Essay on Optics
Chapter 4
On the Formation of Colours
By Madame du Châtelet

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1.

All the colours in Nature arise from this property of light discovered by Mr. Neuton, and which he calls *refrangibility*.
Before him the best philosophers believed that colours were formed by the different modifications impressed on light by bodies, or by the unequal mixture of light and shadow. But Mr. Neuton, through an endless number of experiments that can be seen in his treatise on optics, has demonstrated to both mind and eye that a ray of sunlight, which seems to us a brilliant white inclining to yellow, contains seven kinds of ray which all refract differently in passing through whatever transparent body. Once separated, these rays remain unaltered in their colours. In short, each kind of ray is fixed by Nature to a certain degree of refrangibility, as it is fixed to a certain colour.

2.

However, with all kinds of light rays emanating from the sun at the same time, the colours composing sunlight would be hidden for us, and all bodies would seem to us to be the same colour as sunlight, were the bodies not to act on the rays. So, the action of the bodies on the light is necessary for us to discover its colours. But this action is limited by the nature itself of the rays, and the bodies acting on them changes nothing of their nature. All they do is to provide the occasion for their natures to be discovered.

3.

A prism, for example, receiving a beam of white sunlight, attracts it by its mass and, as we saw in the second chapter, it attracts the force of the beam to bend itself in traversing the prism. If the beam of light contained only rays of a certain kind, they would all yield equally to this force acting on them, and if the prism were not acting on them, they would pass through it wherever they happened to fall. But the light beam being composed of seven different kinds of ray, with the prism attracting them by its mass, the seven rays resist more or less according to their nature the action through which the glass attracts them. This difference in resistance separates them one from the other, making distinct and different impressions on the retina, so that the colours become perceptible. In fact, refrangibility is just the different ways in which each kind of homogeneous ray resists the action of bodies on them.

4.

Since transparent bodies show colours only through the action they exert on light, and since sunlight seems to us homogeneous when nobody is acting on it, it is certain that opaque bodies would appear to us to be of the same single colour of sunlight, were the bodies not to exert an action on the rays that reach them. Thus, the diverse colours of opaque bodies prove to us that these bodies act on light.

Confirmation that this is the origin of colours is to be found in all the experiments. In addition, the more refrangible rays, those that deviate the most from their path on penetrating any transparent body, are always the more reflexible. That is, refrangible rays are reflected at a smaller obliquity of incidence, the rays maintaining their refrangibility after the reflection. After their reflection above somebody the homogeneous rays reunite behind a lens at different foci that correspond to their different degrees of refrangibility. So refrangibility seems to be a property of light where there is never a shortage of rays.

5.

Transparent bodies that are coloured[1] hold a middle position between opaque bodies and bodies that are entirely translucent.[1]

The correspondence found between them and opaque bodies is where one can discover the cause why one body reflects to us one colour rather than another. For it is only in transparent bodies that a lightpath would be perceptible.

All transparent bodies become coloured when they are inflated in bottles, or in whatever way they are stretched into strips. The rays that were transmitted without interruption by the homogeneous contiguous particles of a transparent body, when this body was thick, no longer finding these particles of an equal density when the body is thinner, reflect themselves on meeting the air whose density is different from that of the transparent body, interrupt their transmission and operate their reflexion.

6.

Not only do transparent bodies become coloured when they are very thin, but their colours vary with their thickness and according to the obliquity of the light they return to us. Thus, *aqua crispata* appears with different colours according to the thickness of the bubbles that compose it and the position of the eye looking at it.

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[1] "I have already discussed transparent coloured bodies in ch.2, art. 12. But there I considered these bodies mainly in relation to the rays they transmit. My intention is to show the correspondence between these bodies and the particles of opaque bodies. So here I am considering them more particularly in relation to the rays that they reflect." Du Châtelet, Émilie: *On the Formation of Colours.* Translated by Alan Gabbey. The Saint Petersburg Manuscripts. A Critical and Historical Online Edition (2020-2023). Edited by Ruth E. Hagengruber, Andrew Brown, Ulla Kölving, and Stefanie Ertz.

7.

