OPTICKS

OR

A Treatise of the Reflections, Refractions, Inflections & Colours of Light

SIR ISAAC NEWTON

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frangible Rays which fall upon the Base beyond *p*, that is, between *p* and B, and can by Reflexion come from thence to the Eye, will be reflected thither, but every where between *p* and *c*, many of these Rays will get through the Base, and be refracted; and the same is to be understood of the meanly refrangible Rays on either side of the Point *r*. Whence it follows, that the Base of the Prism must every where between *t* and B, by a total Reflexion of all sorts of Rays to the Eye, look white and bright. And every where between *p* and C, by reason of the Transmission of many Rays of every sort, look more pale, obscure, and dark. But at *r*, and in other Places between *p* and *t*, where all the more refrangible Rays are reflected to the Eye, and many of the less refrangible are transmitted, the Excess of the most refrangible in the reflected Light will tinge that Light with their Colour, which is violet and blue. And this happens by taking the Line C *prt* B any where between the Ends of the Prism HG and EI.

PROP. IX. PROB. IV.

By the discovered Properties of Light to explain the Colours of the Rain-bow.

THIS Bow never appears, but where it rains in the Sun-shine, and may be made artificially by spouting up Water which may break aloft, and scatter into Drops, and fall down like Rain. For the

Sun shining upon these Drops certainly causes the Bow to appear to a Spectator standing in a due Position to the Rain and Sun. And hence it is now agreed upon, that this Bow is made by Refraction of the Sun's Light in drops of falling Rain. This was understood by some of the Antients, and of late more fully discover'd and explain'd by the famous *Antonius de Dominis* Archbishop of *Spalato*, in his book *De Radiis Visûs & Lucis*, published by his Friend *Bartolus* at *Venice*, in the Year 1611, and written above 20 Years before. For he teaches there how the interior Bow is made in round Drops of Rain by two Refractions of the Sun's Light, and one Reflexion between them, and the exterior by two Refractions, and two sorts of Reflexions between them in each Drop of Water, and proves his Explications by Experiments made with a Phial full of Water, and with Globes of Glass filled with Water, and placed in the Sun to make the Colours of the two Bows appear in them. The same Explication *Des-Cartes* hath pursued in his Meteors, and mended that of the exterior Bow. But whilst they understood not the true Origin of Colours, it's necessary to pursue it here a little farther. For understanding therefore how the Bow is made, let a Drop of Rain, or any other spherical transparent Body be represented by the Sphere BNFG, [in *Fig.* 14.] described with the Center C, and Semi-diameter CN. And let AN be one of the Sun's Rays incident upon it at N, and thence refracted to F, where let it either go out of the Sphere by Refraction towards V, or be reflected to G; and at G let it either go out by Re-

fraction to R, or be reflected to H; and at H let it go out by Refraction towards S, cutting the incident Ray in Y. Produce AN and RG, till they meet in X, and upon AX and NF, let fall the Perpendiculars CD and CE, and produce CD till it fall upon the

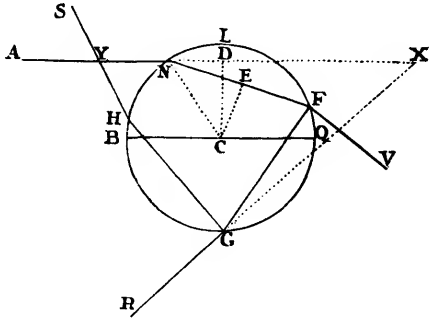

FIG. 14.

