Orange followed an intense bright & copious Yellow, which was also the best of all the Yellows; & this changed first to a Greenish Yellow, & then to a Greenish Blew; but the Green between the Yellow & Blew was very little & dilute, seeming rather a Greenish White then a Green. The Blew which succeeded became very good & of a fair Bright Sky colour, but yet something inferior to the former Blew, And the Violet was intense & deepe with little or no rednesse in it And lesse in quantity then the Blew

In the last Red appeared a tincture of Scarlet next the Violet, which soon changed to a brighter colour inclining to an Orange; And the Yellow which followed was at first pretty good & lively but afterwards it grew more & more dilute untill by degrees it ended in perfect whitenesse. And this whitenesse, if the water was very tenacious & well tempered, would slowly spread & dilate it selfe over the greatest part of the bubble, continually growing paler at the top, where at length it would crack in many places, & those cracks as they dilated would appeare of a pretty good, but yet obscure & dark sky colour; the white between the Blew spots diminishing, untill it resembled the threds of an irregular net=work, & soon after vanished & left all the upper part of the Bubble of the said dark Blew colour. And this colour after the afforesaid manner dilated it self downwards untill sometimes it hath overspread the whole Bubble. In the meane-while at the top, which was of a darker Blew then the bottom & appeared also full of many round blew spots something darker then the rest, there would emerge one or more very black spots & with those other spots of an intenser blacknesse, which I mentioned in the former Observation; And these continually dilated themselves untill the Bubble brake.

If the water was not very tenacious the Black spots would break forth in the white without any sensible intervention of the blew. And sometimes they would break forth within the precedent Yellow, or Red, or perhaps within the Blew of the second order before the intermediate colours had time to display themselves.

By this description you may perceive how great an affinity these colours have with those of Air described in the 4th Observation, although set down in a contrary order by reason that they begin to appeare when the Bubble is the thickest, & are most conveniently recconed from the lowest & thickest part of the Bubble upwards.

Obs: 19. Viewing at severall oblique positions of my eye the Rings of colours emerging on the top of the Bubble, I found that they <505v> were sensibly dilated by increasing the obliquity, but yet not so much by far as those made by thinned Air in the 7th Observation. For there they were dilated so much as, when viewed most obliquely, to arrive at a part of the Plate more then twelve times thicker then that where they appeared when viewed perpendicularly, whereas in this case the thicknesse of the water at which they arrived when viewed most obliquely, was to that thicknesse which exhibited them by perpendicular rays something lesse then 8 to 5. By the best of my Observations it was between 15 & $15\frac{1}{2}$ to 10; an increase about 24 times lesse then in the other case.

Sometimes the Bubble would become of an uniform thicknesse all over except at the top of it neare the black spot, as I knew because it would exhibit the same appeareance of colours in all —— positions of the eye: And then the colours which were seen at its apparent circumference by the obliquest rays would be different from those that were seen in other places by rays lesse oblique to it. And divers Spectators might see the same part of it differing colours by viewing it at very differing obliquities. Now observing how much the colours at the same place of the Bubble or at divers places of equall thicknesse were varied by the severall obliquities of the rays; by assistance of the 4th 14th 16th & 18th Observations, as they are hereafter explained, I collected the thicknesse of the water requisite to exhibit any one & the same colour at severall obliquities to be very nearely in the proportion expressed in this Table.

Incidence on the Water.	Refraction into the Water.	Thicknesse of the water.
00degr. 00min.	00degr. 00min.	10.
15. 00.	11. 11.	$10\frac{1}{4}$.
30. 00.	22. 1.	$10\frac{4}{5}$.
45. 00.	32. 2.	$11\frac{4}{5}$.
60. 00.	40. 30.	13.
75. 00.	46. 25.	$14\frac{1}{2}$.
90. 00.	48. 35.	$15\frac{1}{5}$.

In the first two Collumns are expressed the obliquities of the rays to the superficies of the water, that is their angles of incidence & refraction. Where I suppose that the sines which measure them are in round numbers as 3 to 4, though probably the dissolution of soape in the water may a little alter its refractive virtue. In the third collumn the thicknesses of the Bubble at which any one colour is exhibited in those severall obliquities, is exprest an parts of which ten constitute that thicknesse when the rays are perpendicular.

I have sometimes observed of the colours which arise on polished Steel when heating it, or on Belmstall & some other Metalline substances when melted & poured on the ground <506r> where it may cook in the open Air, that they have, like these of water-bubbles, been a little changed by viewing them at divers obliquities, & particulary that a deep blew of violet when viewed very obliquely hath been changed to a deep Red. But the changes of these colours are not so great & sensible as of those made by water. For the Scoria or vitrified part of the Metall which most Metalls when heated or melted do continually protrude to their surface & which by covering the metalls in forme of a thin glassy skin, causes these colours, is much denser then water; and I find that the change made by the obliquation of the eye is least in colours of the densest thin substances.

Obs: 20. As in the 9th Observation so here the Bubble by transmitted light appeared of a contrary colour to that which it exhited by reflexion. Thus when the Bubble being looked on by the light of the clouds reflected from it, seemed Red at its apparent circumference, if the clouds at the same time or immediately after were viewed through it, the colour at its circumference would be Blew. And on the contrary when by reflected light it appeared Blew, it would appeare Red by transmitted light.

Obs: 21. By wetting very thin Plates of Moscovy-glasse whose thinnesse made the like colours appeare, the colours became more faint; especially by wetting the Plates on that side opposite to the eye; but I could not perceive any variation of their species. So then the thicknesse of a plate requisite to produce any colour depends only on the density of the Plate & not on that of the ambient Medium. And hence by the 10th & 16th

Observations may be known the thicknesse which Bubbles of Water or plates of Moscovy-glasse, or other substances, have at any colour produced by them.

Obs: 22. A thin transparent body which is denser then its ambient Medium, exhibits more brisque & vivid colours then that which is so much rarer; as I have particularly observed in Air & Glasse. For blowing Glasse very thin at a Lamp Furnace, those plates incompassed with Air did exhibit colours much more vivid then those of Air made thin between two glasses.

Obs: 23. Comparing the quantity of light reflected from the severall Rings, I found it was most copious from the first or inmost, & in the exterior Rings became gradually lesse & lesse. Also the whitenesse of the first Ring was stronger then that reflected from those parts of the thinned Medium which were without the Rings; as I could manifestly perceive by viewing at a distance the Rings made by the two Object glasses; Or by compareing two bubbles of water blown at distant times in the first of which the whitenesse appeared which succeded all the colours, & in the other the whitenesse which preceded them all .

Obs: 24. When the two Object-Glasses were layd upon one another so as to make the Rings of Colours appeare, though with my naked eye I <506v> could not discerne above 8 or 9 of those rings yet by viewing them through a Prism I have seen a far greater multitude, insomuch that I could number more then fourty besides many others that were so very small & close together that I could not keep my eye so steddy on them severally as to number them. But by their extent I have sometimes estimated them to be more then a hundred. And I beleive the experiment may be improved to the discovery of far greater numbers. For they seem to be really unlimited, though visible onely so far as they can be separated by the refraction, as I shall hereafter explaine.

