

Mr. Isaac Newton's Answer to some Considerations upon his Doctrine of Light and Colors

Isaac Newton

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<(5084)>

Mr. Isaac Newtons Answer to some Considerations upon his Doctrine of Light and Colors; which Doctrine was printed in Numb. 80. of these Tracts.

SIR, I have already told you, that at the perusal of the considerations, you sent me, on my Letter concerning Refractions and Colors, I found nothing, that, as I conceived, might not without difficulty be answer'd. And though I find the Considerer somewhat more concern'd for an Hypothesis, than I expected; yet I doubt not, but we have one common design; I mean, a sincere endeavour after knowledge, without valuing uncertain speculations for their subtleties, or despising certainties for their plainness: And on confidence of this it is, that I make this return to his discourse.

The first thing that offers it self is less agreeable to me, and I begin with it because it is so. The considerer is pleased to reprehend me for laying aside the thoughts of improving Optiques by Refractions. If he had obliged me by a private Letter on this occasion, I would have acquainted him with my successes on the Tryals I have made of that kind, which I shall now say have been less than I sometimes expected, and perhaps than he at present hopes for. But since he is pleased to take it for granted, that I have let this subject pass without due examination, I shall refer him to my former Letter, by which that conjecture will appear to be un-grounded. For, what I said there, was in respect of Telescopes of the ordinary construction, signifying, that their improvement is not to be expected from the well-figuring of Glasses, as Opticians have imagin'd; but I despaired not of their improvement by other constructions; which made me cautious to insert nothing that might intimate the contrary. For, although successive refractions that are all made the same way, do necessarily more and more augment the errors of the first refraction; yet it seem'd not impossible for contrary refractions so to correct each others inequalities, as to make their difference regular; and, if that <(5085)> could be conveniently effected, there would be no further difficulty. Now to this end I examin'd what may be done not only by Glasses alone, but more especially by a Complication of divers successive Mediums, as by two or more Glasses or Crystals with Water or some other fluid between them; all which together may perform the office of one Glass, especially of the Object-glass, on whose construction the perfection of the instrument chiefly depends. But what the results in Theory or by Tryals have been, I may possibly find a more proper occasion to declare.

To the Assertion, that Rays are less true reflected to a point by a Concave, than refracted by a Convex, I cannot assent; nor do I understand, that the focus of the latter is less a line than that of the former. The truth of the contrary you will rather perceive by this following Table, computed for such a Reflecting Concave, and Refracting convex, on supposition that they have equal Apertures, and collect parallel rays at an equal distance from their vertex; which distance being divided into 15000 parts, the Diameter of the Concave Sphere will be 60000 of those parts, and of the Convex, 10000; supposing the Sines of Incidence and Refraction to be, in round numbers, as 2 to 3.

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And this Table shews, how much the exterior rays, at several Apertures, fall short of their principal focus.

<i>The Diameter of the Aperture</i>	<i>The parts of the Axis intercepted between the vertex and the rays</i>	<i>The Error by</i>		
	<i>Reflected</i>	<i>Refracted</i>	<i>Reflexion</i>	<i>Refraction</i>
2000	14991 $\frac{2}{3}$	14865	8 $\frac{1}{3}$	135
4000	14966	14449	33	551
6000	14924	13699	76	1301
8000	14865	12475	135	2525
10000	14787	9472	213	5528

By this you may perceive, that the Errors of the Refracting convex are so far from being less, that they are more than sixteen times greater than the like errors of the Reflecting Concave, especially in great Apertures; and that without respect to the Heterogeneous constitution of light. So that, however the contrary supposition might make the Author of these Animadversions reject Reflections as useless for the promoting of Op- <(5086)> tiques; yet I must for this as well as other considerations prefer them in the Theory before Refractions.

Whether the Parabola be more difficult to describe than the Hyperbola or Ellipsis, may be a Quære: But I see no absolute necessity of endeavouring after any of their descriptions. For, if Metals can be ground truly Spherical, they will bear as great Apertures, as I believe men will be able to communicate an exact polish to. And for Dioptrique Telescopes, I told you, that the difficulty consisted not in the Figure of the glass, but in the Difformity of Refractions: Which if it did not, I could tell you a better and more easie remedy than the use of the Conic Sections.

Thus much concerning the Practique part of Optiques. I shall now take a view of the Considerations on my Theories. And those consist in ascribing an Hypothesis, which, as to the principal parts, is not against me; in Granting the greatest part of my discourse if explicated by that Hypothesis; and in Denying some things, the truth of which would have appear'd by an experimental examination.

