The Third Book of Opticks (1718)

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THE THIRD BOOK OF OPTICKS

PART I.

Observations concerning the Inflexions of the Rays of Light, and the Colours made thereby.

GRIMALDO has inform'd us, that if a beam of the Sun's Light be let into a dark Room through a very small hole, the Shadows of things in this Light will be larger than they ought to be if the Rays went on by the Bodies in strait Lines, <293> and that these Shadows have three parallel Fringes, Bands or Ranks of colour'd Light adjacent to them. But if the Hole be enlarged the Fringes grow broad and run into one another, so that they cannot be distinguish'd. These broad Shadows and Fringes have been reckon'd by some to proceed from the ordinary refraction of the Air, but without due examination of the Matter. For the circumstances of the Phænomenon, so far as I have observed them, are as follows.

Obs. I. I made in a piece of Lead a small Hole with a Pin, whose breadth was the 42d part of an Inch, For 21 of those Pins laid together took up the breadth of half an Inch. Through this Hole I let into my darken'd Chamber a beam of the Sun's Light, and found that the Shadows of Hairs, Thred, Pins, Straws, and such like slender Substances placed in this beam of Light, were considerably broader than they ought to be, if the Rays of Light passed on by these Bodies in right Lines. And particularly a Hair of a Man's Head, whose breadth was but the 280th part of an Inch, being held in this Light, at the distance of about twelve Feet from the Hole, did cast a Shadow which at the distance of four Inches from the Hair was the sixtieth part of an Inch broad, that is, above four times broader than the Hair, and at the distance of two Feet from the Hair was about the eight and twentieth part of an Inch broad, that is, ten times broader than the Hair, and at the distance of ten Feet was the eighth part of an Inch broad, that is 35 times broader.

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Nor is it material whether the Hair be encompassed with Air, or with any other pellucid Substance. For I wetted a polish'd Plate of Glass, and laid the Hair in the Water upon the Glass, and then laying another polish'd Plate of Glass upon it, so that the Water might fill up the space between the Glasses, I held them in the aforesaid beam of Light, so that the Light might pass through them perpendicularly, and the Shadow of the Hair was at the same distances as big as before. The Shadows of Scratches made in polish'd Plates of Glass were also much broader than they ought to be, and the Veins in polish'd Plates of Glass did also cast the like broad Shadows. And therefore the great breadth of these Shadows proceeds from some other cause than the Refraction of the Air.

Let the Circle X [in *Fig.* I.] represent the middle of the Hair; ADG, BEH, CFI, three Rays passing by one side of the Hair at several distances; KNQ, LOR, MPS, three other Rays passing by the other side of the Hair at

the like distances; D, E, F, and N, O, P, the places where the Rays are bent in their passage by the Hair; G, H, I, and Q, R, S, the places where the Rays fall on a Paper GQ; IS the breadth of the Shadow of the Hair cast on the Paper, and TI, VS, two Rays passing to the Points I and S without bending when the Hair is taken away. And it's manifest that all the Light between these two Rays TI and VS is bent in passing by the Hair, and turned aside from the Shadow IS, because if any part <295> of this Light were not bent it would fall on the Paper within the Shadow, and there illuminate the Paper, contrary to experience. And because when the Paper is at a great distance from the Hair, the Shadow is broad, and therefore the Rays TI and VS are at a great distance from one another, it follows that the Hair acts upon the Rays of Light at a good distance in their passing by it. But the action is strongest on the Rays which pass by at least distances, and grows weaker and weaker accordingly as the Rays pass by at distances greater and greater, as is represented in the Scheme: For thence it comes to pass, that the Shadow of the Hair is much broader in proportion to the distance of the Paper from the Hair, when the Paper is nearer the Hair, than when it is at a great distance from it.

Obs. 2. The Shadows of all Bodies (Metals, Stones, Glass, Wood, Horn, Ice, *&c.)* in this Light were border'd with three parallel Fringes or Bands of colour'd Light, whereof that which was contiguous to the Shadow was broadest and most luminous, and that which was remotest from it was narrowest, and so faint, as not easily to be visible. It was difficult to distinguish the Colours unless when the Light fell very obliquely upon a smooth Paper, or some other smooth white Body, so as to make them appear much broader than they would otherwise do. And then the Colours were plainly visible in this Order: The first or innermost Fringe was violet and deep blue next the Shadow, and then light blue, green and yellow in the middle, and <296> red without. The second Fringe was almost contiguous to the first, and the third to the second, and both were blue within and yellow and red without, but their Colours were very faint, especially those of the third. The Colours therefore proceeded in this order from the Shadow; violet, indigo, pale blue, green, yellow, red; blue, yellow, red; pale blue, pale yellow and red. The Shadows made by Scratches and Bubbles in polish'd Plates of Glass were border'd with the like Fringes of colour'd Light. And if Plates of Looking-glass sloop'd off near the edges with a Diamond-cut, be held in the same beam of Light, the Light which passes through the parallel Planes of the Glass will be border'd with the like Fringes of Colours where those Planes meet with the Diamond-cut, and by this means there will sometimes appear four or five Fringes of Colours. Let AB, CD [in *Fig.* 2.] represent the parallel Planes of a Looking-glass, and BD the Plane of the Diamond-cut, making at B a very obtuse Angle with the Plane AB. And let all the Light between the Rays ENI and FBM pass directly through the parallel Planes of the Glass, and fall upon the Paper between I and M, and all the Light between the Rays GO and HD be refracted by the oblique Plane of the Diamond-cut BD, and fall upon the Paper between K and L; and the Light which passes directly through the parallel Planes of the Glass, and falls upon the Paper between I and M, will be border'd with three or more Fringes at M.

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So by looking on the Sun through a Feather or black Riband held close to the Eye, several Rain-bows will appear; the Shadows which the Fibres or Threds cast on the *Tunica Retina*, being border'd with the like Fringes of Colours.

Obs. 3. When the Hair was twelve Feet distant from this Hole, and its Shadow fell obliquely upon a flat white Scale of Inches and parts of an Inch placed half a Foot beyond it, and also when the Shadow fell perpendicularly upon the same Scale placed nine Feet beyond it; I measured the breadth of the Shadow and Fringes as accurately as I could, and found them in parts of an Inch as follows.

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At the Distance of	*half a Foot.*	*nine Feet.*
The breadth of the Shadow	$\frac{1}{54}$	$\frac{1}{9}$
The breadth between the Middles of the brightest Light of the innermost Fringes on either side the Shadow	$\frac{1}{38}$ or $\frac{1}{39}$	$\frac{7}{50}$
The breadth between the Middles of the brightest Light of the middlemost Fringes on either side the Shadow	$\frac{1}{23\frac{1}{2}}$	$\frac{4}{17}$

The breadth between the Middles of the brightest Light of the outmost Fringes on either side the Shadow	$\frac{1}{18}$ or $\frac{1}{18\frac{1}{2}}$	$\frac{3}{10}$
The distance between the Middles of the brightest Light of the first and second Fringes	$\frac{1}{120}$	$\frac{1}{21}$
The distance between the Middles of the brightest Light of the second and third Fringes	$\frac{1}{170}$	$\frac{1}{31}$
The breadth of the luminous part (green, white, yellow and red) of the first Fringe	$\frac{1}{170}$	$\frac{1}{32}$
The breadth of the darker Space between the first and second Fringes	$\frac{1}{240}$	$\frac{1}{45}$
The breadth of the luminous part of the second Fringe	$\frac{1}{290}$	$\frac{1}{55}$
The breadth of the darker Space between the second and third Fringes	$\frac{1}{340}$	$\frac{1}{63}$

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These Measures I took by letting the Shadow of the Hair at half a Foot distance fall so obliquely on the Scale as to appear twelve times broader than when it fell perpendicularly on it at the same distance, and setting down in this Table the twelfth part of the Measures I then took.

Obs. 4. When the Shadow and Fringes were cast obliquely upon a smooth white Body, and that Body was removed farther and farther from the Hair, the first Fringe began to appear and look brighter than the rest of the Light at the distance of less than a quarter of an Inch from the Hair, and the dark Line or Shadow between that and the second Fringe began to appear at a less distance from the Hair than that of the third part of an Inch. The second Fringe began to appear at a distance from the Hair of less than half an Inch, and the Shadow between that and the third Fringe at a distance less than an inch, and the third Fringe at a distance less than three Inches. At greater distances they became much more sensible, but kept very nearly the same proportion of their breadths and intervals which they had at their first appearing. For the distance between the middle of the first and middle of the second Fringe, was to the distance between the middle of the second and middle of the third Fringe, as three to two, or ten to seven. And the last of these two distances was equal to the breadth of the bright Light or luminous part of the first Fringe. And this breadth was to the breadth of the bright Light of the second Fringe as seven to <300> four, and to the dark Interval of the first and second Fringe as three to two, and to the like dark Interval between the second and third as two to one. For the breadths of the Fringes seem'd to be in the progression of the Numbers 1, $\sqrt{\frac{1}{3}}$, $\sqrt{\frac{1}{5}}$, and their Intervals to be in the same progression with them; that is, the Fringes and their Intervals together to be in the continual progression of the Numbers 1, $\sqrt{\frac{1}{2}}$, $\sqrt{\frac{1}{3}}$, $\sqrt{\frac{1}{4}}$, $\sqrt{\frac{1}{5}}$, or thereabouts. And these Proportions held the same very nearly at all distances from the Hair; the dark Intervals of the Fringes being as broad in proportion to the breadth of the Fringes at their first appearance as afterwards at great distances from the Hair, though not so dark and distinct.

Obs. 5. The Sun shining into my darken'd Chamber through a hole a quarter of an Inch broad; I placed at the distance of two or three Feet from the Hole a Sheet of Pastboard, which was black'd all over on both sides, and in the middle of it had a Hole about three quarters of an Inch square for the Light to pass through. And behind the Hole I fasten'd to the Pastboard with Pitch the Blade of a sharp Knife, to intercept some part of the Light which passed through the Hole. The Planes of the Pastboard and Blade of the Knife were parallel to one another, and perpendicular to the Rays. And when they were so placed that none of the Sun's Light fell on the Pastboard, but all of it passed through the Hole to the Knife, and there part of it fell upon the Blade of the Knife, and part of it passed by its edge: I let this part of <301> the Light which passed by, fall on a white Paper two or three Feet beyond the Knife, and there saw two streams of faint Light shoot out both ways from the beam of Light into the shadow like the Tails of Comets. But because the Sun's direct Light by its brightness upon the Paper obscured these faint streams, so that I could scarce see them, I made a little hole in the midst of the Paper for that Light to pass through and fall on a black Cloth behind it; and then I saw the two streams plainly. They were like one another, and pretty nearly equal in length and breadth, and quantity of Light. Their Light at that end next the Sun's direct Light was pretty strong for the space of about a quarter

of an Inch, or half an Inch, and in all its progress from that direct Light decreased gradually till it became insensible. The whole length of either of these streams measured upon the Paper at the distance of three Feet from the Knife was about six or eight Inches; so that it subtended an Angle at the edge of the Knife of about 10 or 12, or at most 14 Degrees. Yet sometimes I thought I saw it shoot three or four Degrees farther, but with a Light so very faint that I could scarce perceive it, and suspected it might (in some measure at least) arise from some other cause than the two streams did. For placing my Eye in that Light beyond the end of that stream which was behind the Knife, and looking towards the Knife, I could see a line of Light upon its edge, and that not only when my Eye was in the line of the Streams, but also when it was without that line either towards <302> the point of the Knife, or towards the handle. This line of Light appear'd contiguous to the edge of the Knife, and was narrower than the Light of the innermost Fringe, and narrowest when my Eye was farthest from the direct Light, and therefore seem'd to pass between the Light of that Fringe and the edge of the Knife, and that which passed nearest the edge to be most bent, though not all of it.

Obs. 6. I placed another Knife by this, so that their edges might be parallel, and look towards one another, and that the beam of Light might fall upon both the Knives, and some part of it pass between their edges. And when the distance of their edges was about the 400th part of an Inch the stream parted in the middle, and left a Shadow between the two parts. This Shadow was so black and dark that all the Light which passed between the Knives seem'd to be bent, and turn'd aside to the one hand or to the other. And as the Knives still approached one another the Shadow grew broader, and the Streams shorter at their inward ends which were next the Shadow, until upon the contact of the Knives the whole Light vanish'd, leaving its place to the Shadow.

And hence I gather that the Light which is least bent, and goes to the inward ends of the Streams, passes by the edges of the Knives at the greatest distance, and this distance when the Shadow begins to appear between the Streams, is about the 800 part of an Inch. And the Light which passes by the edges of the Knives at distances still less and less is more and <303> more bent, and goes to those parts of the Streams which are farther and farther from the direct Light, because when the Knives approach one another till they touch, those parts of the Streams vanish last which are farthest from the direct Light.

Obs. 7. In the fifth Observation the Fringes did not appear, but by reason of the breadth of the hole in the Window became so broad as to run into one another, and by joining, to make one continued Light in the beginning of the Streams. But in the sixth, as the Knives approached one another, a little before the Shadow appear'd between the two Streams, the Fringes began to appear on the inner ends of the Streams on either side of the direct Light, three on one side made by the edge of one Knife, and three on the other side made by the edge of the other Knife. They were distinctest when the Knives were placed at the greatest distance from the hole in the Window, and still became more distinct by making the hole less, insomuch that I could sometimes see a faint Lineament of a fourth Fringe beyond the three above mention'd. And as the Knives continually approach'd one another, the Fringes grew distincter and larger until they vanish'd. The outmost Fringe vanish'd first, and the middlemost next, and the innermost last. And after they were all vanish'd, and the line of Light which was in the middle between them was grown very broad, enlarging it self on both sides into the Streams of Light described in the fifth Observation, the above mention'd Shadow be <304> gan to appear in the middle of this line, and divide it along the middle into two lines of Light, and increased until the whole Light vanish'd. This enlargement of the Fringes was so great that the Rays which go to the innermost Fringe seem'd to be bent above twenty times more when this Fringe was ready to vanish, than when one of the Knives was taken away.

And from this and the former Observation compared, I gather, that the Light of the first Fringe passed by the edge of the Knife at a distance greater than the 800th part of an Inch, and the Light of the second Fringe passed by the edge of the Knife at a greater distance than the Light of the first Fringe did, and that of the third at a greater distance than that of the second, and that of the Streams of Light described in the fifth and sixth Observations passed by the edges of the Knives at less distances than that of any of the Fringes.

Obs. 8. I caused the edges of two Knives to be ground truly strait, and pricking their points into a Board so that their edges might look towards one another, and meeting near their points contain a rectilinear Angle, I fasten'd their Handles together with Pitch to make this Angle invariable. The distance of the edges of the Knives from one another at the distance of four Inches from the angular Point, where the edges of the Knives met, was the eighth part of an Inch, and therefore the Angle contain'd by the edges, was about 1 Degree 54'.