But it was but one side of these rings, namely that towards which the refraction was made, which by that refraction was rendered distinct, & the other side became more confused then when viewed by the naked eye, insomuch that there I could not discerne above one or two, & sometimes none of those rings, of which I could discerne 8 or 9 with my naked eye. And their segments or arcs which on the other side —— appeared so numerous, for the most part exceed ed not the third part of a circle. If the refraction was very great or the Prisms very distant from the Object-glasses, the middle part of those arcs became also confused so as to disappeare & constitute an eaven whitenesse, whilst on either side their ends , as also the whole arcs furthest from the center became distincter then before, appearing in the forme you see them here designed.

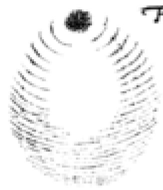


Fig 2.

The arcs when they seemed distinctest were onely white & black successively without any other colours intermixed. But in other places there appeared colours whose order was inverted by the refraction in such manner that if I first held the Prism very neare the Object-Glasses & then gradually removed it further of towards my eye, the colours of the 2^{d} 3^{d} 4^{th} & following Rings shrunk towards the white that emerged between them, untill they wholly vanished into it at the middle of the arcs, & afterwards emerged again in a contrary order. But at the ends of the arcs they retained their order unchanged.

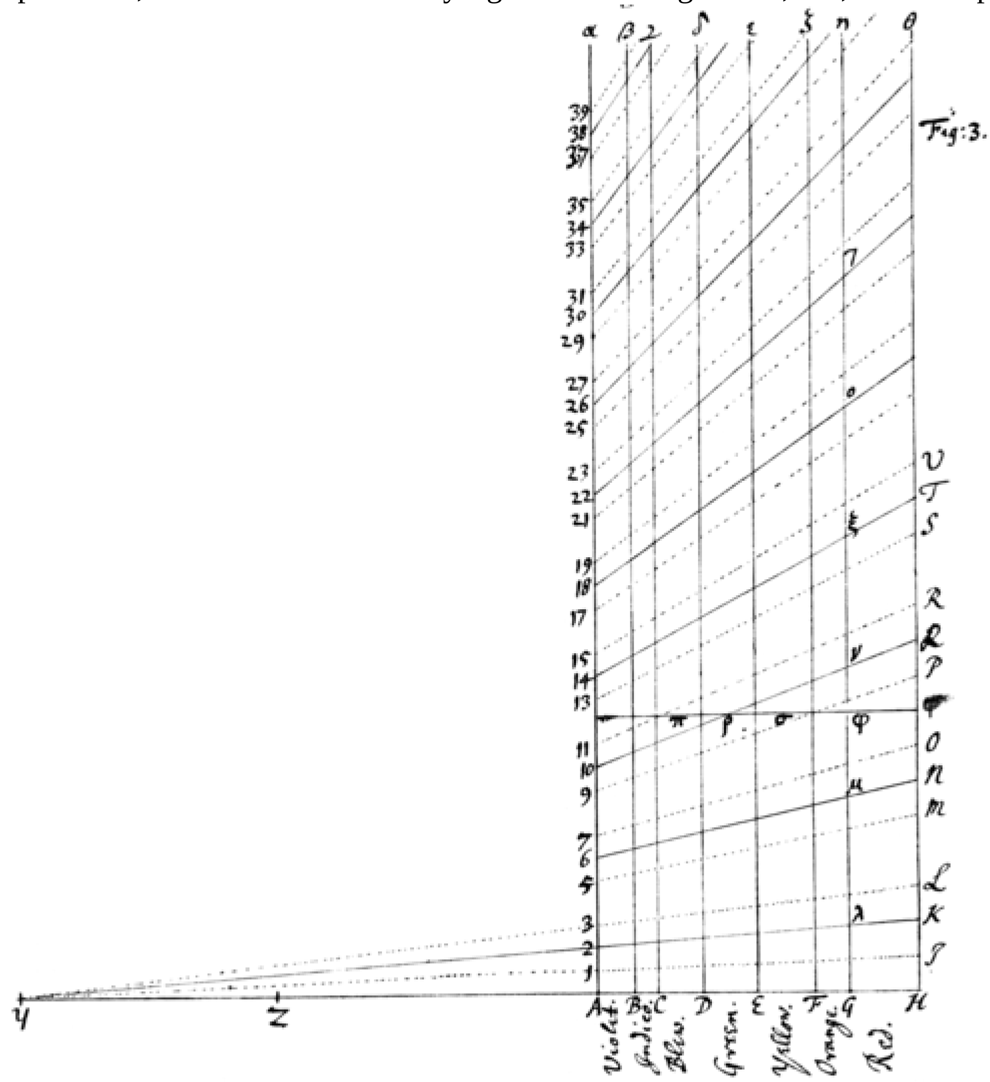
I have sometimes so layd one Object-glasse upon the other that to the naked eye they have all over seemed uniformly white without the least appearance of any of the coloured rings; & yet by viewing them through a Prism great multitudes of those rings have discovered themselves. And in like manner Plates of Moscovy-Glasse & bubbles of Glasse blown at a Lamp-Furnace which were not so thin as to exhibit any colours to the naked eye, have through the Prism exhibited a great variety of them ranged irregularly up & down in the form of waves. And so bubbles of water before they began to exhibit their colours to the naked eye of a by stander have appeared through a Prism, girded about with many parallel & horizontal Rings; to produce which effect, it was necessary to hold the Prism parallel or very nearely parallel to the Horizon, & to dispose it so that the rays might be refracted upwards.

<507r>

The second Part

Remarks upon the foregoing Observations.

Having given my Observations of these colours, before I make use of them to unfold the causes of the colours of naturall bodies, it is convenient that by the simplest of them, such as are the 2^{d}, 3^{d}, 4^{th}, 9^{th}, 12^{th}, 18^{th} 20^{th} & 24^{th}, I first explaine the more compounded. And first to show how the colours in the 4^{th} & 18^{th} Observations are produced, let there be taken in any right line the lengths YZ, YA, & YH in proportion as



4, 9, & 14 | [2 5 & 8] & between ZA & ZH eleven meane proportionalls, of which let ZB be the second, ZC the third, ZD the fift, ZE the seventh, ZF the ninth, & ZG the tenth. And at the points A, B, C, D, E, F, G, H let perpendiculars Aα, Bβ &c be erected, by whose intervalls the extent of the severall colours set underneath against them, is to be represented. Then divide the line Aα in such proportion as the numbers 1, 2, 3; 5, 6, 7; 9, 10, 11; &c. set at the points of division denote. And through those divisions from Y draw lines 1I, 2K, 3L; 5M, 6N, 7O; &c

Now if A2 be supposed to represent the thicknesse 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 13^{th} Observation HK will represent its thicknesse at which the outmost Red is most copiously reflected in the same series. Also by the 5^{t} & 16 Observations A6 & HN will denote the thicknesses at which those extreme colours are most copiously —— reflected in the second series, & A10. HQ the thicknesses at which they are most copiously reflected in the third series & so on. And the thicknesse at which any of the intermediate colours are reflected most copiously, will according to the 14 Observation be defined by the distance of the line AH from the intermediate parts of the lines 2K, 6N, 10Q, &c against which the names of those colours are written below.