For a philosopher nothing is small in Nature. Mr. Neuton went as far as to measure the thicknesses at which a soap-bubble (whose tenuity and colours changed from moment to moment) emitted different colours, and it was with the help of these measurements that he determined the thickness necessary for any particle to reflect such and such a colour. Thus these refined discoveries, which do not seem made for humanity, in his eyes were born within the womb of a trivial distraction, and on this occasion one can say to Mr. Neuton: "*ex jocis infantium et lactentium traxisti veritatem*."

The two lenses of a telescope furnished him with the means to acquire these strange measurements of which the soap-bubbles had given him the idea. One of the lenses was flat, the other convex, so the air or water gliding between them took on different thicknesses and, like soap-bubbles, must produce different colours for different thicknesses. Now the sphere on which the convex lens had been cut being known, Mr. Neuton determined in this way the thickness at which the slat of water between these lenses reflected or transmitted different rays, and then he applied this finding to soap-bubbles which appeared with different colours at their different thicknesses.

8.

Here are the results of the measurements and experiments of Mr. Neuton on this subject:

1. That violet rays, which are the most refrangible and which are reflected at a lesser angle of incidence, are also those rays that thin strips reflect at their lesser thickness and which reflect red rays, which are the least refrangible at their greatest thickness. This proves quite markedly what I said above [Art. 4], that the colours of opaque bodies arise from the different thickness of their particles.
2. That the particles that reflect red ought to be the thickest of all, other things being equal, and that the particles that reflect the other rays ought to be less thick in proportion as these rays become more refrangible.
3. The colours of these reflective strips change according to the angle of the eye looking at them, and that cannot be otherwise, for the different rays are reflected at different angles of incidence, as I said in Art. 3. The rays reflected at a certain oblique angle are therefore different from those that reflect at another oblique angle. So the same reflective strip ought to appear with different colours to different people, seeing that the rays the strip returns to them does so at different angles.
4. The thicknesses at which a strip of water or air reflects colours are between them as the sines of refraction of light in the two media, so that the strip of water that reflects violet, for example, is a quarter less thick than the strip of air that reflects the same colour. The sine of refraction in water is less by a quarter that the sine of refraction in air. Consequently, coloured rings were smaller in water, and larger in air. The more dense a body is, the less thickness is required for it to reflect a given colour, and vice versa.

One concludes that the particles of very dense coloured bodies must be smaller than those of less dense particles of the same colour. For example, the particles of a yellow ribbon must be larger than those of a flake of gold.

This admirable relation between reflection and refraction shows that these two effects depend on the same cause, and this cause is attraction. Attraction acts through mass, and we have just seen that the less thickness a body has to produce whatever effect on light, the greater its density.

5. Suppose you are in a dark room with two telescopic lenses (of the kind with whose help Mr Neuton made the discoveries I am discussing). If you project on both lenses one of the colours emerging from a prism, rays of this colour will be alternately transmitted and reflected by a slat of air or water confined by the two lenses so that each coloured ring will be separated by a dark ring that reflects no light, and this dark ring, when viewed between the air and the eye, will appear with the prismatic colour illuminating the lenses.

This alternate transmission and reflection happen at equal intervals and in the continuous arithmetical proportion of the numbers 1, 2, 3, 4, 5, 6, etc. As there was no reflection at the point of contact of the lenses, the rays that were transmitted at zero thickness continued to be at thicknesses 2, 4, 6, 8, etc., those that were reflected at thickness 1 continued to be at thicknesses 3, 5, 7, etc., and the thicknesses changed according to the species of ray that fell on the lenses.

It is worth noting here that these alternate reflections and transmissions of rays through thin plates following their different thicknesses would on their own suffice to prove that it is not solid parts that reflect light.

This property that rays have of being alternately transmitted and reflected through thin plates is the one that Mr. Neuton calls their "*accès de facille transmission et de facille reflexion*" ["fits of easy transmission and easy reflection"]. I have already spoken about this property of light in Chap. 3 [Art. 6]. These fits signify nothing other than the power, whatever it may be, by which a species of homogeneous rays, which fall at the same single angle on any transparent body and are transmitted at zero thickness, continue thus at thicknesses 2, 4, 6, 8, etc., and are reflected at the intermediary thicknesses 1, 3, 5, 7, etc.

