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## 3

VISION, COLOR INNATENESS, AND  
METHOD IN NEWTON'S *OPTICKS**Philippe Hamou*<sup>1</sup>

In this essay I argue for the centrality of Newton's theory of vision to his account of light and color. Relying on psycho-physical experiments, anatomical observations, and physical hypotheses, Newton, quite early in his career, elaborated an original, although largely hypothetical, theory of vision, to which he remained faithful throughout his life. The main assumptions of this theory, I argue, play an important (although almost entirely tacit) role in the demonstration of one of the most famous theses of the *Opticks*: the thesis that spectral colors are "innately" present in white solar light. The theory of vision is especially crucial to understanding the second 'synthetic' part of the demonstration, which deals with experiments showing how white light can be artificially produced out of prismatic colors. This synthesis is not, as often conceived, a mere reversal of the analysis, brought in for pedagogical reasons, but, as I argue, an integral part of the Newtonian demonstration—and this makes its dependency on the theory of vision all the more striking. In the first two sections of this essay, I propose a reconstruction of the argument developed in Book I of the *Opticks*, and I show why and where a theory of vision is needed. In the third section, I go back to Newton's early researches into the psycho-physiology of vision, in order to give a fuller presentation of Newton's actual theory of vision and to show that this theory, even though it was developed independently of the prismatic experiments, was, in all its component parts, precisely the one needed for the demonstration of color innateness.

Prima facie, the centrality of visual theory for Newton's theory of light and color may appear difficult to maintain. As its subtitle makes quite clear, Newton's book is

<sup>1</sup> Université Lille III UMR "Savoirs, textes, Langage." The research for this chapter was undertaken under the auspices of Pneuma, an international research project funded by the Agence nationale de la Recherche (ANR-09-SSOC-056-1). The author wishes to express his warmest thanks to Zvi Biener, Eric Schliesser and Alan Shapiro for their lucid comments on the first stage of this essay.

not on vision, it is a “treatise on light and colors.”<sup>2</sup> The theory of vision is dealt with in a rather cursory and peripheral way. Its geometrical part is granted a brief appearance in the first pages, in axioms VII and VIII, where Newton gives an account of the way retinal images are formed in the eye through refraction, and describes the law that determines the apparent locus of an object that is seen through reflection or refraction.<sup>3</sup> Then, in the appendix of the treatise, the “Queries,” Newton devotes a few pages to a presentation of his own ideas on the physiology of vision (Queries 12 to 16; plus, in the second English edition, Queries 17 and 23), but he does this in a hypothetical guise, thereby clearly implying that these speculations are not required for establishing the main points of the book concerning refraction and the nature of light and colors.<sup>4</sup> Indeed, except for a couple of interesting but inconspicuous hints to which we shall soon return, the theory of vision is almost absent from the main text of the *Opticks*.

There are certainly good methodological reasons why Newton wanted to keep clear of the theory of vision when enquiring about light and color. One is related to the issue of certainty. Reenacting the experimentalist ban against hypotheses, Newton forcefully claimed that the new theory of light and colors was free from any kind of hypothesis, evinced entirely from phenomena and demonstrations. But, this clearly was not the case for the theory of vision, which requires some amount of hypothetical reasoning both for its physiological part (concerned with mechanisms occurring in the invisible tissues or fluids of the optical nerve) and for the still inchoate psychology of visual representation. The relegation of the theory of vision to the hypothetical Queries of the *Opticks* is a clear indication of this epistemic gap.

A second methodological point concerns order. The theory of light and color had to be considered prior to the theory of vision. The reason for this is expressed with great clarity in an early note from Newton's Cambridge Notebook, a notebook in which the study of vision, and especially its physiology and psychology, is a dominant theme:

The nature of things is more securely & naturally deduced from their operations one upon another than upon our senses. And when by the former Experiments we have found the nature of bodys, by the latter we may more clearly find the nature of our senses. But so long as we are ignorant of the nature of both

<sup>2</sup> The full title is *Opticks, or a Treatise of the Reflections, Refractions, Inflections and Colours of Light*.

<sup>3</sup> The law states that the apparent locus of an object seen through reflection or refraction is the place from which the rays diverge after their last reflection or refraction. On this law, and its sources in Johannes Kepler and Isaac Barrow, see Shapiro (1990).

<sup>4</sup> On the methodological origins of the Newtonian “Queries,” see Anstey (2004).

soule & body wee cannot clearely distinguish how far an act of sensation proceeds from the soule & how far from the body [etc.]<sup>5</sup>

It seems that this is a sort of caveat that Newton supplied in the course of his own study of vision, perhaps realizing that this study was to remain somewhat confused until a clear understanding of the nature of light and of how it affects (or is affected by) bodies in general could be obtained. It recommends an order of inquiry: first to study bodies and their operations one upon another (in order to discover what Locke would label “powers,” or tertiary qualities, which are in effect the principal objects of physical experimental science) and, then, to apply the knowledge obtained to the more composite science of the senses, which requires being able to distinguish and somehow subtract from the phenomena under consideration the bodily affection that is involved in the sensory interaction. In all essentials, this order of study is the one that Newton wanted to follow in the *Opticks*: the experimental study of light, especially through prismatic experiments, permits a ~~kind of~~ third-person view on its physical effects, which serves as an empirical basis for demonstrating its nature, qualities, and powers independently of its sensory effects. Then, and only then, consequences are drawn for the construction of optical instruments, and queries are raised about possible implications for the theory of vision.

This postulated order, however, besides not being the actual, historical order of Newton's inquiries, is not even matched in the systematic organization of Newton's demonstrations in the text of the *Opticks*. This is the main point of the present essay. As we shall see, Newton's thesis that white solar light is a mixture of colors depends ~~upon~~ on the theory of vision both heuristically—the theory of vision makes the thesis conceivable—and for its justification—the thesis rests on premises that require important inputs from the theory of vision. This in turn raises questions on the ambiguous methodological nature of Newton's *Opticks*, poised uneasily between proclaimed experimentalist ideals on the one hand, and a well-articulated, although hypothetical, natural philosophy on the other.

<sup>5</sup> Newton (ms. a, 101v.). The manuscript notebook from the Cambridge University Library is titled *Quaestiones quaedam philosophiae*, and it documents Newton's thoughts and readings between 1661 and 1665. Diplomatic text and a normalized version are provided at <http://www.newtonproject.sussex.ac.uk>. The text is also transcribed in McGuire and Tamny (1983, p. 376–377). A large number of notes are concerned with optical questions, and especially with experiments on after-images, double vision, and other phenomena involving the physiology and psychology of vision. Another manuscript (Newton, ms. b) titled “Of colors” contains Newton's first prismatic researches in a dark room, together with a hypothesis on the anatomy and functioning of the optical nerves. McGuire and Tamny, as well as the editors of the “Newton Project” date it from 1665–1666, but H. Guerlac (1983) has argued that it might be of a later date, suggesting 1668–1969.