But further to define the latitude of these colours in each Ring or series, let A{2} designe the least thicknesse & A3 the greatest thicknesse at which the extreame Violet in the first series is reflected & let HI & HL designe the like limits for the extreame Red, & let <507v> the intermediate colours be limited by the intermediate parts of the lines 1I & 3L against which the names of those colours are written. And in the second series let those limits be the lines 5M & 7O; & so on: But yet with this caution that the reflexions be supposed strongest at the intermediate spaces 2K, 6N, 10Q &c & from thence to decrease gradually towards these limits 1I, 3L; 5M, 7O; &c on either side; where you must not conceive them to be precisely limited but to decay indefinitely. And whereas I have assigned the same latitude to every series, I did it because although the colours in the first series seem to be a little broader then the rest by reason of a stronger reflexion there, yet that inequality is so insensible as scarcely to be determined by observation.

Now according to this Description conceiving that the rays in which severall colours inhere are by turnes reflected at the spaces iIL3, 5MO7, 9PR11 &c:, & transmitted at the spaces AHI1, 3LM5, 7OP9 &c: it is easy to know what colour must in the open Air be exhibited at any thicknesse of a transparent thin Body. For if a Ruler be applyed parallel to AH at that distance from it by which the thicknesse of the Body is represented, the alternate spaces 1IL3, 5MO7 &c which it crosseth will denote the reflected originall colours of which the colour exhibited in the open Air is compounded. Thus if the constitution of the Green in the third series of colours be desired; apply the Ruler as you see at πρσ, φ, And by its passing through some of the Blew at π, & yellow at σ, as well as through the green at ρ, you may conclude that the green exhibited at that thicknesse of the Body is principally constituted of originall green, but not without a mixture of some Blew & Yellow.

By this meanes you may know how the colours from the center of the Rings outwards ought to succede in order as they were described in the 4th & 18th Observations. For if you move the Ruler gradually from AH through all distances, having past over the first space which denotes little or no reflexion to be made by thinnest substances, it will first arrive at 1 the Violet, & then very quickly at the blew & Green which together with that Violet compound blew, & then at the Yellow & Red by whose further addition that Blew is converted into whitenesse, which whitenesse continues during the transit of the edge of the ruler from I to 3, & after that by the successive deficience of its component colours turnes first to compound Yellow & then to Red, & last of all the Red ceaseth at L. Then begin the colours of the second series, which succeed in order during the transit of the edge of the ruler from 5 & O , & are more lively then before because more expanded & severed. And for the same reason instead of the former white there intercedes between the blew & Yellow a mixture of Orange, Yellow, Green, Blew & Indico, all which together ought to exhibit a dilute & imperfect Green. So the colours of <508r> the third series all succeed in order; first the Violet which a little interferes with the Red of the second order & is thereby inclined to a reddish Purple; then the Blew & Green which are lesse mixed with other colours & consequently more lively then before, especially the Green: Then follows the Yellow some of which towards the Green is distinct & good, but that part of it towards the succeding Red, as also that Red is mixed with the Violet & Blew of the fourth series, whereby various degrees of Red very much inclining to Purple are compounded. This Violet & Blew which should succeed this Red being mixed with & hidden in it, there succeeds a Green, And this at first is much inclined to Blew, but soon becomes a good Green, the onely unmixt & lively colour in this fourth series. For as it verges towards the Yellow it begins to interfere with the colours of the fift series, by whose mixture the succeeding Yellow & Red are very much diluted & made dirty, especially the Yellow which being the weaker colour is scarce able to shew it selfe. After this the severall series interfere more & more & their colours become more & more intermixed, till after thre or four more revolutions (in which the Red & Blew —— predominate by turnes) all sorts of colours are in all places pretty equally blended & compound an eaven whitenesse.

And since by the 15th Observation the rays indued with one colour are transmitted where those of another colour are reflected, the reason of the colours made by the transmitted light in the 9th & 20th Observations is also from hence evident.

If not onely the order & species of these colours, but also the precise thicknesse of the Plate or thin Body at which they are exhibited, be desired in parts of an inch, that may be also obteined by assistance of the 6t or 16th Observation. For according to those Observations the thicknesse of the thinned Air which between two Glasses exhibited the most luminous part of the sixt ring , was $\frac{1}{14554}$ parts of an inch. Now suppose this thicknesse be represented by G7 & the eleventh part of it Gλ will be about $\frac{1}{160000}$ of an inch. And so Gμ, Gν, Gξ, Go will be $\frac{3}{160000}$, $\frac{5}{160000}$, $\frac{7}{160000}$, & $\frac{9}{160000}$. And this being known it is easy to determin what thicknesse of Air is represented by Gφ or by any other distance of the Ruler from AH.

But further since by the 10th Observation the thicknesse of Air was to the thicknesse of water which between the same Glasses exhibited the same colour, as 4 to 3; & by the 21th Observation the colours of thin Bodies are not varied by varying the ambient Medium: the thicknesse of a Bubble of water exhibiting any colour will be $\frac{3}{4}$ of the thicknesse of Air produceing the same colour. And so according to the same 10^{th} & 21^{th} Observations the thicknesse of a Plate of Glasse whose refraction is measured by the proportion of the sines <508v> 31 to 20 may be $\frac{21}{31}$ of the thicknesse of Air produceing the same colours. And the like of other Mediums. On these grounds I have composed the following Table wherein the thicknesse of Air, water, & glasse at which each colour is most intense & specific, is expressed in parts of an inch divided into ten hundred thousand equall parts.

		The thicknesse of		
In particles of pellucid bodies lesse then		Air —	Water	Glasse
In those of	Black	2	$1\frac{1}{2}$	$1\frac{1}{4}$, or lesse.
The Colours Of the 1^{st} order	Blew	$2\frac{2}{3}$	2	$1\frac{3}{4}$.
	White	$5\frac{1}{3}$	4	$3\frac{1}{2}$.
	Yellow	8	6	$5\frac{1}{6}$
	Orange	9	$6\frac{3}{4}$	$5\frac{4}{5}$.
	Red.	10	$7\frac{1}{2}$	$6\frac{1}{2}$.
	Violet	12	9	$7\frac{3}{4}$.
	Indico	$13\frac{1}{4}$	$9\frac{11}{12}$	$8\frac{1}{2}$.
	Blew	$14\frac{3}{4}$	11	$9\frac{1}{2}$.
Of the 2^{d} Order	Green	16	12	$10\frac{1}{3}$.
	Yellow	$17\frac{1}{2}$	$13\frac{1}{8}$	$11\frac{1}{3}$.
	Orange	$19\frac{1}{4}$	$14\frac{1}{2}$	$12\frac{2}{5}$.
	Bright Red	20	15	13.
	Scarlet	$21\frac{1}{4}$	16	$13\frac{2}{3}$.
	Purple	23	$17\frac{1}{4}$	$14\frac{5}{6}$
	Indico	24	18	$15\frac{1}{2}$.
	Blew	$25\frac{1}{5}$	19	$16\frac{1}{4}$.
Of the 3^{d} order	Green	$27\frac{1}{5}$	$20\frac{2}{5}$	$17\frac{1}{2}$.
	Yellow	$29\frac{1}{2}$	22	19.
	Red	31	$23\frac{1}{4}$	20.
	Blewish Red	$33\frac{1}{2}$	25	$21\frac{2}{5}$.
	Blewish Green	36	27	$23\frac{1}{4}$.
	Green	$37\frac{2}{3}$	$28\frac{1}{4}$	$24\frac{1}{3}$.
4^{th} Order	Yellowish Green	$39\frac{1}{3}$	$29\frac{1}{2}$	$25\frac{1}{3}$.
	Red	44	33	$28\frac{1}{3}$.
5^{t} Order	Greenish Blew	$50\frac{2}{3}$	38	$32\frac{2}{3}$.
	Red	$57\frac{1}{3}$	43	37.
6^{t} Order	Greenish Blew	64	48	$41\frac{1}{3}$.
	Red	$70\frac{2}{3}$	53	$45\frac{2}{3}$.
7^{th} Order.	Grenish Blew	$77\frac{1}{3}$	58	50.
	Red or white	84	63	$54\frac{1}{2}$.

