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## **A view of Sir Isaac Newton's philosophy**

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Chap. II. Of the properties of bodies, upon which their colours depend.

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yellowish turn of the sun's light causes the blue not to be quite so visible in it, as it should be, were the light perfectly white; but makes the beam of light incline rather towards a pale white.

## CHAP. II.

### Of the properties of BODIES, upon which their COLOURS depend.

**A**FTER having shewn in the last chapter, that the difference between the colours of bodies viewed in open day-light is only this, that some bodies are disposed to reflect rays of one colour in the greatest plenty, and other bodies rays of some other colour; order now requires us to examine more particularly into the property of bodies, which gives them this difference. But this our author shews to be nothing more, than the different magnitude of the particles, which compose each body: this I question not will appear no small paradox. And indeed this whole chapter will contain scarce any assertions, but what will be almost incredible, though the arguments for them are so strong and convincing, that they force our assent. In the former chapter have been explained properties of light, not in the least thought of before our author's discovery of them; yet are they not difficult to admit, as soon as experiments are known to give proof of their reality; but some of the propositions to be stated here will, I fear, be accounted almost past belief; notwithstanding that the arguments, by which they

they are established are unanswerable. For it is proved by our author, that bodies are rendered transparent by the minuteness of their pores, and become opaque by having them large; and more, that the most transparent body by being reduced to a great thinness will become less pervious to the light.

2. BUT whereas it had been the received opinion, and yet remains so among all who have not studied this philosophy, that light is reflected from bodies by its impinging against their solid parts, rebounding from them, as a tennis ball or other elastic substance would do, when struck against any hard and resisting surface; it will be proper to begin with declaring our author's sentiment concerning this, who shews by many arguments that reflection cannot be caused by any such means<sup>a</sup>: some few of his proofs I shall set down, referring the reader to our author himself for the rest.

3. IT is well known, that when light falls upon any transparent body, glass for instance, part of it is reflected and part transmitted; for which it is ready to account, by saying that part of the light enters the pores of the glass, and part impinges upon its solid parts. But when the transmitted light arrives at the farther surface of the glass, in passing out of glass into air there is as strong a reflection caused, or rather something stronger. Now it is not to be conceived, how the light should find as many solid parts in the air to strike against as in the glass, or even a greater num-

<sup>a</sup> Opt. Book II. prop. 8.

ber of them. And to augment the difficulty, if water be placed behind the glass, the reflection becomes much weaker. Can we therefore say, that water has fewer solid parts for the light to strike against, than the air? And if we should, what reason can be given for the reflection's being stronger, when the air by the air-pump is removed from behind the glass, than when the air receives the rays of light. Besides the light may be so inclined to the hinder surface of the glass, that it shall wholly be reflected, which happens when the angle which the ray makes with the surface does not exceed about  $49\frac{1}{3}$  degrees; but if the inclination be a very little increased, great part of the light will be transmitted; and how the light in one case should meet with nothing but the solid parts of the air, and by so small a change of its inclination find pores in great plenty, is wholly inconceivable. It cannot be said, that the light is reflected by striking against the solid parts of the surface of the glass; because without making any change in that surface, only by placing water contiguous to it instead of air, great part of that light shall be transmitted, which could find no passage through the air. Moreover in the last experiment recited in the preceding chapter, when by turning the prisms DEF, GHI, the blue light became wholly reflected, while the rest was mostly transmitted, no possible reason can be assigned, why the blue-making rays should meet with nothing but the solid parts of the air between the prisms, and the rest of the light in the very same obliquity find pores in abundance. Nay farther, when two glasses touch each other, no reflection at all is made; though

it does not in the least appear, how the rays should avoid the solid parts of glass, when contiguous to other glass, any more than when contiguous to air. But in the last place upon this supposition it is not to be comprehended, how the most polished substances could reflect the light in that regular manner we find they do; for when a polished looking glass is covered over with quick silver, we cannot suppose the particles of light so much larger than those of the quicksilver, that they should not be scattered as much in reflection, as a parcel of marbles thrown down upon a rugged pavement. The only cause of so uniform and regular a reflection must be some more secret cause, uniformly spread over the whole surface of the glass.