Of these Particulars I shall discourse in order. And first of the Hypothesis, which is ascribed to me in these words: But grant his first supposition, that light is a body, and that as many colours or degrees as there may be, so many bodies there may be; all of which compounded together would make White, &c. This, it seems, is taken for my Hypothesis. 'Tis true, that from my Theory I argue the Corporeity of Light; but I do it without any absolute positiveness, as the word perhaps intimates; and make it at most but a very plausible consequence of the Doctrine, and not a fundamental Supposition, nor so much as any part of it; which was wholly comprehended in the precedent Propositions. And I somewhat wonder, how the Objector could imagine, that, when I had asserted the Theory with the greatest rigour, I should be so forgetful as afterwards to assert the fundamental supposition it self with no more than a perhaps. Had I intended any such Hypothesis, I should somewhere have explain'd it. But I knew, that the Properties, which I declar'd of Light, were in <(5087)> some measure capable of being explicated not only by that, but by many other Mechanical Hypotheses. And therefore I chose to decline them all, and to speak of Light in general terms, considering it abstractly, as something or other propagated every way in streight lines from luminous bodies, without determining, what that Thing is; whether a confused Mixture of difform qualities, or Modes of bodies, or of Bodies themselves, or of any Virtues, Powers, or Beings whatsoever. And for the same reason I chose to speak of Colours according to the information of our Senses, as if they were Qualities of Light without us. Whereas by that Hypothesis I must have considered them rather as Modes of Sensation, excited in the mind by various motions, figures, or sizes of the corpuscles of Light, making various Mechanical impressions on the Organ of Sense; as I expressed it in that place, where I spake of the Corporeity of Light.

But supposing I had propounded that Hypothesis, I understand not, why the Objector should so much endeavour to oppose it. For certainly it has a much greater affinity with his own Hypothesis, than he seems to be aware of; the Vibrations of the Æther being as useful and necessary in this, as in his. For, assuming the Rays of Light to be small bodies, emitted every way from Shining substances, those, when they impinge on any Refracting or Reflecting superficies, must as necessarily excite Vibrations in the æther, as Stones do in water when thrown into it. And supposing these Vibrations to be of several depths or thicknesses, accordingly as they are excited by the said corpuscular rays of various sizes and velocities; of what use they will be for explicating the manner of Reflection and Refraction, the production of Heat by the Sun-beams, the Emission of Light from burning putrifying, or other substances, whose parts are vehemently agitated, the Phænomena of thin transparent Plates and Bubbles, and of all Natural bodies, the Manner of Vision, and the Difference of Colors, as also their Harmony and Discord; I shall leave to their consideration, who may think it worth their endeavor to apply this Hypothesis to the solution of phænomena.

<(5088)>

In the second place, I told you, that the Objectors Hypothesis, as to the fundamental part of it, is not against me. That fundamental Supposition is; That the parts of bodies, when briskly agitated, do excite Vibrations in the Æther, which are propagated every way from those bodies in streight lines, and cause a Sensation of Light by beating and dashing against the bottom of the Eye, something after the manner that Vibrations in the Air cause a Sensation of Sound by beating against the Organs of Hearing. Now, the most free and natural Application of this Hypothesis to the Solution of phænomena I take to be this: That the agitated parts of bodies, according to their several sizes, figures, and motions, do excite Vibrations in the æther of various depths or bignesses, which being promiscuously propagated through that Medium to our Eyes, effect in us a Sensation of Light of a White colour; but if by any means those of unequal bignesses be separated from one another, the largest beget a Sensation of a Red colour, the least or shortest, of a deep Violet, and the intermediat ones, of intermediat colors; much after the manner that bodies, according to their several sizes, shapes, and motions, excite vibrations in the Air of various bignesses, which, according to those bignesses, make several Tones in Sound: That the largest Vibrations are best able to overcome the resistance of a Refracting superficies, and so break through it with least Refraction; whence the Vibrations of several bignesses, that is, the Rays of several Colors, which are blended together in Light, must be parted from one another by Refraction, and so cause the Phænomena of Prisms and other refracting substances: And that it depends on the thickness of a thin transparent Plate or Buble, whether a Vibration shall be reflected at its further superficies, or transmitted; so that, according to the number of vibrations, interceding the two superficies, they may be reflected or transmitted for many successive thicknesses. And since the Vibrations which make Blue and Violet, are supposed shorter than those which make Red and Yellow, they must be reflected at a less thickness of the Plate: Which is sufficient to explicate all the ordinary phænomena of those Plates or Bubbles, and also of all natural bodies, <(5089)> whose parts are like so many fragments of such Plates.