The Knives thus fix'd together I placed in a beam <305> of the Sun's Light, let into my darken'd Chamber through a Hole the 42d part of an Inch wide, at the distance of 10 or 15 Feet from the hole, and let the Light which passed between their edges fall very obliquely upon a smooth white Ruler at the distance of half an Inch, or an Inch from the Knives, and there saw the Fringes made by the two edges of the Knives run along the edges of the Shadows of the Knives in Lines parallel to those edges without growing sensibly broader, till they met in Angles equal to the Angle contained by the edges of the Knives, and where they met and joined they ended without crossing one another. But if the Ruler was held at a much greater distance from the Knives, the Fringes where they were farther from the place of their meeting, were a little narrower, and became something broader and broader as they approach'd nearer and nearer to one another, and after they met they cross'd one another, and then became much broader than before.

Whence I gather that the distances at which the Fringes pass by the Knives are not increased nor alter'd by the approach of the Knives, but the Angles in which the Rays are there bent are much increased by that approach; and that the Knife which is nearest any Ray determines which way the Ray shall be bent, and the other Knife increases the bent.

Obs. 9. When the Rays fell very obliquely upon the Ruler at the distance of the third part of an Inch from the Knives, the dark Line between the first and second Fringe of the Sha <306> dow of one Knife, and the dark Line between the first and second Fringe of the Shadow of the other Knife met with one another, at the distance of the fifth part of an Inch from the end of the Light which passed between the Knives at the concourse of their edges. And therefore the distance of the edges of the Knives at the meeting of these dark lines was the 160th part of an Inch. For as four Inches to the eighth part of an Inch, so is any length of the edges of the Knives measured from the point of their concourse to the distance of the edges of the Knives at the end of that length, and so is the fifth part of an Inch to the 160th part. So then the dark Lines above mention'd meet in the middle of the Light which passes between the Knives where they are distant the 160th part of an Inch, and the one half of that Light passes by the edge of one Knife at a distance not greater than the 320th part of an Inch, and falling upon the Paper makes the Fringes of the Shadow of that Knife, and the other half passes by the edge of the other Knife, at a distance not greater than the 320th part of an Inch, and falling upon the Paper makes the Fringes of the Shadow of the other Knife. But if the Paper be held at a distance from the Knives greater than the third part of an Inch, the dark lines above mention'd meet at a greater distance than the fifth part of an Inch from the end of the Light which passed between the Knives at the concourse of their edges; and therefore the Light which falls upon the Paper where those dark lines meet passes between the <307> Knives where their edges are distant above the 160th part of an Inch.

For at another time when the two Knives were distant eight Feet and five Inches from the little hole in the Window, made with a small Pin as above, the Light which fell upon the Paper where the aforesaid dark lines met, passed between the Knives, where the distance between their edges was as in the following Table, when the distance of the Paper from the Knives was also as follows.

Distances of the Paper from the Knives in Inches.	*Distances between the edges of the Knives in millesimal parts of an Inch.*
$1\frac{1}{2}$.	0'012.
$3\frac{1}{3}$.	0'020.
$8\frac{2}{5}$.	0'034.
32.	0'057.
96.	0'081.
131.	0'087.

And hence I gather that the Light which makes the Fringes upon the Paper is not the same Light at all distances of the Paper from the Knives, but when the Paper is held near the Knives, the Fringes are made by

Light which passes by the edges of the Knives at a less distance, and is more bent than when the Paper is held at a greater distance from the Knives.

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Obs. 10. When the Fringes of the Shadows of the Knives fell perpendicularly upon a Paper at a great distance from the Knives, they were in the form of Hyperbolas, and their Dimensions were as follows. Let CA, CB [in *Fig*. 3.] represent lines drawn upon the Paper parallel to the edges of the Knives, and between which all the Light would fall, if it passed between the edges of the Knives without inflexion; DE a right line drawn through C making the Angles ACD, BCE, equal to one another, and terminating all the Light which falls upon the Paper from the point where the edges of the Knives meet; *e i s*, *f k t*, and *g l v*, three hyperbolical lines representing the Terminus of the Shadow of one of the Knives, the dark line between the first and second Fringes of that Shadow, and the dark line between the second and third Fringes of the same Shadow; *x i p*, *y k q* and *z l r*, three other hyperbolical lines representing the Terminus of the Shadow of the other Knife, the dark line between the first and second Fringes of that Shadow, and the dark line between the second and third Fringes of the same Shadow. And conceive that these three Hyperbolas are like and equal to the former three, and cross them in the points *i*, *k* and *l*, and that the Shadows of the Knives are terminated and distinguish'd from the first luminous Fringes by the lines *e i s* and *x i p*, until the meeting and crossing of the Fringes, and then those lines cross the Fringes in the form of dark lines, terminating the first luminous Fringes within side, and distinguishing them from another Light which <309> begins to appear at *i*, and illuminates all the triangular space *ip*DE *s* comprehended by these dark lines, and the right line D E. Of these Hyperbolas one Asymptote is the line DE, and their other Asymptotes are parallel to the lines CA and CB. Let *r v* represent a line drawn any where upon the Paper parallel to the Asymptote DE, and let this line cross the right lines A C in *m*, and BC in *n*, and the six dark hyperbolical lines in *p, q, r*; *s, t, v*; and by measuring the distances *p s*, *q t*, *r v*, and thence collecting the lengths of the Ordinates *n p*, *n q*, *nr* or *m s*, *m t*, *m v*, and doing this at several distances of the line *r v* from the Asymptote DD, you may find as many points of these Hyperbolas as you please, and thereby know that these curve lines are Hyperbolas differing little from the conical Hyperbola. And by measuring the lines C *i*, C *k*, C *l*, you may find other points of these Curves.

For instance, when the Knives were distant from the hole in the Window ten Feet, and the Paper from the Knives nine Feet, and the Angle contained by the edges of the Knives to which the Angle A C B is equal, was subtended by a Chord which was to the Radius as 1 to 32, and the distance of the line *r v* from the Asymptote DE was half an Inch: I measured the lines *ps*, *qt*, *rv*, and found them 0'35, 0'65, 0'98 Inches respectively, and by adding to their halfs the line $\frac{1}{2}$ *mn*, (which here was the 128th part of an Inch, or 0'0078 Inches) the Sums *np*, *nq*, *nr*, were 0'1828, 0'3328, 0'4978 Inches. I measured also the distances of the <310> brightest parts of the Fringes which run between *pq* and *st*, *qr* and *tv*, and next beyond *r* and *v*, and found them 0'5, 0'8, and 1'17 Inches.

Obs. 11. The Sun shining into my darken'd Room through a small round hole made in a Plate of Lead with a slender Pin, as above; I placed at the hole a Prism to refract the Light, and form on the opposite Wall the Spectrum of Colours, described in the third Experiment of the first Book. And then I found that the Shadows of all Bodies held in the colour'd Light between the Prism and the Wall, were border'd with Fringes of the Colour of that Light in which they were held. In the full red Light they were totally red without any sensible blue or violet, and in the deep blue Light they were totally blue without any sensible red or yellow; and so in the green Light they were totally green, excepting a little yellow and blue, which were mix'd in the green Light of the Prism. And comparing the Fringes made in the several colour'd Lights, I found that those made in the red Light were largest, those made in the violet were least, and those made in the green were of a middle bigness. For the Fringes with which the Shadow of a Man's Hair were border'd, being measured cross the Shadow at the distance of six Inches from the Hair; the distance between the middle and most luminous part of the first or innermost Fringe on one side of the Shadow, and that of the like Fringe on the other side of the Shadow was in the full red Light $\frac{1}{37\frac{1}{4}}$ of an Inch, and in the full <311> violet $\frac{1}{46}$. And the like distance between the middle and most luminous parts of the second Fringes on either side the Shadow was in the full red Light $\frac{1}{22}$, and in the violet $\frac{1}{27}$ of an Inch. And these distances of the Fringes held the same proportion at all distances from the Hair without any sensible variation.

So then the Rays which made these Fringes in the red Light passed by the Hair at a greater distance than those did which made the like Fringes in the violet; and therefore the Hair in causing these Fringes acted alike upon the red Light or least refrangible Rays at a greater distance, and upon the violet or most refrangible Rays at a less distance, and by those actions disposed the red Light into larger Fringes, and the violet into smaller, and the Lights of intermediate Colours into Fringes of intermediate bignesses without changing the Colour of any sort of Light.

When therefore the Hair in the first and second of these Observations was held in the white beam of the Sun's Light, and cast a Shadow which was border'd with three Fringes of colour'd Light, those Colours arose not from any new modifications impress'd upon the Rays of Light by the Hair, but only from the various inflexions whereby the several sorts of Rays were separated from one another, which before separation by the mixture of all their Colours, composed the white beam of the Sun's Light, but whenever separated compose Lights of the several Colours which they are originally disposed to exhibit. In this 11th Observation, where <312> the Colours are separated before the Light passes by the Hair, the least refrangible Rays, which when separated from the rest make red, were inflected at a greater distance from the Hair, so as to make three red Fringes at a greater distance from the middle of the Shadow of the Hair; and the most refrangible Rays which when separated make violet, were inflected at a less distance from the Hair, so as to make three violet Fringes at a less distance from the middle of the Shadow of the Hair. And other Rays of intermediate degrees of Refrangibility were inflected at intermediate distances from the Hair, so as to make Fringes of intermediate Colours at intermediate distances from the middle of the Shadow of the Hair. And in the second Observation, where all the Colours are mix'd in the white Light which passes by the Hair, these Colours are separated by the various inflexions of the Rays, and the Fringes which they make appear all together, and the innermost Fringes being contiguous make one broad Fringe composed of all the Colours in due order, the violet lying on the inside of the Fringe next the Shadow, the red on the outside farthest from the Shadow, and the blue, green and yellow, in the middle. And, in like manner, the middlemost Fringes of all the Colours lying in order, and being contiguous, make another broad Fringe composed of all the Colours; and the outmost Fringes of all the Colours lying in order, and being contiguous, make a third broad Fringe composed of all the Colours. These are the three Fringes of co <313> lour'd Light with which the Shadows of all Bodies are border'd in the second Observation.

When I made the foregoing Observations, I design'd to repeat most of them with more care and exactness, and to make some new ones for determining the manner how the Rays of Light are bent in their passage by Bodies for making the Fringes of Colours with the dark lines between them. But I was then interrupted, and cannot now think of taking these things into farther Consideration. And since I have not finish'd this part of my Design, I shall conclude, with proposing only some Queries in order to a farther search to be made by others.

Query 1. Do not Bodies act upon Light at a distance, and by their action bend its Rays, and is not this action (*cæteris paribus*) strongest at the least distance?

Qu. 2. Do not the Rays which differ in Refrangibility differ also in Flexibity, and are they not by their different Inflexions separated from one another, so as after separation to make the Colours in the three Fringes above described? And after what manner are they inflected to make those Fringes?

Qu. 3. Are not the Rays of Light in passing by the edges and sides of Bodies, bent several times backwards and forwards, with a motion like that of an Eel? And do not the three Fringes of colour'd Light above mention'd, arise from three such bendings?

Qu. 4. Do not the Rays of Light which fall upon Bodies, and are reflected or refracted, be <314> gin to bend before they arrive at the Bodies; and are they not reflected, refracted, and inflected by one and the same Principle, acting variously in various Circumstances?

Qu. 5. Do not Bodies and Light act mutually upon one another, that is to say, Bodies upon Light in emitting, reflecting, refracting and inflecting it, and Light upon Bodies for heating them, and putting their parts into a vibrating motion wherein heat consists?

Qu. 6. Do not black Bodies conceive heat more easily from Light than those of other Colours do, by reason that the Light falling on them is not reflected outwards, but enters the Bodies, and is often reflected and

refracted within them, until it be stifled and lost?

Qu. 7. Is not the strength and vigor of the action between Light and sulphureous Bodies observed above, one reason why sulphureous Bodies take fire more readily, and burn more vehemently, than other Bodies do?

Qu. 8. Do not all fix'd Bodies when heated beyond a certain degree, emit Light and shine, and is not this Emission perform'd by the vibrating Motions of their parts? And do not all Bodies which abound with terrestrial parts, and especially with sulphureous ones, emit Light as often as those parts are sufficiently agitated; whether that agitation be made by Heat, or by Friction, or Percussion, or Putrefaction, or by any vital Motion, or any other Cause? As for instance; Sea Water in a raging Storm; Quicksilver agitated in *vacuo*; the Back of a Cat, or Neck of a Horse obliquely struck or rubbed in <315> a dark place; Wood, Flesh and Fish while they putrefy; Vapours arising from putrefy'd Waters, usually call'd *Ignes Fatui*; Stacks of moist Hay or Corn growing hot by fermentation; Glow-worms and the Eyes of some Animals by vital Motions; the vulgar *Phosphorus* agitated by the attrition of any Body, or by the acid Particles of the Air; Ambar and some Diamonds by striking, pressing or rubbing them; Scrapings of Steel struck off with a Flint; Iron hammer'd very nimbly till it become so hot as to kindle Sulphur thrown upon it; the Axletrees of Chariots taking fire by the rapid rotation of the Wheels; and some Liquors mix'd with one another whose Particles come together with an Impetus, as Oil of Vitriol distilled from its weight of Nitre, and then mix'd with twice its weight of Oil of Anniseeds. So also a Globe of Glass about 8 or 10 Inches in diameter, being put into a Frame where it may be swiftly turn'd round its Axis, will in turning shine where it rubs against the palm of ones Hand apply'd to it: And if at the same time a piece of white Paper or white Cloth, or the end of ones Finger be held at the distance of about a quarter of an Inch or half an Inch from that part of the Glass where it is most in motion, the electrick Vapour which is excited by the friction of the Glass against the Hand, will by dashing against the white Paper, Cloth or Finger, be put into such an agitation as to emit Light, and make the white Paper, Cloth or Finger, appear lucid like a Glow-worm; and in rushing out of the Glass will sometimes push <316> against the Finger so as to be felt. And the same things have been found by rubbing a long and large Cylinder or Glass or Ambar with a Paper held in ones hand, and continuing the friction till the Glass grew warm.

Qu. 9. Is not Fire a Body heated so hot as to emit Light copiously? For what else is a red hot Iron than Fire? And what else is a burning Coal than red hot Wood?