### 3.1 THE INTENT AND DEMONSTRATIVE STRUCTURE OF BOOK I OF THE *OPTICKS*

Book I of the *Opticks* comprises two parts, both left untitled. The first opens with a set of definitions and axioms, including the important definition of “simple, homogeneous and similar light” as the light “whose rays are all alike refrangible,” whereas “compound, heterogeneous and dissimilar light” is defined as “that whose rays are some more refrangible than others” (DEF. VII). The main body of this first part is principally concerned with establishing an experimental link between homogeneity thus construed, and homogeneity or similarity in color and reflexivity,<sup>6</sup> showing that rays that are similar in refrangibility also agree in color and reflexivity. Newton shows experimentally that solar light is dispersed through refraction into colored rays, each of them possessing a specific refrangibility that is not changed through later successive refractions. This, according to Newton's prior definitions, makes these spectral-colored rays homogeneous, whereas solar white light appears not to be so. To establish these points, Newton offers a set of experiments (prop. II, exp. 3 to 8), most of them taken from his former *Lectiones opticae*. One of them, experiment 6, using two prisms in succession, is the famous *experimentum crucis* of 1672, although it is no longer singled out or presented as “crucial.”<sup>7</sup> It is now presented as one experiment among several others brought in to prove Newton's main thesis: that white light is variously refrangible, and variety in refrangibility entails variety in color. A next set of experiments (exp. 9 and 10; and prop. III) establishes a similar link between variety in refrangibility and variety in reflexivity. Finally, as in the 1672 paper, Newton draws important practical consequences of chromatic dispersion for the improvement of telescopes (prop. VII and VIII). When refracted through a lens, rays of heterogeneous light (such as the solar or stellar rays) cannot be focused properly, on account of their different refrangibility. As a consequence, dioptrical telescopes are deemed to produce chromatic aberrations.

At this point (the end of Part 1), Newton has demonstrated a non-trivial relation between refrangibility, color, and reflexivity: they are qualities so tightly connected that the reader can extend the former definition of homogeneous light: rays of light,

<sup>6</sup> What Newton calls reflexivity is the “disposition” of the rays “to be reflected or turned back into the same medium from any other medium upon whose surface they fall” (Newton 1979, p. 3). Variety of reflexivity is shown in the phenomenon of total reflection when incident rays of light, passing out from glass to air, and being inclined more and more, begin to be reflected at the surface of the glass. The rays that are more refrangible are also the rays that are more reflexible (see *Opticks*, vol. 1, ch. 1, prop. 3; Newton 1979, p. 63).

<sup>7</sup> On the much discussed interpretation of the *experimentum crucis*, see especially Lohne (1968), Laymon (1978), Schaffer (1989), Shapiro (1996), Worrall (2000), and Zemplén and Demeter (2010); Stein (ms. a, ms. b).

being 'homogeneous,' that are similar in terms of refrangibility are also similar, 'homogeneous,' in terms of color and reflexivity.

This is no small result. Yet Newton added a second part to this first because the point he wished to establish was much more ambitious: it is in fact Newton's grand thesis, the one for which his optical work is famous, but also the one most constantly contested by his opponents. It is the thesis in defense of which Newton had to revise and refine his argument throughout his career, with what is generally considered to be only a qualified success (at least as far as formal argumentation, rather than public agreement, is concerned). This thesis is that "Colours are not Qualification of Light, derived from Refractions or Reflections of natural Bodies (as 'tis generally believed,) but Original and Connate properties, which in divers Rays are divers."<sup>8</sup> This entails that "colors" are originally present in white solar light before refraction, even though they are not yet apparent to the eye.<sup>9</sup> So refraction is not a process through which light is ~~modified~~ ~~but rather~~ qualitatively changed, as if a foreign element, a shadow or darkness, was introduced into a formerly pure white in order to produce colors. Colors are, so to speak, 'substantially' present in white solar light, and it should be understood that the prism is simply acting as a sieve or a filter that separates and manifests them.

There is no doubt that Newton strongly believed this to be true. Commentators have pointed out that this belief was "buttressed by, or perhaps even derived from, his corpuscular view of light."<sup>10</sup> If one considers light as a compound of discrete particles, it is indeed easily conceivable that white light be a mixture, similar to the mixture of variously colored powders whose heterogeneity appears when viewed through a microscope. However, even though this corpuscular conviction was firmly rooted in his mind, Newton insists adamantly on the methodological commitment that opens the *Opticks*: "not to explain the Properties of Light by hypotheses, but to propose and prove them by Reason and Experiments."<sup>11</sup>

Newton always claimed that he has demonstrated his strong thesis according to the experimental method; that is, not from hypotheses on the invisible constitution of

<sup>8</sup> This is the "first proposition" of the 1672 *New Theory of Light and Colours* (Newton 1959–1977, vol. 1, p. 292).

<sup>9</sup> Newton was well aware of this claim's paradoxical character, as one can see from the following passage, deleted from the copy of the "Observations" sent to Oldenburg in 1675: "[white being a mixture] I believe hath seemed the most paradoxical of all my assertions, and met with the most universal and obstinate prejudice. But to me it appears as infallibly true & certain, as it can seem extravagant to others. For hitherto I never tried any way to mix all colours by which I could not in some degree or other produce whiteness, and yet I have as many tryalls as I could excogitate ways of mixing colours..." (Newton 1959–1977, vol. 1, p. 385).

<sup>10</sup> See Shapiro (1980, p. 230). The present chapter owes much to the solid scholarship of Shapiro's paper.

<sup>11</sup> Newton (1979, p. 1).

things, but as “a most rigid consequence [ . . . ] evinced by the mediation of experiments, concluding directly without any suspicion of doubt.”<sup>12</sup> However, the rather stern opposition of his first readers, and in consequence, the successive rephrasing of the demonstration, ending in the final text of the *Opticks*, indicate that this much-sought-after inductive proof somehow eluded Newton.<sup>13</sup> In any case, the second part of Book I of the *Opticks* may be considered as its final (re)formulation. But here, as well as in the other parts of the book, Newton does not give his reader an explicit statement of the logical structure of the proof—the demonstration is, so to speak, embedded in the experiments themselves, or rather in a tightly woven net of successive experiments.<sup>14</sup>

Newton began by establishing through experiments (prop. I, exp. 1 to 3) that refracted colors are not affected by changes in the situation of the boundaries of shadows and lights; he went on to show that colors once produced by refraction cannot be changed by further refractions or reflections. It seems clear that these two sets of experiments have a polemical intent (they help discard commonly held misconceptions regarding color production), but they also contribute, together with several experiments from the first part, toward the proof of the immutability of spectral colors after refraction.

Secondly, Newton presented a set of experiments on the composition of spectral colors, using lenses, which result in the production of variously colored light (prop.V, exp. 9 to 15). This allowed him to give an empirical rule for the determination of the compound color that may be obtained when mixing a given quantity of rays of two or more spectral colors (prop.VI). The fifth and main proposition of this second part states that white solar light is a mixture of all the spectral colors in due proportion. In fact white light, according to the aforementioned rule, may be produced in various ways, using only three or four colors in due proportions. The notion that the white or solar light is a rich mixture, requiring “all the primary colors,” is initially introduced in this fifth proposition without substantial justification. But Newton wanted to convince his reader that it is only the rich re-composed white, and not any simpler compound white, that is able to match the whole range of phenomenal properties manifested by solar light. The demonstration of this point is certainly the main purpose of the final

<sup>12</sup> Newton (1959–1977, vol. 1, p. 97).

<sup>13</sup> On this long quest, see Shapiro (1980).

<sup>14</sup> This certainly is one of the most original methodological features of the book—a feature to which its first readers were especially sensitive. See, for example, ‘s Gravesande’s judgment: “His experiments have a kind of connection one with another; and from one experiment he has often, with great Subtility, deduced what was to be tried next, so as to enable him to come nearer to the mark” (‘s Gravesande 1737, p. xv). A similar appreciation appears in Pierre Coste’s preface to the French translation of the *Opticks*. Newton’s work is described as “un tissu merveilleux de raisonnemens solides fondez sur des Experiences toutes nouvelles” (Newton 1720, Preface, p. iii).

propositions (prop VIII, IX, and X), where Newton showed how the new understanding of white solar light as a rich mixture of color is adequate to explain all the appearances of the different kinds of colors that may be seen in this world: not only the colors produced through prisms, but also the colors of the rainbow, as well as the permanent colors of natural bodies.<sup>15</sup> In the two concluding pages of the *Opticks*, Newton presented this final part of Book I as an example of the synthetic procedure that “consists in assuming the causes discover’d and establish’d as Principles, and by them explaining the Phaenomena proceeding from them and proving the Explanation.”<sup>16</sup> It is important to see that this synthetic phase is not in the *Opticks* a mere reversal of the analytic procedure—an abstract reconstruction of the phenomena. The remarkable fact that white light can be artificially recomposed allows Newton to give a concrete dimension to the synthesis, to ground it on experiments, as can be seen in the final experiment of Book I, where artificial white light is created out of the complete recollection of all the spectral rays produced by a prism, and then tested against various colored bodies in order to compare its effects with the direct effects of true solar light.