These seem to be the most plain, genuine and necessary conditions of this Hypothesis: And they agree so justly with my Theory, that if the Animadversor think fit to apply them, he need not, on that account, apprehend a divorce from it. But yet how he will defend it from other difficulties, I know not. For, to me, the Fundamental Supposition it self seems impossible; namely, That the Waves or Vibrations of any Fluid, can, like the Rays of Light, be propagated in Streight lines, without a continual and very extravagant spreading and bending every way into the quiescent Medium, where they are terminated by it. I mistake, if there be not both Experiment and Demonstration to the contrary. And as to the other two or three Hypotheses, which he mentions, I had rather believe them subject to the like difficulties, than suspect the Animadversor should select the worst for his own.

What I have said of this, may easily be applied to all other Mechanical Hypotheses, in which Light is supposed to be caused by any Pression or Motion whatsoever, excited in the æther by the agitated parts of Luminous bodies. For, it seems impossible, that any of those Motions or Pressions can be propagated in Streight lines without the like spreading every way into the shadow'd Medium, on which they border. But yet, if any man can think it possible, he must at least allow, that those Motions or Endeavors to motion, caused in the æther by the several parts of any Lucid body that differ in size, figure, and agitation, must necessarily be unequal: Which is enough to denominate Light an Aggregat of difform rays, according to any of those Hypotheses. And if those Original

inequalities may suffice to difference the Rays in Colour and Refrangibility, I see no reason why they, that adhere to any of those hypotheses, should seek for other Causes of these Effects, unless (to use the Objectors argument) they will multiply entities without necessity.

The third thing to be considered is, the Condition of the Animadversor's Concessions, which is, that I would explicate my Theories by his Hypothesis: And if I could comply with him in that point, <(5090)> there would be little or no difference between Us. For he grants, that without any respect to a different Incidence of rays there are different Refractions; but he would have it explicated, not by the different Refrangibility of several Rays, but by the Splitting and Rarefying of æthereal pulses. He grants my third, fourth and sixth Propositions; the sense of which is, That Un-compounded Colors are unchangeable, and that Compounded ones are changeable only by resolving them into the colors, of which they are compounded; and that all the Changes, which can be wrought in Colours, are effected only by variously mixing or parting them: But he grants them on condition that I will explicate Colors by the two sides of a split pulse, and so make but two species of them, accounting all other Colors in the world to be but various degrees and dilutings of those two. And he further grants, that Whitenesse is produced by the Convention of all Colors; but then I must allow it to be not only by Mixture of those Colors, but by a farther Uniting of the parts of the Ray supposed to be formerly split.

If I would proceed to examine these his Explications, I think it would be no difficult matter to shew, that they are not only insufficient, but in some respects to me (at least) un-intelligible. For, though it be easie to conceive, how Motion may be dilated and spread, or how parallel motions may become diverging; yet I understand not, by what artifice any Linear motion can by a refracting superficies be infinitely dilated and rarefied, so as to become Superficial: Or, if that be supposed, yet I understand as little, why it should be split at so small an angle only, and not rather spread and dispersed through the whole angle of Refraction. And further, though I can easily imagine, how Unlike motions may cross one another; yet I cannot well conceive, how they should coalesce into one uniform motion, and then part again, and recover their former Unlikeness; notwithstanding that I conjecture the ways, by which the Animadversor may endeavour to explain it. So that the Direct, uniform and undisturbed Pulses should be split and disturbed by Refraction; and yet the Oblique and disturbed Pulses persist without splitting or further disturbance by following Refractions, is (to me) as unintelligible. And there is <(5091)> as great a difficulty in the Number of Colours; as you will see hereafter.

But whatever be the advantages or disadvantages of this Hypothesis, I hope I may be excused from taking it up, since I do not think it needful to explicate my Doctrine by any Hypothesis at all. For if Light be consider'd abstractly without respect to any Hypothesis, I can as easily conceive, that the several parts of a shining body may emit rays of differing colours and other qualities, of all which Light is constituted, as that the several parts of a false or uneven string, or of unevenly agitated water in a Brook or Cataract, or the several Pipes of an Organ inspired all at once, or all the variety of Sounding bodies in the world together, should produce sounds of several Tones, and propagate them through the Air confusedly intermixt. And, if there were any natural bodies that could reflect sounds of one tone, and stifle or transmit those of another; then, as the Echo of a confused Aggregat of all Tones would be that particular Tone, which the Echoing body is disposed to reflect; so, since (even by the Animadversor's concessions) there are bodies apt to reflect rays of one colour, and stifle or transmit those of another; I can as easily conceive, that those bodies, when illuminated by a mixture of all colours, must appear of that colour only which they reflect.