4. BUT now, since the reflection of light from bodies does not depend upon its impinging against their solid parts, some other reason must be sought for. And first it is past doubt that the least parts of almost all bodies are transparent, even the microscope shewing as much<sup>a</sup>; besides that it may be experienced by this method. Take any thin plate of the opaquest body, and apply it to a small hole designed for the admission of light into a darkened room; however opaque that body may seem in open day-light, it shall under these circumstances sufficiently discover its transparency, provided only the body be very thin. White metals indeed do not easily shew themselves transparent in these trials, they reflecting almost all the light incident upon them at their first superficies; the cause of which will appear in what

<sup>a</sup> Opt. Book II. par. 3, prop. 2.

follows

follows<sup>a</sup>. But yet these substances, when reduced into parts of extraordinary minuteness by being dissolved in aqua fortis or the like corroding liquors do also become transparent.

5. SINCE therefore the light finds free passage through the least parts of bodies, let us consider the largeness of their pores, and we shall find, that whenever a ray of light has passed through any particle of a body, and is come to its farther surface, if it finds there another particle contiguous, it will without interruption pass into that particle; just as light will pass through one piece of glass into another piece in contact with it without any impediment, or any part being reflected: but as the light in passing out of glass, or any other transparent body, shall part of it be reflected back, if it enter into air or other transparent body of a different density from that it passes out of; the same thing will happen in the light's passage through any particle of a body, whenever at its exit out of that particle it meets no other particle contiguous, but must enter into a pore, for in this case it shall not all pass through, but part of it be reflected back. Thus will the light, every time it enters a pore, be in part reflected; so that nothing more seems necessary to opacity, than that the particles, which compose any body, touch but in very few places, and that the pores of it are numerous and large, so that the light may in part be reflected from it, and the other part, which enters too deep to be returned out of the body, by numerous reflections may be stifled and lost<sup>b</sup>; which in all probabi-

<sup>a</sup> § 17.    <sup>b</sup> Opt. Book II. par. 3. prop. 4.

lity happens, as often as it impinges against the solid part of the body, all the light which does so not being reflected back, but stopt, and deprived of any farther motion<sup>a</sup>.

6. THIS notion of opacity is greatly confirmed by the observation, that opake bodies become transparent by filling up the pores with any substance of near the same density with their parts. As when paper is wet with water or oyl; when linnen cloth is either dipt in water, oyled, or varnished; or the oculus mundi stone steeped in water<sup>b</sup>. All which experiments confirm both the first assertion, that light is not reflected by striking upon the solid parts of bodies; and also the second, that its passage is obstructed by the reflections it undergoes in the pores; since we find it in these trials to pass in greater abundance through bodies, when the number of their solid parts is increased, only by taking away in great measure those reflections; which filling the pores with a substance of near the same density with the parts of the body will do. Besides as filling the pores of a dark body makes it transparent; so on the other hand evacuating the pores of a body transparent, or separating the parts of such a body, renders it opake. As salts or wet paper by being dried, glass by being reduced to powder or the surface made rough; and it is well known that glass vessels discover cracks in them by their opacity. Just so water itself becomes impervious to the light by being formed into many small bubbles, whether in froth, or by being mixed and agitated with any quantity of a liquor

<sup>a</sup> Opt. Book II. pag. 241:

<sup>b</sup> Ibid. pag. 224.

with which it will not incorporate, such as oyl of turpentine, or oyl olive.