Qu. 10. Is not Flame a Vapour, Fume or Exhalation heated red hot, that is, so hot as to shine? For Bodies do not flame without emitting a copious Fume, and this Fume burns in the Flame. The *Ignis Fatuus* is a Vapour shining without heat, and is there not the same difference between this Vapour and Flame, as between rotten Wood shining without heat and burning Coals of Fire? In distilling hot Spirits, if the Head of the Still be taken off, the Vapour which ascends out of the Still will take fire at the Flame of a Candle, and turn into Flame, and the Flame will run along the Vapour from the Candle to the Still. Some Bodies heated by Motion or Fermentation, if the heat grow intense, fume copiously, and if the heat be great enough the Fumes will shine and become Flame. Metals in fusion do not flame for want of a copious Fume, except Spelter, which fumes copiously, and thereby flames. All flaming Bodies, as Oil, Tallow, Wax, Wood, fossil Coals, Pitch, Sulphur, by flaming waste and vanish into burning Smoke, which Smoke, if the Flame be put out, is very thick and visible, and sometimes smells strongly, but in the Flame loses its <317> smell by burning, and according to the nature of the Smoke the Flame is of several Colours, as that of Sulphur blue, that of Copper open'd with sublimate green, that of Tallow yellow, that of Camphire white. Smoke passing through Flame cannot but grow red hot, and red hot Smoke can have no other appearance than that of Flame. When Gun-powder takes fire, it goes away into flaming Smoke. For the Charcoal and Sulphur easily take fire, and set fire to the Nitre, and the Spirit of the Nitre being thereby rarified into Vapour, rushes out with Explosion much after the manner that the Vapour of Water rushes out of an Æolipile; the Sulphur also being volatile is converted into Vapour, and augments the Explosion. And the acid Vapour of the Sulphur (namely that which distils under a Bell into Oil of Sulphur,) entring violently into the fix't Body of the Nitre, sets loose the Spirit of the Nitre, and excites a great Fermentation, whereby the Heat is farther augmented, and the fix'd Body of the Nitre is also rarified into Fume , and the Explosion is thereby made more vehement and quick. For if Salt of Tartar be mix'd with Gun-powder, and that Mixture be warm'd till it takes fire, the Explosion will be more violent and quick than that of Gun-powder alone; which cannot proceed from any other cause than the action of the Vapour of the Gun-powder upon the Salt of Tartar, whereby that Salt is rarified. The Explosion of Gun-powder arises therefore from the violent action whereby all the Mixture being quickly and vehemently

heated, is rarified <318> and converted into Fume and Vapour: which Vapour, by the violence of that action, becoming so hot as to shine, appears in the form of Flame.

Qu. 11. Do not great Bodies conserve their heat the longest, their parts heating one another, and may not great dense and fix'd Bodies, when heated beyond a certain degree, emit Light so copiously, as by the Emission and Re-action of its Light, and the Reflexions and Refractions of its Rays within its Pores to grow still hotter, till it comes to a certain period of heat, such as is that of the Sun? And are not the Sun and fix'd Stars great Earths vehemently hot, whose heat is conserved by the greatness of the Bodies, and the mutual Action and Reaction between them, and the Light which they emit, and whose parts are kept from fuming away, not only by their fixity, but also by the vast weight and density of the Atmospheres incumbent upon them, and very strongly compressing them, and condensing the Vapours and Exhalations which arise from them? For if Water be made warm in any pellucid Vessel emptied of Air, that Water in the *Vacuum* will bubble and boil as vehemently as it would in the open Air in a Vessel set upon the Fire till it conceives a much greater heat. For the weight of the incumbent Atmosphere keeps down the Vapours, and hinders the Water from boiling, until it grow much hotter than is requisite to make it boil *in vacuo*. Also a mixture of Tin and Lead being put upon a red hot Iron *in vacuo* emits a Fume and Flame, but the <319> same Mixture in the open Air, by reason of the incumbent Atmosphere, does not so much as emit any Fume which can be perceived by Sight. In like manner the great weight of the Atmosphere which lies upon the Globe of the Sun may hinder Bodies there from rising up and going away from the Sun in the form of Vapours and Fumes, unless by means of a far greater heat than that which on the Surface of our Earth would very easily turn them into Vapours and Fumes. And the same great weight may condense those Vapours and Exhalations as soon as they shall at any time begin to ascend from the Sun, and make them presently fall back again into him, and by that action increase his Heat much after the manner that in our Earth the Air increases the Heat of a culinary Fire. And the same weight may hinder the Globe of the Sun from being diminish'd, unless by the Emission of Light, and a very small quantity of Vapours and Exhalations.

Qu. 12. Do not the Rays of Light in falling upon the bottom of the Eye excite Vibrations in the *Tunica Retina*? Which Vibrations, being propagated along the solid Fibres of the optick Nerves into the Brain, cause the Sense of seeing. For because dense Bodies conserve their Heat a long time, and the densest Bodies conserve their Heat the longest, the Vibrations of their parts are of a lasting nature, and therefore may be propagated along solid Fibres of uniform dense Matter to a great distance, for conveying into the Brain the impressions made upon all the Organs of Sense. For that Motion <320> which can continue long in one and the same part of a Body, can be propagated a long way from one part to another, supposing the Body homogeneal, so that the Motion may not be reflected, refracted, interrupted or disorder'd by any unevenness of the Body.

Qu. 13. Do not several sorts of Rays make Vibrations of several bignesses, which according to their bignesses excite Sensations of several Colours, much after the manner that the Vibrations of the Air, according to their several bignesses excite Sensations of several Sounds? And particularly do not the most refrangible Rays excite the shortest Vibrations for making a Sensation of deep violet, the least refrangible the largest for making a Sensation of deep red, and the several intermediate sorts of Rays, Vibrations of several intermediate bignesses to make Sensations of the several intermediate Colours?

Qu. 14. May not the harmony and discord of Colours arise from the proportions of the Vibrations propagated through the Fibres of the optick Nerves into the Brain, as the harmony and discord of Sounds arise from the proportions of the Vibrations of the Air? For some Colours, if they be view'd together, are agreeable to one another, as those of Gold and Indigo, and others disagree.

Qu. 15. Are not the Species of Objects seen with both Eyes united where the optick Nerves meet before they come into the Brain, the Fibres on the right side of both Nerves uniting there, and after union going thence into the Brain in the Nerve which is on the right side of <321> the Head, and the Fibres on the left side of both Nerves uniting in the same place, and after union going into the Brain in the Nerve which is on the left side of the Head, and these two Nerves meeting in the Brain in such a manner that their Fibres make but one entire Species or Picture, half of which on the right side of the Sensorium comes from the right side of both Eyes through the right side of both optick Nerves to the place where the Nerves meet, and from thence on the right side of the Head into the Brain, and the other half on the left side of the Sensorium comes in like manner from the left side of both Eyes. For the optick Nerves of such Animals as look the same way with

both Eyes (as of Men, Dogs, Sheep, Oxen, *&c*.) meet before they come into the Brain, but the optick Nerves of such Animals as do not look the same way with both Eyes (as of Fishes and of the Chameleon) do not meet, if I am rightly inform'd.

Qu.16. When a Man in the dark presses either corner of his Eye with his Finger, and turns his Eye away from his Finger, he will see a Circle of Colours like those in the Feather of a Peacock's Tail. If the Eye and the Finger remain quiet these Colours vanish in a second Minute of Time, but if the Finger be moved with a quavering Motion they appear again. Do not these Colours arise from such Motions excited in the bottom of the Eye by the Pressure and Motion of the Finger, as at other times are excited there by Light for causing Vision? And do not the Motions once excited continue about a Se <322> cond of Time before they cease? And when a Man by a stroke upon his Eye sees a flash of Light, are not the like Motions excited in the *Retina* by the stroke? And when a Coal of Fire moved nimbly in the circumference of a Circle, makes the whole circumference appear like a Circle of Fire: Is it not because the Motions excited in the bottom of the Eye by the Rays of Light are of a lasting nature, and continue till the Coal of Fire in going round returns to its former place? And considering the lastingness of the Motions excited in the bottom of the Eye by Light, are they not of a vibrating nature?

Qu. 17. If a stone be thrown into stagnating Water, the Waves excited thereby continue some time to arise in the place where the Stone fell into the Water, and are propagated from thence in concentrick Circles upon the Surface of the Water to great distances. And the Vibrations or Tremors excited in the Air by percussion, continue a little time to move from the place of percussion in concentrick Spheres to great distances. And in like manner, when a Ray of Light falls upon the Surface of any pellucid Body, and is there refracted or reflected: may not Waves of Vibrations, or Tremors, be thereby excited in the refracting or reflecting Medium at the point of Incidence, and continue to arise there, and to be propagated from thence as long as they continue to arise and be propagated, when they are excited in the bottom of the Eye by the Pressure or Motion of the Finger, or by the Light which comes from the Coal of Fire in the Ex <323> periments above mention'd? And are not these Vibrations propagated from the point of Incidence to great distances? And do they not overtake the Rays of Light, and by overtaking them successively, do they not put them into the Fits of easy Reflexion and easy Transmission described above? For if the Rays endeavour to recede from the densest part of the Vibration, they may be alternately accelerated and retarded by the Vibrations overtaking them.

Qu. 18. If in two large tall cylindrical Vessels of Glass inverted, two little Thermometers be suspended so as not to touch the Vessels, and the Air be drawn out of one of these Vessels, and these Vessels thus prepared be carried out of a cold place into a warm one; the Thermometer *in vacuo* will grow warm as much, and almost as soon as the Thermometer which is not *in vacuo*. And when the Vessels are carried back into the cold place, the Thermometer *in vacuo* will grow cold almost as soon as the other Thermometer. Is not the Heat of the warm Room convey'd through the *Vacuum* by the Vibrations of a much subtiler Medium than Air, which after the Air was drawn out remained in the *Vacuum*? And is not this Medium the same with that Medium by which Light is refracted and reflected, and by whose Vibrations Light communicates Heat to Bodies, and is put into Fits of easy Reflexion and easy Transmission? And do not the Vibrations of this Medium in hot Bodies contribute to the intenseness and duration of their Heat? And do not hot Bodies communicate their Heat to contiguous <324> cold ones, by the Vibrations of this Medium propagated from them into the cold ones? And is not this Medium exceedingly more rare and subtile than the Air, and exceedingly more elastick and active? And doth it not readily pervade all Bodies? And is it not (by its elastick force) expanded through all the Heavens?

Qu. 19. Doth not the Refraction of Light proceed from the different density of this Æthereal Medium in different places, the Light receding always from the denser parts of the Medium? And is not the density thereof greater in free and open Spaces void of Air and other grosser Bodies, than within the Pores of Water, Glass, Crystal, Gems, and other compact Bodies? For when Light passes through Glass or Crystal, and falling very obliquely upon the farther Surface thereof is totally reflected, the total Reflexion ought to proceed rather from the density and vigour of the Medium without and beyond the Glass, than from the rarity and weakness thereof.

Qu. 20. Doth not this Æthereal Medium in passing out of Water, Glass, Crystal, and other compact and dense Bodies into empty Spaces, grow denser and denser by degrees, and by that means refract the Rays of Light

not in a point, but by bending them gradually in curve Lines? And doth not the gradual condensation of this Medium extend to some distance from the Bodies, and thereby cause the Inflexions of the Rays of Light, which pass by the edges of dense Bodies, at some distance from the Bodies?

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Qu. 21. Is not this Medium much rarer within the dense Bodies of the Sun, Stars, Planets and Comets, than in the empty celestial Spaces between them? And in passing from them to great distances, doth it not grow denser and denser perpetually, and thereby cause the gravity of those great Bodies towards one another, and of their parts towards the Bodies; every Body endeavouring to go from the denser parts of the Medium towards the rarer? For if this Medium be rarer within the Sun's Body than at its Surface, and rarer there than at the hundredth part of an Inch from its Body, and rarer there than at the fiftieth part of an Inch from its Body, and rarer there than at the Orb of *Saturn*; I see no reason why the Increase of density should stop any where, and not rather be continued through all distances from the Sun to *Saturn*, and beyond. And though this Increase of density may at great distances be exceeding slow, yet if the elastick force of this Medium be exceeding great, it may suffice to impel Bodies from the denser parts of the Medium towards the rarer, with all that power which we call Gravity. And that the elastick force of this Medium is exceeding great, may be gather'd from the swiftness of its Vibrations. Sounds move about 1140 *English* Feet in a second Minute of Time, and in seven or eight Minutes of Time they move about one hundred *English* Miles. Light moves from the Sun to us in about seven or eight Minutes of Time, which distance is about 70000000 *English* Miles, supposing the horizontal Parallax of the Sun to <326> be about 12". And the Vibrations or Pulses of this Medium, that they may cause the alternate Fits of easy Transmission and easy Reflexion, must be swifter than Light, and by consequence above 700000 times swifter than Sounds. And therefore the elastick force of this Medium, in proportion to its density, must be above 700000 x 700000 (that is, above 490000000000) times greater than the elastick force of the Air is in proportion to its density. For the Velocities of the Pulses of elastick Mediums are in a subduplicate *Ratio* of the Elasticities and the Rarities of the Mediums taken together.

As Attraction is stronger in small Magnets than in great ones in proportion to their Bulk, and Gravity is greater in the Surfaces of small Planets than in those of great ones in proportion to their bulk, and small Bodies are agitated much more by electric attraction than great ones; so the smallness of the Rays of Light may contribute very much to the power of the Agent by which they are refracted. And so if any one should suppose that *Æther* (like our Air) may contain Particles which endeavour to recede from one another (for I do not know what this *Æther* is) and that its Particles are exceedingly smaller than those of Air, or even than those of Light: The exceeding smallness of its Particles may contribute to the greatness of the force by which those Particles may recede from one another, and thereby make that Medium exceedingly more rare and elastick than Air, and by consequence exceedingly less able to resist the motions of Projectiles, and <327> exceedingly more able to press upon gross Bodies, by endeavouring to expand it self.

Qu. 22. May not Planets and Comets, and all gross Bodies, perform their Motions more freely, and with less resistance in this *Æthereal* Medium than in any Fluid, which fills all Space adequately without leaving any Pores, and by consequence is much denser than Quick-silver or Gold? And may not its resistance be so small, as to be inconsiderable? For instance; If this *Æther* (for so I will call it) should be supposed 700000 times more elastick than our Air, and above 700000 times more rare; its resistance would be above 600000000 times less than that of Water. And so small a resistance would scarce make any sensible alteration in the Motions of the Planets in ten thousand Years. If any one would ask how a Medium can be so rare, let him tell me how the Air, in the upper parts of the Atmosphere, can be above an hundred thousand thousand times rarer than Gold. Let him also tell me, how an electrick Body can by Friction emit an Exhalation so rare and subtile, and yet so potent, as by its Emission to cause no sensible Diminution of the weight of the electrick Body, and to be expanded through a Sphere, whose Diameter is above two Feet, and yet to be able to agitate and carry up Leaf Copper, or Leaf Gold, at the distance of above a Foot from the electrick Body? And how the Effluvia of a Magnet can be so rare and subtile, as to pass through a Plate of Glass without any Resistance or Diminution of their Force, and yet so potent as to turn a magnetick Needle beyond the Glass?