But when the Objector would insinuate a difficulty in these things, by alluding to Sounds in the string of a Musical instrument before percussion, or in the Air of an Organ Bellows before its arrival at the Pipes; I must confess, I understand it as little, as if one had spoken of Light in a piece of Wood before it be set on fire, or in the oyl of a Lamp before it ascend up the match to feed the flame.

You see therefore, how much it is besides the business in hand, to dispute about Hypotheses. For which reason I shall now in the last place, proceed to abstract the difficulties in the Animadversor's discourse, and, without having regard to any Hypothesis, consider them in general terms. And they may be reduced to these 3 Quæres:

<(5092)>

1. Whether the unequal Refractions, made without respect to any inequality of incidence, be caused by the different Refrangibility of several Rays; or by the splitting, breaking or dissipating the same Ray into diverging parts?

2. Whether there be more than two sorts of Colours?

3. Whether Whiteness be a mixture of all Colours?

The First of these Quæres you may find already determin'd by an Experiment in my former Letter; the design of which was to shew, That the length of the colour'd Image proceeded not from any unevenness in the Glass, or any other contingent Irregularity in the Refractions. Amongst other Irregularities I know not, what is more obvious to suspect, than a fortuitous dilating and spreading of Light after some such manner, as Des-Cartes hath described in his *Æthereal Refractions* for explicating the Tayle of a Comet; or as the Animadversor now supposes to be effected by the Splitting and Rarifying of his *Æthereal* pulses. And to prevent the suspicion of any such Irregularities, I told you, that I refracted the Light contrary ways with two Prismes successively, to destroy thereby the Regular effects of the first Prisme by the second, and to discover the Irregular effects by augmenting them with the iterated refractions. Now, amongst other Irregularities, if the first Prisme had spread and dissipated every ray into an indefinit number of diverging parts, the second should in like manner have spread and dissipated every one of those parts into a further indefinite number, whereby the Image would have been still more dilated, contrary to the event. And this ought to have hapned, because those Linear diverging parts depend not on one another for the manner of their Refraction, but are every one of them as truly and compleatly Rays as the whole was before its Incidence; as may appear by intercepting them severally.

The reasonableness of this proceeding will perhaps better appear by acquainting you with this further circumstance. I sometimes placed the second Prisme in a position Transverse to the first, on design to try, if it would make the long Image become four-sqaure by refractions crossing those that had drawn the round Image into a long one. For, if amongst other Irregularities the Refraction of the first Prisme, did by Splitting <(5093)> dilate a Linear ray into a Superficial, the Cross refractions of that second Prisme ought by further splitting to dilate and draw that Superficial ray into a Pyramidal solid. But, upon tryal, I found it otherwise; the Image bring as regularly Oblong as before, and inclin'd to both the Prismes at an angle of 45. degrees.

I tryed also all other Positions for the second Prisme, by turning the Ends about its middle part; and in no case could observe any such Irregularity. The Image was ever alike inclined to both Prismes, its Breadth answering to the Suns Diameter, and its length being greater or less accordingly as the Refractions more or less agreed, or contradicted one another.

And by these Observations, since the Breadth of the Image was not augmented by the Cross refraction of the second Prisme, that refraction must have been perform'd without any splitting or dilating of the ray; and therefore at least the Light incident on that Prisme must be granted an Aggregat of Rays unequally refrangible in my sense. And since the Image was equally inclin'd to both Prismes, and consequently the Refractions alike in both, it argues, that they were perform'd according to some Constant Law without any irregularity.

To determine the second Quære, the Animadversor refers to an Experiment made with two Wedge-like boxes, recited in the *Micrography* of the Ingenious Mr. Hook *Observ.* 10. pag. 73. the design of which was to produce all Colours out of a mixture of two. But there is, I conceive, a double defect in this instance. For, it appears not, that by this Experiment all colours can be produced out of two; and, if they could, yet the Inference would not follow.

That all Colours cannot by that Experiment be produced out of two, will appear by considering, that the Tincture of Aloes, which afforded one of those Colours, was not all over of one uniform colour, but appear'd yellow near the edge of the Box, and red at other places where it was thicker: affording all variety of colours from a pale yellow to a deep red or Scarlet, according to the various thickness of the liquor. And so the <(5094)> solution of Copper, which afforded the other colour, was of various Blews and Indigo's. So that instead of two colours, here is a great variety made use of for the production of all others. Thus, for instance, to produce all sorts of Greens, the several degrees of Yellow and pale Blew must be mixed; but to compound Purples, the Scarlet and deep Blew are to be the Ingredients.

