Draft of 'A Theory Concerning Light and Colors'

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Sir

To perform my late promise to you, I shall without further ceremony acquaint you, that in the beginning of the year 1666 (at which time I applyed my self to the grinding of Optick glasses of other figures then Sphericall) I procured me a triangular glasse Prisme to try therewith the celebrated phænomena of colours. And in order thereto having darkned my chamber & made a small hole in my window-shuts to let in a convenient quantity of the sun's light, I placed my Prism at its entrance that it might be thereby refracted to the opposite wall. It was at first a very pleasing divertisement to view the vivid & intense colours produced thereby; but after a while applying my selfe to consider them more circumspectly, I became surprized to see them in an oblong form, which according to the received lawes of refraction I expected should have been circular.

They were terminated at the sides with streight lines, but at the ends the decay of light was so graduall that it was difficult to determine justly what was their figure, yet they seemed semicircular.

Comparing the length of this Coloured Spectrum with its bredth I found it about five times greater, a disproportion soe extravagant that it excited me to a more then ordinary curiosity of examining from whence it might proceed; I could scarce think that the various thicknesse of the glasse, or the termination with shaddow or darknesse could have any influence on light to produce such an effect, yet I thought it not amisse to examine first those circumstances, & soe tryed what would happen by transmitting light through parts of the glasse of divers thicknesses, or through holes in the window of divers bignesses, or by setting the Prism without, so that the light might passe through it & bee refracted before it was terminated by the hole: but I found none of those circumstances materiall. The fashion of the colours was in all these cases the same.

Then I suspected whither by any unnevenesse in the glass or other contingent irregularity these colours might be thus dilated. And to try this I took another prism like the former & soe placed it that the light passing through them both might be refracted contrary wayes & so by the latter <460v> returned into that course from which the former had diverted it. ffor by this meanes I thought the regular effects of the first Prism would be destroyed by the sceond Prism, but the irregular ones more augmented by the multiplicity of refractions. The event was that the light which by the first Prism was diffused into an oblong form was by the second reduced into an orbicular one with as much regularity as when it did not at all passe through them. So that what ever was the cause of that length 'twas not any contingent irregularity.

I then proceded to examine more critically what might be effected by the difference of the incidence of rayes comming from divers parts of the Sun, & to that end measured the severall lines & angles belonging to the image. Its distance from the hole or Prism was 22 foot, its utmost length 13$\frac{1}{4}$ inches, its breadth 2$\frac{5}{8}$ inches,

the diameter of the hole $\frac{1}{4}$ of an inch, the angle which the rayes tending towards the midle of the image made with those lines in which they would have proceeded without refraction 44 degr. 56'. And the verticall angle of the Prism 63 ^{degr} 12'. Also the refractions on both sides the Prism, that is of the incident & emergent rayes were as near as I could make them, equall, & consequently about 54 ^{degr} 4'. And the rayes fell perpendicularly upon the wall. Now subducting the diameter of the hole from the length & breadth of the image there remains 13 inches the length & $2\frac{3}{8}$ the breadth comprehended by those rayes which passed through the center of the **{**said**}** hole & consequently the angle at the hole which that breadth su**{**bten**}**ded was about 31' answerable to the sun's diameter, but the ang**{**le**}** which its length subtended was more then five such diameters, namely 2 ^{degr} 49'.

Having made these observations I first computed from them the refractive power of that glasse & found it measured by the ratio of the sines 20 to 31. And then by that ratio I computed the refractions of two rayes flowing from opposite parts of the sun's discus, so as to differ 31' in their obliquity of incidence, & found that the emergent rayes should have comprehended an angle of about 31' as they did before they were incident.

But because this computation was founded on the Hypothesis of the proportionality of the Sines of incidence & refraction, which, though by my own & others experience, I could not imagine to be so erroneous as to make that angle but 31' which in reality was 2 ^{degr} 49' yet my curiosity caused me again to take my Prism. And having placed it at my window as before I observed that by turning it a little about its axis to & fro, so as to vary its obliquity to the light more then by an angle of 4 or 5 degrees, the colours were not thereby sensibly translated from their place on the wall, & consequently by that variation of incidence, the quantity of refraction was not sensibly varied.