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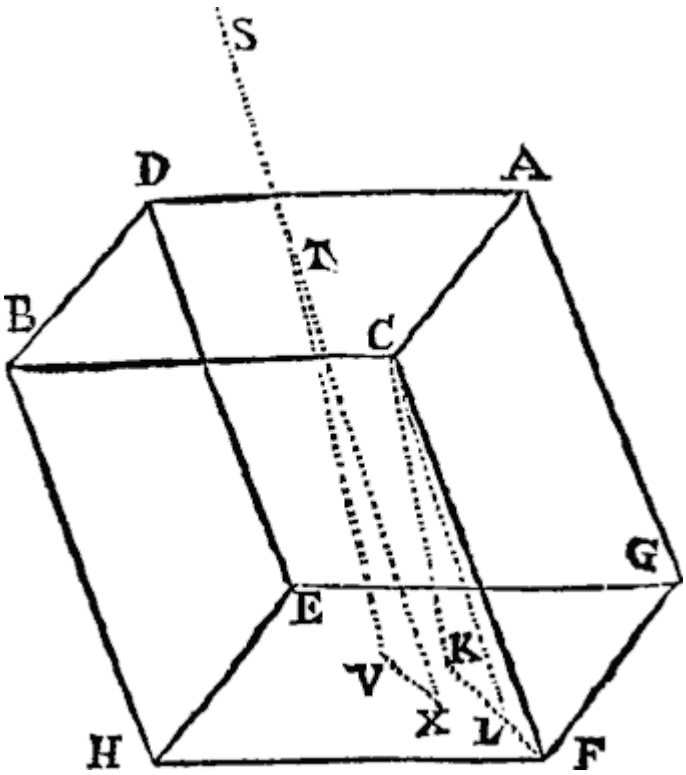
Qu. 23. Is not Vision perform'd chiefly by the Vibrations of this Medium, excited in the bottom of the Eye by the Rays of Light, and propagated through the solid, pellucid and uniform Capillamenta of the optick Nerves into the place of Sensation? And is not Hearing perform'd by the Vibrations either of this or some other Medium, excited in the auditory Nerves by the Tremors of the Air, and propagated through the solid, pellucid and uniform Capillamenta of those Nerves into the place of Sensation? And so of the other Senses.

Qu. 24. Is not Animal Motion perform'd by the Vibrations of this Medium, excited in the Brain by the power of the Will, and propagated from thence through the solid, pellucid and uniform Capillamenta of the Nerves into the Muscles, for contracting and dilating them? I suppose that the Capillamenta of the Nerves are each of them solid and uniform, that the vibrating Motion of the *Æthereal* Medium may be propagated along them from one end to the other uniformly, and without interruption: For Obstructions in the Nerves create Palsies. And that they may be sufficiently uniform, I suppose them to be pellucid when view'd singly, tho' the Reflexions in their cylindrical Surfaces may make the whole Nerve (composed of many Capillamenta) appear opake and white. For opacity arises from reflecting Surfaces, such as may disturb and interrupt the Motions of this Medium.

Qu. 25. Are there not other original Properties of the Rays of Light, besides those already described? An instance of another original <329> Property we have in the Refraction of Island Crystal, described first by *Erasmus Bartholine*, and afterwards more exactly by *Hugenius*, in his Book *De la Lumiere*. This Crystal is a pellucid fissile Stone, clear as Water or Crystal of the Rock, and without Colour; enduring a red Heat without losing its transparency, and in a very strong Heat calcining without Fusion. Steep'd a Day or two in Water, it loses its natural Polish. Being rubb'd on Cloth, it attracts pieces of Straws and other light things, like Ambar or Glass; and with *Aqua fortis* it makes an Ebullition. It seems to be a sort of Talk, and is found in form of an oblique Parallelpiped, with six parallelogram Sides and eight solid Angles. The obtuse Angles of the Parallelograms are each of them 101 Degrees and 52 Minutes; the acute ones 78 Degrees and 8 Minutes. Two of the solid Angles opposite to one another, as C and E, are compassed each of [1]them with three of these obtuse Angles, and each of the other six with one obtuse and two acute ones. It cleaves easily in Planes parallel to any of its Sides, and not in any other Planes. It cleaves with a glossy polite Surface not perfectly plane, but with some little unevenness. It is easily scratch'd, and by reason of its softness it takes a Polish very difficultly. It polishes better upon polish'd Looking-glass than upon Metal, and perhaps better upon Pitch, Leather or Parchment. Afterwards it must be rubb'd with a little Oil or White of an Egg, to fill up its Scratches; whereby it will become very trans <330> parent and polite. But for several Experiments, it is not necessary to polish it. If a piece of this crystalline Stone be laid upon a Book, every Letter of the Book seen through it will appear double, by means of a double Refraction. And if any beam of Light falls either perpendicularly, or in any oblique Angle upon any Surface of this Crystal, it becomes divided into two beams by means of the same double Refraction. Which beams are of the same Colour with the incident beam of Light, and seem equal to one another in the quantity of their Light, or very nearly equal. One of these Refractions is perform'd by the usual Rule of Opticks, the Sine of Incidence out of Air into this Crystal being to the Sine of Refraction, as five to three. The other Refraction, which may be called the unusual Refraction, is perform'd by the following Rule.



Let ADBC represent the refracting Surface <331> of the Crystal, C the biggest solid Angle at that Surface, GEHF the opposite Surface, and CK a perpendicular on that Surface. This perpendicular makes with the edge of the Crystal CF, an Angle of 19 Degr. 3'. Join KF, and in it take KL, so that the Angle KCL be 6 Degr. 40'. and the Angle LCF 12 Degr. 23'. And if ST represent any beam of Light incident at T in any Angle upon the refracting Surface ADBC, let TV be the refracted beam determin'd by the given Proportion of the Sines 5 to 3, according to the usual Rule of Opticks. Draw VX parallel and equal to KL. Draw it the same way from V in which L lieth from K; and joining TX, this line TX shall be the other refracted beam carried from T to X, by the unusual Refraction.

If therefore the incident beam ST be perpendicular to the refracting Surface, the two beams TV and TX, into which it shall become divided, shall be parallel to the lines CK and CL; one of those beams going through the Crystal perpendicularly, as it ought to do by the usual Laws of Opticks, and the other TX by an unusual Refraction diverging from the perpendicular, and making with it an Angle VTX of about $6\frac{2}{3}$ Degrees, as is found by experience. And hence, the Plane VTX, and such like Planes which are parallel to the Plane CFK, may be called the Planes of perpendicular Refraction. And the Coast towards which the lines KL and VX are drawn, may be call'd the Coast of unusual Refraction.

In like manner Crystal of the Rock has a <332> double Refraction: But the difference of the two Refractions is not so great and manifest as in Island Crystal.

When the beam ST incident on Island Crystal, is divided into two beams TV and TX, and these two beams arrive at the farther Surface of the Glass; the beam TV, which was refracted at the first Surface after the usual manner, shall be again refracted entirely after the usual manner at the second Surface; and the beam TX, which was refracted after the unusual manner in the first Surface, shall be again refracted entirely after the unusual manner in the second Surface; so that both these beams shall emerge out of the second Surface in lines parallel to the first incident beam ST.

And if two pieces of Island Crystal be placed one after another, in such manner that all the Surfaces of the latter be parallel to all the corresponding Surfaces of the former: The Rays which are refracted after the usual manner in the first Surface of the first Crystal shall be refracted after the usual manner in all the following Surfaces; and the Rays which are refracted after the unusual manner in the first Surface, shall be refracted after the unusual manner in all the following Surfaces. And the same thing happens, though the Surfaces of the Crystals be any ways inclined to one another, provided that their Planes of perpendicular Refraction be parallel to one another.

And therefore there is an original difference in the Rays of Light, by means of which some Rays are in this Experiment constantly refract <333> ed after the usual manner, and others constantly after the unusual manner: For if the difference be not original, but arises from new Modifications impress'd on the Rays at their first Refraction, it would be alter'd by new Modifications in the three following Refractions; whereas it suffers no alteration, but is constant, and has the same effect upon the Rays in all the Refractions. The unusual Refraction is therefore perform'd by an original property of the Rays. And it remains to be enquired, whether the Rays have not more original Properties than are yet discover'd.

Qu. 26. Have not the Rays of Light several sides, endued with several original Properties? For if the Planes of perpendicular Refraction of the second Crystal, be at right Angles with the Planes of perpendicular Refraction of the first Crystal, the Rays which are refracted after the usual manner in passing through the first Crystal, will be all of them refracted after the unusual manner in passing through the second Crystal; and the Rays which are refracted after the unusual manner in passing through the first Crystal, will be all of them refracted after the usual manner in passing through the second Crystal. And therefore there are not two sorts of Rays differing in their nature from one another, one of which is constantly and in all Positions refracted after the usual manner, and the other constantly and in all Positions after the unusual manner. The difference between the two sorts of Rays in the Experiment mention'd in the 25th Question, was only in the Positions <334> of the Sides of the Rays to the Planes of perpendicular Refraction. For one and the same Ray is here refracted sometimes after the usual, and sometimes after the unusual manner, according to the Position which its Sides have to the Crystals. If the Sides of the Rays are posited the same way to both Crystals, it is refracted after the same manner in them both: But if that side of the Ray which looks towards the Coast of the unusual Refraction of the first Crystal, be 90 Degrees from that side of the same Ray which looks toward the Coast of the unusual Refraction of the second Crystal, (which may be effected by varying the Position of the second Crystal to the first, and by consequence to the Rays of Light) the Ray shall be refracted after several manners in the several Crystals. There is nothing more required to determine whether the Rays of Light which fall upon the second Crystal, shall be refracted after the usual or after the unusual manner, but to turn about this Crystal, so that the Coast of this Crystal's unusual Refraction may be on this or on that side of the Ray. And therefore every Ray may be consider'd as having four Sides or Quarters, two of which opposite to one another incline the Ray to be refracted after the unusual manner, as often as either of them are turn'd towards the Coast of unusual Refraction; and the other two, whenever either of them are turn'd towards the Coast of unusual Refraction, do not incline it to be otherwise refracted than after the usual manner. The two first may therefore be call'd the Sides of unusual Refraction. <335> And since these Dispositions were in the Rays before their Incidence on the second, third and fourth Surfaces of the two Crystals, and suffered no alteration (so far as appears) by the Refraction of the Rays in their passage through those Surfaces, and the Rays were refracted by the same Laws in all the four Surfaces; it appears that those Dispositions were in the Rays originally, and suffer'd no alteration by the first Refraction, and that by means of those Dispositions the Rays were refracted at their Incidence on the first Surface of the first Crystal, some of them after the usual, and some of them after the unusual manner, accordingly as their Sides of unusual Refraction were then turn'd towards the Coast of the unusual Refraction of that Crystal, or sideways from it.

Every Ray of Light has therefore two opposite Sides, originally endued with a Property on which the unusual Refraction depends, and the other two opposite Sides not endued with that Property. And it remains to be enquired, whether there are not more Properties of Light by which the Sides of the Rays differ, and are distinguish'd from one another.

In explaining the difference of the Sides of the Rays above mention'd, I have supposed that the Rays fall perpendicularly on the first Crystal. But if they fall obliquely on it, the Success is the same. Those Rays which are refracted after the usual manner in the first Crystal, will be refracted after the unusual manner in the second Crystal, supposing the Planes of perpendicular Refraction to be at right Angles with <336> one another, as above: and on the contrary.

If the Planes of the perpendicular Refraction of the two Crystals be neither parallel nor perpendicular to one another, but contain an acute Angle: The two beams of Light which emerge out of the first Crystal, will be each of them divided into two more at their Incidence on the second Crystal. For in this case the Rays in each of the two Beams will some of them have their Sides of unusual Refraction, and some of them their other Sides turn'd towards the Coast of the unusual Refraction of the second Crystal.

Qu. 27. Are not all Hypotheses erroneous which have hitherto been invented for explaining the Phenomena of Light, by new Modifications of the Rays? For those Phenomena depend not upon new Modifications, as has been supposed, but upon the original and unchangeable Properties of the Rays.

Qu. 28. Are not all Hypotheses erroneous, in which Light is supposed to consist in Pression or Motion, propagated through a fluid Medium? For in all these Hypotheses the Phenomena of Light have been hitherto explain'd by supposing that they arise from new Modifications of the Rays; which is an erroneous Supposition.

If Light consisted only in Pression propagated without actual Motion, it would not be able to agitate and heat the Bodies which refract and reflect it. If it consisted in Motion propagated to all distances in an instant, it would require an infinite force every moment, in every <337> shining Particle, to generate that Motion. And if it consisted in Pression or Motion, propagated either in an instant or in time, it would bend into the Shadow. For Pression or Motion cannot be propagated in a Fluid in right Lines beyond an Obstacle which stops part of the Motion, but will bend and spread every way into the quiescent Medium which lies beyond the Obstacle. Gravity tends downwards, but the Pressure of Water arising from Gravity tends every way with equal force, and is propagated as readily, and with as much force sideways as downwards, and through crooked passages as through strait ones. The Waves on the Surface of stagnating Water, passing by the sides of a broad Obstacle which stops part of them, bend afterwards and dilate themselves gradually into the quiet Water behind the Obstacle. The Waves, Pulses or Vibrations of the Air, wherein Sounds consist, bend manifestly, though not so much as the Waves of Water. For a Bell or a Cannon may be heard beyond a Hill which intercepts the sight of the sounding Body, and Sounds are propagated as readily through crooked Pipes as through streight ones. But Light is never known to follow crooked Passages nor to bend into the Shadow. For the fix'd Stars by the Interposition of any of the Planets cease to be seen. And so do the Parts of the Sun by the Interposition of the Moon, *Mercury* or *Venus*. The Rays which pass very near to the edges of any Body, are bent a little by the action of the Body, as we shew'd above; but this bending is not towards but from the Shadow, <338> and is perform'd only in the passage of the Ray by the Body, and at a very small distance from it. So soon as the Ray is past the Body, it goes right on.

To explain the unusual Refraction of Island Crystal by Pression or Motion propagated, has not hitherto been attempted (to my knowledge) except by *Huygens*, who for that end supposed two several vibrating Mediums within that Crystal. But when he tried the Refractions in two successive pieces of that Crystal, and found them such as is mention'd above: he confessed himself at a loss for explaining them. For Pressions or Motions, propagated from a shining Body through an uniform Medium, must be on all sides alike; whereas by those Experiments it appears, that the Rays of Light have different Properties in their different Sides. He suspected that the Pulses of *Æther* in passing through the first Crystal might receive certain new Modifications, which might determine them to be propagated in this or that Medium within the second Crystal, according to the [2]Position of that Crystal. But what Modifications those might be he could not say, nor think of any thing satisfactory in that Point. And if he had known that the unusual Refraction depends not on new Modifications, but on the original and unchangeable Dispositions of the Rays, he would have found it as difficult to explain how those Dispositions which he supposed to be impress'd <339> on the Rays by the first Crystal, could be in them before their Incidence on that Crystal, and in general, how all Rays emitted by shining Bodies, can have those Dispositions in them from the beginning. To me, at least, this seems inexplicable, if Light be nothing else than Pression or Motion propagated through *Æther*.