7. A CERTAIN electrical experiment made by Mr. HAUKEBEE may not perhaps be useles to clear up the present speculation, by shewing that something more is necessary besides mere porosity for transmitting freely other fine substances. The experiment is this; that a glass cane rubbed till it put forth its electric quality would agitate leaf brass inclosed under a glass vessel, though not at so great a distance, as if no body had intervened; yet the same cane would lose all its influence on the leaf brass by the interposition of a piece of the finest muslin, whose pores are immensely larger and more patent than those of glass.

8. THUS I have endeavoured to smoothe my way, as much as I could, to the unfolding yet greater secrets in nature; for I shall now proceed to shew the reason why bodies appear of different colours. My reader no doubt will be sufficiently surprized, when I inform him that the knowledge of this is deduced from that ludicrous experiment, with which children divert themselves in blowing bubbles of water made tenacious by the solution of soap. And that these bubbles, as they gradually grow thinner and thinner till they break, change successively their colours from the same principle, as all natural bodies preserve theirs.

9. OUR author after preparing water with soap, so as to render it very tenacious, blew it up into a bubble, and plac-

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ing it under a glass, that it might not be irregularly agitated by the air, observed as the water by subsiding changed the thickness of the bubble, making it gradually less and less till the bubble broke; there successively appeared colours at the top of the bubble, which spread themselves into rings surrounding the top and descending more and more, till they vanished at the bottom in the same order in which they appeared<sup>a</sup>. The colours emerged in this order: first red, then blue; to which succeeded red a second time, and blue immediately followed; after that red a third time, succeeded by blue; to which followed a fourth red, but succeeded by green; after this a more numerous order of colours, first red, then yellow, next green, and after that blue, and at last purple; then again red, yellow, green, blue, violet followed each other in order; and in the last place red, yellow, white, blue; to which succeeded a dark spot, which reflected scarce any light, though our author found it did make some very obscure reflection, for the image of the sun or a candle might be faintly discerned upon it; and this last spot spread itself more and more, till the bubble at last broke. These colours were not simple and uncompounded colours, like those which are exhibited by the prism, when due care is taken to separate them; but were made by a various mixture of those simple colours, as will be shewn in the next chapter: whence these colours, to which I have given the name of blue, green, or red, were not all alike, but differed as follows. The blue, which appeared next the dark spot, was a pure colour, but very faint, resembling the sky-colour; the

<sup>a</sup> Ibid. Obs. 17. &c.

white next to it a very strong and intense white, brighter much than the white, which the bubble reflected, before any of the colours appeared. The yellow which preceded this was at first pretty good, but soon grew dilute; and the red which went before the yellow at first gave a tincture of scarlet inclining to violet, but soon changed into a brighter colour; the violet of the next series was deep with little or no redness in it; the blue a brisk colour, but came much short of the blue in the next order; the green was but dilute and pale; the yellow and red were very bright and full, the best of all the yellows which appeared among any of the colours: in the preceding orders the purple was reddish, but the blue, as was just now said, the brightest of all; the green pretty lively better than in the order which appeared before it, though that was a good willow green; the yellow but small in quantity, though bright; the red of this order not very pure: those which appeared before yet more obscure, being very dilute and dirty; as were likewise the three first blues.

10. Now it is evident, that these colours arose at the top of the bubble, as it grew by degrees thinner and thinner: but what the express thickness of the bubble was, where each of these colours appeared upon it, could not be determined by these experiments; but was found by another means, viz. by taking the object glass of a long telescope, which is in a small degree convex, and placing it upon a flat glass, so as to touch it in one point, and then water being put between them, the same colours appeared as in the bubble,

bubble, in the form of circles or rings furrounding the point where the glasses touched, which appeared black for want of any reflection from it, like the top of the bubble when thinnest<sup>a</sup>: next to this spot lay a blue circle, and next without that a white one; and so on in the same order as before, reckoning from the dark spot. And henceforward I shall speak of each colour, as being of the first, second, or any following order, as it is the first, second, or any following one, counting from the black spot in the center of these rings; which is contrary to the order in which I must have mentioned them, if I should have reputed them the first, second, or third, &c. in order, as they arise after one another upon the top of the bubble.

