# Draft of the 'Discourse concerning Light and Colors'

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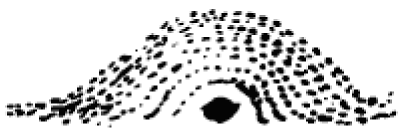
I suppose you understand that all transparent substances (as Glasse, water, Air &c) when made very thinne by being blown into bubbles or otherwise formed into plates, doe exhibite various colours according to their various thinnesse, although at a greater thicknesse they appear very clear & colourlesse. In my former discourse about the constitution of light, I omitted those colours, because they seemed of a more difficult consideration, & were not necessary for stablishment 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 principall 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 somwhere touch one another, I found the place in which they touched to become *[1] absolutely transparent, as if they had been there one continued peice of Glasse. for when the light fell so obliquely on the Air, which in other places was between them, as to be all reflected; in that place of contact it seemed wholy transmitted: in so much that when looked upon it apeared like a black or dark spot by reason that no sensible light was reflected from thence as from other places; & when looked through it seemed as it were, a hole in that Air that was formed into a thinner plate by being compressed between that 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 **{illeg}** considerable breadth, which breadth seemed principally **{illeg}** proceed from the yeilding inwards of the parts of the glasses **{illeg}** **{**reason**}** of their mutual pressure. For by pressing them **{illeg}** hard together it would become much broader then other. <549v> Obs: 2. When the plate of Air, by turning the Prisms about their common Axis became so little inclined to the incident rays, that some of them began to be transmitted; there arose in it many slender Arcs of coloures which at first were shaped almost like the conchoid as you see them here delineated. And by continuing the motion of the Prisms, those Arcs increased & b**{**e**}**nded more & more about the said transparent spot, till they were completed into circles or rings incompassing it, & afterwards continually 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 became a little tinged in their inward limbs with red & yellow, & to their outward limbs the blew was adjacent. So that the order of those colours from the Centrall dark spot, was at that time white, Blew, Violet; Black; Red, Orang, 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 those 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 **{at}** some parts of them appeared only black & white, they were very distinct & wel-defined & the blacknesse seemed as intense as that of the Centrall Spot. Also in the Borders of these 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 smalnesse I could not number. But in other Positions of the Prisms at which the **{illeg}** appeared of many colours, I could not distinguish above **{illeg}** of them, & the exteriour of those too were **{illeg}** **{illeg}** dilute.

In these two Observations to see the ring **{illeg}** any other colour but black & white, I found **{illeg}** <550r> that I held my eye at a good distance from them. For by approaching nearer, although in the same inclination of my eye, yet there **{illeg}**ged 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 paralell 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 Objectglasses the one a plano-convex for a fourteen foot Telescope, & the other a large double convex for one of fifty foot, & upon this laying the other with its plane side downwards, I pressed them slowly together to make the colours successively emerge in the middle of the Circles & then slowly lifted the upper glasse from the lower to make them successively vanish again in the same place, where being of a considerable bredth, I could more easily discern them. And by this meanes I observed their succession & quantity to be as followeth.

Next to the pellucid centrall pot made by the contact of the glasses succeeded Violet, Blew, White, Yellow, & Red. The Violet & blew were soe very little in quantity that I could not discerne them in the circles made by the Prisms, but the yellow & Red were pretty copious, & seemed about as much in extent as the white, & 4 or 5 times more then the blew & Violet. The next circuit or order of colours imediately 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 redish then the Violet in the former circuit, & the green was much more conspicuous, being as bris & 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 succeded **{Green}** & Red. The Green was very copious & lively inclining on the **{illeg}** side to blew & the other to yellow. But in this 4th circuit **{illeg}** was neither Violet, blew, nor yellow & the red was very imperfect & dirty. Also the succeeding colours became more & more imperfect & dilute after three or four more <550v> Revolutions they ended in perfect whitenesse.

Obs: 5. To determine 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 of 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 those measures exactly I repeated them diverse 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 first ring at the most lucid part of its orbit was $\frac{58}{100}$ parts of an inch & the diameter of the Sphere on which the double convex object glasse 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 semi diameter of the ring $\frac{29}{100}$ so very nearly is that semi diameter to $\frac{1}{14554}$ the said distance of the glasses. Now by the precedent observation the eleventh part of this distance ($\frac{1}{160094}$) is the thicknesse of the Air at that part of the first ring where the yellow would be most vivid were it not mixed with other colours in the white, & this doubled gives the difference of its thicknesses at the 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. Those dimensions were taken when my eye was placed perpendicularly over the glasses in or near the Axis of the Rings, but when I viewed them -->obli▯ly 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 **{illeg}** as also by making use of the two Prisms for**{illeg}** **{illeg}**tios, I found its diameter, & consequently the thicknesse **{illeg}** at its Perimeter in all those obliquities to be **{illeg}** Proportions expressed in this Table.

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| Incidence on the Air. | Refraction into the Air. | Diameter of the Ring | Thicknesse of the Air. |
|---|---|---|---|
| gr. min. | gr. min | | |
| 00. 00. | 00. 00. | 10. | 10. |
| 6. 26. | 10. 00. | $10\frac{1}{13}$ . | $10\frac{2}{13}$ . |
| 12. 45. | 20. 00. | $10\frac{1}{3}$. | $10\frac{2}{3}$. |
| 18. 49. | 30. 00. | $10\frac{2}{4}$. | $11\frac{1}{2}$. |
| 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. | $15\frac{1}{4}$. | $23\frac{1}{3}$. |
| 37. 19. | 70. 00. | $16\frac{4}{5}$. | $28\frac{1}{2}$. |
| 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. |
| 40. 11. | 90. 00. | 35 | $122\frac{1}{2}$. |

In the two first Columns are expressed the obliquities of the rayes to the Plate of Air, that is their angles of inciden**{illeg}** & refraction. In the third Column the diameter, of any coloured Ring in those obliquities, is exprest in parts of which ten constitute that diameter when the rayes are perpendicular. And in the fourth 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 rayes are perpendicular.