And it is as difficult to explain by these Hypotheses, how Rays can be alternately in Fits of easy Reflexion and easy Transmission; unless perhaps one might suppose that there are in all Space two Æthereal vibrating Mediums, and that the Vibrations of one of them constitute Light, and the Vibrations of the other are swifter, and as often as they overtake the Vibrations of the first, put them into those Fits. But how two *Æthers* can be diffused through all Space, one of which acts upon the other, and by consequence is re-acted upon, without retarding, shattering, dispersing and confounding one anothers Motions, is inconceivable. And against filling the Heavens with fluid Mediums, unless they be exceeding rare, a great Objection arises from the regular and very lasting Motions of the Planets and Comets in all manner of Courses through the Heavens. For thence it is manifest, that the Heavens are void of all sensible Resistance, and by consequence of all sensible Matter.

For the resisting Power of fluid Mediums arises partly from the Attrition of the Parts of the Medium, and partly from the *Vis inertiæ* of the Matter. That part of the Resistance of <340> a spherical Body which arises

from the Attrition of the Parts of the Medium is very nearly as the Diameter, or, at the most, as the *Factum* of the Diameter, and the Velocity of the spherical Body together. And that part of the Resistance which arises from the *Vis inertiæ* of the Matter, is as the Square of that *Factum*. And by this difference the two sorts of Resistance may be distinguish'd from one another in any Medium; and these being distinguish'd, it will be found that almost all the Resistance of Bodies of a competent Magnitude moving in Air, Water, Quick-silver, and such like Fluids with a competent Velocity, arises from the *Vis inertiæ* of the Parts of the Fluid.

Now that part of the resisting Power of any Medium which arises from the Tenacity, Friction or Attrition of the Parts of the Medium, may be diminish'd by dividing the Matter into smaller Parts, and making the Parts more smooth and slippery: But that part of the Resistance which arises from the *Vis inertiæ*, is proportional to the Density of the Matter, and cannot be diminish'd by dividing the Matter into smaller Parts, nor by any other means than by decreasing the Density of the Medium. And for these Reasons the Density of fluid Mediums is very nearly proportional to their Resistance. Liquors which differ not much in Density, as Water, Spirit of Wine, Spirit of Turpentine, hot Oil, differ not much in Resistance. Water is thirteen or fourteen times lighter than Quick-silver, and by consequence thirteen or fourteen times rarer, and its Resistance is less than that <341> of Quick-silver in the same Proportion, or thereabouts, as I have found by Experiments made with Pendulums. The open Air in which we breathe is eight or nine hundred times lighter than Water, and by consequence eight or nine hundred times rarer, and accordingly its Resistance is less than that of Water in the same Proportion, or thereabouts; as I have also found by Experiments made with Pendulums. And in thinner Air the Resistance is still less, and at length, by rarifying the Air, becomes insensible. For small Feathers falling in the open Air meet with great Resistance, but in a tall Glass well emptied of Air, they fall as fast as Lead or Gold, as I have seen tried several times. Whence the Resistance seems still to decrease in proportion to the Density of the Fluid. For I do not find by any Experiments, that Bodies moving in Quick-silver, Water or Air, meet with any other sensible Resistance than what arises from the Density and Tenacity of those sensible Fluids, as they would do if the Pores of those Fluids, and all other Spaces, were filled with a dense and subtile Fluid. Now if the Resistance in a Vessel well emptied of Air, was but an hundred times less than in the open Air, it would be about a million of times less than in Quick-silver. But it seems to be much less in such a Vessel, and still much less in the Heavens, at the height of three or four hundred Miles from the Earth, or above. For Mr. *Boyle* has shew'd that Air may be rarified above ten thousand times in Vessels of Glass; and the Heavens are much emptier of Air than any *Va* <342> *cuum* we can make below. For since the Air is compress'd by the weight of the incumbent Atmosphere, and the Density of Air is proportional to the Force compressing it, it follows by Computation, that at the height of about seven *English* Miles from the Earth, the Air is four times rarer than at the Surface of the Earth; and at the height of 14 Miles, it is sixteen times rarer than that at the Surface of the Earth; and at the height of 21, 28, or 35 Miles, it is respectively 64, 256, or 1024 times rarer, or thereabouts; and at the height of 70, 140, 210 Miles, it is about 1000000, 1000000000000 or 1000000000000000000 times rarer; and so on.

Heat promotes Fluidity very much, by diminishing the Tenacity of Bodies. It makes many Bodies fluid which are not fluid in cold, and increases the Fluidity of tenacious Liquids, as of Oil, Balsam and Honey, and thereby decreases their Resistance. But it decreases not the Resistance of Water considerably, as it would do if any considerable part of the Resistance of Water arose from the Attrition or Tenacity of its Parts. And therefore the Resistance of Water arises principally and almost entirely from the *Vis inertiæ* of its Matter; and by consequence, if the Heavens were as dense as Water, they would not have much less Resistance than Water; if as dense as Quick-silver, they would not have much less Resistance thant Quick-silver; if absolutely dense, or full of Matter without any *Vacuum*, let the Matter be never so subtle and fluid, they would have a greater <343> Resistance than Quick-silver. A solid Globe in such a Medium would lose above half its Motion in moving three times the length of its Diameter, and a Globe not solid (such as are the Planets) would be retarded sooner. And therefore to make way for the regular and lasting Motions of the Planets and Comets, it's necessary to empty the Heavens of all Matter, except perhaps some very thin Vapours, Steams or Effluvia, arising from the Atmospheres of the Earth, Planets and Comets, and from such an exceedingly rare Æthereal Medium as we decribed above. A dense Fluid can be of no use for explaining the Phænomena of Nature, the Motions of the Planets and Comets being better explain'd without it. It serves only to disturb and retard the Motions of those great Bodies, and make the frame of Nature languish: And in the Pores of Bodies, it serves only to stop the vibrating Motions of their Parts, wherein their Heat and Activity consists. And as it is of no use, and hinders the Operations of Nature, and makes her languish, so there is no evidence for its Existence, and therefore it ought to be rejected. And if it be rejected, the Hypotheses that Light consists in Pression or Motion propagated through such a Medium, are rejected with it.

And for rejecting such a Medium, we have the Authority of those the oldest and most celebrated Philosophers of *Greece* and *Phoenicia*, who made a *Vacuum* and Atoms, and the Gravity of Atoms, the first Principles of their Philosophy; tacitly attributing Gravity to some o <344> ther Cause than dense Matter. Later Philosophers banish the Consideration of such a Cause out of Natural Philosophy, feigning Hypotheses for explaining all things mechanically, and referring other causes to Metaphysicks: Whereas the main Business of Natural Philosophy is to argue from Phænomena without feigning Hypotheses, and to deduce Causes from Effects, till we come to the very first Cause, which certainly is not mechanical; and not only to unfold the Mechanism of the World, but chiefly to resolve these and such like Questions. What is there in places almost empty of Matter between them? Whence is it that Nature doth nothing in vain; and whence arises all that Order and Beauty which we see in the World? To what end are Comets, and whence is it that Planets move all one and the same way in Orbs concentrick, while Comets move all manner of ways in Orbs very excentrick, and what hinders the fix'd Stars from falling upon one another? How came the Bodies of Animals to be contrived with so much Art, and for what ends were their several Parts? Was the Eye contrived without Skill in in Opticks, and the Ear without Knowledge of Sounds? How do the Motions of the Body follow from the Will, and whence is the Instinct in Animals? Is not the Sensory of Animals that place to which the sensitive Substance is present, and into which the sensible Species of Things are carried through the Nerves and Brain, that there they may be perceived <345> by their immediate presence to that Substance? And these things being rightly dispatch'd, does it not appear from Phænomena that there is a Being incorporeal, living, intelligent, omnipresent, who in infinite Space, as it were in his Sensory, sees the things themselves intimately, and throughly perceives them, and comprehends them wholly by their immediate presence to himself: Of which things the Images only carried through the Organs of Sense into our little Sensoriums, are there seen and beheld by that which in us perceives and thinks. And tho' every true Step made in this Philosophy brings us not immediately to the Knowledge of the first Cause, yet it brings us nearer to it, and on that account is to be highly valued.

Qu. 29. Are not the Rays of Light very small Bodies emitted from shining Substances? For such Bodies will pass through uniform Mediums in right Lines without bending into the Shadow, which is the Nature of the Rays of Light. They will also be capable of several Properties, and be able to conserve their Properties unchanged in passing through several Mediums, which is another Condition of the Rays of Light. Pellucid Substances act upon the Rays of Light at a distance in refracting, reflecting and inflecting them, and the Rays mutually agitate the Parts of those Substances at a distance for heating them; and this Action and Re-action at a distance, very much resembles an attractive Force between Bodies. If Refraction be perform'd by Attraction of the Rays, the Sines of Incidence must be to the Sines of Re <346> fraction in a given Proportion, as we shew'd in our Principles of Philosophy: And this Rule is true by Experience. The Rays of Light in going out of Glass into a *Vacuum*, are bent towards the Glass; and if they fall too obliquely on the *Vacuum* they are bent backwards into the Glass, and totally reflected; and this Reflexion cannot be ascribed to the Resistance of an absolute *Vacuum*, but must be caused by the Power of the Glass attracting the Rays at their going out of it into the *Vacuum*, and bringing them back. For if the farther Surface of the Glass be moisten'd with Water or clear Oil, or liquid and clear Honey; the Rays which would otherwise be reflected, will go into the Water, Oil, or Honey, and therefore are not reflected before they arrive at the farther Surface of the Glass, and begin to go out of it. If they go out of it into the Water, Oil or Honey, they go on, because the Attraction of the Glass is almost balanced and render'd ineffectual by the contrary Attraction of the Liquor. But if they go out of it into a *Vacuum* which has no Attraction to balance that of the Glass, the Attraction of the Glass either bends and refracts them, or brings them back and reflects them. And this is still more evident by laying together two Prisms of Glass, or two Object-glasses of very long Telescopes, the one plane the other a little convex, and so compressing them that they do not fully touch, nor are too far asunder. For the Light which falls upon the farther Surface of the first Glass where the Interval between the Glasses is not above the ten <347> hundred thousandth part of an Inch, will go through that Surface, and through the Air or *Vacuum* between the Glasses, and enter into the second Glass, as was explain'd in the first, fourth and eighth Observations of the first Part of the second Book. But if the second Glass be taken away, the Light which goes out of the second Surface of the first Glass into the Air or *Vacuum*, will not go on forwards, but turns back into the first Glass, and is reflected; and therefore it is drawn back by the Power of the first Glass, there being nothing else to turn it back. Nothing more is requisite for producing all the variety of Colours and degrees of Refrangibility, than that the Rays of Light be Bodies of different Sizes, the least of which may make violet the weakest and darkest of the Colours, and be more easily diverted by refracting Surfaces from the right Course; and the rest as they are bigger and bigger, may make the stronger and more lucid Colours, blue, green, yellow and red, and be more and more difficultly diverted. Nothing more is requisite for putting the Rays of Light into Fits of

easy Reflexion and easy Transmission, than that they be small Bodies which by their attractive Powers, or some other Force, stir up Vibrations in what they act upon, which Vibrations being swifter than the Rays, overtake them successively, and agitate them so as by turns to increase and decrease their Velocities, and thereby put them into those Fits. And lastly, the unusual Refraction of Island Crystal looks very much as if it were perform'd by some kind of attractive vir <348> tue lodged in certain Sides both of the Rays, and of the Particles of the Crystal. For were it not for some kind of Disposition or Virtue lodged in some Sides of the Particles of the Crystal, and not in their other Sides, and which inclines and bends the Rays towards the Coast of unusual Refraction, the Rays which fall perpendicularly on the Crystal, would not be refracted towards that Coast rather than towards any other Coast, both at their Incidence and at their Emergence, so as to emerge perpendicularly by a contrary Situation of the Coast of unusual Refraction at the second Surface; the Crystal acting upon the Rays after they have pass'd through it, and are emerging into the Air; or, if you please, into a *Vacuum*. And since the Crystal by this Disposition or Virtue does not act upon the Rays, unless when one of their Sides of unusual Refraction looks towards that Coast, this argues a Virtue or Disposition in those Sides of the Rays, which answers to and sympathizes with that Virtue or Disposition of the Crystal, as the Poles of two Magnets answer to one another. And as Magnetism may be intended and remitted, and is found only in the Magnet and in Iron: So this Virtue of refracting the perpendicular Rays is greater in Island Crystal, less in Crystal of the Rock, and is not yet found in other Bodies. I do not say that this Virtue is magnetical: It seems to be of another kind. I only say, that what ever it be, it's difficult to conceive how the Rays of Light, unless they be Bodies, can have a permanent Virtue in two of their Sides <349> which is not in their other Sides, and this without any regard to their Position to the Space or Medium through which they pass.

What I mean in this Question by a *Vacuum*, and by the Attractions of the Rays of Light towards Glass or Crystal, may be understood by what was said in the 18th, 19th and 20th Questions.

Qu. 30. Are not gross Bodies and Light convertible into one another, and may not Bodies receive much of their activity from the Particles of Light which enter their Composition? For all fix'd Bodies being heated emit Light so long as they continue sufficiently hot, and Light mutually stops in Bodies as often as its Rays strike upon their Parts, as we shew'd above. I know no Body less apt to shine than Water; and yet Water by frequent Distillations changes into fix'd Earth, as Mr. *Boyle* has tried; and then this Earth being enabled to endure a sufficient Heat, shines by Heat like other Bodies.

The changing of Bodies into Light, and Light into Bodies, is very conformable to the Course of Nature, which seems delighted with Transmutations. Water, which is a very fluid tasteless Salt, she changes by Heat into Vapour, which is a sort of Air, and by Cold into Ice, which is a hard, pellucid, brittle, fusible Stone: and this Stone returns into Water by Heat, and Vapour returns into Water by Cold. Earth by Heat becomes Fire, and by Cold returns into Earth. Dense Bodies by Fermentation rarify into several sorts of Air, and this Air by Fermentation, and sometimes without it, returns into dense <350> Bodies. Mercury appears sometimes in the form of a fluid Metal, sometimes in the form of a hard brittle Metal, sometimes in the form of a corrosive pellucid Salt call'd Sublimate, sometimes in the form of a tastless, pellucid, volatile white Earth, call'd *Mercurius dulcis*; or in that of a red opake volatile Earth, call'd Cinnaber; or in that of a red or white Precipitate, or in that of a fluid Salt; and in Distillation it turns into Vapour, and being agitated *in vacuo*, it shines like Fire. And after all these Changes it returns again into its first form of Mercury. Eggs grow from insensible Magnitudes, and change into Animals; Tadpoles into Frogs; and Worms into Flies. All Birds, Beasts and Fishes, Insects, Trees, and other Vegetables, with their several parts, grow out of Water and watry Tinctures and Salts, and by Putrefaction return again into watry Substances. And Water standing a few Days in the open Air, yields a Tincture, which (like that of Mault) by standing longer yields a Sediment and a Spirit, but before Putrefaction is fit Nourishment for Animals and Vegetables. And among such various and strange Transmutations, why may not Nature change Bodies into Light, and Light into Bodies?