In sum, the demonstrative structure of Book I is as follows: it starts with an “analytical part,” progressing with where Newton shows that white light is variously refrangible, that similarity in refrangibility entails similarity in color and reflexivity, and finally that homogeneous colors produced by refraction are immutable, cannot be changed or dispersed by new refractions. This analysis is followed by a synthesis that shows that these homogeneous colors can be artificially recombined, in order to produce heterogeneous ones, and that a recombination of the whole set of spectral colors produces a white light whose behavior is in all essentials similar to the behavior of solar light. The conclusion of the whole demonstration (*analysis plus synthesis*) is the “grand” thesis: the innateness of spectral colors in white solar light.

### 3.2 VISUAL INGREDIENTS IN THE DEMONSTRATION OF COLOR INNATENESS

To prove the innateness of colors, Newton had to meet two distinct challenges. One is conceptual: to understand that colors are actually in white light without our being able to see them there, it seems that we need a new definition of color and color homogeneity that does not draw on phenomenal properties. Perceptually, or phenomenally, heterogeneous light rays always present themselves as homogeneously colored, and,

<sup>15</sup> An exception is made for the colors produced in the imagination by “the power of phantasy in a dream,” or in “a Mad-man seeing things before him which are not there,” or by striking or pressing the eyes... (Newton 1979, p. 161).

<sup>16</sup> Newton (1979, Query 31, p. 405).



reciprocally, simple homogeneous colors are indistinguishable from compound, heterogeneous ones. For any sighted reader, it may seem somewhat of a paradox to say that certain colors are present in certain lights but remain unseen. The second challenge concerns the argument itself: Newton had to convince his readers that the immutability of the spectral rays after refraction argues for their innateness in the solar light before refraction. This was not a simple task. It might very well have been the case that “immutable” colors were created through refraction, rather than merely separated or made apparent. So what Newton had to find was a way to reverse the analysis, to show that if the effects (the colors) were not already in the cause (the solar light), they would be different: light would behave differently in some experimentally accessible way. As Newton was aware, the old “crucial experiment” was not fit for the task. As an argument for the innateness of color, it had insuperable weaknesses—among them the fact, often pointed out by Newton’s challengers, that it was almost impossible to obtain pure colors after the second refraction,<sup>17</sup> a fact that indeed could give the disastrous impression that refraction itself created the colors. It seems that in the *Opticks*, the task of proving the innateness of colors had now been taken up afresh and attempted in terms of composition experiments, that is, the ‘concrete’ synthesis that operates backward from the causes to the effects, from homogeneous colors to white light. Thus, as far as innateness of colors is concerned, this synthesis is not a mere confirmation of a proposition that had already been fully proved in a purely analytical way. It is an integral and essential part of a two-sided, regressive demonstration, which needs to go from effects to causes and back, in order to be completed.

My contention is that the way back, the second synthetic part of the demonstration, is tightly connected with, and dependent on, hypothetical premises taken from Newton’s theory of vision. Discrete ingredients from the theory of vision are brought in twice in the text of the second part of Book I. The first mention occurs rather abruptly at the end of proposition II, where Newton proposes a revision of his former definition of “homogeneous light,”<sup>18</sup> and introduces a dispositional definition of “homogeneous colors” in terms of powers “to stir up sensations.” The second mention (concerning how the human sensorium

<sup>17</sup> This particular issue was raised both by Mariotte and Lucas, when reporting their failed attempt to replicate the experiment. Laymon (1978) shows that Newton, after Lucas and Mariotte’s criticisms, was forced to acknowledge that the (1672) description of the crucial experiment was somehow idealized. Answering his critics, Newton tried to minimize the difficulty, in arguing that the second, unwelcomed, dispersion observed after the light had passed through the second prism would disappear if the hole through which the colors are selected were small enough to let only one single color ray pass through. This was of course impossible in practice.

<sup>18</sup> Compare to definitions VII and VIII (Newton 1979, p. 4) where Newton speaks of the “colours of homogenous lights” without mentioning the fact that the rays are not really colored, but only endowed with colorific properties.

is supposed to react to quick successive visual stimuli) plays a central role in the explanation of the tenth experiment (prop. V), a composition experiment using an oversized comb whose importance for the demonstration of innateness cannot be overrated. It appears that both the conceptual and the logical challenges are confronted in these two passages.

### 3.2.1 The Dispositional Definition of Color

According to the new definition of color given at the end of proposition II, a red homogeneous light is a light that makes the objects that reflect it, and itself, appear red—a 'rubrifick' or 'red-making' light:

The homogeneal Light and Rays which appear red, or rather make the Objects appear so, I call Rubrifick or Red-making; those which make Objects appear yellow, green, blue, and violet, I call Yellow-making, Green-making, Violet-making, and so of the rest.

Newton then explains that if at times he speaks of rays as colored or endowed with color, he should be understood as speaking not philosophically:

For the Rays to speak properly are not coloured. In them there is nothing else than a certain Power or Disposition to stir up a certain Sensation of this or that Colour. For as Sound in a Bell or musical String or other sounding Body, is nothing but that Motion propagated from the Object, and in the Sensorium 'tis a Sense of that motion under the Form of Sound; so Colours in the Object are nothing but a Disposition to reflect this or that Sort of Rays more copiously than the rest; in the Rays they are nothing but their disposition to propagate this or that Motion into the Sensorium, and in the Sensorium they are Sensations of those Motions under the Forms of Colours.<sup>19</sup>

It's tempting to hear here an echo of the famous doctrine of secondary qualities, a doctrine associated with Boyle and Locke whose central tenet was already present in Galileo or Descartes: colors, as well as sounds or tastes or smells are not to be counted among the true original qualities of bodies. Secondary qualities are in fact not real qualities of bodies at all, but "imputed"<sup>20</sup> ones, falsely attributed to the body or to the

<sup>19</sup> Newton (1979, p. 124–125). On the topic of dispositions in Newton and his contemporaries, see Joy (2012).

<sup>20</sup> See Locke (1975, Book II, viii. 22): "[...] those secondary and imputed qualities, which are but the powers of several combinations of those primary ones, when they operate without being distinctly discerned."

light that produces in us the sensation of such or such color, sound, etc. They would not exist if there were no sensing animal in the world to perceive them.<sup>21</sup> In Locke's terms, in the bodies themselves, they are nothing but the "powers" to produce a sensation in us. What grounds these powers in the material realm cannot be anything other than primary (that is, real) qualities. Drawing on the philosophy of the "Corpuscularians," Locke suggested that the real qualities directly responsible for our sensing of these secondary qualities are in fact the primary qualities of the minute invisible bodies acting upon our senses.

