



## **Philosophical Transactions**

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

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.\*

\* Which Discourse was thought needless to be here printed at length, because in the body of this Answer are to be met with the chief particulars, wherein the Answerer was concern'd.

1. Of the *Practique* part of *Optiques*.

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 could

\* Printed in Numb. 80. of these *Traacts*.

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

The Diameter between the vertex and the rays. of the Aperture.	The parts of the Axis intercepted		The Error by	
	Reflected.	Refracted.	Reflexion.	Refraction.
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	2515 .
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-

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 *Quere* : 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 well 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*.

2. *Of the Theorique part.*

Thus much concerning the *Prastique* part of Optiques. I shall now take a view of the Considerations on my *Theories*. And those consist in ascribing an *Hypothesis* to me, which is not mine; in Asserting 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.

3. *Of an Hypothesis mistaken to be mine.*

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 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 some

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 thickneses, 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 Bubles, 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*.

In the second place, I told you, that the Objectors *Hypothesis*,

*A. Of the Objector's Hypothesis, and that the most free and genuine Con-  
struction of that and all other Mecha-  
nical Hypotheses is conformable to my  
Doctrine.*

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 Aether, which are propagated every way from those bodies in straight 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 *phenomena* I take to be this: *That the agitated parts of bodies, according to their several sizes, figures, and motions, do excite Vibrations in the aether 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 intermedial ones, of intermedial 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 *Phenomena* of *Prismes* 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 *Blew* 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 *phenomena* of those Plates or Bubles, and also of all natural bodies, whose*

whose parts are like to 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 be easily 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,

*S. Of the Animadversor's Concessions, and their limitation to his Hypothesis.*

there

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 *Animadverfor* 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



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

6. That it is not necessary, to limit or explain my Doctrine by any Hypothesis.

needful to explicate my Doctrine by any *Hypothesis* at all. For if *Light* be consider'd abstractedly 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 uneavenly 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

7. The difficulties of the Animadversors discourse abstracted from Hypotheses, and consider'd more generally.

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 *Queres*: L IIII 1. Whe-

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?

3. That the Ray is not split, or any otherwise dilated.

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 Prisms successively, to destroy thereby the *Regular effects* of the *first* Prism by the *second*, and to discover the *Irregular effects* by augmenting them with iterated refractions. Now, amongst other Irregularities, if the *first* Prism had spread and dissipated every ray into an indefinite 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 completely 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* Prism in a position Transverse to the *first*, on design to try, if it would make the long Image become four-square by refractions crossing those that had drawn the round Image into a long one. For, if amongst other Irregularities the Refraction of the *first* Prism, did by Splitting dilate

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 being as regularly Oblong as before, and inclin'd to both the Prismes at an angle of 45. degrees.

I tryed also all other Positions of 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 inclin'd 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* Quæ-  
re, the *Animadverfor* refers to an  
Experiment made with two

9. That there are more than two Original Colors.

*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

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 only various degrees and dilutings of the same Colour, and not 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 *Nepbritick 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 *Orenge*. 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.

But

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 for 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'd 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 Prime, 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 is it *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.

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*, *Blew*, 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.

10. That *Whiteness* is a mixture of all Colours.

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 *Animadverser* 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  
the

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 concurrence 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 concurrence exhibit colours, do in the concurrence 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 concurrence, 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 Blew 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 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 it self, without any new unequal impressions, depart into a great variety of motions regularly unequal. 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 coggs 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 concurrence

of the colours, one half of the Colours may be intercepted by a spoake or cogg, 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 concurrence; 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 spoaks or coggs 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 concurrence 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 Experiment



ment. But this, I conceive, is enough to enforce it, and so to decide the controversy. However, I shall now proceed to shew some other ways of producing *Whiteness* by mixtures, since I persuade myself, 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 Aggregate of them will be much weakened 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 Sun's 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 threds, 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 distinguished 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-

tribution of diversly colour'd rays ; such as ought to be caus'd by Reflexion from a Mixture of white and black, or of diversly colour'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 caus'd in *Sounds* of the same tone by irregular and uneven jar-rings. 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 confus'dly on the paper, I see no reason to doubt of ; because, if the Light became Uniform and Similar before it fell confus'dly 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 polish'd piece of Metal be so plac'd, 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.

But

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 *Phenomena* 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

I have describ'd 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 Prisms upon the same place; by Refracting a Beam of Light with two or three Prisms 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 ways distated.

In the Considerations of my first and second Propositions, the *Animadverfor* hath rendred 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.

12. Some particulars recommended to further consideration.

#### An Account of two Books.

I. *Otonis de Guericke EXPERIMENTA NOVA MAGDEBURGICA, de VACUO SPATIO, &c.* Amstelodami A. 1672. in fol.

AFTER that the famous Author of this Book hath made a Narrative of the chief *Hypotheses* and Opinions of both Antient and Recent Astronomers concerning the Systeme of the world, and represented the great difficulties in the *Ptolemaique* and *Tychonique*, and repeated the Answers to the Objections against the *Copernican*; he at large gives us his own Thoughts of the Frame and Constitution of the *World*; By which *World* he understands in this Treatise the Complex of the Planets, disposed and order'd much after the *Copernican* way; the *Sun* being seated in the midst, having his Spots about him, and moving and influencing all the rest of the Planets according to their several distances from him; *Saturn* making the utmost of all the Planets, and the End of this his World being there, where the diffusive power and vertue of the Sun; the King and Governor of them all, terminates; which bounds he conjectures to extend themselves, beyond *Saturn*, to those Fixt Stars that are of the nearer rank to *Saturns* Orbe.

Concerning the Bodies lodged in these Planets, he thinks it consonant to the Power and Wisdom of the Great Creator, that there should be such a variety of them, as to stock each of the said Planets,