Circumference at L. Parallel to the incident Ray AN draw the Diameter BQ, and let the Sine of Incidence out of Air into Water be to the Sine of Refraction as I to R. Now, if you suppose the Point of Incidence N to move from the Point B, continually till it come to L, the Arch QF will first increase and then decrease, and so will the Angle AXR which the Rays AN and GR contain; and the Arch QF and Angle AXR will be biggest when ND is to CN as $\sqrt{II - RR}$ to $\sqrt{3}RR$, in which case NE will be to ND as 2R to I. Also the Angle AYS, which the Rays AN and HS contain will first decrease, and then increase and grow least when ND is to CN as $\sqrt{II - RR}$ to $\sqrt{8}RR$,

in which case NE will be to ND, as 3R to I. And so the Angle which the next emergent Ray (that is, the emergent Ray after three Reflexions) contains with the incident Ray AN will come to its Limit when ND is to CN as $\sqrt{\text{II} - \text{RR}}$ to $\sqrt{15}$RR, in which case NE will be to ND as 4R to I. And the Angle which the Ray next after that Emergent, that is, the Ray emergent after four Reflexions, contains with the Incident, will come to its Limit, when ND is to CN as $\sqrt{\text{II} - \text{RR}}$ to $\sqrt{24}$RR, in which case NE will be to ND as 5R to I; and so on infinitely, the Numbers 3, 8, 15, 24, *&c.* being gather'd by continual Addition of the Terms of the arithmetical Progression 3, 5, 7, 9, *&c.* The Truth of all this Mathematicians will easily examine.*

Now it is to be observed, that as when the Sun comes to his Tropicks, Days increase and decrease but a very little for a great while together; so when by increasing the distance CD, these Angles come to their Limits, they vary their quantity but very little for some time together, and therefore a far greater number of the Rays which fall upon all the Points N in the Quadrant BL, shall emerge in the Limits of these Angles, than in any other Inclinations. And farther it is to be observed, that the Rays which differ in Refrangibility will have different Limits of their Angles of Emergence, and by consequence according to their different Degrees of Refrangibility emerge most copiously in different

* *This is demonstrated in our* Author's Lect. Optic. *Part.* I. *Sect.* IV. *Prop.* 35 *and* 36.

Angles, and being separated from one another appear each in their proper Colours. And what those Angles are may be easily gather'd from the foregoing Theorem by Computation.

For in the least refrangible Rays the Sines I and R (as was found above) are 108 and 81, and thence by Computation the greatest Angle AXR will be found 42 Degrees and 2 Minutes, and the least Angle AYS, 50 Degrees and 57 Minutes. And in the most refrangible Rays the Sines I and R are 109 and 81, and thence by Computation the greatest Angle AXR will be found 40 Degrees and 17 Minutes, and the least Angle AYS 54 Degrees and 7 Minutes.

Suppose now that O [in *Fig.* 15.] is the Spectator's Eye, and OP a Line drawn parallel to the Sun's Rays and let POE, POF, POG, POH, be Angles of 40 Degr. 17 Min. 42 Degr. 2 Min. 50 Degr. 57 Min. and 54 Degr. 7 Min. respectively, and these Angles turned about their common Side OP, shall with their other Sides OE, OF; OG, OH, describe the Verges of two Rain-bows AF, BE and CHDG. For if E, F, G, H, be drops placed any where in the conical Superficies described by OE, OF, OG, OH, and be illuminated by the Sun's Rays SE, SF, SG, SH; the Angle SEO being equal to the Angle POE, or 40 Degr. 17 Min. shall be the greatest Angle in which the most refrangible Rays can after one Reflexion be refracted to the Eye, and therefore all the Drops in the Line OE shall send the most refrangible Rays most copiously to the Eye, and thereby strike the Senses with the deepest violet Colour in that Region.