It may seem an odd fact that Newton felt the urge in the main text of the *Opticks* to introduce a definition of color that was, for many of his contemporaries, so tightly connected with philosophical conceptions and hypotheses. The theory of secondary qualities was in the earlymodern period a distinctive sequel to the corpuscular and mechanical hypothesis.<sup>22</sup> The heuristic value and, so to speak, completeness of the mechanical philosophy depended on its ability to account for every process in the material world. This meant that the qualitative residue, the whatever-it-is that is not reducible to figure and movement, should be explained away, ascribed to another, incorporeal realm. This was precisely the function of secondary qualities. The oddity here is that Newton—as is well known—was not at all committed to the truth or completeness of mechanism. And even if he were, the first book of the *Opticks*, with its neat web of experiments and its claim for inductive certainty, was certainly not a hospitable place for such a speculative definition. Indeed, one of Newton's eighteenth-century French translators, Jean-Paul Marat, probably felt that it was out of place, and shamelessly omitted it in his 1787 translation.<sup>23</sup>

But this is clearly wrong: Newton crucially needed the "philosophical definition." He needed it not for the sake of defending any Lockean or Boyleian view of primary qualities and mechanical philosophy, but because of the conceptual challenge just mentioned. Newton needed a definition of color that allowed for the paradoxical assertion that colors are present in white light 'unseen.' Color needed to be defined in a way that strips it of its phenomenal clothing. For this purpose, as will soon become clearer, the dispositional definition, which construes colors *in the rays* as powers to transmit a certain kind of movement to the brain, was framed.

<sup>21</sup> Ibid., xxxi.2): "there would yet be no more Light, or Heat in the World, than there would be Pain if there were no sensible Creature to feel it, though the Sun should continue just as it is now, and Mount Aetna flame higher than ever it did."

<sup>22</sup> For a presentation of the philosophical core of the doctrine of secondary qualities, and a discussion of its main justifications in seventeenth-century philosophical thought, see Hamou (2011).

<sup>23</sup> See Newton (1989).

### 3.2.2 The Comb Experiment and the Physiological Threshold for Color Sensation

In proposition 4, Newton had stated that the mingling of different spectral rays produces new colors. These colors, although sometimes indiscernible from the homogeneous, prismatic ones, should be described as “heterogeneous,” since their composite character in regard to refraction is manifested when they are viewed through a prism. Experiments in proposition 5 show that a recombined “white” light is also obtained through the mingling of several colored rays—the recombination occurs for example when the colored lights produced by the prism illuminate a piece of paper held at a certain distance from the beam: if duly positioned, the paper appears white, not tainted with any of the colors of the spectrum from which it receives its light. In the next set of experiments the refracted beam is made to converge into one white spot on a paper at the focus of a lens. One variant of this experiment is of crucial interest, because it is clearly devised to show that the new “composite” white is not the result of an alteration of the various colored rays—an alteration which would result from the mixing of the rays on the paper—but their mere superposition or concatenation, each keeping its color, or rather its colorific quality, exactly as it was before the blending. In this experiment, a large comb with oversized teeth is inserted into the beam of light between a prism that has dispersed that beam into colors and a lens that recombines it into white on a paper at its focus.

The comb allows the experimenter to block certain colors of the spectrum, and the immediate effect is that the recombined white disappears and “degenerates” into a given color. The reason whereof, is that the suppression of some colors by the teeth of the comb makes the composition of the resulting light different, and accordingly produces heterogeneous colors instead of white. A slow movement of the comb makes the composite resulting color change and causes a “perpetual succession of colors” on the paper. However, when the movement of the comb is quicker, this effect changes dramatically:

But if I so much accelerated the Motion, that the Colours by reason of their quick Succession could not be distinguished from one another, the Appearance of the single Colours ceased. There was no red, no yellow, no green, no blue, nor purple to be seen any longer, but from a Confusion of them all there arose one uniform white Colour.<sup>24</sup>

The experiment is beautifully devised. It clearly shows that the white obtained here cannot possibly be the result of an alteration of the qualities of the rays that are

<sup>24</sup> Newton (1979, p. 140).

mingled. As a matter of fact, there cannot be any causal action of the rays on one another because in this special case the variously colored rays do not reach the paper at the same time but only successively. In a letter to Robert Hooke, explaining for the first time the same kind of experiment, Newton made this point very clearly, insisting on the impossibility of any causal interaction between physically discrete events that occur at different times:

and that this whiteness is produce onely by a successive intermixture of the colours without their being assimilated or reduced to any uniformity, is certainly beyond all possibility of doubting unlesse things that exist not at the same time may notwithstanding act on one another.<sup>25</sup>

Once it is understood that the various colors in succession cannot really interact on the paper, the white appearance remains all the more perplexing. How are we to account for it? To Newton, no doubt the final answer is a psycho-physiological one: white is to be understood as a mental effect of the successive inputs of the colored rays on the retina and the part of the brain where these inputs are conveyed (a part that Newton calls the sensorium).

By the Quickness of the Successions, the Impressions of the several Colours are confounded in the Sensorium, and out of that Confusion ariseth a mix'd Sensation. If a burning Coal be nimblely moved round in a Circle with Gyration continually repeated, the whole circle will appear like fire. The reason of which is, that the Sensation of the Coal in the several places of that Circle remains impress'd on the Sensorium, until the Coal return again to the same place.<sup>26</sup>

The rotating burning coal is provided as an example for the existence of a physiological threshold, a time lapse, under which two successive appearances are no longer perceived as distinct. The coalescence of colors into white is not in the first instance a physical phenomenon, because it is not properly the light rays that are mixed, but the impressions they are making on our sensorium, impressions that, for some physiological reason, cannot be perceived distinctly, and therefore result in a sensation of whiteness. It should be clear that the comb experiment is not in itself a demonstration that white (solar) light is actually composed of distinct immutable colored rays, but it is clearly a demonstration that white light can be so composed. The experiment provides

<sup>25</sup> Newton (1959–1977, vol. 1, p. 182–183). This letter, dated 1672, describes an equivalent of the comb experiment, where the spectrum is intercepted by a rotating toothed wheel.

<sup>26</sup> Newton (1979, p. 141).

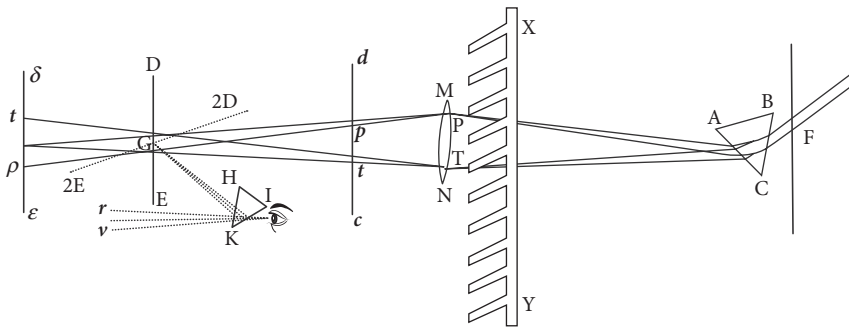


FIGURE 3.1 Comb Experiment

Source: *Opticks*, Book I, Part 2, exp. 10. Reproduced by permission of the Newton Project.

AQ: Please include reference to both figures 3.1 and 3.2 within text.

an explanatory model: it indicates a possible way out of the phenomenological puzzle of color innateness—the fact that colors cannot be seen in white light is no longer an objection to ‘unseen’ presence, since we are now in a position to show, through an ingenious experiment, that a white appearance can be produced by the successive effects of discrete color rays on the sense organs. In the comb experiment, no one ray can properly be said to be “white,” or whitening, but what we see on the paper is nevertheless clearly whiteness. The white-making property belongs to the whole set of successive rays, each endowed with a specific colorific property.

Through the comb experiment, we also understand more fully the need for a dispositional definition of color. The definition says: what allows us to say that a ray is colored in a philosophical sense is not a form or an appearance of the ray, but its ability or disposition to propagate a certain motion to the sensorium. When the rays are blended (as they are in heterogeneous lights), the sensation changes, but the ability of each ray to propagate motion is not really affected. Each ray keeps its own movement, that is, its own colorific property, although the composition of movements in the brain produces there a sensation that necessarily differs from the one each ray separately would produce.