Obs. 8. The dark Spot in the middle of the Rings increased also by the obliquation of the eye although almost in sensibly But if in stead of the Object-glasses the Prisms were made use of, its increase was more manifest when viewed soe obliquely that no colours appeared about it. It was least when the rays were incident most obliquely on the interjacent Air & increased more & more untill the coloured rings appeared, & then decreased again but not soe much as it increased before. And hence **{**it**}** is evident that the transparency was not only at the absolute contac**{illeg}** of the glasses but also where they had some little intervall. I have sometimes observed the diameter of that spot to be between halfe & 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, wheras when viewed obli□ly it hath wholy vanish'd & become opake & white like the other parts of the glasse. Whence it may be collected that the glasse did then scarcely or not at all touch one another, & that their intervall at the perimeter of that Spot when viewed perpendi**{**cu**}**larly was about a 5**{illeg}**th or 6th part of their intervall at the circumference of the said Red.

Obs: 9. By looking through the two contiguous )bject-glasses, I **{illeg}**the interjacent Air exhibited Rings of colours as well **{illeg}** by reflecting it. <551v> 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 means they became pretty vivid. Onely the first yellowish-Red, like the blew in the 4th Observation was soe little & faint as scearcely, to be discerned: comparing the coloured Rings made by reflexion, with those 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 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 halfe of them at which it first arrived would appear broken off from the other halfe & 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 or the glasses at like circles caused by those two mediums water & Air are as about three to four. Perhaps it may be a generall Rule that if any other medium more or lesse dense then water be compressed between the glasses, their intervall at the Rings caused thereby will be to their intervall caused by interjacent Air, as the sines are which measure the refraction made out of that Medium into Air.

Obs: 11. When the water was between the glasses If I pressed the upper 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; Its 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 **{illeg}** which could recede through the glasse at **{illeg}** Water

Obs: 12 These observations were made in **{illeg}**ther to examine the effects of coloured light **{illeg}** **{illeg}** darkned the Room & viewed them by reflex**{**ein**}** **{illeg}** cast on a sheet of white paper. And by this **{illeg}** **{illeg}** & visible to a **{**far**}** another number **{illeg}** <552r> I have sometimes seen more then 20 of them, wheras in the open Air I could not discerne above 8 or 9.

Obs: 13. Appointing an Assistant to move the Prism to & from about its Axis, that all its colours might successively fall on the same place of the paper & be reflected from the circles to my eye whilst I held it immoveable; I found the circles which the red light made to be manifestly bigger 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 intervall 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 9 to 14. And this proportion seemed very nearly 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 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 uniformly, 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 which each colour obteined by this contraction or dilatation 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 of the Red 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 extreames: 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 them 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 Prismati□ colours only with which they were illuminated. And by projecting the Prismati□ colours immediately upon the glasses I found that the light **{illeg}** fell on the dark Spaces which were between the coloured Rings **{illeg}** as transmitted through the Glasses without any variation of colou**{illeg}** **{illeg}** on a white paper placed behind, it would paint Rings of the **{illeg}** colour with those which were reflected & of the bignesse. <552v> And from hence the origine of those 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 transmitt the light of any colour, & in the same place to reflect one colour where it transmitts another.

Obs: 16. The squares of the diameters of these Rings made by any Prismati□ colour were in Arithmeticall progression as in the $5^{t}$ Observation. And the diameter of the $6^{t}$ circle when made by the yellow & viewed almost perpendicularly was about $\frac{58}{100}$ parts of an inch, agreeable 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 compressed betwixt 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 on all sides with Air.

Obs: 17. If a Bubble be blown with water, first made tenacious by dissolving a little soap in it tis a common observation that after a while it will appear tinged with a great variety of colours. To defend these Bubbles from being agitated by the externall Air (wherby their colours are irregularly moved one among another, so that no acurate observation can be made of them,) as soon as I had blown any of them I covered it with a clear glasse, & by that means its colours emerged in a very regular order like soe many concentrick Rings incompassing the top of the Bubbles And 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 mean while after all the colours were emerged at the top, there grew in the center of the Rings a small round black Spot, like that in the first observation, which continually dilated it selfe till it became sometimes more then $\frac{1}{2}$ or $\frac{3}{4}$ of an inch in breadth before the Bubble broak. At first I thought there had been noe 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 know that there was some reflection at the other places which were not soe dark as those Spots. And by further tryall I found that I could see the images of **{illeg}** of a candle or the Sun) very faintly reflected **{illeg}** great black spot but also from the little **{illeg}** within it.

Besides the aforesaid coloured Rings **{illeg}** **{illeg}** pear small Spots of colours ascending **{illeg}** **{illeg}** the sides of the Bubble **{illeg}** <553r> 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 thin'd between two Glasses, & so more easie to be distinguished. I shall now 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, specially the first where the Red seemed in a manner to be white; Amongst those there was scarcely any other colour sensible, onely the Blewes (& principally the second,) 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 was inclined a little to yellow, & then became a pretty bris□ and good willow Green, & afterwards changed to a blewish colour; but there succeeded neither Blew nor Violet.

The fift Red at first was very much inclined to purple & afterwards became more bright & brisk 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 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 fair & lively scarlet, & soon after of a brighter colour being very pure & brisk & 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 **{illeg}** & of a fair bright sky colour, but yet something **{**inferior**}** to the former Blew, And the Violet was intense & **{illeg}** which little or no rednesse in it, And lesse in quantity **{illeg}** the Blew.

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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 appear 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 nett-work & soon after vanished & left all the upper part of the Bubble of the said dark blew colour. And this colour after the aforesaid manner dilated it selfe downwards untill sometimes it hath overspread the whole Bubble. In the mean while at the top which was of a darker Blew then the bottom & appeared also of many round blew Spots something darker then the rest, there would emerge one or more very black Spots & within those other Spots of an intenser blacknesse, which I mentioned in the former observation And these continually dilated them selves untill the Bubble broak.