Now if this Table be compared with the 3^{d} Scheme [1] you will there see the constitution of each colour as to its ingredients or the originall colours of which it is compounded, & thence be enabled to judg of its intensenesse or imperfection, which may suffice in explication of the 4^{th} & 18^{th} Observations, unlesse it be further desired to delineate the manner how the colours appeare when the two Object-glasses are layd upon one another. To doe which let there be described a large Arc of a circle & a <509r> streight line which may touch that Arc, & parallel to that Tangent severall occult lines at such distances from it as the numbers set against the severall colours in the Table denote. For the Arc & its Tangent will represent the superficies of the glasses terminating the interjacent Air, & the places where the occult lines cut the Arc will show at what distances from the center or point of contact each colour is reflected.

There are also other uses of this Table: For by its assistance the Thicknesse of the Bubble in the 19th Observation was determined by the colours which it exhibited. And so the bignesse of the parts of naturall bodies may be conjectured at by their colours, as shall be hereafter shown. Also if two or more very thin Plates be layd one upon another so as to compose one Plate equalling them all in thicknesse, the resulting colour may be hereby determined. For instance, Mr Hook in his Micrographia observes that a faint yellow Plate of Moscovy-Glasse layd upon a blew one constituted a very deep purple. The Yellow of the first order is a faint one, & the thicknesse of the Plate exhibiting it, according to the Table, is $5\frac{1}{6}$ to which add $9\frac{2}{3}$ the thicknesse exhibiting Blew of the second order, & the summe will be $14\frac{5}{6}$, which is the thicknesse exhibiting the Purple of the third order.

To explain in the next place the circumstances of the 2d & 3d Observations, that is, how the rings of colours may, (by turning the Prisms about their common Axis the contrary way to that expressed in those Observations,) be converted into white & black Rings, & afterwards into rings of colours again the colours of each ring lying now in an inverted order: it must be remembered that those rings of colours are dilated by the obliquation of the rays to the Air which intercedes the Glasses, & that according to the Table in the 7th Observation their dilatation or increase of their diameter is most manifest & speedy when they are obliquest. Now the rays of Yellow being more refracted by the first superficies of the said Air then those of red are thereby made more oblique to the second superficies at which they are reflected to produce the coloured Rings, & consequently the Yellow circle in each Ring will be more dilated then the Red; & the excesse of its dilatation will be so much the greater by how much the greater is the obliquity of the rays, untill at last it become of equall extent with the Red of the same Ring. And for the same reason the Green blew & violet will be also so much dilated by the still greater obliquity of their rays as to become all very nearely of equall extent with the Red, that is, equally distant from the center of the Rings. And then all the colours of the same ring must be coincident, & by their mixture exhibit a white Ring. And these white Rings must have black or dark Rings between them because they doe not spread & interfere with one another as before. <509v> And for that reason also they must become distincter & visible to far greater numbers. But yet the Violet being obliquest will be something more dilated in proportion to its extent then the other colours, & so very apt to appeare at the exterior verges of the white.

Afterwards by a greater obliquity of the rays, the Violet & Blew become sensibly more dilated then the Red & Yellow & so being further removed from the center of the Rings, the colours must emerge out of the white in an order contrary to that which they had before, the Violet & Blew at the exterior limbs of each ring, & the Red & Yellow at the interior. And the Violet by reason of the greatest obliquity of its rays being in proportion most of all expanded will soonest appeare at the exterior limb of each white Ring & become more conspicuous then the rest. And the severall series of colours belonging to the several rings will by their unfolding & spreading begin again to interfere, & thereby render the Rings lesse distinct, & not visible to so great numbers.

If instead of the Prisms the Object-Glasses be made use of; the Rings which they exhibit become not white & distinct by the obliquity of the eye by reason that the rays in their passage through that Air which intercedes the Glasses are very nearely parallel to those lines in which they were first incident on the Glasses, & consequently the rays indued with severall colours are not inclined one more then another to that Air, as it happens in the Prisms.

There is yet another circumstance of these experiments to be considered, & that is why the black & white Rings which when viewed at distance appeare distinct, should not onely become confused by viewing them neare at hand, but also yeild a Violet colour at both the edges of every white Ring. And the reason is that the rays which enter the eye at severall parts of the pupill, have severall obliquities to the Glasses, & those which are most oblique, if considered apart, would represent the Rings bigger then those which are the least oblique.

Whence the breadth of the perimeter of every white Ring is expanded outwards by the obliquest rays, & inwards by the least oblique. And this expansion is so much the greater by how much the greater is the difference of the obliquity; that is, by how much the Pupill 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 the second or further superficies of the thind Air at which they are reflected, & have also the greatest variation of obliquity, which makes that colour soonest emerge out of the edges of the white. And the breadth of every Ring is thus augmented, the dark intervalls must be diminished untill the neighbouring Rings become continuous, & are blended, the exterior first, & then those nearer center, so that they can no longer be distinguished apart but seem to constitute an eaven & uniform whitenesse.

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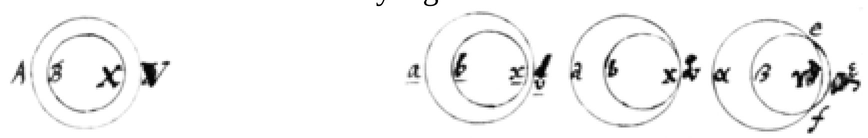
Amongst all the Observations there is none accompanied with so add circumstances as the 24th. Of those the principall are that in thin Plates which to the naked eye seem of an eaven & uniforme trans-parent whitenesse without any terminations of shadows, the refraction of a Prism should make Rings of colours appeare, whereas it usually makes Objects appeare coloured onely there where they are terminated with shaddows or have parts unequally luminous; & that it should make those Rings exceedingly distinct & white, although it usually renders Objects confused & coloured. The cause of these things you will understand by considering that all the Rings of colours are really in the Plate when viewed with the naked eye, although by reason of the great breadth of their circumferences they so much interfere & are blended together that they seem to constitute an eaven whitenesse. But when the rays passe through the Prism to the eye the orbits of the severall colours in every Ring are refracted some more then others according to their degrees of refrangibility: by which meanes the colours on one side of the Ring (that is on one side of its center) become more unfolded & dilated & those on the other side more complicated and contracted. And where by a due refraction they are so much contracted that the severall Rings become narrower then to interfere with one another, they must appeare distinct & also white if the constituent colours be so much contracted as to be wholly coincident. But on the other side where the orbit of every Ring is made broader by the further unfolding of its colours, it must interfere more with other Rings then before & so become lesse distinct.