To sum up, I argue that the comb experiment is a turning point in Newton’s demonstration of color innateness, because it helps to make sense of the conceptual puzzle of color mutability and immutability. I also argue that in order to understand the full implications of this experiment, the reader has to be apprised of a general framework of philosophical ideas on color perception supposed by Newton. The dispositional definition of color together with the suggestion of a physiological threshold for color perception are the main constituents of this framework.

Newton was certainly aware that the “physiological” explanation (the “mixing” of impressions in the sensorium), as it stands in the main text of the *Opticks*, is rather sketchy, not to say sibylline. In the *Queries*, he offers a certain number of elements that

allow this explanation to be somewhat fleshed out. Here is my own reconstruction of this explanation:

- 1) Query 15: The images (“species”) of objects figured at the back of both eyes are united into one single image in the brain through the pairing and junction of the individual fibers contained in the optical nerves. It is there, and only there that it stirs up sensations. This place in the brain is what Newton calls the “sensorium.”<sup>27</sup>
- 2) Query 16: A pressure of the finger, or a stroke on the eye makes some colored phantasm appear, and this appearance lasts for about one second. A coal of fire moved rapidly in the circumference of a circle appears as a continuous circle. These phenomena indicate that the movements that go through the nerves and reach the sensorium are of a lasting nature.
- 3) Query 17: This, in turn, suggests that these movements are vibrations rather than pressures or a translation of solid particles. Rays of light striking on the back of the eye may excite vibrations propagated in the solid fibers of the optical nerve (Query 12) up to the common sensorium, where the final image is formed.
- 4) Query 23: A vehicle for these vibrations may be the very aetherial medium “much subtler than air” that (Newton suspects) fills every empty space in the world, accounting for the transmission of heat in a vacuum, for fits of easy transmission, for magnetism, or for attraction. This medium probably pervades the “solid pellucid and uniform capillamenta,” that is, some transparent substance, filling the inside of the fibers.<sup>28</sup>
- 5) Query 13: Variety in the “bigness” of vibrations determines variety in color perception.
- 6) When several rays of different colors strike the back of the eye in a time less than one second in duration, the vibrating motions made in the pellucid liquor of the

<sup>27</sup> The definition of ‘sensorium,’ and the characterization of space as *tanquam sensorium dei* (Query 31), will become important bones of contention in the Leibniz-Clarke controversy. Leibniz mentioned Goclenius’ Philosophical Lexicon, where ‘sensorium’ is defined as ‘organ of sense.’ But Newton’s usage of the term is clearly related to Henry More’s, and should be understood as a brief form for “common sensorium”: in *The Cambridge Notebook* under the entry “sensation” (fol. 33, 104 r; McGuire and Tamny 1983, p. 382). Newton, drawing on the heads established by More in his fourth chapter of *The Immortality of the Soul*, lists the principal competing conceptions of the seat of common sense, or “sensorium”: 1) the whole body, 2) the stomach, 3) the heart (Hobbes), 4) the brain, 5) the membranes 6) the septum lucidum, 7) a perfectly solid part of the body, 8) the conarion, 9) the fourth ventricle of the brain where the spinal narrow meets the nerves (More), and 10) the animal spirits in the fourth ventricle.

<sup>28</sup> Query 23, specifically devoted to vision, is inserted in a set of new queries in the second English edition of 1717, where Newton speculates on the role of an aether, rarer than air, but more elastic and more active, apt to explain attraction, refraction and reflection of light, fits of transmission, and finally the nervous transmission of motive action and sensation. On this important addition, see Guerlac (1967).

optical filaments will blend together before arriving to the sensorium. The resulting effect will be the production of a sensation different from the one each color separately would have produced.

- 7) White is the resulting sensation of the mixing/confusing of a large number of vibrations of various sizes. These waves arrive to the sensorium either successively but in rapid succession (in the case of the comb experiment), or simultaneously (in the ordinary experience of solar light).

Premises 1 to 5 are drawn almost verbatim from the Queries. Premises 6 and 7 are needed in order to account for the comb experiment on the basis of 1–5. They allow us to make sense of what Newton says in Book I, the second part, prop V: that white is a “mix'd sensation” arising from the confusion in the sensorium of the impression made by several colors.

Although the complete argument on vision that we tried to reconstruct here is composed of disconnected pieces that the Queries introduce in a seemingly non-committal way, it is quite obvious that it stems from a coherent, non-trivial theory—a theory that appears to cover a large range of questions commonly debated in seventeenth-century discussions of vision, as for example, the merging of retinal images in the brain, the location and nature of the sensorium, the mechanism of transmission in the nerves, or the nature of psychological awareness as it results from sensory affections. However, the Queries are not the best place in which to get the clearest picture of this theory. One remarkable fact about Newton's theory of vision is that it is worked out, almost fully, at an early stage in his career, probably even before the time he began to experiment with prisms, and certainly before he reached his mature doctrine of light and colors. Since the literature has been rather silent on this aspect of Newtonian science,<sup>29</sup> it may be worth giving a brief account here of the theory and the context in which it was originally devised, before drawing our conclusions about its relationship to the general argument of Book I of the *Opticks*.

### 3.3 NEWTON'S EARLY RESEARCHES ON VISION

Several notes of the Cambridge Notebook of 1661–1665 are concerned with visual sensations and sensory faculties. Some of them are accounts of psycho-physical experiments and observations, while others, of a more theoretical nature, testify to Newton's extensive reading on a broad range of contemporary texts on vision, from Kepler and Descartes, to Hobbes, Walter Charleton, and Henry More. The 1666 manuscript “Of Colours” (Newton, ms. “b”) contains a description of an anatomical dissection of the

<sup>29</sup> With a few exceptions, among them notably Stein (2004).



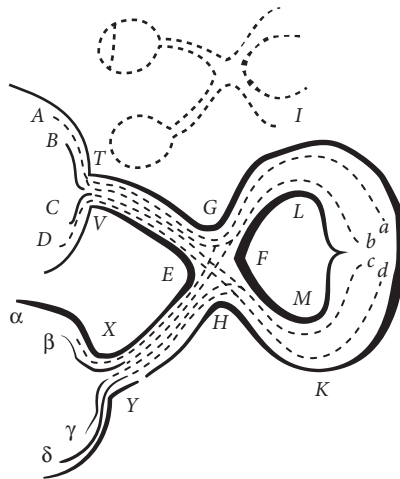
81 Vision, Color Innateness, and Method in Newton's *Opticks*

FIGURE 3.2 Binocular Vision in "Of Colours"

Source: Add. Ms. 3975, Cambridge University Library. Reproduced by permission of the Newton Project (Newton ms. b, p. 17).

visual system of a mammal, with an illustration representing the merging of the retinal filaments at the optical chiasma.<sup>30</sup> These texts (and illustrations) clearly show that the young Newton, like many of his contemporaries, approached the question of vision from within a general framework or paradigmatic account that I shall call for convenience's sake the 'Cartesian paradigm' (although it certainly owes as much to Kepler as it does to Descartes). According to this paradigm, the visual process must be understood as a multistep process, which consists in a progressive 'disfiguration' of the visual image and in its transformation into physical events in the brain apt to stir up appropriate mental reactions. The Keplerian account of the formation of the retinal image shows that the eye works as a *camera obscura*. The image produced in the eye is not a simulacrum detached from the object, but a mere physical effect of light rays impinging on the back of the eye. Some mechanistic account of brain and nerve, involving the action of subtle bodies or animal spirits, is required to explain the transmission

<sup>30</sup> Newton does not say who *is* performed the dissection, and what animal is dissected. Perhaps Newton was already at this time in contact with William Briggs (1642–1704), who was a fellow of Corpus Christi College Cambridge. Briggs trained as a physicist, and wrote several texts on the anatomy of the eye. He corresponded on the topic with Newton. In a letter to Briggs of April 25, 1685, which Newton wrote as a dedicatory epistle for Briggs' *Nova theoria visionis* (Briggs 1685), Newton mentions that he had once attended a dissection performed by Briggs, and he highly praises the latter's skill: "Your skill and artistry in its dissection once, I remember, afforded me no small enjoyment. You neatly displayed the motor muscles in their natural positions and so disposed all the other tissues before us, that we could not so much understand as perceive the functions and services of each, with the result that there is no refinement that I have not long expected of your knife" (Newton 1959–1977, vol. 3, p. 418).

of motion from the external organs (the eyes) down to a central organ, the seat of the “common sense.” Finally, a dualistic account of human sensation is needed in order to understand how a material event, or chain of movements ending in the brain, can be connected to a visual idea or mental awareness. The connection is usually considered arbitrary, attributed to the will of the Creator who has “instituted” that such or such motion in the brain make the soul have such or such an idea.