II. BUT now by measuring the diameters of each of these rings, and knowing the convexity of the telescope glass, the thickness of the water at each of those rings may be determined with great exactness: for instance the thickness of it, where the white light of the first order is reflected, is about  $3\frac{7}{8}$  such parts, of which an inch contains 1000000<sup>b</sup>. And this measure gives the thickness of the bubble, where it appeared of this white colour, as well as of the water between the glasses; though the transparent body which furrounds the water in these two cases be very different: for our author found, that the condition of the ambient body would not alter the species of the colour at all, though it might its strength and brightness; for pieces of Muscovy glass, which were so thin as to appear coloured by being

<sup>a</sup> Ibid. Obs. 10.    <sup>b</sup> Ibid. pag. 206.

wet with water, would have their colours faded and made less bright thereby; but he could not observe their species at all to be changed. So that the thickness of any transparent body determines its colour, whatever body the light passes through in coming to it<sup>a</sup>.

12. BUT it was found that different transparent bodies would not under the same thicknesses exhibit the same colours: for if the forementioned glasses were laid upon each other without any water between their surfaces, the air itself would afford the same colours as the water, but more expanded, insomuch that each ring had a larger diameter, and all in the same proportion. So that the thickness of the air proper to each colour was in the same proportion larger, than the thickness of the water appropriated to the same<sup>b</sup>.

13. IF we examine with care all the circumstances of these colours, which will be enumerated in the next chapter, we shall not be surprized, that our author takes them to bear a great analogy to the colours of natural bodies<sup>c</sup>. For the regularity of those various and strange appearances relating to them, which makes the most mysterious part of the action between light and bodies, as the next chapter will shew, is sufficient to convince us that the principle, from which they flow, is of the greatest importance in the frame of nature; and therefore without question is designed for no less a purpose than to give bodies their various colours, to which end it seems very fitly suited. For if any such trans-

<sup>a</sup> Obser. 21.<sup>b</sup> Observ. 5. compared with Observ. 10.<sup>c</sup> Ibid. prop. 5.

parent substance of the thickness proper to produce any one colour should be cut into slender threads, or broken into fragments, it does not appear but these should retain the same colour; and a heap of such fragments should frame a body of that colour. So that this is without dispute the cause why bodies are of this or the other colour, that the particles of which they are composed are of different sizes. Which is farther confirmed by the analogy between the colours of thin plates, and the colours of many bodies. For example, these plates do not look of the same colour when viewed obliquely, as when seen direct; for if the rings and colours between a convex and plane glass are viewed first in a direct manner, and then at different degrees of obliquity, the rings will be observed to dilate themselves more and more as the obliquity is increased<sup>a</sup>; which shews that the transparent substance between the glasses does not exhibit the same colour at the same thickness in all situations of the eye: just so the colours in the very same part of a peacock's tail change, as the tail changes posture in respect of the sight. Also the colours of silks, cloths, and other substances, which water or oyl can intimately penetrate, become faint and dull by the bodies being wet with such fluids, and recover their brightness again when dry; just as it was before said that plates of Muscovy glass grew faint and dim by wetting. To this may be added, that the colours which painters use will be a little changed by being ground very elaborately, without question by the diminution of their parts. All which particulars, and many more that

<sup>a</sup> Observ. 7.

might

might be extracted from our author, give abundant proof of the present point. I shall only subjoin one more: these transparent plates transmit through them all the light they do not reflect; so that when looked through they exhibit those colours, which result from the depriving white light of the colour reflected. This may commodiously be tryed by the glasses so often mentioned; which if looked through exhibit coloured rings as by reflected light, but in a contrary order; for the middle spot, which in the other view appears black for want of reflected light, now looks perfectly white, opposite to the blue circle; next without this spot the light appears tinged with a yellowish red; where the white circle appeared before, it now seems dark; and so of the rest<sup>a</sup>. Now in the same manner, the light transmitted through foliated gold into a darkened room appears greenish by the loss of the yellow light, which gold reflects.