To explaine this a little further suppose the concentrik circles AV & BX represent the red & Violet of any order which together with the intermediate colours constitute any one of these Rings. Now these being viewed through a Prism the violet circle BX will by a greater



refraction be further translated from its place then the Red AV & so approach nearer to it on that side towards which the refractions are made. For instance, if the Red be translated to av the Violet may be translated to bx so as to approach nearer to it at x then before, & if the Red be further translated to aV the Violet may be so much further translated to bX as to convene with it at X, & if the Red be yet further translated to αγ the Violet may be still so much further translated to βξ as to passe beyond it at ξ & convene with it at e & f. And this being understood not onely of the Red & Violet but of all the other intermediate colours, & also of every revolution of those colours, you will easily perceive how those of the same revolution or <510v> order by their nearenesse at xv & γξ, & their coincidence at XV, e, & f ought to constitute pretty distinct arcs of circles, especially at XV or at e &f, & that they will appeare severall at xv & at XV exhibit whitenesse by their coincidence & again appeare severall at γξ, but yet in a contrary order to that which they had before & still retaine beyond e & f. But on the other side at ab, ab, or αβ these colours must become much more confused by being dilated & spread so as to interfere with those of the other orders. And the same confusion will happen at γξ between e & f if the refraction be very great, or the Prism very distant from the Object-Glasses: in which case no parts of the Ring will be seen save onely two little Arcs at e & f whose distance from one another will be augmented by removing the Prism still further from the Object-Glasses. And these little Arcs must be distinctest & whitest at their Middle, & at their ends where they begin to grow confused 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 crosse in the intermediate white. Namely their ends which verge towards γξ will be red & yellow on that side next the center, & blew & violet on the other side. But their other ends which verge from γξ will on the contrary be blew & violet on that side towards the center & on the other side red & yellow.

Now as all these things follow from the properties of light of a mathematical way of reasoning so the truth of them may be manifested by experiment. For in a dark Room by viewing these Rings through a Prism by reflexion of the severall Prismatique colour which an Assistant causes to move to & fro upon a wall or paper from whence they are reflected, whilst the spectators eye, the Prism and the Object glasses (as in the 13^{th} Observation) are placed steddy: the position of the circles made successively by the severall colours will be found such in respect of one another as I have described in the figures abxv, or abXV, or αβξγ. And by the same method the truth of the explications of other Observations may be examined.

By what hath been said, the like Phænomena of Bubbles of water & thin Plates of Glasse may be understood. But in small fragments of those Plates, there is this further observable, that when lying flat upon a Table are turned about their centers whilst they are viewed through a Prism they will in some postures exhibit waves of various colours &: some of them do exhibit these waves in one or two **{illeg}** onely; but the most of them do in all positions exhibit **{illeg}** **{illeg}** thin the most part appeare almost all **{illeg}** <511r> the plates. The reason is that the superficies of such Plates are not eaven but have many cavities & swellings which how shallow soever do a little vary the thicknesse of the Plate: For at the severall sides of those cavities for the reasons newly described there ought to be produced waves in severall postures of the Prism. Now though it be but some very small & narrow parts of the Glasse by which these waves for the most part are caused, yet they may seem to extend themselves over the whole Glasse, because from the narrowest of those parts there are colours of severall orders that is of several rings confusedly reflected, which by refraction of the Prism are unfolded separated & according to their degrees of refraction, dispersed to severall places so as to constitute so many severall waves as there were divers orders of the colours promiscuously reflected from that part of the Glasse.

These are the principall Phænomena of thin Plates or Bubbles whose explications depend on those properties of light which I have heretofore delivered. And these you see do necessarily follow from them & agree with them even to their very least circumstances; & not onely so, but do very much tend to their proof. Thus by the 24^{th} Observation it appeares that the rays of severall colours made as well by thin Plates or Bubbles as by the refractions of a Prism have severall degrees of refrangibility whereby those of each order which at their reflexion from the Plate or Bubble are intermixed with those of the other orders, are separated from them by refraction, & associated together so as to become visible by themselves like Arcs of Circles. For if the rays were all alike refrangible, tis impossible that the whitenesse which to the naked sense appeares uniforme should by refraction have its parts transposed & ranged into those black & white Arcs.

It appeares also that the unequall refractions of difform rays proceed not from any contingent irregularities: Such as are Veines an uneaven polish, or fortuitous position of the pores of Glasse; unequall & casual motions in the Air or Æther; the spreading, breaking, or dividing the same ray into many diverging parts; or the like. For admitting any such irregularities, it would be impossible for refractions to render those Rings so very distinct & well defined as they doe in the 24^{th} Observation. It is necessary therefore that every ray have its proper & constant degree of refrangibility connate with it, according to which its refraction is ever justly & regularly performed; & that severall rays have severall of those degrees.

And what is said of their Refrangibility may be also understood of their Reflexibility; that is of their dispositions to be reflected <511v> some at a greater & others at a lesse thicknessesse of thin Plates or Bubbles namely that those dispositions are also connate with the rays & immutable; as may appeare by the 13^{th} 14^{th} & 15^{th} Observations compared with the 4^{th} &18^{th}.

By the precedent Observations it appeares also that whitenesse is a dissimilar mixture of all colours, & that light ia a mixture of rays indued with all those colours. For considering the multitude of the Rings of colours in the 3^{d}, 12^{t}, & 24^{th} Observations, it is manifest that although in the 4^{th} & 18^{th} Observations there appeare no more then 8 or 9 of those Rings, yet there are really a far greater number which so much interfere & mingle with one another as after those 8 or 9 revolutions to dilute one another wholly & constitute an eaven & sensibly uniforme whitenesse. And consequently that whitenesse must be allowed a mixture of all colours, & the light which conveys it to the eye must be a mixture of rays indued with all those colours.

But further by the 24^{th} Observation it appeares that there is a constant relation between Colours & Refrangibility, the most refrangible rays being Violet, the least refrangible Red, & those of intermediate colours having proportionally intermediate degrees of refrangibility. And by the 13^{th}, 14^{th}, & 15^{th} Observations compared with the 4^{th} or 18^{th}, there appeares to be the same constant relation between Colour & Reflexibility, the Violet being in like circumstances reflected at least thicknesses of any thin Plate or Bubble, the Red at greatest thicknesses, & the intermediate colours at intermediate thicknesses. Whence it follows that the colorifique dispositions of rays are also connate with them & immutable, & by consequence that all the productions & appearances of colours in the world are derived not from any Physicall change caused in light by refraction or reflexion, but onely from the various mixtures or separations of rays by vertue of their different Refrangibility or Reflexibility. And in this respect the Science of colours becomes a Speculation as truly Mathematical as any other part of Optiques.

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The third Part
Conclusions drawn from the foregoing Observations.

I am now come to another part of this designe which is to consider how the Phænomena of thin transparent Plates stand related to those of all other naturall bodies. Of these bodies I have already told you that they appeare of divers colours accordingly as they are disposed to reflect most copiously the rays originally indued with those colours. But their constitutions whereby they reflect some rays more copiously then others remaines to be discovered, & these I shall endeavour to manifest in the following Propositions.