Qu. 31. Have not the small Particles of Bodies certain Powers, Virtues or Forces, by which they act at a distance, not only upon the Rays of Light for reflecting, refracting, and inflecting them, but also upon one another for producing a great part of the Phænomena of Nature? For it's well known, that Bodies act <351> one upon another by the Attractions of Gravity, Magnetism and Electricity; and these Instances shew the Tenor and Course of Nature, and make it not improbable but that there may be more attractive Powers than these. For Nature is very consonant and conformable to her self. How these Attractions may be perform'd, I do not here consider. What I call Attraction may be perform'd by impulse, or by some other means unknown to me. I use that Word here to signify only in general any Force by which Bodies tend towards one another,

whatsoever be the Cause. For we must learn from the Phænomena of Nature what Bodies attract one another, and what are the Laws and Properties of the Attraction, before we enquire the Cause by which the Attraction is perform'd. The Attractions of Gravity, Magnetism and Electricity, reach to very sensible distances, and so have been observed by vulgar Eyes, and there may be others which reach to so small distances as hitherto escape Observation; and perhaps electrical Attraction may reach to such small distances, even without being excited by Friction.

For when Salt of Tartar runs *per deliquium*, is not this done by an Attraction between the Particles of the Salt of Tartar, and the Particles of the Water which float in the Air in the form of Vapours? And why does not common Salt, or Salt-petre, or Vitriol, run *per deliquium*, but for want of such an Attraction? Or why does not Salt of Tartar draw more Water out of the Air than in a certain Proportion to its quantity, but for want of an attractive Force <352> after it is satiated with Water? And whence is it but from this attractive Power that Water which alone distils with a gentle lukewarm Heat, will not distil from Salt of Tartar without a great Heat? And is it not from the like attractive Power between the Particles of Oil of Vitriol and the Particles of Water, that Oil of Vitriol draws to it a good quantity of Water out of the Air, and after it is satiated draws no more, and in Distillation lets go the Water very difficultly? And when Water and Oil of Vitriol poured successively into the same Vessel grow very hot in the mixing, does not this Heat argue a great Motion in the parts of the Liquors? And does not this Motion argue that the Parts of the two Liquors in mixing coalesce with Violence, and by consequence rush towards one another with an accelerated Motion? And when *Aqua fortis* or Spirit of Vitriol poured upon Filings of Iron, dissolves the Filings with a great Heat and Ebullition, is not this Heat and Ebullition effected by a violent Motion of the Parts, and does not that Motion argue that the acid Parts of the Liquor rush towards the Parts of the Metal with violence, and run forcibly into its Pores till they get between its outmost Particles and the main Mass of the Metal, and surrounding those Particles loosen them from the main Mass, and set them at liberty to float off into the Water? And when the acid Particles, which alone would distil with an easy Heat, will not separate from the Particles of the Metal without a very vio <353> lent Heat, does not this confirm the Attraction between them?

When Spirit of Vitriol poured upon common Salt or Salt-petre makes an Ebullition with the Salt and unites with it, and in Distillation the Spirit of the common Salt or Salt-petre comes over much easier than it would do before, and the acid part of the Spirit of Vitriol stays behind; does not this argue that the fix'd Alcaly of the Salt attracts the acid Spirit of the Vitriol more strongly than its own Spirit, and not being able to hold them both, lets go its own? And when Oil of Vitriol is drawn off from its weight of Nitre, and from both the Ingredients a compound Spirit of Nitre is distilled, and two parts of this Spirit are poured on one part of Oil of Cloves or Carraway Seeds, or of any ponderous oil of vegetable or animal Substances, or Oil of Turpentine thicken'd with a little Balsam of Sulphur, and the Liquors grow so very hot in mixing, as presently to send up a burning Flame: Does not this very great and sudden Heat argue that the two Liquors mix with violence, and that their Parts in mixing run towards one another with an accelerated Motion, and clash with the greatest Force? And is it not for the same reason that well rectified Spirit flashes; and that the *Pulvis fulminans*, composed of Sulphur, Nitre, and Salt of Tartar, goes off with a more sudden and violent Explosion than Gun-powder, the acid Spirits of the Sulphur and Nitre rushing towards one another, and towards the Salt of Tartar, with so <354> great a violence, as by the shock to turn the whole at once into Vapour and Flame? Where the Dissolution is slow, it makes a slow Ebullition and a gentle Heat; and where it is quicker, it makes a greater Ebullition with more Heat; and where it is done at once, the Ebullition is contracted into a sudden Blast or violent Explosion, with a heat equal to that of Fire and Flame. So when a Drachm of the above mention'd compound Spirit of Nitre was poured upon half a Drachm of Oil of Caraway Seeds *in vacuo*; the Mixture immediately made a flash like Gun-powder, and burst the exhausted Receiver, which was a Glass six Inches wide, and eight Inches deep. And even the gross Body of Sulphur powder'd, and with an equal weight of Iron Filings, and a little Water made into Paste, acts upon the Iron, and in five or six Hours grows too hot to be touch'd, and emits a Flame. And by these Experiments compared with the great quantity of Sulphur with which the Earth abounds, and the warmth of the interior Parts of the Earth, and hot Springs, and burning Mountains, and with Damps, mineral Coruscations, Earthquakes, hot suffocating Exhalations, Hurricanes and Spouts; we may learn that sulphureous Steams abound in the Bowels of the Earth and ferment with Minerals, and sometimes take fire with a sudden Coruscation and Explosion; and if pent up in subterraneous Caverns, burst the Caverns with a great shaking of the Earth, as in springing of a Mine. And then the Vapour generated by the Explosion, expiring through the Pores of the <355> Earth, feels hot and suffocates, and makes Tempests and Hurricanes, and sometimes causes the Land to slide, or the Sea to boil, and carries up the Water thereof in Drops, which by their weight fall down again in Spouts. Also some sulphureous Steams, at all

times when the Earth is dry, ascending into the Air, ferment there with nitrous Acids, and sometimes taking fire cause Lightening and Thunder, and fiery Meteors. For the Air abounds with acid Vapours fit to promote Fermentations, as appears by the rusting of Iron and Copper in it, the kindling of Fire by blowing, and the beating of the Heart by means of Respiration. Now the above mention'd Motions are so great and violent as to shew that in Fermentations, the Particles of Bodies which almost rest, are put into new Motions by a very potent Principle, which acts upon them only when they approach one another, and causes them to meet and clash with great violence, and grow hot with the Motion, and dash one another into pieces, and vanish into Air, and Vapour, and Flame.

When Salt of Tartar *per deliquium*, being poured into the Solution of any Metal, precipitates the Metal, and makes it fall down to the bottom of the Liquor in the form of Mud: Does not this argue that the acid Particles are attracted more strongly by the Salt of Tartar than by the Metal, and by the stronger Attraction go from the Metal to the Salt of Tartar? And so when a Solution of Iron in *Aqua fortis* dissolves the *Lapis Calaminaris* and lets go the Iron, or a Solution of Copper dissolves Iron im <356> mersed in it and lets go the Copper, or a Solution of Silver dissolves Copper and lets go the Silver, or a Solution of Mercury in *Aqua fortis* being poured upon Iron, Copper, Tin or Lead, dissolves the Metal and lets go the Mercury, does not this argue that the acid Particles of the *Aqua fortis* are attracted more strongly by the *Lapis Calaminaris* than by Iron, and more strongly by Iron than by Copper, and more strongly by Copper than by Silver, and more strongly by Iron, Copper, Tin and Lead, than by Mercury? And is it not for the same reason that Iron requires more *Aqua fortis* to dissolve it than Copper, and Copper more than the other Metals; and that of all Metals, Iron is dissolved most easily, and is most apt to rust; and next after Iron, Copper?

When Oil of Vitriol is mix'd with a little Water, or is run *per deliquium*, and in Distillation the Water ascends difficultly, and brings over with it some part of the Oil of Vitriol in the form of Spirit of Vitriol, and this Spirit being poured upon Iron, Copper, or Salt of Tartar, unites with the Body and lets go the Water, doth not this shew that the acid Spirit is attracted by the Water, and more attracted by the fix'd Body than by the Water, and therefore lets go the Water to close with the fix'd Body? And is it not for the same reason that the Water and acid Spirits which are mix'd together in Vinegar, *Aqua fortis*, and Spirit of Salt, cohere and rise together in Distillation; but if the *Menstruum* be poured on Salt of Tartar, or on Lead or Iron, or any fix'd Body <357> which it can dissolve, the Acid by a stronger Attraction adheres to the Body, and lets go the Water? And is it not also from a mutual Attraction that the Spirits of Soot and Sea-Salt unite and compose the Particles of Sal-armoniac, which are less volatile than before, because grosser and freer from Water; and that the Particles of Sal-armoniac in Sublimation carry up the Particles of Antimony, which will not sublime alone; and that the Particles of Mercury uniting with the acid Particles of Spirit of Salt compose Mercury sublimate, and with the Particles of Sulphur, compose Cinnaber; and that the Particles of Spirit of Wine and Spirit of Urine well rectified unite, and letting go the Water which dissolved them, compose a consistent Body; and that in subliming Cinnaber from Salt of Tartar, or from quick Lime, the Sulphur by a stronger Attraction of the Salt or Lime lets go the Mercury, and stays with the fix'd Body; and that when Mercury sublimate is sublimed from Antimony, or from Regulus of Antimony, the Spirit of Salt lets go the Mercury, and unites with the antimonial Metal which attracts it more strongly, and stays with it till the Heat be great enough to make them both ascend together, and then carries up the Metal with it in the form of a very fusible Salt, called Butter of Antimony, although the Spirit of Salt alone be almost as volatile as Water, and the Antimony alone as fix'd as Lead?

When *Aqua fortis* dissolves Silver and not Gold, and *Aqua regia* dissolves Gold and not <358> Silver, may it not be said that *Aqua fortis* is subtile enough to penetrate Gold as well as Silver, but wants the attractive Force to give it Entrance; and that *Aqua regia* is subtile enough to penetrate Silver as well as Gold, but wants the attractive Force to give it Entrance? For *Aqua regia* is nothing else than *Aqua fortis* mix'd with some Spirit of Salt, or with Sal armoniac; and even common Salt dissolved in *Aqua fortis*, enables the *Menstruum* to dissolve Gold, though the Salt be a gross Body. When therefore Spirit of Salt precipitates Silver out of *Aqua fortis*, is it not done by attracting and mixing with the *Aqua fortis*, and not attracting, or perhaps repelling Silver? And when Water precipitates Antimony out of the Sublimate of Antimony and Sal-armoniac, or out of Butter of Antimony, is it not done by its dissolving, mixing with, and weakening the Sal-armoniac or Spirit of Salt, and its not attracting, or perhaps repelling the Antimony? And is it not for want of an attractive Virtue between the Parts of Water and Oil, of Quick-silver and Antimony, of Lead and Iron, that these Substances do not mix; and by a weak Attraction, that Quick-silver and Copper mix difficultly; and from a strong one, that Quick-silver and Tin, Antimony and Iron, Water and Salts, mix readily? And in

general, is it not from the same Principle that Heat congregates homogeneal Bodies, and separates heterogeneal ones?

When Arsnick with Soap gives a Regulus, and with Mercury sublimate a volatile fusible <359> Salt, like Butter of Antimony, doth not this shew that Arsnick, which is a Substance totally volatile, is compounded of fix'd and volatile Parts, strongly cohering by a mutual Attraction, so that the volatile will not ascend without carrying up the fixed? And so, when an equal weight of Spirit of Wine and Oil of Vitriol are digested together, and in Distillation yield two fragrant and volatile Spirits which will not mix with one another, and a fix'd black Earth remains behind; doth not this shew that Oil of Vitriol is composed of volatile and fix'd Parts strongly united by Attraction, so as to ascend together in form of a volatile, acid, fluid Salt, until the Spirit of Wine attracts and separates the volatile Parts from the fixed? And therefore, since Oil of Sulphur *per Campanam* is of the same Nature with Oil of Vitriol, may it not be inferred, that Sulphur is also a mixture of volatile and fix'd Parts so strongly cohering by Attraction, as to ascend together in Sublimation. By dissolving Flowers of Sulphur in Oil of Turpentine, and distilling the Solution, it is found that Sulphur is composed of an inflamable thick Oil or fat Bitumen, an acid Salt, a very fix'd Earth, and a little Metal. The three first were found not much unequal to one another, the fourth in so small a quantity as scarce to be worth considering. The acid Salt dissolved in Water, is the same with Oil of Sulphur *per Campanam*, and abounding much in the Bowels of the Earth, and particularly in Markasites, unites it self to the other Ingredients of the Markasite, which are, Bitumen, I <360> ron, Copper and Earth, and with them compounds Alume, Vitriol and Sulphur. With the Earth alone it compounds Alume; with the Metal alone, or Metal and Earth together, it compounds Vitriol; and with the Bitumen and Earth it compounds Sulphur. Whence it comes to pass that Markasites abound with those three Minerals. And is it not from the mutual Attraction of the Ingredients that they stick together for compounding these Minerals, and that the Bitumen carries up the other Ingredients of the Sulphur, which without it would not sublime? And the same Question may be put concerning all, or almost all the gross Bodies in Nature. For all the Parts of Animals and Vegetables are composed of Substances volatile and fix'd, fluid and solid, as appears by their Analysis: and so are Salts and Minerals, so far as Chymists have been hitherto able to examine their Composition.

When Mercury sublimate is resublimed with fresh Mercury, and becomes *Mercurius dulcis*, which is a white tasteless Earth scarce dissolvable in Water, and *Mercurius dulcis* resublimed with Spirit of Salt returns into Mercury sublimate; and when Metals corroded with a little acid turn into Rust, which is an Earth tasteless and indissolvable in Water, and this Earth imbibed with more acid becomes a metallick Salt; and when some Stones, as Spar of Lead, dissolved in proper *Menstruums* become Salts; do not these things shew that Salts are dry Earth and watry Acid united by Attraction, and that the Earth will not become a Salt without so <361> much Acid as makes it dissolvable in Water? Do not the sharp and pungent Tastes of Acids arise from the strong Attraction whereby the acid Particles rush upon and agitate the Particles of the Tongue? And when Metals are dissolved in acid *Menstruums*, and the Acids in conjunction with the Metal act after a different manner, so that the Compound has a different taste much milder than before, and sometimes a sweet one; is it not because the Acids adhere to the metallick Particles, and thereby lose much of their Activity? And if the Acid be in too small a Proportion to make the Compound dissolvable in Water, will it not by adhering strongly to the Metal become unactive and lose its taste, and the Compound be a tasteless Earth? For such things as are not dissolvable by the Moisture of the Tongue, act not upon the Taste.