These alternating transmissions and reflections are perceptible only when the transparent body is very thin. When the bodies are of a certain thickness, the rays are forced to travel without interruption through the body by the equal attraction of all its parts, and the body seems to us entirely transparent. These fits are one of the causes why very thin transparent bodies become coloured, for the rays which were in a fit of easy transmission find their transmission interrupted when the thickness of the body is reduced and they are forced to be reflected by meeting with a new medium which takes the place of the homogeneous particles which transmitted them.

These fits keep in step with the differing refrangibility of the rays, the same as reflection so that they are larger and less numerous in the red rays who are less refrangible, and they are smaller and more frequent in the violets, which are the more refrangible, and that nearly in the proportion of 14 1/3 to 9, which is nearly one tenth and about the inverse proportion of the intensity of violet and red in the prismatic image, for in this image the violets are to reds as 80 to 45.[2]

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[2] The violet rays being in all cases those on which the bodies act the most, the violet ought to be more dilated in the image of the prism and more contracted in the coloured rings of the thin strips, for in the first case the prism separates the rays, and in the second case the thin strip reflects them, therefore etc.

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9.

When the lenses in this experiment were illuminated by direct sunlight, there was only the central spot formed through contact with the lenses, there was no dark spot except for the central mark [formed by the contact between the lenses]. In this spot there was no perceptible reflection, but the air or water held between the lenses had become coloured with different colours at all its different thicknesses, for the sunlight, being compounded of all kinds of rays of different refrangibility, and these rays being transmitted or reflected at different thicknesses depending on their different refrangibility, rays reflected at all the differing thicknesses of the strip of air compressed between the glasses, whereas when they were lighted by a single kind of prismatic light the rings were alternately coloured and darkened.

It follows from this observation

1. That the air or water compressed between the glasses transmitted one colour and reflected another. So, for the same thickness, looking at these glasses compared with daylight, the rings formed between the two appeared a colour different from both transmitted and reflected light, in such a way that the same strip that reflected the blue rays transmitted the red rays, the strip that reflected the yellow rays transmitted the violet rays, etc.
2. That the colours are all the brighter the thinner the strip that reflects them, for the colours are brighter as the rays are more homogeneous [and] less mingled with other rays. So it can be said in passing that there are no colours more vivid than those of the rainbow, because there are none that are more pure. Now for rays of differing refrangibility reflecting down from thin strips of differing thickness, the thicker a strip is, the more different kinds of rays it will reflect and consequently the more the colour of the strip will be *languissante*. Therefore, bodies of very vivid colours ought to have very thin particles.
3. Again, it follows that there are different orders of colours according as they are more pure or more mingled. The most pure orders of colour, those produced by the thinnest strip, are called *a colour of the first order;* those produced by a strip three time thicker than the first strip, are called *a colour of the second order*, and so on according as the colours are mingled more or less, and as the thickness of the reflecting strip increases as the numerical progression 1, 3, 5, 7, etc.

10.

The reflection of rays of differing refrangibility, with different thicknesses and obliquities, is what makes it that the colours of thin bodies change with the obliquity of the eye looking at them. The reason for this is that the colour arriving at our eye at some angle is not the same colour as one arriving at any other angle. That is the true cause of the colours of the rainbow, a cause that was unknown until Mr Neuton.

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11.