<461r>

By this experiment therefore as well as by the former computation it was evident that the difference of the incidence of rayes flowing from divers parts of the Sun, could not make them after decussation diverge at a sensibly greater angle then that at which they before converged. which being at most but about 31. or 32 minutes, there still remained some other cause to be found out from whence it could be 2 ^{degr} 49'.

Then I began to suspect whither the rayes after their trajection through the Prism did not move in curve lines & acording to their more or lesse curvity tend to divers parts of the wall. And it increased my suspicion when I remembred that I had often seen a Tennis-ball struck with an oblique Racket describe such a curve line. for a circular as well as a progressive motion being communicated to it by that stroak, its parts on that side where the motions conspire must presse & beat the contiguous air more violently then on the other, & there excite a reluctancy & reaction of the air proportionally greater. And for the same reason, if the rayes of light should possibly bee globular bodyes & by their oblique passage out of one medium into another acquire a circulating motion, they ought to feel the greater resistance from the ambient Æther on that side where the motions conspire & thence be continually bowed to the other. But notwithstanding this plausible ground of suspicion when I came to examine it I could observe noe such curvity in them. And besides (which was enough for my purpose) I observed that the difference betwixt the length of the image & diameter of the hole through which the light was transmitted, was proportionable to their distance.

The graduall removall of these suspicions at length led me to the experimentum crucis; which was this. I took two boards, & placed one of them close behind the Prism at the window, so that the light might passe through a small hole made in it for that purpose & fall on the other board which I placed at about twelve foot distance, having first made a small hole in it also for some of that incident light to passe through. Then I placed another Prism behind this second board so that the light trajected through both the boards might passe through that also <461v> & be again refracted before it arrived at the wall. This done, I took the first Prism in my hand & turned it to & fro slowly about its axis so much as to make the severall parts of the image cast on the second board, successively passe through the hole in it, that I might observe to what places on the wall the second Prism would refract them. And I saw by the variation of those places, that the light tending to that end of the image towards which the refraction of the first Prism was made, did in the second Prism suffer a refraction considerably greater then the light tending to the other end. And soe the true cause of the length of that image was detected to be noe other then that light consists of rayes differently refrangible which without any respect

to a difference in their incidence were according to their degrees of refrangibility transmitted towards diverse parts of the wall.

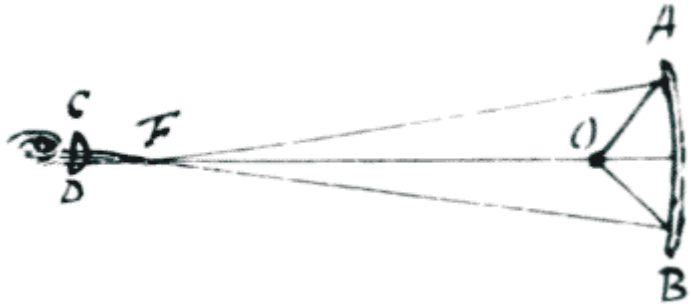
When I understood this, I left of my aforesaid glassworkes, for I saw that the perfection of Telescopes was hitherto limited, not so much for want of glasses truly figured according to the prescriptions of Optick Authors, which all men have hitherto imagined, as because that light it selfe is a heterogeneous mixture of differently refrangible rayes. So that were a Glasse so exactly figured as to collect any one sort of rayes into one point, it could not collect those also int{o} the same point which having the same incidence upon the same medium are apt to suffer a different refraction. I wondered that seing the difference of refrangibility was soe great as I found it, Telescopes should arrive to that perfection thay are now at. ffor measuring the refractions in one of my Prisms I found that supposing the common sine of incidence upon one of its planes was 44 parts, the sine of refraction of the utmost rayes on the red end of the colours made out of the glasse into the air would be 68 parts, & the sine of refraction of the utmost rayes on the other end 69 parts. So that the difference is about a 24^{th} or 25^{t} part of the whole refraction. And consequently the objectglasse of any Telescope cannot collect all the rayes which come from one point of an object, so as to make them convene at its focus in lesse room then in a circular space whose diameter is the part of the diameter of its spectrum. <462r> which is an irregularity some hundreds of times greater then a circularly figured lens, of so small a section as the objectglasses of long Telescopes are, would cause by the unfitnesse of its figure, were light uniform.