One needs to distinguish between these basic tenets and the interpretations that they allowed for vis-à-vis different physiological and/or philosophical hypotheses. It seems clear to me that Newton's research in the early manuscripts aimed at constructing an interpretation of the Cartesian paradigm that on many points takes issue with Descartes' way of fleshing out the paradigm. Three main issues are tackled in the 1665–1666 manuscripts: binocular vision, the mechanism of nervous transmission, and the relation between visual representation and cerebral images. The three topics need to be reviewed here because, quite surprisingly, each of them had an important part to play in the final explanation of color innateness.

### 3.3.1 Binocular Vision

The question of whether we see with both eyes or with only one eye at a time had been long debated. Alhazen and Witelo maintained the fusion of images coming from both eyes. Descartes was also of this opinion, and thought that the merging of the images from both eyes takes place at the surface of the pineal gland. This view was challenged by Gassendi and his followers. According to Charleton's *Physiologia*, one sees (distinctly) with only one eye at a time, through which the soul preferentially directs the flux of animal spirits.<sup>31</sup> Henry More offers another option: to make our vision distinct, the retinal images are indeed united, but not in the brain or in any other part of the body. One should think of them as united in the outside world, on the object itself, with the soul, according to More, being able to sense the converging path of the external rays connecting the object seen to the eyes.<sup>32</sup> Newton, who quotes Charleton

<sup>31</sup> See Charleton (1654, ch. 3, p. 166, art. 22): “that all men see (distinctly) but with one Eye at once.”

<sup>32</sup> See More (1659, ch.10). More rejects the Cartesian idea that an image is “corporeally produced in the inside of the brain,” on the basis that “colours and figures would be strangely depraved if not quite obliterated” if they were to be seen in the opaque substance of the brain. He contends that the soul is not strictly confined to the sensorium, but has the power to reach the back of the eyes through visual spirits, and there to directly perceive the retinal images, with their proper colors. The idea that the immediate object of the sight should be the retinal pictures themselves, since they faithfully conserve the colors and figures of the external objects, is completely at odds with Descartes' explanation of vision—it misses the very point of Descartes' rejection of intentional species, namely, that we do not need resemblance and colored images in order to perceive.

and More in his Cambridge Manuscripts, does not follow them in their departure from Cartesian orthodoxy. He maintains the idea that the ultimate cause of our perception is some sort of “motional picture,” produced, not in the *camera obscura* of the eye, but well inside the brain, where the two optical nerves converge again after their first crossing. Experimental justifications are offered for this ‘cerebralist’ thesis: on the one hand, the anatomical dissection already mentioned allows Newton to follow the path of nervous transmission from each point of the retina to each point of the sensorium, arguing that a one-to-one pairing of the filaments of both eyes occurs in the chiasma, connecting to the same spot in the brain the two corresponding points on the retinas that share the same spatial position within the eye. Here is how Newton describes it:

Now I conceive that every point in the retina of one eye hath its correspondent point in the other, from which two very slender pipes filled with a most lympid liquor doe without either interruption or any other uneavenesse or irregularity in their processe, goe along the optick nervesto the juncture EFGH where they meeteeither twixt GFor FH, & there unite into one pipe as big as bothe of them, & so continue in one passing either twixt IL or MK into the braine where they are terminated perhaps at the next meeting of the nerves twixt the Cerebrum & cerebellum, in the same order that their extemities were scituate in the Retinals.<sup>33</sup>

One should note that the description is not entirely derived from observation. As Newton acknowledges, the distinction of the various optical filaments, still perceptible by touch before the chiasma, is no longer apparent behind it—so the pairing of the corresponding points on both eyes, although suggested by the form of the chiasma, is no more than a physiological hypothesis. The main argument for its truth is not anatomy, but rather the fact that a physiology of this sort would account for a number of psycho-physical observations. Newton presents these observations just after the anatomical description. He mentions first the basic fact that in visual experience we see with both eyes, but perceive only one image. This suggests that some fusion takes place. Then, if one eye is pressed laterally with some protruding object, we tend to see double, and this is easily explained if we understand that, because of the slight deformation of the retina, the same distinct point of an object projected on both eyes is no longer pictured by a couple of homologous filaments. Again, when objects are seen very close up, they often appear double,

<sup>33</sup> Newton (ms. b, p. 17). Newton's description is close enough to the contemporary one: it gives an adequate-enough account of how the axons of the optical nerve are distributed. The fusion however does not takes place in the chiasma, as Newton thought, but directly in the cerebral cortex cells, and in such a way that a discrimination of the information from each eye is still possible. Such discrimination is the neurological basis of the stereoscopic effect, which entirely eluded Newton.

because in this situation the distance between the eyes creates a sensible discrepancy of the retinal images. Newton adds an interesting suggestion: if one could make a blue color and a yellow one strike the left and right retina respectively on homologous filaments at the same time, the resulting image would certainly be green. Although it is very improbable that Newton succeeded in realizing this psychological blending of color, the opinion expressed here is very suggestive of his later thoughts on production of a heterogeneous color, or white, as the result of a “mix'd impression.”<sup>34</sup>

To sum up this first point: Newton's opinion on the fusion of retinal images clearly shows his adoption of a Cartesian-like, cerebralist theory of vision: the end term of the visual process is not the retinal image (as in the Gassendist tradition), but some “picture” in the brain, constructed out of retinal information—a picture that could no longer be defined as luminous or colored. The only properties of retinal images that can conceivably be transmitted in the entirely opaque space of the brain are indeed figures and movements. Although it has not often been acknowledged, adherence to a cerebralist account of visual perception, such as the one offered by Newton or Descartes, was itself a strong motive for holding a dispositional theory of light and color, quite independently of the “mechanistic” justification of the distinction between primary and secondary qualities. Light and colors cannot be transmitted as such into the sensorium, and yet a cerebralist doctrine of sense perception requires that they are nevertheless perceived there, in a completely opaque substance. Thus, they cannot be ‘real’ qualities but only dispositional properties or powers (grounded on figures and motions) to stir up certain sensory ideas.