The obliquity of the rays that return to our eyes brings a greater change to the colours of the thin strips when they are rarer than the surrounding medium, than when they are denser than this medium. So, the colours of the soap-bubble were brighter and less changeable than those of water or air compressed between two lenses. That is easy to deduce from the laws of refraction, for refraction happens in moving away from the perpendicular when light passes from a denser medium into a rarer one, and on approaching the perpendicular in the contrary case. If R and T are two thin strips of equal density and thickness, with R being denser and T rarer than the surrounding medium, the ray in R will move closer to the perpendicular and further away in the other strip T. Now the line that moves way from the perpendicular is longer than the line BC that approaches the perpendicular. Therefore, the light returning to the eye will do so at angles that are different for particle R from those for particle T, and the more the density of particle R is increased (the surrounding medium remaining the same), the less becomes the difference between BD and BC. So, if the density of this particle is such that the difference in the refraction of rays is imperceptible in all sorts of obliquities of incidence, this strip will appear to be of the same single colour for all positions of the eye.
This shows that the particles of opaque bodies are much denser than the matter that passes through their pores, because the colours of these bodies are permanent and do not change with the position of the eye that is observing them.
The colours of the thin strips are brighter when the medium surrounding them is rarer than these strips, and they are less bright when the medium is denser than these strips, and that is because the colours are all the brighter the more pure they are. And it is easy to see that the colours reflected by particle R must be less mingled than those reflected by particle T.
The colours are all the brighter as the medium surrounding the strips differs in their density, and that ought to be so, since we have seen the one of the causes of reflection is the different density of contiguous media. Now the more reflection is abundant, the more colours ought to be bright, so colours are brighter in air compressed between two glasses/lenses than in water slipped in between these glasses, for air differs more than water on the density of glass. So that for the colours of a body to be brilliant, the particles that compose it must be much denser than the medium that separates them. The medium that surrounds thin strips therefore makes their colours more or less bright, according as it differs more or less from them in their density. So, the colours *des etoffes mouillées languissent*, but they do not change, if it is only in drying, and then it is only that the density of their particles has been altered, so the colours depend on the thickness and the density of the bodies' particles, and their brightness depends on the medium that surrounds them.

12.

Unfocussed curiosity should never be the aim of our researches, and all the experiments and observations on the colours of thin transparent bodies, which I have just related, would be just fruitless discoveries if they did not lead us to know, as far as is possible, the causes of the colours of different bodies. Moreover, I have not related with as much exactitude the phenomena that the thin strips of transparent bodies make appear to apply these phenomena to the colours of natural bodies.

Natura est tibi semper consona, says the great Neuton [ref. in fn.] Thus, there is *bien de l'appearance* which uses the same way in the formation of the colours of opaque bodies, and in those of thin bodies, transparent. Let us therefore follow as I have already done the analogy between the constituent parts of opaque coloured bodies, and the thin strips [*lames*] of transparent bodies.

13.

1. The most opaque bodies reduced to very thin strips, or dissolved in *menstrues sifisantes, [?]* appear transparent when viewed through the hole of a dark-room, or with a good microscope. The fits of easy transmission or easy reflection of rays cause this transparence of opaque bodies, just as one has seen that they produced the colours of transparent thin bodies, for bodies are opaque only because they extinguish, they absorb in their substance the rays which they do not reflect back to us, and these rays are stopped in bodies only by the reflections and internal refractions that the particles of these bodies and the rarer medium passing in their pores test the rays by attracting them unequally, according to the different density of these particles and the medium. Now the rays that are in fits of easy transmission when they arrive at the final/last surface of a body reduced to thin strips, instead of breaking up, as they did between the different surfaces composing this body when it was thicker, are transmitted in a straight line through the air which becomes contiguous to the strip of this body now thinned down, and the rays that find themselves in a fit of easy reflection, and whose fit is not finished instead of being reflected by the uneven action of the particles of this body and of the medium separating them, finding their reflection interrupted by the air, are transmitted in/into this air and this strip is transparent.[3] So when opaque bodies become transparent, what happens between their internal parts becomes so to speak perceptible to us. The rays that refracted internally, and were extinguished and absorbed in these refractions, then arrive in our eyes and show the transparence of these bodies. It seems therefore that transparent and opaque bodies differ only in the size of their pores. The arrangement of their parts and the matter more or less dense that goes through them, reducing them to very thin strips, the transparent bodies become coloured and the opaque bodies become diaphanous, without any perceptible change in the density of the particles composing them.
2. Mercury, sand, small animals, etc. might seem transparent through a microscope, because for us the microscope augments the intervals separating their particles, and the rays that lose themselves between these particles are then transmitted to our eyes. So, if our eyes were natural microscopes the majority of bodies would appear diaphanous. But in distinguishing their imperceptible parts, we would become incapable of seeing the

[3] Even so, one would [not] admit in light fits of easy transmission and of easy reflection that would not be less true, for whatever the cause that makes the light to reflect or transmit, it is not less certain that finding its transmission or reflection interrupted by the different density of this thinned-down particle, it should transit instead of reflect or reflect instead of transmit according to the combinations indicated in the article.