This made me take reflections into consideration; & finding them regular, so that the angle of reflection of all sorts of rayes was equall to their angle of incidence I understood that by their mediation Optick instruments might be brought to any degree of perfection imaginable provided a reflecting substance could be found which would polish as finely as glasse, & reflect as much light as glasse transmitts, & the art of communicating to it a Parabolick figure bee also attained. But those seemed very great difficulties, & I almost thought them insuperable when I further considered that every irregularity in a reflecting superficies makes the rayes stray 5 or 6 times more out of their due course then the like irregularities in a refracting one. So that a much greater curiosity would be here requisite then in figuring glasses for refraction.

Amidst these thoughts I was forced from Cambridge by the intervening Plague & it was more then two years before I proceeded further. But then having thought on a tender way of polishing proper for mettall, wherby as I imagined the figure also would be corrected to the last, I began to try what might be effected in this kind, & by degrees so far perfected an instrument (in the essential parts of it like that I sent to London) by which I could discern Iupiters four concomitants, & showed them divers times to two others of my acquaintance. I could also discern the moon-like phase of Venus, but not very distinctly nor without some nicenesse in disposing the instrument.

ffrom that time I was interrupted till this last Autumn, when I made the other. And as that was sensibly better then the first, (especially for day Objects) so I doubt not but they will be still brought to a much greater perfection by their endeavours who as you inform me are taking care about it at London.

I have sometimes thought to make a microscope which in like manner should have instead of an objectglasse a relecting piece of metall. And this I hope they will also take into consideration <462v> For those instruments seem as capable of improvement as Telescopes, & perhaps more because but one reflective peice of metall is requisite in them, as you may perceive by the annexed diagram where A B representeth the object metall, C D the eyeglasse, F their common focus, & O the other focus of the metall in which the object is placed. But to return from this digression, I told you that light is not similar or homogeneall but consists of difform rayes, some of which are more refrangible then others. So that of those which are alike incident on the same medium, some shall be more refracted then others, & that not by any virtue of the glasse or other externall cause, but from a predisposition which every particular ray hath to suffer a particular degree of refraction. I shall now proceed to acquaint you with another more notable difformity in its rayes wherin the origen of colours is infolded. A naturalist would scarce expect to see the science of those become mathematicall, & yet I dare affirm that there is as much



certainty in it as in any other part of Opticks. ffor what I shall tell concerning them is not an Hypoth{esis} but most rigid consequence, not conjectured by barely infer{ring} 'tis thus because not otherwise or because it satisfies all phænomena (the Philosophers universall Topick,) but evinced by the mediation of experiments concluding directly & without any suspicion of doubt. To continue the historicall narration of these experiments would make a discourse too tedious & confused, & therefore I shall rather lay down the doctrine first, & then for its examination give you an instance or two of the experiments as a Specimen of the rest.

The Doctrine you will find comprehended & illustrated in the following propositions.

1. As the rayes of light differ in degrees of refrangibility, so they also differ in their disposition to exhibit this or that particular colour. Colours are not qualifications of light derived from refractions or reflections of naturall bodies as 'tis generally beleived, but originall & connate properties, which in diverse rayes are divers, some rayes are disposed to exhibit a red colour & noe other, <463r> some a yellow & noe other, some a green & noe other & so of the rest. Nor are there only rayes proper & peculiar to the more eminent colours, but even to all their intermediate gradations.

2. To the same degree of refrangibility ever belongs the same colour, & to the same colour ever belongs the same degree of refrangibility. The least-refrangible rayes are all disposed to exhibit a red colour & contrarily those rayes which are disposed to exhibit a red colour are all the least refrangible. So the most refrangible rayes are all disposed to exhibit a deep violett colour & contrarily those which are apt to exhibit such a violet colour are all the most refrangible. And so to all the intermediate colours in a continued series belong intermediate degrees of refrangibility. And this Analogy 'twixt colours & refrangibility is very precise & strict: the rayes always either exactly agreeing in both or proportionally disagreeing in both.