As Gravity makes the Sea flow round the denser and weightier Parts of the Globe of the Earth, so the Attraction may make the watry Acid flow round the denser and compacter Particles of Earth for composing the Particles of Salt. For otherwise the Acid would not do the office of a Medium between the Earth and common Water, for making Salts dissolvable in the Water; nor would Salt of Tartar readily draw off the Acid from dissolved Metals, nor Metals the Acid from Mercury. Now as in the great Globe of the Earth and Sea, the densest Bodies by their Gravity sink down in Water, and always endeavour to go towards the Center of the Globe; so in Particles of Salt, the <362> densest Matter may always endeavour to approach the Center of the Particle: So that a Particle of Salt may be compared to a Chaos; being dense, hard, dry, and earthy in the Center; and rare, soft, moist, and watry in the Circumference. And hence it seems to be that Salts are of a lasting Nature, being scarce destroy'd, unless by drawing away their watry Parts by violence, or by letting them soak into the Pores of the central Earth by a gentle Heat in Putrefaction, until the Earth be dissolved by the Water, and separated into smaller Particles, which by reason of their smallness make the rotten Compound appear of a black Colour. Hence also it may be that the Parts of Animals and Vegetables preserve their several Forms, and assimilate their Nourishment; the soft and moist Nourishment easily changing its Texture by a

gentle Heat and Motion, till it becomes like the dense, hard, dry, and durable Earth in the Center of each Particle. But when the Nourishment grows unfit to be assimilated, or the central Earth grows too feeble to assimilate it, the Motion ends in Confusion, Putrefaction and Death.

If a very small quantity of any Salt or Vitriol be dissolved in a great quantity of Water, the Particles of the Salt or Vitriol will not sink to the bottom, though they be heavier in Specie than the Water, but will evenly diffuse themselves into all the Water, so as to make it as saline at the top as at the bottom. And does not this imply that the Parts of the Salt or Vitriol recede from one another, and endeavour to ex <363> pand themselves, and get as far asunder as the quantity of Water in which they float, will allow? And does not this Endeavour imply that they have a repulsive Force by which they fly from one another, or at least, that they attract the Water more strongly than they do one another? For as all things ascend in Water which are less attracted than Water, by the gravitating Power of the Earth; so all the Particles of Salt which float in Water, and are less attracted than Water by any one Particle of Salt, must recede from that Particle, and give way to the more attracted Water.

When any saline Liquor is evaporated to a Cuticle and let cool, the Salt concretes in regular Figures; which argues, that the Particles of the Salt before they concreted, floated in the Liquor at equal distances in rank and file, and by consequence that they acted upon one another by some Power which at equal distances is equal, at unequal distances unequal. For by such a Power they will range themselves uniformly, and without it they will float irregularly, and come together as irregularly. And since the Particles of Island Crystal act all the same way upon the Rays of Light for causing the unusual Refraction, may it not be supposed that in the Formation of this Crystal, the Particles not only ranged themselves in rank and file for concreting in regular Figures, but also by some kind of polar Virtue turned their homogeneal Sides the same way.

The Parts of all homogeneal hard Bodies which fully touch one another, stick together <364> very strongly. And for explaining how this may be, some have invented hooked Atoms, which is begging the Question; and others tell us that Bodies are glued together by rest, that is, by an occult Quality, or rather by nothing; and others, that they stick together by conspiring Motions, that is, by relative rest amongst themselves. I had rather infer from their Cohesion, that their Particles attract one another by some Force, which in immediate Contact is exceeding strong, at small distances performs the chymical Operations above mention'd, and reaches not far from the Particles with any sensible Effect.

All Bodies seem to be composed of hard Particles: For otherwise Fluids would not congeal; as Water, Oils, Vinegar, and Spirit or Oil of Vitriol do by freezing; Mercury by Fumes of Lead; Spirit of Nitre and Mercury, by dissolving the Mercury and evaporating the Flegm; Spirit of Wine and Spirit of Urine, by deflegming and mixing them; and Spirit of Urine and Spirit of Salt, by subliming them together to make Sal-armoniac. Even the Rays of Light seem to be hard Bodies; for otherwise they would not retain different Properties in their different Sides. And therefore Hardness may be reckon'd the Property of all uncompounded Matter. At least, this seems to be as evident as the universal Impenetrability of Matter. For all Bodies, so far as Experience reaches, are either hard, or may be harden'd; and we have no other Evidence of universal Impenetrability, besides a large Experience without an experi <365> mental Exception. Now if compound Bodies are so very hard as we find some of them to be, and yet are very porous, and consist of Parts which are only laid together; the simple Particles which are void of Pores, and were never yet divided, must be much harder. For such hard Particles being heaped up together, can scarce touch one another in more than a few Points, and therefore must be separable by much less Force than is requisite to break a solid Particle, whose Parts touch in all the Space between them, without any Pores or Interstices to weaken their Cohesion. And how such very hard Particles which are only laid together and touch only in a few Points, can stick together, and that so firmly as they do, without the assistance of something which causes them to be attracted or press'd towards one another, is very difficult to conceive.

The same thing I infer also from the cohering of two polish'd Marbles *in vacuo*, and from the standing of Quick-silver in the Barometer at the height of 50, 60 or 70 Inches, or above, when ever it is well purged of Air and carefully poured in, so that its Parts be every where contiguous both to one another and to the Glass. The Atmosphere by its weight presses the Quick-silver into the Glass, to the height of 29 or 30 Inches. And some other Agent raises it higher, not by pressing it into the Glass, but by making its Parts stick to the Glass, and to one another. For upon any discontinuation of Parts, made either by Bubbles or by shaking the <366> Glass, the whole Mercury falls down to the height of 29 or 30 Inches.

And of the same kind with these Experiments are those that follow. If two plane polish'd Plates of Glass (suppose two pieces of a polish'd Looking-glass) be laid together, so that their sides be parallel and at a very small distance from one another, and then their lower edges be dipped into Water, the Water will rise up between them. And the less the distance of the Glasses is, the greater will be the height to which the Water will rise. If the distance be about the hundredth part of an Inch, the Water will rise to the height of about an Inch; and if the distance be greater or less in any Proportion, the height will be reciprocally proportional to the distance very nearly. For the attractive Force of the Glasses is the same, whether the distance between them be greater or less; and the weight of the Water drawn up is the same, if the height of it be reciprocally proportional to the height of the Glasses. And in like manner, Water ascends between two Marbles polish'd plane, when their polished sides are parallel, and at a very little distance from one another. And if slender Pipes of Glass be dipped at one end into stagnating Water, the Water will rise up within the Pipe, and the height to which it rises will be reciprocally proportional to the Diameter of the Cavity of the Pipe, and will equal the height to which it rises between two Planes of Glass, if the Semidiameter of the Cavity of the Pipe be equal **{**to**}** the distance between the Planes, or thereabouts. <367> And these Experiments succeed after the same manner *in vacuo* as in the open Air, (as hath been tried before the Royal Society,) and therefore are not influenced by the Weight or Pressure of the Atmosphere.

And if a large Pipe of Glass be filled with sifted Ashes well pressed together in the Glass, and one end of the Pipe be dipped into stagnating Water, the Water will rise up slowly in the Ashes, so as in the space of a Week or Fortnight to reach up within the Glass, to the height of 30 or 40 Inches above the stagnating Water. And the Water rises up to this height by the Action only of those Particles of the Ashes which are upon the Surface of the elevated Water; the Particles which are within the Water, attracting or repelling it as much downwards as upwards. And therefore the Action of the Particles is very strong. But the Particles of the Ashes being not so dense and close together as those of Glass, their Action is not so strong as that of Glass, which keeps Quick-silver suspended to the height of 60 or 70 Inches, and therefore acts with a Force which would keep Water suspended to the height of above 60 Feet.

By the same Principle, a Sponge sucks in Water, and the Glands in the Bodies of Animals, according to their several Natures and Dispositions, suck in various Juices from the Blood.

If two plane polish'd Plates of Glass three or four Inches broad, and twenty or twenty five long, be laid, one of them parallel to the Hor <368> izon, the other upon the first, so as at one of their ends to touch one another, and contain an Angle of about 10 or 15 Minutes, and the same be first moisten'd on their inward sides with a clean Cloth dipp'd into Oil of Oranges or Spirit of Turpentine, and a Drop or two of the Oil or Spirit be let fall upon the lower Glass at the other end; so soon as the upper Glass is laid down upon the lower so as to touch it at one end as above, and to touch the Drop at the other end, making with the lower Glass an Angle of about 10 or 15 Minutes; the Drop will begin to move towards the Concourse of the Glasses, and will continue to move with an accelerated Motion, till it arrives at that Concourse of the Glasses. For the two Glasses attract the Drop, and make it run that way towards which the Attractions incline. And if when the Drop is in motion you lift up that end of the Glasses where they meet, and towards which the Drop moves, the Drop will ascend between the Glasses, and therefore is attracted. And as you lift up the Glasses more and more, the Drop will ascend slower and slower, and at length rest, being then carried downward by its Weight, as much as upwards by the Attraction. And by this means you may know the Force by which the Drop is attracted at all distances from the Concourse of the Glasses.

Now by some Experiments of this kind, (made by Mr. *Hawksby)* it has been found that the Attraction is almost reciprocally in a duplicate Proportion of the distance of the middle of the Drop from the Concourse of the Glasses, <369> *viz*. reciprocally in a simple Proportion, by reason of the spreading of the Drop, and its touching each Glass in a larger Surface; and again reciprocally in a simple Proportion, by reason of the Attractions growing stronger within the same quantity of attracting Surface. The Attraction therefore within the same quantity of attracting Surface, is reciprocally as the distance between the Glasses. And therefore where the distance is exceeding small, the Attraction must be exceeding great. By the Table in the second Part of the second Book, wherein the thicknesses of colour'd Plates of Water between two Glasses are set down, the thickness of the Plate where it appears very black, is three eighths of the ten hundred thousandth part of an Inch. And where the Oil of Oranges between the Glasses is of this thickness, the Attraction collected by the foregoing Rule, seems to be so strong, as within a Circle of an Inch in diameter, to suffice to hold up a Weight equal to that of a Cylinder of Water of an Inch in diameter, and two or three Furlongs in

length. And where it is of a less thickness the Attraction may be proportionally greater, and continue to increase, until the thickness do not exceed that of a single Particle of the Oil. There are therefore Agents in Nature able to make the Particles of Bodies stick together by very strong Attractions. And it is the Business of experimental Philosophy to find them out.

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Now the smallest Particles of Matter may cohere by the strongest Attractions, and compose bigger Particles of weaker Virtue; and many of these may cohere and compose bigger Particles whose Virtue is still weaker, and so on for divers Successions, until the Progression end in the biggest Particles on which the Operations in Chymistry, and the Colours of natural Bodies depend, and which by cohering compose Bodies of a sensible Magnitude. If the Body is compact, and bends or yields inward to Pression without any sliding of its Parts, it is hard and elastick, returning to its Figure with a Force arising from the mutual Attraction of its Parts. If the Parts slide upon one another, the Body is malleable or soft. If they slip easily, and are of a fit size to be agitated by Heat, and the Heat is big enough to keep them in Agitation, the Body is fluid; and if it be apt to stick to things, it is humid; and the Drops of every fluid affect a round Figure by the mutual Attraction of their Parts, as the Globe of the Earth and Sea affects a round Figure by the mutual Attraction of its Parts by Gravity.

Since Metals dissolved in Acids attract but a small quantity of the Acid, their attractive Force can reach but to a small distance from them. And as in Algebra, where affirmative Quantities vanish and cease, there negative ones begin; so in Mechanicks, where Attraction ceases, there a repulsive Virtue ought to succeed. And that there is such a Virtue, seems to follow from the Reflexions and Inflexions of the <371> Rays of Light. For the Rays are repelled by Bodies in both these Cases, without the immediate Contact of the reflecting or inflecting Body. It seems also to follow from the Emission of Light; the Ray so soon as it is shaken off from a shining Body by the vibrating Motion of the Parts of the Body, and gets beyond the reach of Attraction, being driven away with exceeding great Velocity. For that Force which is sufficient to turn it back in Reflexion, may be sufficient to emit it. It seems also to follow from the Production of Air and Vapour. The Particles when they are shaken off from Bodies by Heat or Fermentation, so soon as they are beyond the reach of the Attraction of the Body, receding from it, and also from one another with great Strength, and keeping at a distance, so as sometimes to take up above a million of times more space than they did before in the form of a dense Body. Which vast Contraction and Expansion seems unintelligible, by feigning the Particles of Air to be springy and ramous, or rolled up like Hoops, or by any other means than a repulsive Power. The Particles of Fluids which do not cohere too strongly, and are of such a smallness as renders them most susceptible of those Agitations which keep Liquors in a Fluor, are most easily separated and rarified into Vapour, and in the Language of the Chymists, they are volatile, rarifying with an easy Heat, and condensing with Cold. But those which are grosser, and so less susceptible of Agitation, or cohere by a strong <372> er Attraction, are not separated without a stronger Heat, or perhaps not without Fermentation. And these last are the Bodies which Chymists call fix'd, and being rarified by Fementation, become true permanent Air: those Particles receding from one another with the greatest Force, and being most difficultly brought together, which upon Contact cohere most strongly. And because the Particles of permanent Air are grosser, and arise from denser Substances than those of Vapours, thence it is that true Air is more ponderous than Vapour, and that a moist Atmosphere is lighter than a dry one, quantity for quantity. From the same repelling Power it seems to be that Flies walk upon the Water without wetting their Feet; and that the Object-glasses of long Telescopes lie upon one another without touching; and that dry Powders are difficultly made to touch one another so as to stick together, unless by melting them, or wetting them with Water, which by exhaling may bring them together; and that two polish'd Marbles, which by immediate Contact stick together, are difficultly brought so close together as to stick.