Prop: 1. Those superficies of transparent bodies reflect the greatest quantity of light which have the greatest refracting power; that is, which intercede Mediums that differ most in their refractive densities: And in the confines of equally refracting Mediums there is no reflexion.

The Analogy between reflexion & refraction will appeare by considering that when light passeth obliquely out of one Medium into another which refracts from the Perpendicular, the greater is the difference of their refractive density the lesse obliquity is requisite to cause a totall reflexion. For as the sines are which measure the refraction, so is the sine of incidence at which the totall reflexion begins; to the Radius of the Circle, & consequently that incidence is least where there is the greatest difference of the sines. Thus in the passing of light out of water into Air where the refraction is measured by the ratio of the sines 3 to 4 the totall reflexion begins when the angle of incidence is about 48^{degr} 35^{min}. In passing out of Glasse into Air where the refraction is measured by the ratio of the sines 20 to 31 the totall reflexion begins when the angle of incidence is 40^{degr} 10^{min}. And so in passing out of the Cristall or more strongly refracting Mediums into Air, there is still a lesse obliquity requisite to cause a totall reflexion. Superficies therefore which refract most do soonest reflect all the light, which is incident on them, & so must be allowed most strongly reflexive.

But the truth of this Proposition will further appeare by observing that in the superficies interceding two transparent Mediums (such as are Air, Water, , oyle Common Glasse, Crystall, Metalline Glasse Island glass, white transparent Arsnick, Diamonds &c,) the reflexion is stronger or weaker accordingly as the superficies hath a greater or lesse refracting power. For in the confine of Air & common glass the reflexion is stronger then in the confine of air & water & still stronger in the confine of Air & Crystal & stronger in the confine of Air & a Diamond. If any of these & such like transparent solids be immerged in water or oyle or in spirit of wine or spirit of Turpentine its reflexion becomes much weaker then before, & still weaker if they be immer <512v> ged in the heavy liquor of well rectified oyle of Vitriol which differs less from them in density If water be distinguished 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 & ice tis very little, in that of water & oyle tis something greater, in that of water & glass still greater & in that of water & crystal or other denser substances still greater, accordingly as those mediums differ more or less in density. Hence in the confine of common Glasse & Crystall there ought to be a weake reflexion & a stronger reflexion in the confine of common & Metalline Glasse tho I have not yet tried this: But in the confine of two Glasses of equall density, there is not any sensible reflexion as was shown in the 1^{st} Observation. And the same may be understood of the superficies interceding two crystalls or liquors or any other substances in which no refraction is caused. So then the reason why uniforme pellucid Mediums (such as water glass or crystal) have no sensible reflexion but in their externall superficies where they are adjacent to other Mediums of a different density, is because all their contiguous parts have one & the same degree of density.

Prop 2. The least parts of almost all naturall bodies are in some measure transparent. And the opacity of those bodies ariseth from the multitude of reflexions caused in their internall parts.

That this is so has been observed by others & will easily be granted by them that have been conversant with Microscopes. And it may also be tryed by applying any substance to a hole through which some light is immitted into a dark Room. For how opake soever that substance may seem in the open Air, it will by that meanes appeare very manifestly transparent if it be of a sufficient thinnesse. Only white Metalline Bodies must be excepted which by reason of their excessive density seem to reflect almost all the light incident on their first superficies, unless by solution in menstruums they be reduced into very small particles, & then they become transparent.

Prop: 3. Between the parts of opake or coloured bodies are many spaces, either empty or replenished with Mediums of other densities: as water between the tinging corpuscles wherewith any liquor is impregnated; Air between the aqueous globules that constitute Clouds or mists; & for the most part spaces voyd of both Air & Water but yet perhaps not wholy void of all substance. between the parts of hard bodies.

The truth of this is evinced by the two precedent Propositions For by the second Proposition there are many reflexions made by the internall parts of Bodies, which, by the 1st Proposition would not happen if the parts of those bodies were continued without any such interstices between them, because reflexions are caused onely in superficies which intercede Mediums of a differing density. by Prop 1 But further that this discontinuity of parts is the principall cause of the opacity of Bodies will appeare by considering that opake substances become transparent by filling their pores with any <513r> substance of equall or almost equall density with their parts. Thus Paper dipped in water or oyle, the Oculus Mundi stone steeped in water, Linnen cloth oyled or varnished, & many other substances soaked in such Liquors as will intimately pervade their little pores become by that meanes more transparent then otherwise. So on the contrary the most transparent substances may by evacuating their pores or separating their parts be rendered sufficiently opake, as salts or wet paper or the Oculus mundi stone by being dried, horn by being scraped, Glasse by being reduced to pouder or otherwise flawed, turpentine by being stirred about with water till they more imperfectly & water by being formed into many small bubbles either alone in the forme of froth, or by shaking it together either with Oyle of Turpentine or with some other convenient Liquor with which it will not perfectly incorporate. .

And To the increase of the opacity of these bodies it conduces something that by the 23rd Observation the reflexions of very thin transparent substances are considerably stronger then those made by the same substances of a greater thicknesse. [And to the reflexion of solid bodies it may further add, that the interstices of their parts are voyd of Air. For that for the most part they are so is reasonable to beleive considering the ineptitude which Air hath to pervade small cavities as appeares by the ascension of water in slender glasse pipes, paper, cloth & other such like substances whose pores are found too small to be replenished with Air, & yet large enough to admit water; & by the difficulty wherewith Air pervades the pores of a Bladder through which water finds ready passage. And according to the 11th Observation the cavities thus voyd of Air will cause the same kind of effects as to reflexion which those do that are replenished with it, but yet something more manifestly because the Medium in relation to refractions is rarest when most empty of Air as Mr Hook hath proved in his Micrographia. In which Book he hath also largely discoursed of this & the precedent Proposition, & delivered many other very excellent things concerning the colours of thin Plates & other naturall Bodies which I have not scrupled to make use of so far as they were for my purpose.]

Prop: 4. The parts of bodies & their interstices must not be lesse then of some definite bignesse to render them opake & coloured. For the opakest bodies of their parts be subtily divided (as Metall{s} by being dissolved in Acid Menstruums, &c) become perfectly transparent. And you may also remember that in the 8th Observation there was no sensible reflexion at the superficies of the Object-glasses where they were very neare one another though they did not absolutely touch. And in the 17th Observation the reflexion of the Water-bubble <513v> where it became thinnest, was almost insensible so as to cause very black spots to appear on the top of the bubble by the want of reflected light.

On these grounds I conceive it is that water, salte, glasse, stones & such like substances are transparent. For upon divers Considerations they seem to be as full of pores or interstices between their parts as other bodies are, but yet their parts & interstices to be too small to cause reflexions in their common surfaces.

Prop: 5. The transparent parts of bodies according to their severall sizes must reflect rays of one colour & transmit those of another, on the same grounds that thin Plates or Bubbles doe reflect or transmit those rays. And this I take to be the ground of all their colours.

For if a thind or plated Body which being of an eaven thicknesse appeares all over of one uniforme colour should be slit into threds or broken into fragments of the same thicknesse with the Plate. I see no reason why a heap of those threds or fragments should not constitute a masse or pouder of the same colour which the Plate exhibited before it was broken. And the parts of all naturall bodies being like so — many fragments of a Plate must on the same grounds exhibit the same colours.