Now, if the Animadversor contend, that all the Reds and Yellows of the one Liquor, or Blews and Indigo's of the other, are divers colours, that is a Begging of the Question: And I should as soon grant, that the two Thirds or Sixths in Musick are but several degrees of the same sound, and not divers sounds. Certainly it is much better to believe our Senses, informing us, that Red and yellow are divers colours, and to make it a Philosophical Quære, Why the same Liquor doth, according to its various thickness, appear of those divers colours, than to suppose them to be the same colour because exhibited by the same liquor? For, if that were a sufficient reason, then Blew and Yellow must also be the same colour, since they are both exhibited by the same Tincture of Nephritick Wood. But that they are divers colours, you will more fully understand by the reason, which, in my Judgment, is this: The Tincture of Aloes is qualified to transmit most easily the rays indued with red, most difficultly the rays indued with violet, and with intermediat degrees of facility the rays indued with intermediat colours. So that where the liquor is very thin, it may suffice to intercept most of the violet, and yet transmit most of the other colours; all which together must compound a middle Colour, that is, a faint yellow. And where it is so much thicker as also to intercept most of the Blew and Green, the remaining Green, Yellow, and Red, it must compound an Orange. And where the thickness is so great, that scarce any rays can pass through it besides those indued with Red, must appear of that colour, and that so much the deeper and obscurer, by how the liquor is thicker. And the same may be understood of the various degrees of Blew, exhibited by the Solution of Copper, by reason of its disposition to intercept Red most easily, and transmit a deep Blew or Indigo Colour most freely.

<(5095)>

But, supposing that all Colours might, according to this experiment, be produced out of two by mixture; yet it follows not, that those two are the only Original colours, and that four a double reason. First, because those two are not themselves Original colours, but compounded of others; there being no liquor nor any other body in nature, whose colour in Day-light is wholly un-compounded. And then, because, though those two were Original, and all others might be compounded of them, yet it follows not, that they cannot be otherwise produced. For I said, that they had a double Origin, the same Colours to sense being in some cases compounded and in others un-compounded; and sufficiently declar'd in my third and fourth Propositions, and in the Conclusion, by what Properties the one might be known and distinguish't from the other. But, because I suspect by some Circumstances, that the Distinction might not be rightly apprehended, I shall once more declare it, and further explain it by Examples.

That Colour is Primary or Original, which cannot by any Art be changed, and whose Rays are not alike refrangible: And that Compounded, which is changeable into other colours, and whose Rays are not alike refrangible. For instance, to know, whether the colour of any Green object be compounded or not, view it through a Prisme, and if it appear confused, and the edges tinged with Blew, Yellow, or any variety of other colours, then is that Green compounded of such colours as at its edges emerge out of it: But if it appear distinct, and well defin'd, and entirely Green to the very edges, without any other colours emerging, it is of an Original and un-compounded Green. In like manner, if a refracted beam of light, being cast on a white wall, exhibit a Green colour, to know whether that be compounded, refract the beam with an interposed Prisme; and if you find any Difformity in the refractions, and the Green be transform'd into Blew, Yellow, or any variety of other colours, you may conclude, that it was compounded of those which emerge: But if the Refractions be uniform, and the Green persist without any change of colour, then it is Original and un-compounded. And the reason why I call it so, is, because a Green indued with such properties cannot be produced by any mixing of other colours.

<(5096)>

Now, if two Green Objects may to the naked eye appear of the same colour, and yet one of them through a prisme seem confused and variegated with other colours at the edges, and the other distinct and entirely Green; or, if there may be two Beams of Light, which falling on a white wall do to the naked eye exhibit the same Green colour, and yet one of them, when transmitted through a Prisme, be uniformly and regularly refracted, and retain its colour unchanged, and the other be irregularly refracted and to divaricate into a multitude of other colours; I suppose, these two greens

will in both cases be granted of a different Origin and constitution. And if by mixing colours, a green cannot be compounded with the properties of the Unchangeable Green, I think, I may call that an Un-compounded colour, especially since its rays are alike refrangible, and uniform in all respects.

The same rule is to be observ'd in examining, whether Red, Orange, Yellow, Blue, or any other colour be compounded or not. And, by the way, since all White objects through the Prisme appear confus'd and terminated with colours, Whiteness must, according to this distinction, be ever compounded, and that the most of all colours, because it is the most confus'd and changed by Refractions.

From hence I may take occasion to communicate a way for the improvement of Microscopes by Refraction. The way is, by illuminating the Object in a darkned room with Light of any convenient colour not too much compounded: for by that means the Microscope will with distinctness bear a deeper Charge and larger Aperture, especially if its construction be such, as I may hereafter describe; for, the advantage in Ordinary Microscopes will not be so sensible.