### 3.3.2 The mechanism of nervous transmission: The vibratory model

In *Dioptrique IV*, Descartes offered a mechanistic account of sensory transmission in the nerves, which paralleled his explanation of light transmission in the second

<sup>34</sup> See Newton (ms. b, p. 18): “Why a blew seen by one eye and a yellow by the other at the same time produces a green unless the fantasy makes one colour predominant.” The role given here to ‘phancy’ or ‘fantasy’ is noteworthy: in the Cambridge Notebook, Newton had noted (see Newton ms. a, 125r, 130r) that the very same sensation can be either physically produced or simply fancied, and this fact serves here as an auxiliary clause which provides an easy escape when the observation does not fit the prediction of the ‘cerebralist’ theory. The role of ‘fantasy’ in vision and binocularity will be stressed again twenty-five years later, in a long letter to John Locke (June 30, 1691; Newton 1659–1677, vol. 3, p. 152–153) reporting dangerous experiments on after images: the impression produced on one eye by a direct contemplation of the sun will degenerate into colored circles and finally vanish, but for quite a long time it can be reactivated at will, not only in the eye affected but also, more surprisingly, in the other one. Newton ascribes this strange phenomenon to the action of the imagination: “the man's phansy probably concurred with the action of the sun to produce that phantasm of the sun...”

element.<sup>35</sup> In both cases, a certain tendency to movement is instantly transmitted through a perfectly dense and rigid medium, similar to a stick. The stick analogy, however, does not apply very well to soft cerebral parts, such as optical nerves; and Descartes had to explain, in a rather ad hoc manner, that in living organisms, a current of animal spirits propagated into the nerves acts as a sort of tensor of the internal substance, allowing the transmission of the “pressure” of light. Newton did not follow Descartes in this rather contrived explanation. His own understanding of light transmission put him in mind of another model of nervous transmission. In “Of Colours,” he describes the resulting effects of the impact of light rays on the retina in these terms:

Light seldom striks upon the parts of grosse bodyes (as may bee seen in its passing through them), its reflection & refraction is made by the diversity of æthers, & therefore its effect on the Retina can only bee to make this vibrate which motion then must bee either carried in the optick nerve to the sensorium or produce other motions that are carried thither.<sup>36</sup>

The passage contains a clear hint at an atomistic conception of light and bodies: both are constituted out of small corpuscles disseminated into large empty spaces. This explains why light “seldom strikes” the parts of (gross) bodies—it usually passes through them into the ‘diversities of æthers’ filling the empty spaces left inside these bodies. The kind of movement transmitted to the æther by the impact of light rays is not described as a pressure, but as a vibration whose effect may be compared to the concentric waves produced when a stone strikes the smooth surface of water. The vehicle for this sensory wave is conceived as a “pure transparent liquor” contained in the tube-like structure of the nervous filaments. These filaments behave like “trunks” filled with a homogeneous substance like air that transmits sound along their length with almost no dissipation. Newton’s attention to psycho-physiological phenomena, like rotating the burning coals, and after-images is also congruent with a physical interpretation in terms of vibrations, since it suggests that the visual phantasms produced by the action of light on the retina do not immediately vanish but endure for a certain time.

Newton retained this vibratory model of nervous transmission. Before the publication of the *Opticks*, he went back to it on various occasions and added some refinements. First, in his *Hypothesis of Light* (1675), he suggested the existence of a fixed correlation between “bigness of vibrations” and colors similar to the correlation between tonality and length of sound waves. The most vivid colors (the reds and yellows) should be caused by the biggest pulses, and the darkest ones (blues and purples)

<sup>35</sup> See Descartes (1964–1976, vol. 7, p. 109–112).

<sup>36</sup> Newton (ms. b, p. 19–20).

by the smallest.<sup>37</sup> This musical analogy was very important to Newton and, since the time of the *Lectiones opticae*, it convinced him of the existence of a certain “harmony” of colors, similar to the harmony of sounds. Newton even speculated that the seven colors of the spectrum might divide its length, as the successive chords (tone, third, fourth, fifth) do on the strings of an instrument.<sup>38</sup> A second important locus for understanding the exact scope of Newton's vibratory model is Newton's 1682 correspondence with William Briggs. Briggs, in his *New Theory* (1685) was also interested in the musical analogy, but applied it almost literally: he contended that in visual sensation, the two optical nerves act like musical instruments, or vibrating lyres, each filament of the nerve being like a string, whose consonance with the corresponding one in the other eye was supposed to explain the mental uniting of the two retinal images. Newton strongly disagreed, arguing that unisons cannot possibly be the cause of a perceived unity of situation, this not even being the case for sounds: “the situation of sounds depends not on their tone.”<sup>39</sup> As for ‘visible objects,’ another principle is needed to account for the fact that, with both eyes, we see them situated at one and the same place. This principle is clearly the aforementioned cerebralist analysis, according to which “the two motional pictures in the sensorium come together and become coincident.”<sup>40</sup> So Newton is keen to distinguish on the one hand the physiological principle governing the formation of cerebral images (which strictly depends on the location and distributions of the small filaments connecting the retinas to a certain location in

<sup>37</sup> In these texts, the vibration size seems to be related to the mass of light corpuscles, rather than their speed. Newton however never tried to apply this “mass model” to the physical explanation of color dispersion. In a brilliant paper, Bechler (1973) has shown that a mass model for color dispersion was somewhat unsatisfactory to Newton on account of its “abnormality” (it would require that another dynamic prevailed at the microscopic level of the light corpuscles, which cannot be accounted for in terms of attractive or repulsive forces). A model discriminating color rays according to their speed would have been much more appealing to Newton because it would have allowed a physical explanation of refraction in terms of attractive or repulsive forces acting on the separating surface of the mediums, an explanation that would fit the physico-mathematical description given in the *Principia*, showing that the trajectory of the corpuscles crossing such surface would be more or less ‘refracted,’ according to their speed (but not their mass) (see *Principia*, Book I, section 14, prop. 94–96). Unfortunately Newton could not follow this: realizing that the ‘speed model’ would be corroborated if the last light coming from Jupiter's satellites before their disappearance behind the planet was red, and the first light seen at their exit blue, he asked Flamsteed, the Greenwich astronomer, to tell him whether such a difference in color was observable. The negative answer seems to have ruined Newton's hopes of explaining refraction in terms of attractive forces.

<sup>38</sup> See *An Hypothesis of Light*, in a Letter to Henry Oldenburg, December 7, 1675, Newton (1959–1977, vol. 1, pp. 362–383). See also *Opticks*, Book I, section 2, prop. 3 (1979, pp. 125–128) and Query 14 (p. 346).

<sup>39</sup> Newton (1959–1977, vol. 2, letter 264, September 12, 1682, p. 383).

<sup>40</sup> *Ibid.*, p. 384.

the brain); and on the other hand, the physiological principle governing the production of color sensation, that is, a vibratory motion propagated into these filaments. The various lengths of the pulse determine various color sensations. The aesthetic fact that certain associations of colors are pleasing can be understood along the lines of the musical analogy, the soul being able to sense certain exact ratios in the said lengths. Confused or composed color sensation is produced when several trains of waves with differing lengths are superposed—white being the resulting effect of a cacophonous superposition, in which the composing lengths are no longer distinguishable.

### 3.3.3 Visual representation and cerebral images: Newton's indirect realism

The last stage of the visual process is the one through which 'motional pictures' in the brain cause our ideas of visible objects, clad with colors and situated in the external world. Newton commented less on this than on other aspects of the Cartesian legacy. However a passage of the Cambridge Notebook, placed under the heading "of the soule," offers a clear hint of how Newton understood the status of our mental representation of visible objects:

Quaere. 1 Why Objects appeare not inverst, Resp: The mind or Soule cannot judge the image in the Braine to be inversed unlesse shee perceived externall things with which shee might compare that Image.