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 $4^{th}$ Observation although set down in a contrary order by reason that they begin to appear when the Bubble is thickest, & are most conveniently reckoned 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 were sensibly dilated by increasing the obliquity but yet not so much by far as those made by thin'd Air in the $7^{th}$ Observation. For there they distended **{illeg}** viewed most obli□ly to arrive at a part **{illeg}** **{illeg}**12 times thicker then that where they **{illeg}** **{illeg}** perpendicularly, whereas in this case the **{illeg}** at which they arriv'd when viewed most obli□ly **{illeg}** which exhibited them by perpendicular Rayes **{illeg}** **{illeg}** <554r> By the best of my Observations it was between 15 and $15\frac{1}{2}$ 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 near the black Spot; as I knew because it would exhibit the same appearance of colours in all positions of the eye: And then the colours which were seen at its apparent circumference by the obliquest rays would be different from those that were seen in other places by rayes lesse oblique to it. And divers spectators might see the same part of it of differing colours by viewing it at very differing obliquities. Now observing how much the colours at the same place of the Bubble or at divers places of equall thicknesse were varied by the severall obliquities of the rayes; by assistance of the $4^{th}$, $14^{th}$, $16^{th}$ & $18^{th}$ observations as they are hereafter explained, I collected the thicknesse of the water requisite to exhibit any one the same colour as severall obliquities to be very nearly in the proportion expressed in this Table.

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

In the two first columns are expressed the obliquities of the rayes 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 three to four, though probably the dissolution of soape in the water may a little alter its refractive Virtue. In the third column the thicknesses of the Bubble at which any one colours is exhibited in those severall obliquities, is exprest in parts of which {ten} constitute that thicknesse when the rays are perpendicular.

I have sometimes observed of the colours which arise on polished steel by heating it, or on Bell-metall & some other me**{illeg}** substances when melted & poured on the ground where **{illeg}** {cool} in the open Air, that they have like those of <554v> water-bubbles, been a little changed by viewing them at divers obliquities, & particularly that a deep Blew or Violet when viewed very obli⌷ly hath been changed to a deep Red. But the Changes of these colours are not so sensible as of those made by water For the coria or vitrified part of the metall which most metalls when heated or melted continually protrude to their surface where by covering them in form of a thin glassy skin it 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 exhibited 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 very suddenly 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 appear Red by transmitted light.

Obs: 21. By wetting Plates of Muscovy-glasse whose thinnesse made the like colours appear, 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 that the thicknesse of a Plate requisite to produce any colour depends only on the density of the Plate & not of the ambient medium. And hence by the 10th & 16th observations may be known the thicknesse of Bubbles of water or Plates of Moscovy-glasse, or of any other substances which they have at any colour produced by them.

Obs: 22. A thin transparent body which is denser then its ambient medium, exhibits more brisk & 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 encompassed 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 **{illeg}** were without the Rings; as I could manifest**{illeg}** **{illeg}** at distance the Rings made by the two {colours} **{illeg}** comparing two Bubbles of water blown **{illeg}** the first of which the whitenesse appeared **{illeg}** lours, & the whitenesse which preceded **{illeg}**

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Obs: 24. When the two object glasses were layd upon one another so as to make the Ringes of colours appear, though with my naked eye I could not discern above 8 or 9 of those Ringes yet by viewing them through a Prism I have seen a far greater multitude, in so much 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 explain.

But it was but one side of the Rings, namely that towards which the refraction was made , which by that refraction was rendered distinct, & the other side became more confused then to the naked eye, In so much that there I could not discerne above one or two, & sometimes none of those Rings, of which I could discern 8 or 9 with my naked eye. And their segments or arcs which on the other side appeared so numerous, for the most part exceeded 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 disappear & constitute an even whitenenesse, whilst on either side their ends, as also the whole arcs furthest from the center became distincter then before, appearing in the form you see them here designed.

Fig 2.

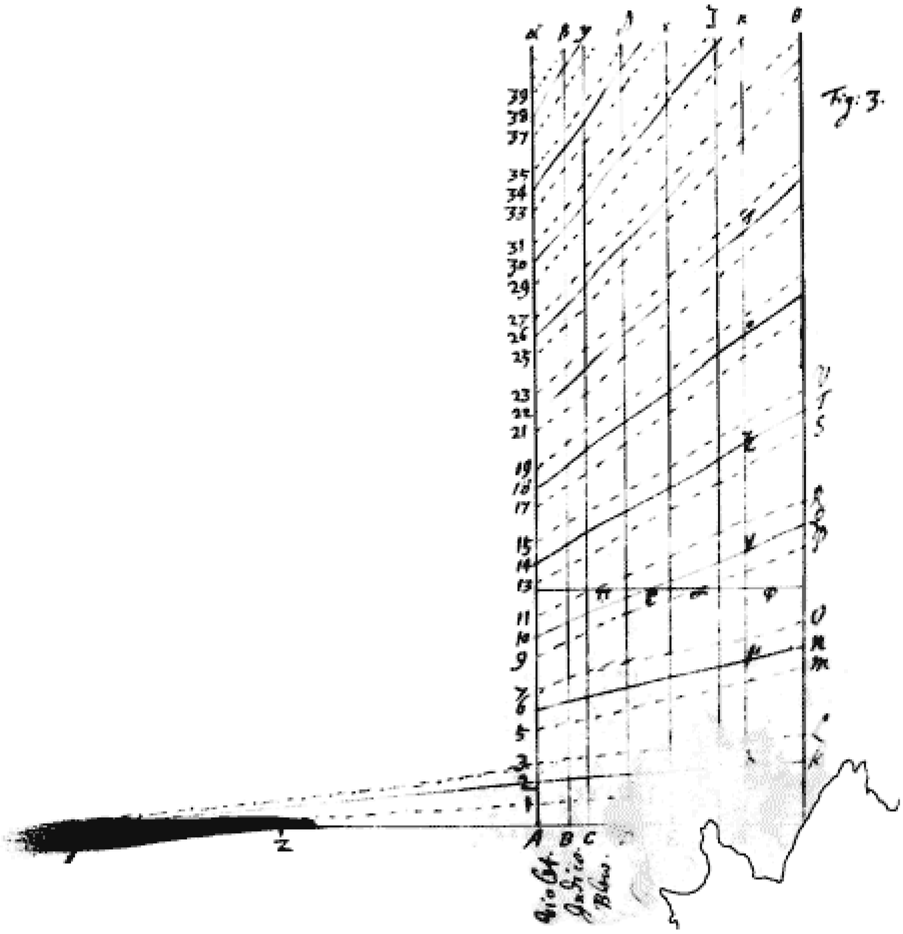
The arcs where they seemed distinctest were only white & black successively without any other colours intermixed. But in other places there appeared colours whose order was inverted by the refraction in such manner that if I first held the Prism very near the Object glasses & then gradually removed it farther 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 wholy 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 <555v> Discovered themselves. And in like manner Plates of Moscovy-glasse & bubbles of glasse blown at a lamp-furnace which were not soe 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 parallell & horizontal Rings: to produce which effect, it was necessary to hold the Prism parallel or very nearly parallel to the Horizon, & to dispose it so that the rayes might be refracted upwards.