There remains now the third Quære to be consider'd, which is, Whether Whiteness be an Uniform Colour, or a dissimilar Mixture of all colours? The Experiment which I brought to decide it, the Animadversor thinks may be otherwise explain'd, and so concludes nothing. But he might easily have satisfied himself by trying, what would be the result of a Mixture of all colours. And that very Experiment might have satisfied him, if he had pleased to examine it by <(5097)> the various circumstances. One circumstance I there declared, of which I see no notice taken; and it is, That if any colour at the Lens be intercepted, the Whiteness will be changed into the other colours: If all the colours but red be intercepted, that Red alone in the concourse or crossing of the Rays will not constitute Whiteness, but continues as much Red as before; and so of the other colours. So that the business is not only to shew, how rays, which before the concourse exhibit colours, do in the concourse exhibit White; but to shew, How in the same place, where the several sorts of rays apart exhibit several colours, a Confusion of all together make White. For instance, if red alone be first transmitted to the paper at the place of concourse, and then the other colours be let fall on that Red, the Question will be, Whether they convert it into White, by mixing with it only, as Blue falling on Yellow light is suppos'd to compound Green; or, Whether there be some further change wrought in the colours by their mutual acting on one another, untill, like the contrary Peripatetic qualities, they become assimilated. And he that shall explicate this last Case mechanically, must conquer a double impossibility. He must first shew, that many unlike motions in a Fluid can by clashing so act on one another, and change each other, as to become one Uniform motion; and then, that an Uniform motion can of itself, without any new unequal impressions, depart into a great variety of motions regularly un-equal. And after this he must further tell me, Why all Objects appear not of the same colour, that is, why their colours in the Air, where the rays that convey them every way are confusedly mixt, do not assimilate one another and become Uniform before they arrive at the Spectators eye?

But if there be yet any doubting, 'tis better to put the Event on further Circumstances of the Experiment, than to acquiesce in the possibility of any Hypothetical Explication. As, for instance, by trying, What will be the apparition of these colours in a very quick Consecution of one another. And this may be easily perform'd by the rapid gyration of a Wheel with many Spokes or cogs in its perimeter, whose Interstices and thicknesses may be equal and of such a largeness, that, if the Wheel be interposed between the Prisme and the white concourse <(5098)> of the colours, one half of the Colours may be intercepted by a spoke or cog, and the other half pass through an interstice. The Wheel being in this posture, you may first turn it slowly about, to see all the colours fall successively on the same place of the paper, held at their aforesaid concourse; and if you then accelerate its gyration, until the Consecution of those colours be so quick, that you cannot distinguish them severally, the resulting colour will be a Whiteness perfectly like that, which an un-refracted beam of Light exhibits, when in like manner successively interrupted by the spokes or cogs of that circulating Wheel. And that this Whiteness is produced by a successive Intermixture of the Colours, without their being assimilated, or reduc'd to any Uniformity, is certainly beyond all doubt, unless things that exist not at the same time may notwithstanding act on one another.

There are yet other Circumstances, by which the Truth might have been decided; as by viewing the White concourse of the Colours through another Prisme plac'd close to the eye, by whose Refraction that whiteness may appear again transform'd into Colours: And then, to examine their Origin, if an Assistant intercept any of the colours at the Lens before their arrival at the Whiteness,

the same colours will vanish from amongst those, into which that Whiteness is converted by the second Prisme. Now, if the rays which disappear be the same with those that are intercepted, then it must be acknowledged, that the second Prisme makes no new colours in any rays, which were not in them before their concurrence at the paper. Which is a plain indication, that the rays of several colours remain distinct from one another in the Whiteness, and that from their previous dispositions are deriv'd the Colours of the second Prisme. And, by the way, what is said of their Colors may be applied to their Refrangibility.

The aforesaid Wheel may be also here made use of; and, if its gyration be neither too quick nor too slow, the succession of the colours may be discern'd through the Prisme, whilst to the naked eye of a Bystander they exhibit whiteness.

There is something still remaining to be said of this Experi- <(5099)> ment. But this, I conceive, is enough to enforce it, and so to decide the controversy. How-ever, I shall now proceed to shew some other ways of producing Whiteness by mixtures, since I perswade my self, that this Assertion above the rest appears Paradoxical, and is with most difficulty admitted. And because the Animadversor desires an instance of it in Bodies of divers colours, I shall begin with that. But in order thereto it must be consider'd, that such colour'd Bodies reflect but some part of the Light incident on them; as is evident by the 13 Proposition: And therefore the Light reflected from an Aggregat of them will be much weakned by the loss of many rays. Whence a perfect and intense Whiteness is not to be expected, but rather a Colour between those of Light and Shadow, or such a Gray or Dirty colour as may be made by mixing White and Black together.