14. HENCE it follows, that the colours of bodies give a very probable ground for making conjecture concerning the magnitude of their constituent particles<sup>b</sup>. My reason for calling it a conjecture is, its being difficult to fix certainly the order of any colour. The green of vegetables our author judges to be of the third order, partly because of the intenseness of their colour; and partly from the changes they suffer when they wither, turning at first into a greenish or more perfect yellow, and afterwards some of them to an orange or red; which changes seem to be effected from their ringing particles growing denser by the exhalation of their

<sup>a</sup> Observ. 9.<sup>b</sup> Ibid prop. 7.

moisture, and perhaps augmented likewise by the accretion of the earthy and oily parts of that moisture. How the mentioned colours should arise from increasing the bulk of those particles, is evident; seeing those colours lie without the ring of green between the glasses, and are therefore formed where the transparent substance which reflects them is thicker. And that the augmentation of the density of the colorific particles will conspire to the production of the same effect, will be evident; if we remember what was said of the different size of the rings, when air was included between the glasses, from their size when water was between them; which shewed that a substance of a greater density than another gives the same colour at a less thickness. Now the changes likely to be wrought in the density or magnitude of the parts of vegetables by withering seem not greater, than are sufficient to change their colour into those of the same order; but the yellow and red of the fourth order are not full enough to agree with those, into which these substances change, nor is the green of the second sufficiently good to be the colour of vegetables; so that their colour must of necessity be of the third order.

15. THE blue colour of syrup of violets our author supposes to be of the third order; for acids, as vinegar, with this syrup change it red, and salt of tartar or other alcalies mixed therewith turn it green. But if the blue colour of the syrup were of the second order, the red colour, which acids by attenuating its parts give it, must be of the first order, and the green given it by alcalies by incrassating  
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its particles should be of the second; whereas neither of those colours is perfect enough, especially the green, to answer those produced by these changes; but the red may well enough be allowed to be of the second order, and the green of the third; in which case the blue must be likewise of the third order.

16. THE azure colour of the skies our author takes to be of the first order, which requires the smallest particles of any colour, and therefore most like to be exhibited by vapours, before they have sufficiently coalesced to produce clouds of other colours.

17. THE most intense and luminous white is of the first order, if less strong it is a mixture of the colours of all the orders. Of the latter sort he takes the colour of linnen, paper, and such like substances to be; but white metals to be of the former sort. The arguments for it are these. The opacity of all bodies has been shewn to arise from the number and strength of the reflections made within them; but all experiments shew, that the strongest reflection is made at those surfaces, which intercede transparent bodies differing most in density. Among other instances of this, the experiments before us afford one; for when air only is included between the glasses, the coloured rings are not only more dilated, as has before been said, than when water is between them; but are likewise much more luminous and bright. It follows therefore, that whatever medium pervades the pores of bodies, if so be there

is any, those substances must be most opaque, the density of whose parts differs most from the density of the medium, which fills their pores. But it has been sufficiently proved in the former part of this tract, that there is no very dense medium lodging in, at least pervading at liberty the pores of bodies. And it is farther proved by the present experiments. For when air is inclosed by the denser substance of glass, the rings dilate themselves, as has been said, by being viewed obliquely; this they do so very much, that at different obliquities the same thickness of air will exhibit all sorts of colours. The bubble of water, though surrounded with the thinner substance of air, does likewise change its colour by being viewed obliquely; but not any thing near so much, as in the other case; for in that the same colour might be seen, when the rings were viewed most obliquely, at more than twelve times the thickness it appeared at under a direct view; whereas in this other case the thickness was never found considerably above half as much again. Now the colours of bodies not depending only on the light, that is incident upon them perpendicularly, but likewise upon that, which falls on them in all degrees of obliquity; if the medium surrounding their particles were denser than those particles, all sorts of colours must of necessity be reflected from them so copiously, as would make the colours of all bodies white, or grey, or at best very dilute and imperfect. But on the other hand, if the medium in the pores of bodies be much rarer than their particles, the colour reflected will be so little changed by the obliquity of the rays, that the colour produced by the rays, which fall near the perpendicular, may