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, I first explain the more compounded, such as are the $2^{d}$, $3^{d}$, $4^{th}$, $9^{th}$, $12^{th}$, $18^{th}$, $20^{th}$, & $24^{th}$.

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 & between ZA & ZH eleven mean 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 point of division denote. And through those divisions from Y draw lines 1J, 2K, 3L; 5M, 6N, 7O; &c

Now if A2 be supposed to represent the thicknesse of any thin transparent body at which the utmost violet is most copiously reflected in the first Ring or series of colours, then by the $13^{th}$ Observa**{illeg}** **{illeg}** sent its thicknesse at which the utmost Red **{illeg}** <556r> in the same series. Also by the $5^{t}$ & $16^{th}$ Observations **{illeg}** HN will denote the thicknesses at which those extream colours are most copiously reflected in the



second series, & so on. And the thicknesse at which any of the intermediate colours are reflected most copiously will according to the 14th Observation, be defined by the intermediate parts of the lines 2K, 6N, &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 A1 design the least thicknesse & A3 the greatest thicknesse at which the extream Violet in the first series is reflected, & let HJ & HL design the like limits for the extream Red, & the intermediate colours be limited by the intermediate parts of the lines 1J & 3L; against which the names of those colours are written. And in the second series let those limits of the lines 5M & 7O; & so on: But yet with this caution that the reflexions be supposed strongest at the intermediate spaces 2K, 6N, 10R &c & to decrease gradually towards these limits 1J,3L; 5M, 7O; &c on either side, where you must not conceive them to be precisely limited but to decay indefinitely. And wheras 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 that severall colours in here are by turnes reflected at the spaces 1J, L3, 5MO7, 9PR11, &c; & transmitted at the Spaces AHJ1, 3LM5, 7OP9 &c; it is easie 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 1JL3, 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 π, ρ σ, φ, And by its passing through some of**{**f**}** the Blew at π, & yellow at σ, as well as through the green ρ, you may conclude that 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 water of the Rings outwards ought to succeed in order as they were described in the fourth & 18th observations. <556v> 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 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 from J 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 between 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 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 followes the yellow some of which towards the Green is distinct & good, but that part of it towards the succeeding 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. The 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 only 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 show it selfe. After this the severall series interfere more & more & their colours become more & more intermixed till after three or four more revolutions (in which the Red & blew predominate by turnes) all sorts of colours are in all places pretty equally blended & compound one eaven whitenesse.

And since by the 15th Observation the rayes indued with one colour are transmitted where those of another clolour **{illeg}** reason of the colours made by the transmitted **{illeg}** **{illeg}** Observations is also from hence evident.

If not only the order & Species of **{**these**}** **{illeg}** the precise thicknesse of the Plate of thin**{illeg}** **{illeg}** are exhibited, be defined in parts of an **{illeg}** performed by performed by assistance of the 6t or 6th **{illeg}** <557r> For according to those observations the thicknesse of the thin Air which between two glasses exhibited the Orange as bright red of the 6th order was $\frac{1}{14554}$ parts of an inch. Now suppose this thicknesse to be represented by Gτ & the eleventh part of it Gλ as will be about $\frac{1}{160000}$ of an inch. And so Gμ, Gν, Gζ, Go, will be $\frac{3}{160000}$, $\frac{5}{160000}$, $\frac{7}{160000}$, & $\frac{9}{160000}$. And this being known it is easie to determine what thicknesse of Air is represented by Gφ or 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 producing the same colour. And so according to the same 10th &. 21th Observations the thicknesse of a Plate of glasse whose refraction is measured by the proportion of the sines 31 to 20 may be $\frac{20}{31}$ of the thicknesse of Air producing the same colours. And the like of other Mediums. On these grounds I have composed the following Table wherin 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 | | |
|---|---|---|---|---|
| | | Air | water | Glasse |
| | Black | 2 | $1\frac{1}{2}$ | $1\frac{1}{4}$, or lesse |
| The colours | Blew | $2\frac{2}{3}$ | 2 | $1\frac{3}{4}$. |
| of thefirst | white | $5\frac{1}{3}$ | 4 | $3\frac{1}{2}$. |
| order | Yellow | 8 | 6 | $5\frac{1}{4}$. |
| | 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 | $13\frac{1}{4}$ | $9\frac{11}{12}$ | $8\frac{1}{2}$. |

| | | | | |
|---|---|---|---|---|
| Of the | Blew | $14\frac{3}{4}$ | 11 | $9\frac{1}{2}$. |
| second | Green | 16 | 12 | $10\frac{1}{3}$. |
| order | 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 | $17\frac{1}{4}$ | $14\frac{4}{5}$. |
| | Indico | 24 | 18 | $15\frac{1}{2}$. |
| Of the | Blew | $25\frac{1}{5}$ | 19 | $16\frac{1}{4}$. |
| third 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 | $21\frac{2}{5}$. |