3. The Species of colour & degree of refrangibility proper to any particular sort of rayes, is not mutable by refraction, nor by reflection from naturall bodies, nor by any other cause that I could yet observe. When any one sort of rayes hath been well parted from those of other kinds it hath afterwards obstinately retained its colour notwithstanding my utmost endeavours to chang it. I have refracted it with Prismes, & reflected it with bodies which in day light were of other colours; I have intercepted it with the coloured film of air interceding two compressed plates of Glasse, transmitted it through coloured mediums & through mediums irradiated with other sort of rayes, & diversly terminated it, & yet could not produce any new colour out of it. It would by contracting or dilating become more brisk or faint, & by the losse of many rayes in some cases very obscure & dark, but I could never see it changed in Specie.

4 Yet seeming transmutations of colours may be made where there is any mixture of divers sorts of rayes: ffor in such mixtures the component colours appear not, but by their mutuall allaying each other constitute a midling colour. And therefore if by refraction <463v> or any other of the aforesaid causes the difform rayes latent in such a mixture bee seperated, there shall emerge colours different from the colour of the composition. Which colours are not new generated but only made apparent by being parted. ffor if they be again intirely mixed & blended together, they will again compose that colour which they did before seperation. And for the same reason transmutations made by the convening of divers colours are not reall; for when the difform rayes are again severed they will exhibit the very same colours which they did before they entered the composition. As you see blew & yellow powders when finely mixed appear to the naked eye green & yet the colours of the component corpuscles are not thereby really transmuted, but only blended. ffor when veiwed with a good Microscope they still appear blew & yellow interspersedly.

5 There are therefore two sorts of colours. The one originall & simple; the other compounded of these. The originall or primary colours are Red, yellow, Green, Blew, & a violet purple; together with Orang, Indico, & an indefinite varietie of intemediate gradations.

6 The same colours in Specie with these primary ones may be also produced by composition: ffor a mixture of yellow & blew makes green, of red & yellow makes Orang of Orang & yellowish green makes yellow. And in generall if any two colours be mixed, which in the series of those generated by the Prism are not too far distant one from another, they by their mutuall alloy compound that colour which in the said series appeareth in the midway between them. But those which are situated at too great a distance doe not soe. Orang & Indico produce not the intermediate green, nor Scarlet & green the intermediate yellow.

7 But the most surprizing & wonderfull composition was that of whitenesse. There is noe one sort of rayes which alone can exhibit this. Tis ever compounded & to its composition are requisite all the aforesaid primary colours mixed in a due proportion. I have often with admiration beheld that all the colours of the Prism being made <464r> made to converge & thereby to be again mixed as they were in the light before it was incident upon the Prism, reproduced light intirely & perfectly white, & not at all sensibly differing from the direct light of the sun; unlesse when the glasses I used were not sufficiently clear, for then they would a little incline it to their colour.

8. Hence therefore it comes to passe that whitenesse is the usuall colour of light: ffor light is a confused agregate of rayes indued with all sorts of colours as they are promiscuously darted from the various parts of luminous bodies. And of such a confused agregate as I said is generated whitenesse if there be a due proportion of the ingredients; But if any one predominate, the light must incline to that colour as it happens in the blew flame of Brimstone, the yellow flame of a candle & the various colours of the fixt starrs.

9. These thinges considered, the manner how colours are produced by the Prism is evident. ffor of the rayes constituting the incident light since those which differ in colour proportionally differ in refrangibility, they by their unequall refractions must be severed & dispersed into an oblong form in an orderly succession from the least refracted scarlet to the most refracted violet. And for the same reason it is that objects when looked upon through a Prism appear coloured. ffor the difform rayes by their unequall refractions are made to diverge toward severall parts of the Retina & there expresse the images of thinges coloured as in the former case they did the sun's image upon a wall. And by this inequality of refractions they become not only coloured but also very confused & indistinct.