Now that they doe so will appeare by the affinity of their Properties. As that the infusion of Lignum Nephriticum & many other substances reflect one colour & transmit another like thin bodies in the 19th & 20th Observations. That the colours of Silks, Cloths, & other substances which water or Oyle can intimately penetrate become more faint & obscure by being immerged in those liquors, & recover their vigor again by being dryed much after the manner declared of thin Bodies in the 10th & 21th Observations. And that some of those coloured pouders which Painters use may have their colours a little changed by being very elaborately & finely ground. Where I see not what can be justly pretended for those changes besides the breaking of their parts into lesse parts by that contrition after the same manner that the colour of a thin Plate is changed by varying its thicknesse. For which reason also it is that the coloured Flowers of Plants & vegetables by being bruised usually become more transparent then before, or at least in some degree or other change their colours. Nor is it much lesse to my purpose that by mixing divers liquors very odd & remarqueable productions & changes of colours may be effected, of which no cause can be more obvious & rationall then <514r> that the saline corpuscles of one liquor do variously act upon or unite with the tinging corpuscles of another, so as to make them swell or shrink (whereby not onely their bulk but their density also may be changed,) or to divide them into smaller corpuscles, or make many of them associate into one cluster. For we see how apt those saline Menstruums are to penetrate & dissolve substances to which they are applyed & some of them to precipitate what others dissolve. In like manner if we consider the various Phænomema of the Atmosphære, we may observe that when vapors are first raised, they hinder not the transparency of the Air, being divided into parts too small to cause any reflexion in their superficies. But when in order to compose drops of rain they begin to coalesce & constitute globules of all intermediate sizes, those globules when they become of a convenient size to reflect some colours & transmit others, may constitute clouds of various colours according to their sizes. And I see not what can be rationally conceived in so transparent a substance as water for the production of these colours besides the various sizes of its fluid & globular parcells, [which seem to affect a globular figure most; but yet perhaps not without some instability in the smallest of them by reason that those are most easily agitated by heat or any trembling motions in the Air.]

Prop: 6. The parts of Bodies on which their colours depend are denser then the Medium which pervades their interstices.

This will appeare by considering that the colour of a Body depends not onely on the rays which are incident perpendicularly on its parts, but on those also which are incident at all other angles. And that according to the 7th Observation a very little variation of obliquity will change the reflected colour where the thin body or small particle is rarer then the ambient Medium, insomuch that such a small particle will at diversly oblique incidences reflect all sorts of colours in so great a variety that the colour resulting from them all confusedly reflected from a heap of such particles must rather be a white or grey then any other colour, or at best it must be but a very imperfect & dirty colour. Whereas if the thin Body or small particle be much denser then the ambient Medium, the colours according to the 19th Observation are so little changed of the variation of obliquity, that the rays which are reflected least obliquely may predominate over the rest so much as to cause a heap of such particles to appear very intensely of their colour. It conduces also something to the confirmation of this Proposition that according <514v> to the 22th Observation, the colours exhibited by the denser thin body within the rarer are more brisque then those exhibited by the rarer within the denser.

Prop: 7. The bignesse of the component parts of Naturall Bodies may be conjectured by their colours.

For since the parts of these bodies by Prop: 5 doe most probably exhibit the same colours with a Plate of equall thicknesse, provided they have the same refractive density; & since their parts seem for the most part to have much the same density with water or glasse, as by many circumstances is obvious to collect: to determin the sizes of those parts you need onely have recourse to the precedent Tables in which the thicknesse of Water or Glasse exhibiting any colour is expressed. Thus if it be desired to know the diameter of a corpuscle which being of equall density with glasse shall reflect Green of the third order; the number $17\frac{1}{2}$ shows it to be about $\frac{17\frac{1}{2}}{1000000}$ 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 4^{th} & 18^{th} Observations from whence may be collected these particulars

Scarlets & other Reds, Oranges & Yellows if they be pure & intense are most probably of the second Order. Those of the first & third order also may be pretty good, onely the yellow of the first order is faint & the Orange & Red of the third order have a great mixture of Violet & Blew.

There may be good Greens of the fourth order but the purest are of the third. And of this order the Green of all Vegetables seemes to be, partly by reason of the intensenesse of their colours, & partly because when they wither some of them turne to a greenish Yellow, & others to a more perfect Yellow or Orange or perhaps to Red, passing first through all the affore said intermediate colours. Which changes seem to be effected by the exhaling of the moisture which may leave the tinging corpuscles more dense, & something aumented by the accretion of the oyly & earthy part of that moisture. Now the Green without doubt is of the same order with those colours into which it changeth because the changes are graduall, & those colours though usually not very full yet are often too full & lively to be of the fourth order.

Blews & Purples may be either of the second or third order But the best are of the third. Thus the colour of violets seems to be of that order becaus their Syrup by acid liquors turnes red <515r> and by urinous & alcalizate turne green. For since it is of the nature of acids to dissolve or attenuate, & of Alcalies to precipitate or incrassate, if the purple colour of the Syrup was of the second order, as acid liquor by attenuating its tinging corpuscles would change it to a red of the first order, & an Alcaly by incrassating them would change it to a green of the second order; which red & Green, especially the Green, seem too imperfect to be the colours produced by these changes. But if the said purple be supposed of the third order, its change to red of the second & green of the third may without any inconvenience be allowed

If there be found any body of a deeper & lesse reddish purple then that of Violets its colour most probably is of the second order. But yet there being no body commonly known whose colour is constantly more deep then theirs, I have made use of their name to denote the deepest & least reddish Purples, such as manifestly transcent their colour in purity.

The Blew of the first Order though very faint & little may possibly be the colour of some substances. And particularly the Azure colour of the skys seems to be of this order. For all vapors when they begin to condense & coalesce into small parcells become first of that bignesse whereby such an Azure must be reflected before they can constitute clouds of other colours. And so this being the first colour which vapors begin to reflect, it ought to be the colour of the finest & most transparent Skys in which vapors are not arrived to that grosnesse requisite to reflect other colours as we find it is by experience.

Whitenesse if it be the most intense & luminous is that in the first order of colours. For of this sort I take the colour of white metals to be; or else it is a mixture of those succeeding the third or fourth order, such as is the colour of paper linnen, & most white substances. If corpuscles of various sizes exhibiting the colours of the second & third order be mixed, they should rather constitute an imperfect whitenesse or Grey of which I have already spoken. But yet it seems not impossible for them to exhibit an intense whitenesse if they be disposed to transmit all the light which they reflect not, & do not retain & stifle much of it For thus I told you that Froth at a distance hath appeared very white & yet neare at hand the severall Bubbles of which it was constituted were seen tinged all over with rings of colours of the four or five first orders.