And in like manner the Angle SFO being equal to the Angle POF, or 42 Degr. 2 Min. shall be the greatest in which the least refrangible Rays after one Reflexion can emerge out of the Drops, and therefore those Rays shall come most copiously to the Eye

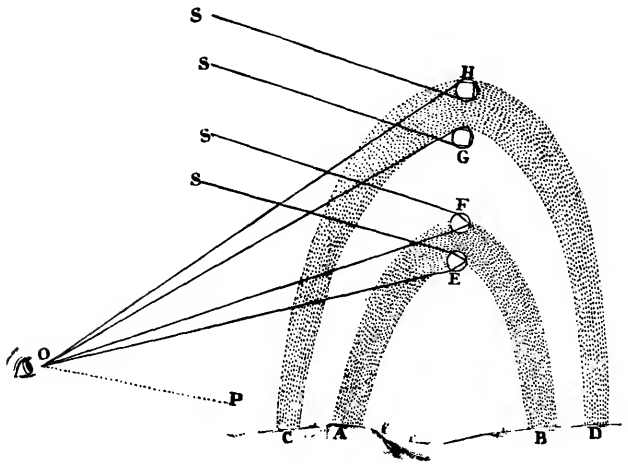

FIG. 15.

from the Drops in the Line OF, and strike the Senses with the deepest red Colour in that Region. And by the same Argument, the Rays which have intermediate Degrees of Refrangibility shall come most copiously from Drops between E and F, and strike the Senses with the intermediate Colours, in the Order which their Degrees of Refrangibility require, that is in the Progress from E to F, or from the inside of the Bow to the outside in this order, violet, indigo,

blue, green, yellow, orange, red. But the violet, by the mixture of the white Light of the Clouds, will appear faint and incline to purple.

Again, the Angle SGO being equal to the Angle POG, or 50 Gr. 51 Min. shall be the least Angle in which the least refrangible Rays can after two Reflexions emerge out of the Drops, and therefore the least refrangible Rays shall come most copiously to the Eye from the Drops in the Line OG, and strike the Sense with the deepest red in that Region. And the Angle SHO being equal to the Angle POH, or 54 Gr. 7 Min. shall be the least Angle, in which the most refrangible Rays after two Reflexions can emerge out of the Drops; and therefore those Rays shall come most copiously to the Eye from the Drops in the Line OH, and strike the Senses with the deepest violet in that Region. And by the same Argument, the Drops in the Regions between G and H shall strike the Sense with the intermediate Colours in the Order which their Degrees of Refrangibility require, that is, in the Progress from G to H, or from the inside of the Bow to the outside in this order, red, orange, yellow, green, blue, indigo, violet. And since these four Lines OE, OF, OG, OH, may be situated any where in the above-mention'd conical Superficies; what is said of the Drops and Colours in these Lines is to be understood of the Drops and Colours every where in those Superficies.

Thus shall there be made two Bows of Colours, an interior and stronger, by one Reflexion in the Drops, and an exterior and fainter by two; for the Light be-

comes fainter by every Reflexion. And their Colours shall lie in a contrary Order to one another, the red of both Bows bordering upon the Space GF, which is between the Bows. The Breadth of the interior Bow EOF measured cross the Colours shall be 1 Degr. 45 Min. and the Breadth of the exterior GOH shall be 3 Degr. 10 Min. and the distance between them GOF shall be 8 Gr. 15 Min. the greatest Semi-diameter of the innermost, that is, the Angle POF being 42 Gr. 2 Min. and the least Semi-diameter of the outermost POG, being 50 Gr. 57 Min. These are the Measures of the Bows, as they would be were the Sun but a Point; for by the Breadth of his Body, the Breadth of the Bows will be increased, and their Distance decreased by half a Degree, and so the breadth of the interior Iris will be 2 Degr. 15 Min. that of the exterior 3 Degr. 40 Min. their distance 8 Degr. 25 Min. the greatest Semi-diameter of the interior Bow 42 Degr. 17 Min. and the least of the exterior 50 Degr. 42 Min. And such are the Dimensions of the Bows in the Heavens found to be very nearly, when their Colours appear strong and perfect. For once, by such means as I then had, I measured the greatest Semi-diameter of the interior Iris about 42 Degrees, and the breadth of the red, yellow and green in that Iris 63 or 64 Minutes, besides the outmost faint red obscured by the brightness of the Clouds, for which we may allow 3 or 4 Minutes more. The breadth of the blue was about 40 Minutes more besides the violet, which was so much obscured by the brightness of the Clouds, that