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ensemble, and this view, far from being useful to us, would be very harmful. God seems to have adjusted all our senses to our needs, rather than to our curiosity. Thus, we scarcely see beyond the flea, because it is the smallest of the animals that we have to defend ourselves against. It is therefore very likely that all the particles of bodies are transparent, since those that we see through the microscope appear to be transparent, and it is only the perfectly solid parts of matter that are opaque. This transparence with which all bodies seem to us to come from a default in our organs, for if our eyes or microscopes could make us discover the *minimum* of these particles, this *minimum* would certainly appear opaque to us, since it must be solid and then all bodies would seem like puzzles to us. Mr Neuton believes that the transparence of the constituent particles of bodies is what opposes the more to the discoveries that one could make in their structure/contexture. The colours reflected by opaque bodies reduced into very thin strips are more feeble, because then they send to us only [the] rays that are reflected from between the pores of their first surfaces. But these colours do not change for all that, because as I have said, they depend on the particles of these bodies, and on [the fact that] these particles are not altered. The transparence [cy?] of these thin opaque bodies proves that the pores of opaque bodies are either entirely empty, or that the matter traversing them is even finer than air, because it reflects the rays that the are transmit.

3. The feathers of certain animals, such as the peacock's tail, the throat of pigeons etc. change colour as these animals move. These changes of colour arise from the fineness of the threads or stubble [?] at the tips of these feathers, which being very thin reflect different rays depending on their thickness. Just like the thin strips I have spoken about. Now the rays that return to our eye in a certain position are not the same as those that return in another position, for the more oblique the rays the thicker the strip reflecting them. And the rays of differing refrangibility are reflected at differing thicknesses, as we saw above. It's the same reason why spiders' webs, certain silk threads, and several other bodies change colour depending on the position of the eye looking at them, and it is on this principle that fabrics are worked on to change the web/woof of one colour and the warp of another. This is how the rays of one colour all return to our eyes at a certain angle and those of another colour at another angle. When extended and perfected, this art has produced *tableaux changeants*, those masterpieces of optics. One knows them before knowing that they are due to refrangibility, but it is refrangibility alone that can fully explain the artifice.
4. Several bodies change their colour though the attrition of their parts. Some of the powders that painters use change their colour through their grinding, silver becomes brown on being rubbed, etc. These are certain indications that the colours of these bodies depend on the size of the particles in their composition.
5. The colours of the atmosphere change visibly as the particles composing them are more or less condensed. At their least thickness these particles offer sky blue, which enchants the sight, and which is the sure sign of entirely serene weather. Then they form thick clouds of different colours as they condense and their thickness increases.
6. We have seen that at their greatest thickness thin strips reflected red. That is why in withering nearly all plants take successively the colours yellow and red, for the thickness of the particles of these plants increases through the evaporation of their aqueous parts, and

these particles being thicker reflect the least refrangible rays, which are the yellows and the reds in place of the greens, which they were reflecting previously.

7. Opaque bodies that are thin transmit one colour, and reflect another like the thin strips of the transparent bodies I have spoken about. Which proves that the bodies extinguish and intercept certain rays in their substances while they reflect the others in abundance. These are the rays they reflect more abundantly than the others, which form their colour, and the thickness of their particles decides which kind of ray they are to reflect or absorb in a greater quantity, the same as we have seen that the thickness of the thin strip of air or water confined between two glasses decided if it would reflect certain rays, or if it would transmit them. Gold leaf, for example, examined through a microscope, seems green verging on blue, has a transmitted light, and remains yellow in reflected light, which proves that gold reflects red rays, orange-coloured rays, and yellows in great abundance, while it absorbs the greens, the blues, etc. into its substance. It is the same with other bodies according to their different colours.