10 Why the colours of the rainbow appear in falling drops of rain is also from hence evident. ffor those drops which refract the rayes disposed to appear purple in greatest quantity to the Spectators eye, refract the rayes of other sorts soe much lesse as to make them passe beside it; & such are the dropes in the inside of the primary Bow & on the outside of the second or exterior one. <464v> So those drops which refract in greatest plenty the rayes apt to appear red toward the Spectators eye, refract those of other sorts soe much more as to make them passe beside it, & such are the drops on the exterior part of the Primary & interior part of the secondary Bow.

11. The odd Phænomena of an infusion of Lignum Nephriticum, leaf-Gold, fragments of coloured glasse, & some other transparently coloured bodies appearing in one position of one colour, & of another in another are on these grounds noe longer riddles. ffor those are substances apt to reflect one sort of light & transmit another; as may be seen in a dark Room by illuminating them with similar or uncompounded light. ffor then they appear of that colour only with which they are illuminated, but yet in one position more vivid & luminous then in another, accordingly as they are disposed more or lesse to reflect or transmit the incident colour.

12 ffrom hence also is manifest the reason of an unexpected experiment which M^{r} Hook somewhere in his Micrographia relates to have made with two Wedg-like transparent vessells filled the one with a red, the other with a blew liquor: Namely that though they were severally transparent enough yet both together became opake. ffor if one transmitted only red & the other only blew, no rayes could passe through both.

13 I might add more instances of this nature, but I shall conclude with this generall one, that the colours of all naturall bodies have noe other origin then this, that they are variously qualified to reflect one sort of light in greater plenty then another. And this I have experimented in a dark Room by illuminating those bodies with uncompounded light of divers colours. ffor by that means any bodie may be made to appear of any colour. They have there noe appropriate colour but ever appear of the colour cast upon them, but yet with this difference that they are most brisk & vivid in the light of their own day-light-colour. Minium appeareth there of any <465r> colour indifferently with which 'tis illustrated, but yet most luminous in red; & so Bise appeareth indifferently of any colour with which 'tis illustrated, but yet most luminous in blew. And therefore Minium reflecteth rayes of any colour, but most copiously those endowed with red; & consequently when illustrated with day-light, that is with all sorts of rayes promiscuously blended, those qualified with red shall abound most in the reflected light, & by their prevalence cause it to appear of that colour. And for the same reason Bise reflecting blew most copiously, shall appear blew by the excesse of those rayes in its reflected light; & the like of other bodies. And that this is the intire & adequate cause of their colours is manifest,

because they have noe power to change or alter the colour of any sort of rays incident apart, but put on all colours indifferently with which they are enlightened.

These thinges being so, it can be no longer disputed whither there be colours in the dark, nor whither they be the qualityes of the objects wee see, no nor perhaps whether light be a bodie. ffor since colours are qualityes of light, having its rayes for their entire & imediate subject, how can wee think those rayes qualityes also, unlesse one quality may be the subject of & sustain another, which in effect is to call it substance. Wee should not know bodies for substances were it not for their sensible qualityes, & the principall of those being now found due to something else, wee have as good reason to beleive that to be a substance also. Besides who ever thought any quality to be a heterogeneous agregate such as light is discovered to be. But to determine more absolutely what light is, after what manner refracted, & by what modes or actions it produceth in our minds the Phantasms of colours, is not so easie. . And I shall not mingle conjectures with certaintyes.

Reviewing what I have written, I see the discours it selfe will lead to divers experiments sufficient <465v> for its examination: And therefore I shall not trouble you farther then to describe one of those which I have already insinuated.

In a darkned Room make a hole in the shutt of a window, whose diameter may conveniently be about a third part of an inch, to admitt a convenient quantity of the Sun's light. And then place a clear & colourlesse Prism to refract the entering light towards the further part of the Room: which as I said will thereby be diffused into an oblong coloured image. Then place a lens of about three foot radius (suppose a broad object-glasse of a three foot Telescope) at the distance of about 4 or 5 foot from thence, through which all those colours may at once be transmitted, & made by its refraction to convene at a further distance of about 10 or 12 foot. If at that distance you intercept this light with a sheet of white paper, you will see the colours converted into whitenesse again by being mingled. But it is requisite that the Prism & lens be placed steddy, & that the paper on which the colours are cast bee moved to & fro; for by such motion you will not only find at what distance the whitenesse is most perfect, but also see how the colours gradually convene & vanish into whitenesse, & afterwards having crossed one another in that place where they compound whitenesse, are again dissipated & severed & in an inverted order retain the same colours which they had before they entered the composition. You may also see that if any of the colours at the lens be intercepted, the whitenesse will be changed into the other colours. And therefore that the composition of whitenesse be perfect, care must be taken that none of the colours fall beside the lens.