<557v>

| | | | | |
|---|---|---|---|---|
| | Blewish Green | 36 | 27 | $23\frac{1}{4}$. |
| 4th Order | Green | $37\frac{2}{3}$ | $28\frac{1}{4}$ | $24\frac{1}{3}$. |
| | Yellowish green | $39\frac{1}{3}$ | $29\frac{1}{2}$ | $25\frac{1}{3}$. |
| | Red. | 44 | 33 | $28\frac{1}{3}$. |
| 5t Order | Greenish blew | $50\frac{2}{3}$ | 38 | $32\frac{2}{3}$. |
| | Red | $57\frac{1}{3}$ | 43 | 37. |
| 6t Order | Greenish blew | 64 | 48 | $41\frac{1}{3}$. |
| | Red | $\frac{2}{3}$ | 53 | $45\frac{2}{3}$. |
| 7th Order | Greenish blew | $77\frac{1}{3}$ | 58 | 50. |

| | | | |
|---|---|---|---|
| Red or white | 84 | 63 | $54\frac{1}{2}$. |

Now if this Table be compared with the third Scheme 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 judge of its intensenesse or imperfection; which may suffice in explication of the fourth & 18th Observations unlesse it be further desired to delineate the manner how the colours appear when the two Object-glasses are layd upon one another. To doe which let there be described a large Arc of a Circle, & a 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 $5\frac{1}{4}$ to which add $9\frac{1}{2}$ **{**the thicknesse**}** exhibiting Blew of the second order, & the summe **{illeg}** nearly approaching $14\frac{4}{5}$ the thicknesse **{illeg} {illeg}** the third order.

To explain in the next place the **{illeg}** 2d & 3d Observations, that is, how these colours **{illeg}** Prisms about their common Axis the **{illeg}** <558r> that expressed in those Observations) may be converted into white & black Rings, & afterwards into colours again in an inverted order: it must be remembred that those colours are dilated by the obliquation of the rayes to the Air which intercedes the Glasses, & that according to the Table in the 7th Observation their dilatation or recession from their common center is most manifest & speedy when they are obliquest. Now the rays of yellow being more refracted by the first superficies at the said Air then those of Red, are therby made more obli to the second superficies at which they are reflected to produce the coloured Rings, & consequently the yellow 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 rayes, 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 rayes as to become all very nearly of equall extent with the Red, that is, equally distant from the center of the Rings. And then all the colours of the same series 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. 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 then the other colours, & so very apt to appear at the exterior verges of the white.

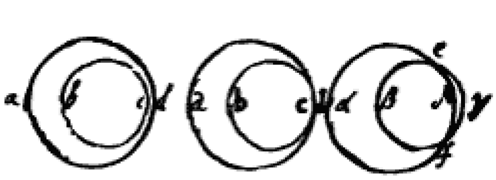
Afterwards by a greater obliquity of the rays, the Violet & Blew become sensibly more dilated then the Red & Yellow, & so being further removed from the center of the Rings, the colours must emerge out of the white in an order contrary to that which they had before, the Violet & Blew at the exterior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

If instead of the Prisms the objectglasses be made use of the Rings which they exhibit become not white & distinct **{**by the**}** obliquity of the eye, by reason that the rayes in their <558v> Passage through that Air which interceded the glasses are very nearly parallel to themselves when first incident on the glasses, & consequently those 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 appear distinct, should not only becom confused by viewing them near at hand, but also yeild a Violet colour at both the edges of every white Ring. And the reason is that the rayes which enter the eye at severall parts of the Pupill have severall obliquities to the glasses, & those which are most obli, 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 rayes apt to excite a sensation of that colour are most oblique to the second or further superficies of the thin'd 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 as 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 the center, so that they can no longer be distinguished apart but seem to constitute an eaven & uniform whitenesse.

Amongst all the Observations theire is none accompanied with so odd circumstances as the 24th. Of those the Principall are that in thin Plates which to the naked eye seem of an eaven & uniform transparent whitenesse the refraction of a Prism should make the Rings of colours appear; wheras it usually makes Objects appear coloured onely where they are terminated with shadows, 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 **{illeg}** although by reason of the great breadth of **{illeg}** **{illeg}**rency they so much interfere & are blended **{illeg}** they seem to constitute an eaven whitenesse **{illeg}** rayes passe through the Prism to the eye **{illeg}** severall colours in every Ring are **{illeg}** <559r> then others according to their degree of refrangibility which meanes the colours on one side of the Ring become more unfolded & dilated & on the other side more complicated & 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 appear distinct & also white if the constituent colors be so much contracted as to be wholy coincident. But on the other side where 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 explain this a little further, suppose the concentrick circles AB and CD 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 BC will by a greater refraction

be further translated from its place then the Red AD & so approach nearer to it on that side towards which the refractions are made. For instance, if the Red be translated to ad the Violet may be translated to bc so as to approach nearer to it at c then before, & if the Red be further translated to ad the Violet may be so much further translated to bc as to convene with it at c, & if the Red be yet further translated to αδ, the Violet may be still so much further translated to βγ as to pass beyond it at γ & convene with it at e & f. And this being understood not only of the Red & Violet but of all the other intermediate colours, & also of every revolution of those colours, you will easily perceive how these of the same revolution or order by their nearnesse **{**at**}** cd & δγ & their coincidence at cd, e, & f ought to constitute pretty distinct arcs of circles, especially at cd or at e & f **{**&**}** that they will appear severall at cd, at cd exhibit whitenesse by their coincidence, & again appear severall at δγ, but yet in a contrary order to that which they had before & still retain beyond e and f. But on the other side at ab, ab, **{illeg}** αβ these colours must become much more confused <559v> by being dilated & spread soe as to interfere with those of other orders. And the same confusion will happen at δγ 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 only 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 the those at the other end, by reason that they crosse in the intermediate white. Namely their ends which verge towards δγ will be red & yellow on that side next the center & blew & Violet on the other side. But their other ends which verge from δγ will on the contrary be blew & Violet on that side towards the center & on the other side red & yellow.