And thus Nature will be very conformable to her self and very simple, performing all the great Motions of the heavenly Bodies by the Attraction of Gravity which intercedes those Bodies, and almost all the small ones of their Particles by some other attractive and repelling Powers which intercede the Particles. The *Vis inertiæ* is a passive Principle by which Bo <373> dies persist in their Motion or Rest, receive Motion in proportion to the Force impressing it, and resist as much as they are resisted. By this Principle alone there never could have been any Motion in the World. Some other Principle was necessary for putting Bodies into Motion; and now they are in Motion, some other Principle is necessary for conserving the Motion. For from the various Composition of two Motions, 'tis very certain that there is not always the same quantity of Motion in the

World. For if two Globes joined by a slender Rod, revolve about their common Center of Gravity with an uniform Motion, while that Center moves on uniformly in a right Line drawn in the Plane of their circular Motion; the Sum of the Motions of the two Globes, as often as the Globes are in the right Line described by their common Center of Gravity, will be bigger than the Sum of their Motions, when they are in a Line perpendicular to that right Line. By this Instance it appears that Motion may be got or lost. But by reason of the Tenacity of Fluids, and Attrition of their Parts, and the Weakness of Elasticity in Solids, Motion is much more apt to be lost than got, and is always upon the Decay. For Bodies which are either absolutely hard, or so soft as to be void of Elasticity, will not rebound from one another. Impenetrability makes them only stop. If two equal Bodies meet directly *in vacuo*, they will by the Laws of Motion stop where they meet, and lose all their Motion, and remain in rest, unless <374> they be elastick, and receive new Motion from their Spring. If they have so much Elasticity as suffices to make them rebound with a quarter, or half, or three quarters of the Force with which they come together, they will lose three quarters, or half, or a quarter of their Motion. And this may be tried, by letting two equal Pendulums fall against one another from equal heights. If the Pendulums be of Lead or soft Clay, they will lose all or almost all their Motions: If of elastick Bodies they will lose all but what they recover from their Elasticity. If it be said, that they can lose no Motion but what they communicate to other Bodies, the consequence is, that *in vacuo* they can lose no Motion, but when they meet they must go on and penetrate one anothers Dimensions. If three equal round Vessels be filled, the one with Water, the other with Oil, the third with molten Pitch, and the Liquors be stirred about alike to give them a vortical Motion; the Pitch by its Tenacity will lose its Motion quickly, the Oil being less tenacious will keep it longest, but yet will lose it in a short time. Whence it is easy to understand, that if many contiguous Vortices of molten Pitch were each of them as large as those which some suppose to revolve about the Sun and fix'd Stars, yet these and all their Parts would, by their tenacity and stiffness, communicate their Motion to one another till they all rested among themselves. Vortices of Oil or Water, or some fluider Matter, might <375> continue longer in Motion; but unless the Matter were void of all Tenacity and Attrition of Parts, and Communication of Motion, (which is not to be supposed) the Motion would constantly decay. Seeing therefore the variety of Motion which we find in the World is always decreasing, there is a necessity of conserving and recruiting it by active Principles, such as are the cause of Gravity, by which Planets and Comets keep their Motions in their Orbs, and Bodies acquire great Motion in falling; and the cause of Fermentation, by which the Heart and Blood of Animals are kept in perpetual Motion and Heat; the inward Parts of the Earth are constantly warm'd, and in some places grow very hot; Bodies burn and shine, Mountains take fire, the Caverns of the Earth are blown up, and the Sun continues violently hot and lucid, and warms all things by his Light. For we meet with very little Motion in the World, besides what is owing to these active Principles. And if it were not for these Principles the Bodies of the Earth, Planets, Comets, Sun, and all things in them would grow cold and freeze, and become inactive Masses; and all Putrefaction, Generation, Vegetation and Life would cease, and the Planets and Comets would not remain in their Orbs.

All these things being consider'd, it seems probable to me, that God in the Beginning form'd Matter in solid, massy, hard, impenetrable, moveable Particles, of such Sizes and Figures, and with such other Properties, and in such Proportion <376> to Space, as most conduced to the End for which he form'd them; and that these primitive Particles being Solids, are incomparably harder than any porous Bodies compounded of them; even so very hard, as never to wear or break in pieces: No ordinary Power being able to divide what God himself made one in the first Creation. While the Particles continue entire, they may compose Bodies of one and the same Nature and Texture in all Ages: But should they wear away, or break in pieces, the Nature of Things depending on them, would be changed. Water and Earth composed of old worn Particles and Fragments of Particles, would not be of the same Nature and Texture now, with Water and Earth composed of entire Particles, in the Beginning. And therefore that Nature may be lasting, the Changes of corporeal Things are to be placed only in the various Separations and new Associations and Motions of these permanent Particles; compound Bodies being apt to break, not in the midst of solid Particles, but where those Particles are laid together, and only touch in a few Points.

It seems to me farther, that these Particles have not only a *Vis inertiæ*, accompanied with such passive Laws of Motion as naturally result from that Force, but also that they are moved by certain active Principles, such as is that of Gravity, and that which causes Fermentation, and the Cohesion of Bodies. These Principles I consider not as occult Qualities, supposed to result from the specifick Forms of Things, but <377> as general Laws of Nature, by which the Things themselves are form'd: their Truth appearing to us by Phænomena, though their Causes be not yet discover'd. For these are manifest Qualities, and their Causes only are occult. And the *Aristotelians* gave the Name of occult Qualities not to manifest Qualities, but to such Qualities only

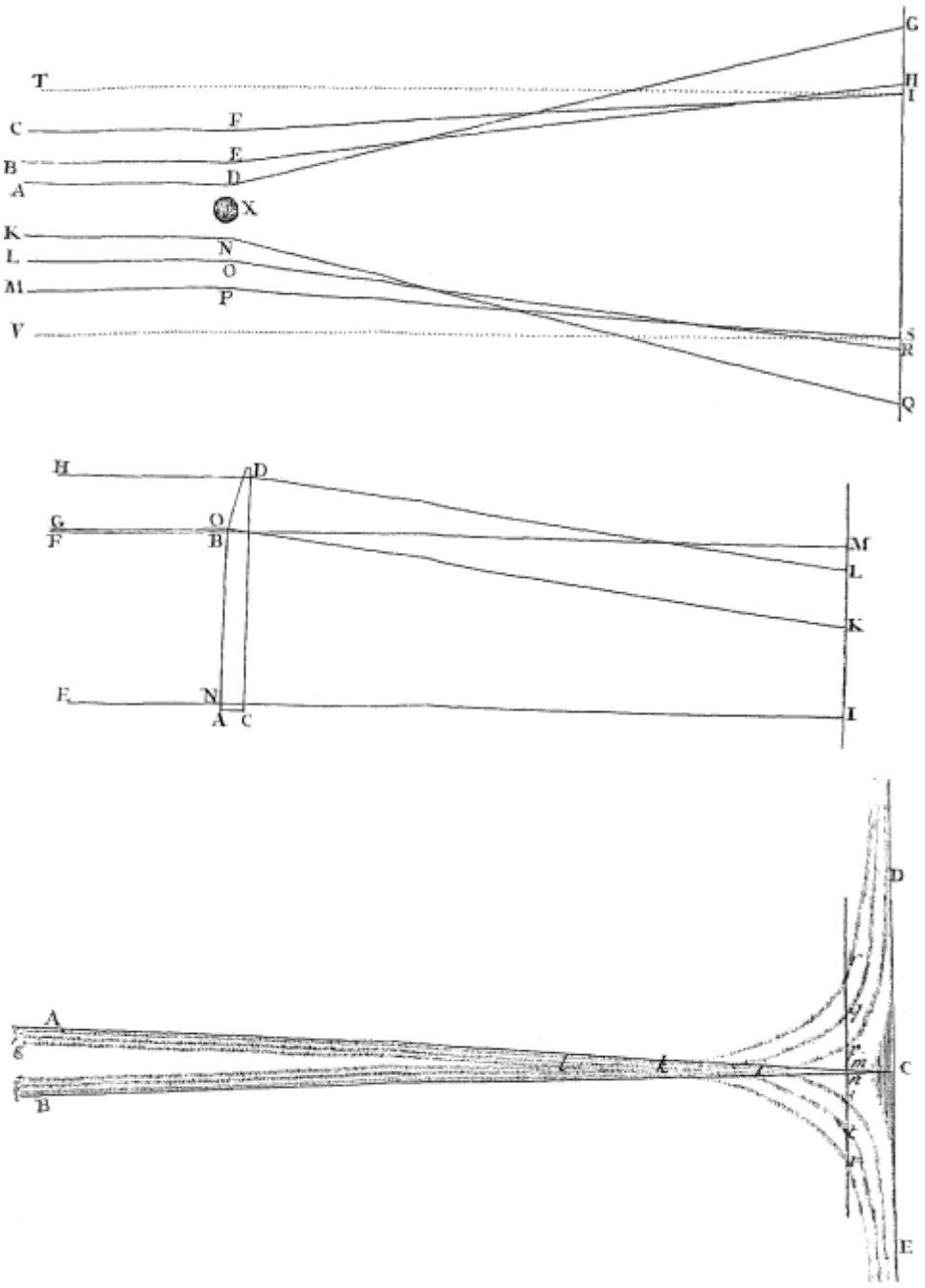
as they supposed to lie hid in Bodies, and to be the unknown Causes of manifest Effects: Such as would be the Causes of Gravity, and of magnetick and electrick Attractions, and of Fermentations, if we should suppose that these Forces or Actions arose from Qualities unknown to us, and uncapable of being discovered and made manifest. Such occult Qualities put a stop to the Improvement of natural Philosophy, and therefore of late Years have been rejected. To tell us that every Species of Things is endow'd with an occult specifick Quality by which it acts an produces manifest Effects, is to tell us nothing: But to derive two or three general Principles of Motion from Phænomena, and afterwards to tell us how the Properties and Actions of all corporeal Things follow from those manifest Principles, would be a very great step in Philosophy, though the Causes of those Principles were not yet discover'd: And therefore I scruple not to propose the Principles of Motion above mention'd, they being of very general Extent, and leave their Causes to be found out.

Now by the help of these Principles, all material Things seem to have been composed of <378> the hard and solid Particles above mention'd, variously associated in the first Creation by the Counsel of an intelligent Agent. For it became him who created them to set them in order. And if he did so, it's unphilosophical to seek for any other Origin of the World, or to pretend that it might arise out of a Chaos by the mere Laws of Nature; though being once form'd, it may continue by those Laws for many Ages. For while Comets move in very excentrick Orbs in all manner of Positions, blind Fate could never make all the Planets move one and the same way in Orbs concentrick, some inconsiderable Irregularities excepted which may have risen from the mutual Actions of Comets and Planets upon one another, and which will be apt to increase, till this System wants a Reformation. Such a wonderful Uniformity in the Planetary System must be allowed the Effect of Choice. And so must the Uniformity in the Bodies of Animals, they having generally a right and a left side shaped alike, and on either side of their Bodies two Legs behind, and either two Arms, or two Legs, or two Wings before upon their Shoulders, and between their Shoulders a Neck running down into a Back-bone, and a Head upon it; and in the Head two Ears, two Eyes, a Nose, a Mouth and a Tongue, alike situated. Also the first Contrivance of those very artificial Parts of Animals, the Eyes, Ears, Brain, Muscles, Heart, Lungs, Midriff, Glands, Larynx, Hands, Wings, Swimming Bladders, na <379> tural Spectacles, and other Organs of Sense and Motion; and the Instinct of Brutes and Insects, can be the effect of nothing else than the Wisdom and Skill of a powerful ever-living Agent, who being in all Places, is more able by his Will to move the Bodies within his boundless uniform Sensorium, and thereby to form and reform the Parts of the Universe, than we are by our Will to move the Parts of our own Bodies. And yet we are not to consider the World as the Body of God, or the several Parts thereof, as the Parts of God. He is an uniform Being, void of Organs, Members or Parts, and they are his Creatures subordinate to him, and subservient to his Will; and he is no more the Soul of them, than the Soul of a Man is the Soul of the Species of Things carried through the Organs of Sense into the place of its Sensation, where it perceives them by means of its immediate Presence, without the Intervention of any third thing. The Organs of Sense are not for enabling the Soul to perceive the Species of Things in its Sensorium, but only for conveying them thither; and God has no need of such Organs, he being every where present to the Things themselves. And since Space is divisible *in infinitum*, and Matter is not necessarily in all places, it may be also allow'd that God is able to create Particles of Matter of several Sizes and Figures, and in several Proportions to Space, and perhaps of different Densities and Forces, and thereby to vary the Laws of Nature, and make Worlds of several sorts in <380> several Parts of the Universe. At least, I see nothing of Contradiction in all this.

As in Mathematicks, so in Natural Philosophy, the Investigation of difficult Things by the Method of Analysis, ought ever to precede the Method of Composition. This Analysis consists in making Experiments and Observations, and in drawing general Conclusions from them by Induction, and admitting of no Objections against the Conclusions, but such as are taken from Experiments, or other certain Truths. For Hypotheses are not to be regarded in experimental Philosophy. And although the arguing from Experiments and Observations by Induction be no Demonstration of general Conclusions; yet it is the best way of arguing which the Nature of Things admits of, and may be looked upon as so much the stronger, by how much the Induction is more general. And if no Exception occur from Phænomena, the Conclusion may be pronounced generally. But if at any time afterwards any Exception shall occur from Experiments, it may then begin to be pronounced with such Exceptions as occur. By this way of Analysis we may proceed from Compounds to Ingredients, and from Motions to the Forces producing them; and in general, from Effects to their Causes, and from particular Causes to more general ones, till the Argument end in the most general. This is the Method of Analysis: And the Synthesis consists in assuming the Causes discover'd and establish'd as Principles, and by them explaining the Phæ <381> nomena proceeding from them, and proving the Explanations.

In the two first Books of these Opticks, I proceeded by this Analysis to discover and prove the original Differences of the Rays of Light in respect of Refrangibility, Reflexibility, and Colour, and their alternate Fits of easy Reflexion and easy Transmission, and the Properties of Bodies, both opake and pellucid, on which their Reflexions and Colours depend. And these Discoveries being proved, may be assumed in the Method of Composition for explaining the Phænomena arising from them: An Instance of which Method I gave in the End of the first Book. In this third Book I have only begun the Analysis of what remains to be discover'd about Light and its Effects upon the Frame of Nature, hinting several things about it, and leaving the Hints to be examin'd and improved by the farther Experiments and Observations of such as are inquisitive. And if natural Philosophy in all its Parts, by pursuing this Method, shall at length be perfected, the Bounds of moral Philosophy will be also enlarged. For so far as we can know by natural Philosophy what is the first Cause, what Power he has over us, and what Benefits we receive from him, so far our Duty towards him, as well as that towards one another, will appear to us by the Light of Nature. And no doubt, if the Worship of false Gods had not blinded the Heathen, their moral Philosophy would have gone farther than to the four Cardinal Virtues; and <382> instead of teaching the Transmigration of Souls, and to worship the Sun and Moon, and dead Heroes, they would have taught us to worship our true Author and Benefactor.

FINIS.



[1] *See the following Scheme.*

[2] *Mais pour dire comment cela se fait, je n'ay rien trove jusqu' ici qui me sati fasse.* C.H. de la lumiere. c. 5. p 91.