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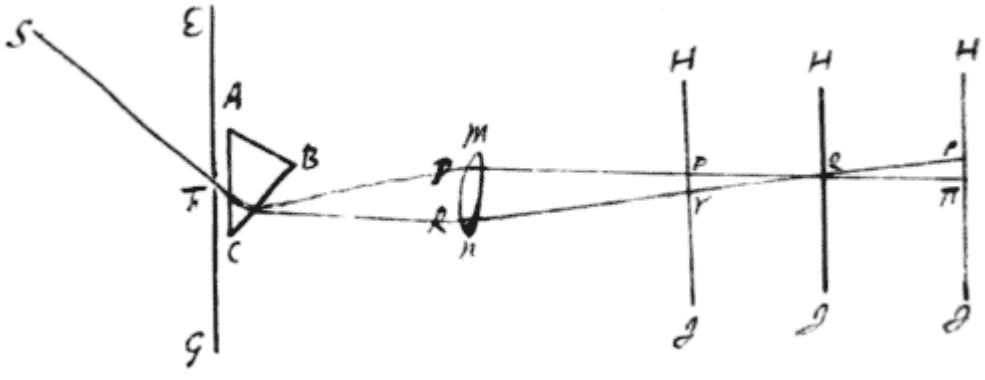
In the annexed designe of this experiment A B C representeth the Prism set endwise to sight, close by the



hole F of the window E G. Its vertical angle A C B may conveniently be about 60 degrees. M N designes the lens. Its breadth $2\frac{1}{2}$ or 3 inches. S F one of the streight lines in which difform rayes may be conceived to flow successively from the Sun. F P & F R two of those rayes unequally refracted, which the Lens makes to converg towards Q, & after decussation to diverge again. And H I the paper at divers distances on which the colours are projected: which in Q constitute whitenesse, but are red & yellow in R, r, & ρ; & blew & purple in P, p & π.

If you proceed further to try the impossibility of changing any uncompounded colour, which I have asserted in the 3^{d} and 13th propositions; 'tis requisite that the Room be made very dark, least any scattering light mixing with the colour, disturb & allay it & render it compound, contrary to the design of the experiment 'Tis also requisite that there be a perfecter seperation of the colours then after the manner above described can be made by the refraction of one single Prism; & how to make such further seperations will scarce be difficult to them that consider the discovered lawes of refractions. But if tryall shall be made with colours not throughly

seperated there must be allowed changes proportionable <466v> to the mixture. Thus if compound yellow light fall upon blew Bise, the Bise will not appear perfectly yellow, but rather green, because there are in the yellow mixture many rayes indued with green, & green being lesse remote from the usuall blew colour of Bise then yellow, is more copiously reflected by it.

In like manner if any of the Prismatick colours, suppose Red, be intercepted on design to try the asserted impossibility of reproducing that colour out of the others which are pretermitted 'tis necessary either that the colours be very well parted before the red be intercepted, or that together with the red the neighbouring colours into which any red is secretly dispersed (that is the yellow & perhaps green too) bee intercepted, or else that allowance be made for the emerging of so much red out of the yellow & green as may possibly have been diffused & scattering**{**ly**}** blended in those colours. And if these thinges be observed the new production of Red or any intercepted colour will be found impossible.

This I conceive is enough for an introduction to experiments of this kind; which if any of the R Society shall be so curious as to prosecute, I should be very glad to be informed with what successe. That if any thing seem to be defective or to thwart this relation, I may have an opportunity of giving further direction about it, or of acknowledging my errors if I have committed any.

Your humble servant

Isaac Newton