For confirmation of all this I need alledge no more than that it is mathematically demonstrable from my former Principles. But yet I shall add that they which please to take the pains, may by the Testimony of their senses be assured that these explications are not Hypotheticall but infallibly true & genuine. For in a dark Room by viewing these Rings through a Prism by reflexion of the severall Prismati colours which an Assistant causes to move to & fro upon a wall or paper from whence they are reflected, whilst the spectators eye, the Prism & Object-glasses (as in the 13 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 at abcd, or abcd or αβγδ. And by the same Method, the truth of the **{**explications**}** **{**of**}**the other Observations, is to be examined.

By what hath been said, the the like **{illeg}** Bubbles & thin Plates of Glasse may be **{illeg}** small fragments of those Plates there is **{illeg}** servable, that if they lying flatt **{illeg}** <560r> be turned about their centers whilst they are viewed through a Prism: some of them exhibit waves in one or two positions only, but the most of them do in all positions exhibit those waves & that for the most part appearing, almost all over the Glasse. 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: And by the severall sides of those cavities there must be produced waves in severall postures of the Prism. Now though it be but some very small and 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 confusedly reflected which by refraction of the Prism are unfolded & 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 the Properties of light that I have heretofore delivered: And these you see doe neccessarily follow from them & agree with them even to their very least circumstances; & not onely so, but doe very much tend to their proof. Thus by the 24th Observation it appears that the rayes 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 other orders, are seperated from them by refraction, & associated together so as to become visible by themselves like Arcs of Circles. For if the rayes were all alike refrangible, 'tis impossible that the whitenesse which to the naked sense appears uniform should by refraction have its parts transposed & ranged into those black & white Arcs.

It appears also that the unequall refractions **{**difform**}** rayes proceed not from any contingent irregularities. Such as are V**{illeg}**, an uneaven polish, or for fortuitous position of the pores of the Glasse; unequall motions in the Air or Æther**{.}** <560v> 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 24th 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 rayes 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 some at a greater & others at a lesse thicknesse of thin Plates or Bubbles, namely that those dispositions are also connate with the rayes & immutable**{,}** as may appear by the 13th 14th & 15th Observations compared with the 4th & 18th.

By the precedent Observations it appears also that whitenesse is a dissimilar mixture of all colours, & that light is a mixture of rayes endewed with all those colours. For considering the multitude of the Rings of colours in the 3d, 12t, & 24th Observations, it is manifest that although in the 4th & 18th Observations there appear noe more than 8 or 9 of those Rings, yet there are really a far greater number which soe much interfere & mingle with one another as after those 8 or 9 revolutions to dilute one another wholy & 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 rayes endewed with all those colours.

But further by the $24^{th}$ Observation it **{illeg}** is a constant relation between colours & **{illeg}** refrangible rayes being Violet, the least **{illeg}** of intermediate colours having proportionally **{illeg}** <561r> refrangibility. And by the $13^{th}$, $14^{th}$, & $15^{th}$ Observations compared with the $4^{th}$ or $18^{th}$, there appears to be the same constant relation between colour & reflexibility, the Violet being on equall termes reflected at least thicknesse of any thin Plate or Bubble, the Red at greatest thicknesse, & the intermediate colours at intermediate thicknesses. Whence it followes that the colorifi□ dispositions of rayes 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 only from the various mixtures or seperations of rayes by virtue of their different Refrangibility or Reflexibility. And in this respect it is that the science of colours becomes a speculation more proper for Mathematicians then naturalists,

I am now come to the last part of this design 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 appear of divers colours accordingly as they are disposed to reflect most copious by the rayes endewed with those colours. But their constitutions wherby they reflect some rayes more copiously then others, remaines to be enquired after. And this I shall endeavour in the following Propositions.

Prop.1. Those superficies reflect the greatest quantity of light which have the greatest refracting power, that is, which intercede mediums that differ most in their refracting densities. And in the confines of equally dense mediums there is noe reflexon.

The analogy between reflexion & refraction will appear by considering that when light passeth obli□ly out of one Medium into another which refracts from the perpendicular, the greater is the difference of their density the lesse obliquity is requisite to cause a totall reflexion; because 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 <561v> 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 sbout $48^{degr}$ $35^{min}$. 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 Crystall or more strongly refracting Mediums into Air, there is still a lesse obliquity requisite to cause a totall reflexion. Superficies therfore which refract most do soonest reflect all the light which is incident on them, & so must be allowed most strongly reflective.

But the truth of this Proposition will further appear by observing that in the superficies interceding any two of those Mediums, Air of water or other liquors, common Glasse, Crystall, & Metalline Glasses, the reflexion is stronger or weaker accordingly as the superficies hath a greater or lesse refracting power. Thus when other Mediums are contiguous to Air; the reflexion is stronger in the superficies of Glasse then of water; still stronger in the superficies of Crystall, & strongest in the superficies of metalline Glasse. So in the confine of water & common Glasse the reflexion is very weak, but yet stronger then in the confine of water & oyle or almost any other two liquors, & still stronger in the confine of water & Crystall or Metalline Glasse: accordingly as those Mediums differ more or lesse in density. So in the confine of common Glasse & Chrystall there is a weak reflexion & a stronger reflexion in the confine of common & mealline Glasse. 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 of two Crystalls or liquors or any other substances in which no refraction is caused. Whence it comes to passe that uniform Mediums have no sensible reflexion but in their externall superficies where they are adjacent to other Mediums of a different densi**{**ity.**}**

Prop: 2. The least parts of naturall bodies **{**are**}** in **{**some**}**measure transparent; And the opacity of those **{illeg}** the multitude of reflexions caused caused in their **{illeg}**

That this is so will easily be granted **{illeg}** been conversant with Microscopes. <562r> And it may be also tried by applying any substance to a hole through which some light is immitted into a dark room For how opake sooner that substance may seem in the open Air, it will by that means appear very manifestly transparent if it be of a sufficient thinnesse. Onely metalline bodies must be exempted which by reason of their excessive density seem to reflect almost all the light incident on their first superficies.