2. Why doe appeare to bee without our body? Resp: Because in the image of things delineated in the braine by sight, the bodys image is placed in the midst of the images of other things, is moved at our command {towards} & from those other images [etc.]:

3. But why are not these objects then judged to bee in the braine? Resp: Because the image of the braine is not painted there, nor is the Braine perceived by the soule it not being in motion, & probably the soule perceives noebodys but by the helpe of their motion. But were the Braine perceived together with those images in it wee should thinke wee saw a body like the braine encompassing & comprehending our selves the stars & all other visible objects [etc].<sup>41</sup>

What emerges from this set of questions and responses is a typically "representationalist," or indirect realist doctrine of visual representation. Here the departure from Descartes is noticeable. Although Descartes seems sometimes to suggest that the mind "inspects" the images in the brain, his usual position in the *Dioptrique* and elsewhere is

<sup>41</sup> Newton (ms. a, "Of the Soule," p. 130v.).

that cerebral images are not properly seen in the brain.<sup>42</sup> Just as material signs, written in a familiar language, may convey their meaning without themselves being objects of awareness (so that the reader cannot even tell afterward in which language they were written),<sup>43</sup> cerebral signs act on the mind and excite ideas without being themselves seen or represented to consciousness. Newton's conception seems somewhat cruder if not naïve:<sup>44</sup> to him, the cerebralist analysis entails that whatever is perceived visually is actually perceived in the brain—it is only indirectly, through inference, that the objects are judged to be outside the brain, located in external space. The last remark in Newton's answer to the last question is especially telling on this score: if we could see the background of our visual images, every visible scene would appear as surrounded by the very substance of the brain! With such conceptions, Newton can easily dispose of the old question of inverted retinal (or cerebral) images: inversion is not an issue because we never perceive the external objects where they are, and we do not compare our images with them. Our only business is with what happens inside the head. Our sense of what is in the top part or bottom part in our visual field does not come from any independent, inner compass—it comes from directional clues that belong to the image itself (as, for example, the way the image changes when we raise the head, or the place in the image where the ground or the sky are represented). The fact that external objects appear to be outside the body and not in the head (see the second question) may be explained along the same lines: here again the true situation of the objects is not perceived, but judged from internal clues, and especially from the visual representation that one can have of his own body, which is perceived to be “in the midst of the images of other things,” and not all around them.

As we said, Newton's approach may be labeled indirect realism: the direct object of perception is not and cannot in any sense be the external object itself. It is some sort of physical avatar, a picture hung in a gallery inside the brain. The mind perceives in being vitally united and present to this part of the brain where the images of things are transmitted. Newton never felt the need to give any justification for this view. It seems rather that it was for him a most natural consequence of the mechanistic, modern analysis of the senses. In fact this sort of indirect realism was rather common in England, and can also be found in Robert Hooke and probably in Locke—at least this view is a plausible way to make sense of the theory according to which we perceive through “ideas” that are “in the mind.” The prevalence of this view in England

<sup>42</sup> On this ambiguity in Descartes, see Hatfield (1992).

<sup>43</sup> See Descartes (1964–1977, vol.11, p. 4).

<sup>44</sup> Tamny judges Newton's version of the representative theory of perception as somewhat naïve; see Tamny (1979), McGuire and Tamny (1983), p. 232. Whatever its “naivety,” the idea that we inspect “images in our brain” is still commonly held today, especially among neurophysiologists.



is also attested *a contrario* by the attacks that John Norris, the British Malebranchist, mounted against Locke, and all the authors whom he sarcastically named “the optical men,” on account of their gross, materialistic understanding of ideas as material images in the brain.<sup>45</sup>

I shall add one last word on the Newtonian understanding of human visual representation. In the Queries of the *Opticks*, one famous passage offers a clear confirmation that he still held to his early 1665 conceptions even at the end of his career. Here is how Newton introduces the much-discussed idea that space may be understood as, so to speak, God's sensorium. God, a powerful ever-living Agent . . .

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 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.<sup>46</sup>

This famous text, besides expressing the metaphysical view that God exists and acts everywhere, also contains a rare, and rarely commented on<sup>47</sup> explicit statement of Newton's representationalist theory of perception: external objects are not sensed where they are, they are not even sensed in the organs of sense—those latter being only media or vehicles for the transmission of the species (or images) of external objects. It is only those images that are sensed, through their immediate presence to the brain, or, more specifically, to the human sensorium—the soul's dwelling place. So sensation occurs when the images are in a literal sense present to the soul. If the soul were able to extend its presence to the outer world, or be omnipresent, as God is, it would sense things directly, with no need of any organs. It seems clear that Newton is here relying

<sup>45</sup> See Norris (1701).

<sup>46</sup> Newton (1679, Query 31).

<sup>47</sup> With the notable exception of Tamny (1979).

on what he thinks is a rather common account of how human perception works, in order to make sense, analogically, of God's presence and action.

### 3.4 CONCLUSION

Newton elaborated a coherent and rather original theory of vision to which he remained faithful throughout his life. He devised it at an early stage of his career, drawing on his readings of modern authors such as Kepler, Descartes, Hobbes, Charleton, and Henry More, discussing them and adding important elements of his own based on dissection and psycho-physical experiments. This theory of vision was elaborated prior to and independently of what would become the central focus of Newton's optical researches—prismatic experiments and the theory of differential refraction of light. As far as method is concerned, the theory of vision and the doctrine of light are clearly at variance. Newton addresses the question of vision as his predecessors did, using the basic tenets of the corpuscular philosophy and mechanistic physiology, coming up with hypotheses on the inner constituents of nerves and brain, and drawing tacitly on a dualistic metaphysical conception of soul and body. Thus it cannot be a surprise that the theory should not easily fit into the inductive architecture of the *Opticks*, where experiments alone are admitted as a basis for demonstrations, and that it was relegated to the margins of the book, under the headings of the Queries. However, the theory of vision was an important ingredient in Newton's conception of white light as a heterogeneous mixture of innately colored rays. It is implicated both at a psychological and at a logical level. First, the fact that Newton had, ready at hand, a theory of color perception allowing for the possibility of a "mix'd sensation," must have been the reason why to him the composite nature of white solar light was not the utter paradox that it was for others, and why it could present itself as a plausible solution to the problem of spectral dispersion. Second, in the *Lectiones opticae*, his 1672 letter to Hooke, and later in the *Opticks*, Newton devised a set of "composition" experiments whose purpose was to make clearly apparent that we do in fact have "mix'd sensations" of colors, resulting in the perception of different kinds of apparently homogeneous colors, including white. In my view, these experiments constitute the backbone of Newton's demonstration of the innateness of colors in white light. Moreover, as I have sought to show in the first part of this paper, their intelligibility requires considerable input from the theory of vision: basically it requires all the theory's component parts—the account of nervous transmission in terms of vibrations, the cerebralist physiology of binocular vision, the dispositional theory of light and color, and finally the concept of the human sensorium and the brand of representational theory of perception that it involves. When this is properly taken into account, it appears that those few Queries dealing with the theory of vision at the end of the volume are not quite what they are often taken to be. Far

from their being a mere hypothetical sequel of the demonstration—suggested by the experiments, but unnecessary for the demonstration itself—the queries in fact formulate the key argument, an argument only tacitly expressed in the main text, yet crucially needed in order to make the composition experiments serve their end: that is, to make the very concept of color innateness intelligible.

Newton has often been taken to task by recent commentators for his somewhat “rhetorical” inductivism.<sup>48</sup> It has not been my aim here to join this battle. I have however wanted to stress the fact that Newtonian ‘empiricism,’ if it means anything at all, cannot mean that natural philosophy must be raised on a conceptual tabula rasa. You may be able to “evince” theories directly from phenomena, but you won’t make sense of them without a set of definitions, and without some axiom-like principles and background theories.<sup>49</sup> I have tried to show in this paper that to make sense of Newton’s theory of light and color, a non-trivial theory of vision—of Cartesian pedigree, but with specific Newtonian ingredients—is needed, and should be included among these quasi-axiomatic principles.

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<sup>48</sup> For instance in Sabra (1981).

<sup>49</sup> See for similar considerations on background principles, Worall (2000).

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