so much abound in the reflected light, as to give the body their colour with little alloy. To this may be added, that when the difference of the contiguous transparent substances is the same, a colour reflected from the denser substance reduced into a thin plate and surrounded by the rarer will be more brisk, than the same colour will be, when reflected from a thin plate formed of the rarer substance, and surrounded by the denser; as our author experienced by blowing glass very thin at a lamp furnace, which exhibited in the open air more vivid colours, than the air does between two glasses. From these considerations it is manifest, that if all other circumstances are alike, the densest bodies will be most opaque. But it was observed before, that these white metals can hardly be made so thin, except by being dissolved in corroding liquors, as to be rendered transparent; though none of them are so dense as gold, which proves their great opacity to have some other cause besides their density; and none is more fit to produce this, than such a size of their particles, as qualifies them to reflect the white of the first order.

18. FOR producing black the particles ought to be smaller than for exhibiting any of the colours, viz. of a size answering to the thickness of the bubble, whereby reflecting little or no light it appears colourless; but yet they must not be too small, for that will make them transparent through deficiency of reflections in the inward parts of the body, sufficient to stop the light from going through it; but they must be of a size bordering upon that disposed

disposed to reflect the faint blue of the first order, which affords an evident reason why blacks usually partake a little of that colour. We see too, why bodies dissolved by fire or putrefaction turn black: and why in grinding glasses upon copper plates the dust of the glass, copper, and sand it is ground with, become very black: and in the last place why these black substances communicate so easily to others their hue; which is, that their particles by reason of the great minuteness of them easily overspread the grosser particles of others.

19. I SHALL now finish this chapter with one remark of the exceeding great porosity in bodies necessarily required in all that has here been said; which, when duly considered, must appear very surprizing; but perhaps it will be matter of greater surprize, when I affirm that the sagacity of our author has discovered a method, by which bodies may easily become so; nay how any the least portion of matter may be wrought into a body of any assigned dimensions how great so ever, and yet the pores of that body none of them greater, than any the smallest magnitude proposed at pleasure; notwithstanding which the parts of the body shall so touch, that the body itself shall be hard and solid<sup>a</sup>. The manner is this: suppose the body be compounded of particles of such figures, that when laid together the pores found between them may be equal in bigness to the particles; how this may be effected, and yet the body be hard and solid, is not difficult to understand; and the pores of such a bo-

<sup>a</sup> Opt. pag. 243.

dy may be made of any proposed degree of smallness. But the solid matter of a body so framed will take up only half the space occupied by the body; and if each constituent particle be composed of other less particles according to the same rule, the solid parts of such a body will be but a fourth part of its bulk; if every one of these lesser particles again be compounded in the same manner, the solid parts of the whole body shall be but one eighth of its bulk; and thus by continuing the composition the solid parts of the body may be made to bear as small a proportion to the whole magnitude of the body, as shall be desired, notwithstanding the body will be by the contiguity of its parts capable of being in any degree hard. Which shews that this whole globe of earth, nay all the known bodies in the universe together, as far as we know, may be compounded of no greater a portion of solid matter, than might be reduced into a globe of one inch only in diameter, or even less. We see therefore how by this means bodies may easily be made rare enough to transmit light, with all that freedom pellucid bodies are found to do. Though what is the real structure of bodies we yet know not.

### CHAP. III.

#### Of the REFRACTION, REFLECTION, and INFLECTION of LIGHT.

**T**HUS much of the colours of natural bodies; our method now leads us to speculations yet greater, no less