And that such a Colour will result, may be collected from the colour of Dust found in every corner of an house, which hath been observ'd to consist of many colour'd particles. There may be also produced the like Dirty colour by mixing several Painters colours together. And the same may be effected by Painting a Top (such as Boys play with) of divers colours. For, when it is made to circulate by whipping it, it will appear of such a dirty colour.

Now, the Compounding of these colours is proper to my purpose, because they differ not from Whiteness in the Species of colour, but only in degree of Luminousness: which (did not the Animadversor concede it) I might thus evince. A beam of the Suns Light being transmitted into a darkned room, if you illuminate a sheet of White Paper by that Light, reflected from a body of any colour, the paper will always appear of the colour of that body, by whose reflected light it is illuminated. If it be a red body, the paper will be red; if a green body, it will be green; and so of the other colours. The reason is, that the fibers or threads, of which the paper consists, are all transparent and specular; and such substances are known to reflect colours without changing them. To know therefore, to what Species of colour a Grey belongs, place any Gray body (suppose a Mixture of Painters colours,) in the said Light, and the paper, being illuminated by its reflexion, shall appear White. And the same thing will happen, if it be illuminated by reflexion from a black substance.

These therefore are all of one Species; but yet they seem distinguisht not only by degrees of Luminousness, but also by some other Inequalities, whereby they become more harsh or pleasant. And the distinction seems to be, that Greys and perhaps Blacks are made by an uneven defect of Light, consisting as it were of many little veins or streams, which differ either in Luminousness or in the Unequal di- <(5100)> stribution of diversly colour'd rays; such as ought to be caus'd by Reflexion from a Mixture of white and black, or of diversly color'd corpuscles. But when such imperfectly mixt Light is by a second Reflexion from the paper more evenly and uniformly blended, it becomes more pleasant, and exhibits a faint or shadow'd Whiteness. And that such little irregularities as these may cause these differences, is not improbable, if we consider, how much variety may be caused in Sounds of the same tone by irregular and uneven jarrings. And besides, these differences are so little, that I have sometimes doubted, whether they be any at all, when I have consider'd that a Black and White Body being plac'd together, the one in a strong light, and the other in a very faint light, so proportion'd that they might appear equally luminous; it has been difficult to distinguish them, when view'd at distance, unless when the Black seem'd more blewish; and the White body in a light still fainter, hath, in comparison of the Black body, it self appear'd Black.

This leads me to another way of Compounding Whiteness; which is, That, if four or five Bodies of the more eminent colours, or a Paper painted all over, in several parts of it, with those several

colours in a due proportion, be placed in the said Beam of Light; the Light, reflected from those Colours to another White paper, held at a convenient distance, shall make that paper appear White. If it be held too near the Colours, its parts will seem of those colours that are nearest them; but by removing it further, that all its parts may be equally illuminated by all the colours, they will be more and more diluted, until they become perfectly White. And you may further observe, that if any of the colours be intercepted, the Paper will no longer appear White, but of the other colours which are not intercepted. Now, that this Whiteness is a Mixture of the severally colour'd rays, falling confusedly on the paper, I see no reason to doubt of; because, if the Light became Uniform and Similar before it fell confusedly on the paper, it must much more be Uniform, when at a greater distance it falls on the Spectators eye, and so the rays, which come from several colours, would in no qualities differ from one another, but all of them exhibit the same colour to the Spectator, contrary to what he sees.

Not much unlike this Instance it is, That, if a polisht piece of Metal be so placed, that the colours appear in it as in a Looking-glass, and then the Metal be made rough, that by a confus'd reflexion those apparent colours may be blended together, they shall disappear, and by their mixture cause the Metall to look White.

<(5101)>

But further to enforce this Experiment; if, instead of the Paper, any White Froth, consisting of small bubbles, be illuminated by reflexion from the aforesaid Colours, it shall to the naked eye seem White, and yet through a good Microscope the several Colours will appear distinct on the bubbles, as if seen by reflexion from so many spherical surfaces. With my naked eye, being very near, I have also discern'd the several colours on each bubble; and yet at a greater distance, where I could not distinguish them apart, the Froth hath appear'd entirely White. And at the same distance, when I look'd intently, I have seen the colours distinctly on each bubble; and yet, by straining my eyes as if I would look at something far off beyond them, thereby to render the Vision confus'd, the Froth has appear'd without any other colour than Whiteness. And what is here said of Froths, may easily be understood of the Paper or Metal in the foregoing Experiments. For, their parts are specular bodies, like these Bubbles: And perhaps with an excellent Microscope the Colours may be also seen intermixedly reflected from them.