Prop: 3: Between the parts of opake or coloured bodies are many interstices replenished with mediums of other densities: as water between the tinging corpuscles wherwith any liquor is impregnated; Air between the aqueous globules that constitute Clouds or mists; & for the most part spaces void of both Air & water; but yet perhaps replenished with some subtiler Medium 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 from 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 only in superficies which intercede Mediums of a differing density.

But further that this discontinuity of parts is the Principall cause of the opacity of bodies will appear by considering that opake substances become transparent by filling their pores with any 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 oyl'd or varnished, & many other substances soaked in such liquors as will intimately pervade their little pores become by that means more transparent then otherwise. So on the contrary the most transparent substances may by seperating their parts be rendered sufficiently opake, as Glasse by being reduced to powder or otherwise flawed, water by being formed into many small bubbles either alone in the form of froth, or by shaking it together with oyle of Turpentine or some other convenient liquor with which it will not incorporate, & Horn by being scraped.

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To the increase of of the opacity of these bodies it conduces something that by the 23d 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 void 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 appears by the ascention 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 void of Air will cause the same kind of effects as to reflexion which those doe 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 & precedent Proposition, & declined 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 if their parts be subtily divided (as Metalls by being dissolved in acid Menstruums, &c) become perfectly transparent. And you may also remember that in the 8th Observation there was no reflexion at the superficies of the Object-glasses where they were very near one another though they did not **{**abso**}**lutely touch. And in the 17th Observation **{illeg}** **{illeg}** the water-bubble where it became thin **{illeg}** insensible so as to cause the apparitions **{illeg}** spots.

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On these grounds I conceive it is that water, salt, glasse, stones & such like substances are transparent For upon divers considerations they seem to be as porous as other bodies, but yet their pores & parts too small to cause any opacity.

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

For if a thin'd or plated body which being of an eaven thicknesse appeares all over of **{**one**}** uniform colour should be broken into fragments of the same thicknesse with the plate, I see noe reason why a heap of those fragments should not constitute a powder of the same colour which the Plate exhibited before it was broken.

And the parts of all naturall bodies being like soe many fragments of a Plate must on the same grounds exhibit the same colours.

Now that they doe soe will further appear by the affinity of their properties. As that the infusion of Nephritic wood & many other substances reflect one colour & transmitt another like thin bodies in the $9^{th}$ & $20^{th}$ Observations. That the colours of silks, cloths, & other substances which water or oyle can intimately penetrate become more faint & obscure by being immmerged in those liquors, & recover their vigor again by being dryed much after the manner declared of thin bodies in the $10^{th}$ & 21 Observations. And that some of those coloured powders 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 Plate is changed by varying its thicknesse. For which reason also it is that many flowers by being bruised become more transparent then before; or at least <563v> in some degree or another change their colours. Nor is it much lesse to my purpose that by mixing divers liquors very odd & remarkable productions & changes of colours may be effected, of which no cause can be more obvious & naturall than 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 only 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 wee 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 wee consider the various Phæ nomena of the Atmosphere, wee may observe that when vapours are first raised, they hinder not the transparency of the Air, being divided into parts too small to cause any reflexion in their superficies. But when in order to compose drops of rain they begin to coalesce & constitute globules of all intermediate sizes, those globules when they become of a convenient size to reflect some colours & transmitt others, may constitute clouds of various colours acording 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 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. <u>Then parts of Bodies on which their colours depend are denser then the medium which pervades the interstices.</u>

This will appear by considering that the colour **{illeg}** body depends not only on the rayes which are **{illeg}**pendicularly on its parts, but on those **{**also**}** **{illeg}**dent at all other angles. And that **{illeg}** <564r> $7^{th}$ Observation a very little variation of obliquity will change the reflected colour where the thinne body or small particle is rarer then the ambient Medium, in so much 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 $19^{th}$ Observation are so little changed by the variation of obliquity, that the rayes which are reflected least obli□ly, may predominate over the rest so much as to cause a heap of such particles to appear very intensly of their colour.

It conduces also something to this Proposition that according to $22^{th}$ Observation, the colours exhibited by the denser thin body within the rarer are more bris□ then those exhibited by the rarer within the denser.

Prop: $7^{th}$. <u>The bignesse of the component parts of naturall bodies may be conjectured by their colours.</u>

For since the parts of those 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 determine the sizes of those parts you need only 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 **{illeg}** the diameter of a corpuscle which being of equall density with glasse, shall reflect Green of the third order; the number $17\frac{1}{2}$ showes it to be about $\frac{17\frac{1}{2}}{1000000}$ parts of an inch. The greatest difficulty is here to know of what order

<564v> the colour of any body is. And for this end wee must have recourse to the 4th & 18th Observations from whence may be collected these perticulars.

Scarlets & other Reds, Oreanges & yellows if they be pure & intense are most probably of the second order. Those of the first & third order also may be pretty good, only the Orange & Red of the third order have too great a 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 seems to be, partly by reason of the intensnesse of their colours, & partly because when they wither some of them turn to a greenish yellow, & others to a more perfect yellow or Orange or perhaps to Red, passing first through all the aforesaid intermediate colours. which changes seem to be effected by the exhaling of the moisture which may leave the tinging corpuscles more dense, & something augmented 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 pure yet for the most part are too pure & lively to be of the fourth order.