Lastly for the production of Black the corpuscles must be lesse then any of those which exhibit colours. For at all greater sizes there is too much light reflected to constitute this colour. But if they be <515v> supposed a little lesse then is requisite to reflect the white & very faint blew of the first order they will according to the 4^{th}, 8^{th}, 17^{th}, & 18^{th} Observations reflect so very little light as to appeare intensely black, & yet may perhaps varioully refract it to & fro with in themselves so long untill it happen to be stifled & lost, by which means they will appear black in all positions of the eye without any transparency. And from hence may be understood why Fire & the more subtile dissolver Putrefaction turne substances to black; why small quantities of black substances impart their colour very freely & intensely to other substances to which they are applied; [x] why Glasse ground very elaborately with sand on a Copper plate till it be well polished makes the sand together with what is worne of from the glasse & Copper become very black; why black substances do soonest of all others become hot in the sun's light & burne, (which effect may proceed partly from the multitude of refractions in a little room, & partly from the easy commotion of so very small corpuscles;) & why blacks are usually a little inclined to a blewish colour. For that they are so may be seen by illuminating white paper by light reflected from black substances, For the paper will usually appeare of a blewish white. And the reason is that Black borders on the obscure Blew of the first order described in the 18th Observation, & therefore reflects more rays of that colour then of any other.

In these descriptions I have been the more particular because it is not imposible but that Microscopes may at length be improved to the discovery of the particles of Bodies on which their colours depend if they are not already in some measure arrived to that degree of perfection. For if those Instruments are or can be so far improved as with sufficient distinctnesse to represent Objects five or six hundred times bigger then at a foot distance they appear to our naked eyes, I should hope that we might be able to discover some of the greatest of those corpuscles. And by one that would magnify thre or four thousand times perhaps they might all be discovered but those which produce blacknesse. In the meane while I see nothing materiall in this discourse that rationally may be doubted of excepting this Position, That transparent corpuscles of the same thicknesse & density with a Plate, do exhibit the same colour. And this I would have understood not without some latitude, as well because those corpuscles may be of irregular figures, & many rays must be obliquely incident on them, & so have a shorter way through them then the length of their diameters, as because the straitnesse of the Medium pent in on all sides which in such corpuscles may a little after its motions or other qualities on which the reflexion depends. But yet I cannot much suspect the last because I have observed of some small Plates of Moscovy-Glasse which were of an eaven thicknesse, that through a Microscope they have appeared of the same colour at their edges & corners where the included <516r> Medium was terminated, which they appeared of in other places. However it will add much to our satisfaction if those corpuscles can be discovered with Microscopes, which if we shall at length attain to I feare it will be the utmost improvement of this Sense. For it seems impossible to see the more secret & noble works of Nature within those corpuscles by reason of their transparency.

This may suffice concerning the constitution of naturall bodies on which their colours depend. But for further understanding the nature of reflexions I shall add these two following Propositions.

Prop: 8. The cause of Reflexion is not the impinging of Light on the solid or impervious parts of bodies, as is commonly beleived.

This will appear by the following Considerations. First that in the passage of light out of Glasse into Air there is a reflexion as strong as in its passage out of Air into Glasse or rather a little stronger & by many degrees stronger then in its passage out of Glass into Water. And it seems not probable that Air should have more reflecting parts then water of Glass. But if that should possibly be supposed yet it will availe nothing: for the reflexion is as strong or stronger when the Air is drawn away from the Glass, (suppose in the Air-Pump invented by Mr Boyle) as when it is adjacent to it. Secondly if light in its passage out of Glass into Air be incident more obliquely then at an angle of 40 or 41 degrees it is wholly reflected, if lesse obliquely it is in great measure transmitted. Now it is not to be imagined that light at one degree of obliquity should meet with pores enew in the Air to transmit the greater part of it, & at another degree of obliquity should meet with nothing but parts to reflect it wholly: especially considering that in its passage out of Air into Glass, how oblique soever be its incidence, it finds pores enew in the Glass to transmit the greatest part of it. If any man suppose that it is not reflected by the Air but by the outmost superficiall parts of the Glasse, there is still the same difficulty: besides that such a supposition is unintelligible, & will also appear to be false by applying water behind some part of the Glasse instead of Air. For so in a convenient obliquity of the rays suppose of 45 or 46 degrees at which they are all reflected where the Air is adjacent to the Glass, they shall be in great measure transmitted where the water is adjacent to it: which argues that their reflexion **{illeg}** or transmission depends on the constitution of the Air & water behind the glass & not on striking of the rays upon the parts of the glass. Thirdly if the colours made by a Prism placed at the entrance of a beam of light into a darkened Room be successively cast on a second Prism placed at a great distance from the former, in such manner that they are all alike incident upon it the second Prism may be so inclined <516v> to the incident rays that those which are of a blew colour shall be all reflected by it, & yet those of a red colour pretty copiously transmitted. Now if the reflexion be caused by the parts of Air or Glass I would ask why at the same obliquity of incidence the Blew should wholly impinge on those parts so as to be all reflected, & yet the red find pores enew to be in great measure transmitted Fourthly where two Glasses touch one another there is no sensible reflexion as was declared in the 1st Observation; & yet I see no reason why the rays should not impinge on the parts of Glass when contiguous to another Glasse as much as when contiguous to Air. Fiftly when the top of a water-Bubble (in the 17th Observation) by the continuall subsiding & exhaleing of the water grew very thin there was such a little & almost insensible quantity of light reflected from it that it appeared intensely black, whereas round about that black spot where the water was thicker the reflexion was so strong as to make the water seem very white. Nor is it onely at the least thicknesse of thin Plates or Bubbles that there is no manifest reflexion but at many other thicknesses continually greater & greater. For in the 15th Observation the rays of the same colour were by turnes transmitted at one thicknesse & reflected at another thicknesse for an indeterminate number of successions. And yet in the superficies of the thinned Body where it is of any one thicknesse there are as many parts for the rays to impinge on, as where it is of any other thicknesse. Lastly if reflexion were caused by the parts of reflecting bodies it would be impossible for thin Plates or Bubbles at the same place to reflect the rays of one colour & transmit those of another as they do according to the 13 & 15 Observations. For it is not to be imagined that at one place the rays which for instance exhibit a blew colour should have the fortune to dash upon the parts & those which exhibit a Red to hit upon the pores of the Body; & then at another place where the body is either a little thicker or a little thinner, that on the contrary the Blew should hit upon its pores & the Red upon its parts. Lastly were the rays of light reflected by impinging on the solid parts of bodies, their reflexions from polished bodies could not be so regular as they are. For ✝

Prop. 9. Tis most probable that the rays which impinge on the solid parts of any body, are not reflected but shifted & lost in the body.

This is consentaneous to the precedent Proposition & will further appear by considering that if all the rays should be reflected which impinge on the internall parts of clear water or crystall, those substances should rather have a cloudy colour then so very clear <517r> transparency. And further there would be no Principle of the obscurity or blacknesse which some bodies have in all positions of the eye. For if all or almost all the light incident on those bodies did after many reflexions & refractions come out again it would make those bodies as lucid as other bodies are, & therefore to make them look black it is necessary that many rays be stopt retained & lost in them , & it seems not probable that any rays can be stopt & stifled in them which do not impinge on their parts

If you now ask how rays are reflected without impinging on the parts of a body, & how those which impinge on its parts may be stopped & stifled, it requires an Hypothesis to explaine it by. And so the manner how severall rays are unequally refrangible & reflexible, & originally indued with powers of striking the sense with several colours remaines to be explained Hypothetically: And the inventing of such an Hypothesis is no part of my designe I undertook only to discover the properties of light so far as I could derive them from experiments; & therefore content my self with having shewn those properties.

[1] pag. 13