I could not measure its breadth. But supposing the breadth of the blue and violet together to equal that of the red, yellow and green together, the whole breadth of this Iris will be about $2\frac{1}{4}$ Degrees, as above. The least distance between this Iris and the exterior Iris was about 8 Degrees and 30 Minutes. The exterior Iris was broader than the interior, but so faint, especially on the blue side, that I could not measure its breadth distinctly. At another time when both Bows appeared more distinct, I measured the breadth of the interior Iris 2 Gr. 10′, and the breadth of the red, yellow and green in the exterior Iris, was to the breadth of the same Colours in the interior as 3 to 2.

This Explication of the Rain-bow is yet farther confirmed by the known Experiment (made by *Antonius de Dominis* and *Des-Cartes*) of hanging up any where in the Sun-shine a Glass Globe filled with Water, and viewing it in such a posture, that the Rays which come from the Globe to the Eye may contain with the Sun's Rays an Angle of either 42 or 50 Degrees. For if the Angle be about 42 or 43 Degrees, the Spectator (suppose at O) shall see a full red Colour in that side of the Globe opposed to the Sun as 'tis represented at F, and if that Angle become less (suppose by depressing the Globe to E) there will appear other Colours, yellow, green and blue successive in the same side of the Globe. But if the Angle be made about 50 Degrees (suppose by lifting up the Globe to G) there will appear a red Colour in that side of the Globe towards the Sun,

and if the Angle be made greater (suppose by lifting up the Globe to H) the red will turn successively to the other Colours, yellow, green and blue. The same thing I have tried, by letting a Globe rest, and raising or depressing the Eye, or otherwise moving it to make the Angle of a just magnitude.

I have heard it represented, that if the Light of a Candle be refracted by a Prism to the Eye; when the blue Colour falls upon the Eye, the Spectator shall see red in the Prism, and when the red falls upon the Eye he shall see blue; and if this were certain, the Colours of the Globe and Rain-bow ought to appear in a contrary order to what we find. But the Colours of the Candle being very faint, the mistake seems to arise from the difficulty of discerning what Colours fall on the Eye. For, on the contrary, I have sometimes had occasion to observe in the Sun's Light refracted by a Prism, that the Spectator always sees that Colour in the Prism which falls upon his Eye. And the same I have found true also in Candle-light. For when the Prism is moved slowly from the Line which is drawn directly from the Candle to the Eye, the red appears first in the Prism and then the blue, and therefore each of them is seen when it falls upon the Eye. For the red passes over the Eye first, and then the blue.

The Light which comes through drops of Rain by two Refractions without any Reflexion, ought to appear strongest at the distance of about 26 Degrees from the Sun, and to decay gradually both ways as the distance from him increases and decreases. And

the same is to be understood of Light transmitted through spherical Hail-stones. And if the Hail be a little flatted, as it often is, the Light transmitted may grow so strong at a little less distance than that of 26 Degrees, as to form a Halo about the Sun or Moon; which Halo, as often as the Hail-stones are duly figured may be colour'd, and then it must be red within by the least refrangible Rays, and blue without by the most refrangible ones, especially if the Hail-stones have opake Globules of Snow in their center to intercept the Light within the Halo (as *Hugenius* has observ'd) and make the inside thereof more distinctly defined than it would otherwise be. For such Hail-stones, though spherical, by terminating the Light by the Snow, may make a Halo red within and colourless without, and darker in the red than without, as Halos used to be. For of those Rays which pass close by the Snow the Rubriform will be least refracted, and so come to the Eye in the directest Lines.

The Light which passes through a drop of Rain after two Refractions, and three or more Reflexions, is scarce strong enough to cause a sensible Bow; but in those Cylinders of Ice by which *Hugenius* explains the *Parhelia*, it may perhaps be sensible.