In proportioning the severally Colour'd bodies to produce these effects, there may be some niceness; and it will be more convenient, to make use of the colours of the Prisme, cast on a Wall, by whose reflexion the Paper, Metal, Froth, and other White substances may be illuminated. And I usually made my Tryals this way, because I could better exclude any scattering Light from mixing with the colours to dilate them.

To this way of Compounding Whiteness may be referr'd that other, by Mixing light after it hath been trajected through transparently colour'd substances. For instance, if no Light be admitted into a room but only through Colour'd glass, whose several parts are of several colours in a pretty equal proportion; all White things in the room shall appear White, if they be not held too near the Glass. And yet this light, with which they are illuminated, cannot possibly be uniform, because, if the Rays, which at their entrance are of divers colours, do in their progress through the room suffer any alteration to be reduced to an Uniformity; the Glass would not in the remotest parts of the room appear of the very same colour, which it doth when the Spectators eye is very near it: Nor would the rays, when transmitted into another dark room through a little hole in an opposite door or partition-wall, project on a Paper the Species or representation of the glass in its proper colours.

And, by the by, this seems a very fit and cogent Instance of some other parts of my Theory, and particularly of the 13 Proposition. For, in this room all natural Bodies whatever appear in their proper colours. And all the Phænomena of colours in nature, made either by Refraction or without it, are here the same as in the Open Air. Now, the Light in this room being such a Dissimilar mixture, as <(5102)> I have described in my Theory, the Causes of all these Phænomena must be the same that I have there assign'd. And I see no reason to suspect, that the same Phænomena should have other causes in the Open Air.

The success of this Experiment may be easily conjectur'd by the appearances of things in a Church or Chappel, whose windores are of colour'd glass; or in the Open Air, when it is illustrated with Clouds of various colours.

There are yet other ways, by which I have produced Whiteness; as by casting several Colours from two or more Prismes upon the same place; by Refracting a Beam of Light with two or three Prismes successively, to make the diverging colours converge again; by Reflecting one colour to another; and by looking through a Prisme on an Object of many colours; and, (which is equivalent to the above mention'd way of mixing colours by concave Wedges fill'd with colour'd liquors,) I have observ'd the shadows of a painted Glass-window to become White, where those of many colours have at a great distance interfered. But yet, for further satisfaction, the Animadversor may try, if he please, the effects of four or five of such Wedges filled with liquors of as many several colours.

Besides all these, the Colours of Water-bubbles and other thin pellucid substances afford several instances of Whiteness produced by their mixture; with one of which I shall conclude this particular. Let some Water, in which a convenient quantity of Soap or wash ball is dissolv'd, be agitated into Froth, and, after that froth has stood a while without further agitation, till you see the bubbles, of which it consists, begin to break, there will appear a great variety of colours all over the top of every bubble, if you view them near at hand; but, if you view them at so great a distance that you cannot distinguish the colours one from another, the Froth will appear perfectly White.

Thus much concerning the design and substance of the Animadversor's Considerations. There are yet some particulars to be taken notice of, before I conclude; as the denial of the Experimentum Crucis. On this I chose to lay the whole stress of my discourse; which therefore was the principal thing to have been objected against. But I cannot be convinced of its insufficiency by a bare denial without assigning a Reason for it. I am apt to believe, it has been misunderstood; for otherwise it would have prevented the discourses about Rarifying and Splitting of rays; because the design of it is, to shew, that Rays of divers colours, consider'd a part, do at Equal Incidences suffer Unequal Refractions, without being split, rarified, or any way dilated.

<(5103)>

In the Considerations of my first and second Propostions, the Animadversor hath rendered my Doctrine of Un-equal Refrangibility very imperfect and maimed, by explicating it wholly by the Splitting of rays; whereas I chiefly intended it in those Refractions that are perform'd without that suppos'd Irregularity; such as the Experimentum Crucis might have inform'd him of. And, in general I find, that, whilst he hath endeavour'd to explicate my Propositions Hypothetically, the more material suggestions, by which I design'd to recommend them, have escap'd his consideration; such as are, the Unchangeableness of the degree of Refrangibility peculiar to any sort of rays; the strict Analogy between the degrees of Refrangibility and Colours; the Distinction between compounded and un-compounded colours; the Unchangeableness of un-compounded colours; and the Assertion, that if any one of the Prismatic colours be wholly intercepted, that colour cannot be new produced out of the remaining Light by any further Refraction or Reflexion whatsoever. And of what strength and efficacy these Particulars are for enforcing the Theory, I desire therefore may be now consider'd.

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