Blewes & Purples may be either of the second or third order. But the best are of the third. Thus the colour of Violets seems to be of that order, because their syrrup by acid liquors turnes red and by urinous & alcalizate turn 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 syrrup was of the second order, an acid liquor by attenuating its tinging corpuscles would change it to **{illeg}** Red of the first order, & an Alcaly by **{**incrassate**}** them would change it to a green of the second **{illeg}** red & Green, especially the Green, seem **{illeg}** be the colours produced by these **{**changes**}** **{illeg}** <565r> 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 transcend their colour in purity.

The Blew of the first Order though very faint & little, may possibly be the colour of some substances. And perticularly 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 grossnesse requisite to reflect other colours as we find it is by experience.

Whitenesse if it be intense is either that in the first order of colours, of which sort perhaps is the colour of white lead; 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 transmitt 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 near 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.

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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 supposed a little lesse then is requisite to reflect the blew of the first order they will according to the 4th , 8th, 17th, & 18th Observations reflect so very little light as to appear intensely black, & yet may perhaps variously refract it to & fro within themselves so long untill it happen to be stifled & lost, by which meanes 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;* why Glasse ground very elaborately with sand on a Copper plate till it be well polished makes the sand together with what is worne off from the Glasse, & copper become very black; why black substances do soonest of all others become hot & burne, which effect may proceed partly from the multitude of refractions in a little room, & partly from the easie 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 reflexion from black substances, which will usually appear of a blewish white. And the reason is that black bodies on the obscure blew of the first order, as described in the 18th Observation, whence the corpuscles of black substances are most apt to reflect that colour.

In these descriptions I have been the more **{popu}**lar because its not impossible but that Microscopes may **{illeg}** be improved to the discovery of corpuscles **{illeg}** which their colours depend. For if those **{illeg}** be so far improved as with sufficient **{illeg}** represent objects five or six hundred **{illeg}** <566r> then at a foot distance they appear to our naked eyes I should hope that wee might be able to discover some of the greatest of those corpuscles. And by one that would magnifie three or four thousand times perhaps they might all be discovered but those which produce blacknesse. In the mean while I see nothing material that rationally can 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 rayes must be oblily incident, & so have a shorter way through them then the length of their diameter, as because the straitnesse of the Medium pent in on all sides may a little alter its motions or other qualities on which the reflexion depends. But yet I cannot much suspect the last because I have observed of some small plates of Moscovy-Glasse which were of an eaven thicknesse, that through a Microscope they have appeared of the same colour at their edges & corners where included the Medium was terminated, which they appeared of in other places. However it would add much to our satisfaction if those corpuscles can be discovered with Microscopes, which if wee shall ever attain to I fear 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. <u>The cause of Reflexion is not the impinging of light on the solid & impervious parts of bodies, as is commonly supposed.</u>

This will appear by the following consideration First that in the passage of light out of glasse into Air <566v> there is a reflexion as strong or stronger then in its passage out of Air into Glasse & by many degrees stronger then in its passage out of Glasse into water. And it seems not probable that Air should have more reflecting parts then water or Glasse. But if that should possibly be supposed it will availe nothing: for the reflexion is as strong if not stronger when the Air is drawn away from the Glasse, (suppose in the Air-Pump invented by Mr Boyle) as when it is adjacent to it. Secondly, if light in its passage out of Glasse into Air be incident more oblily 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 enough in the Air to transmitt the greater part of it, & at another degree of obliquity meet with nothing but parts to reflect it wholly: especially considering that in its passage out of Air into Glasse, how oblique soever be its incidence it finds pores enough in the Glass to transmitt the greatest part of it; If any man suppose that it is not reflected by the Air but by the utmost 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 rayes suppose of 45 or 46 degrees at which they are all reflected where the Air is adjacent to the Glasse, they shall be in great measure transmitted where the water is adjacent to it: which argues that their reflexion or **{trans}**mission depends on the constitution of the Air & water. hind the glass, & not on the parts of the glass Thirdly if the colours made by a Prism placed at the **{illeg}** of a beam of light into a darkned Room **{illeg}** cast on a second Prism placed at a **{illeg}** the former, in such manner that they **{illeg}** incident upon it: the second Prism **{illeg}** <567r> to the incident rayes 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 Glasse 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 enough 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 rayes should not impinge on the parts of Glasse when contiguous to one another Glasse as much as when contiguous to Air. Firstly when the top of a water-Bubble (in the 17th Observation) by the continuall subsiding & exhaling of the water grew very thin there was such a little & almost insensible quantity of light reflected from it that it appeared intensly black, wheras round about that black spot where the water was thicker the reflexion was soe 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 rayes 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 thin'd body where it is of any one thicknesse there are as many parts for the rayes 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 rayes of one colour & transmitt those of another as they do according to the 13 & 15 Observations. For it is not to be immagined that at one place the rayes which for instance exhibit a blew colour should have the fortune to dash upon the parts & those which exhibit a Red to let upon the <567v> Pores of the body; & then at another place **{**soe**}** the Body is either a little thicker, or a little thinner **{illeg}** that on the contrary the Blew should hit upon its pores & the Red upon its parts.

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

This is consentaneous to the Precedent Proposition & will further appear by considering that if all the rayes should be reflected which impinge on the internall parts of clear water or Crystall, those substances should rather have a cloudy then so very clear transparency. And further there would be no Principle of the obscurity or blacknesse which some bodies have in all positions of the eye. For to produce this effect it is necessary that many rayes be retained & lost in the body & it seems not probable that any rayes can be stopt & retained in it which do not impinge on its parts.

Sir I am Your humble servant
Isaac Newton.

[1] *Note that there is some little light reflected from those parts of this black spot where the glasses by reason of their convexity & some little uneavenness of their surfaces do not come to absolute contact. For by viewing the sun by reflexion from this spot, not only the verges of it became lucid, but divers lucid veins & specks appeared into the midst of the thickness. But **{**yet**}** some parts of the spot seemed still **{**as**}** black as before **{illeg}** I **{**take**}** **{illeg}**.

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