# Newton's Rejection of the Modificationist Tradition[1]

*Gábor Zemplén*

*Abstract*: Newton, unaware of important modes of modificationism – like *medium modificationism,* existing since the time of Aristotle and forming the basis of Goethe's later theory as well – developed his views based only on a weak theory of modification, but claimed that his theory is superior to *any* modificationist account. In his "New Theory" he did not demonstrate strong immutability – thus leaving modificationism still defensible. The early development of Newton's view on colours is reconstructed, including the 1672 "New Theory".

## INTRODUCTION

The two major breakthroughs announced by Newton in his first publication in optics are his "discovery" of differential refraction, and his theory of colour replacing contemporary modificationist theories[2]. The former was a modification of the recently discovered law of refraction, and was generally treated as an improvement within the bounds of mathematical optics proper. The latter was the rejection of the whole modificationist tradition – the only existing alternative scientific theory to account for the colours of the spectrum and other colour phenomena. This step was clearly seen as the extension of the bounds of the mathematisable parts of natural science into territories earlier claimed by natural philosophy and believed to be unmathematisable by most[3]. Although Newton is mostly hailed for

1 For the two years 2000-2002 I learnt a lot under the kindly paternal tutelage of Prof. Dr. Ivo Schneider. I was also financially supported by the Bavarian Free State, could enjoy the benefits of working in the Deutsches Museum, Munich, and received additional research aid from the OTKA (grants F 032218, T 037575, and T 037504) and the Sasakawa YLFF.

2 His first letter to the Royal Society through Oldenburg had no title, and contained a: "New Theory about Light and Colors: where Light is declared to be not Similar or Homogeneal, but consisting of difform rays, some of which are more refrangible than others: And Colors are affirm'd to be not Qualifications of Light, deriv'd from Refractions of natural Bodies, (as 'tis generally believed;) but Original and Connate properties, which in divers rays are divers: Where several Observations and Experiments are alleged to prove the said Theory." (Newton 1671-72: 3075).

3 In a passage of the 'New Theory' omitted by Oldenburg from the printed version (but probably read by Hooke) Newton wrote: "A naturalist would scearce expect to see ye science of those [colours] become mathematicall, & yet i dare affirm that there is as much certainty in it as in any other part of Opticks." (Turnbull 1959: 96) Later Newton wrote to Oldenburg (21 September 1672): "To comply w$^{th}$ your intimation … I drew up a series of such Expts on designe to reduce y$^{e}$ Theory of colours to Propositions & prove each Proposition from one or more of those Expts by the assistance of common notions set down in the form of Definitions & Axioms in imitation of the Method by w$^{ch}$ Mathematitians are wont to prove their

the former discovery, he was fully conscious of the implications of the latter, and, as he wrote to Oldenburg, this was "the oddest, if not the most considerable detection w$^{ch}$ hath hitherto been made in the operations of Nature" (Turnbull 1959: I/83).

In the following discussion I will investigate this most significant discovery concerning the nature of colours. After presenting the confusion that prevails among historians as to how to deal with the modificationist tradition and giving a preliminary taxonomy of the main types of modificationist theories, I give a quick overview of the development of Newton's early views. Newton first incorporated but later rejected modificationist theories of colour, and he publicly argued against these theories in his first, 1672 publication. I will draw attention to the most important factors that allowed Newton to develop his own theory and to go against two thousand years of tradition. I will only concentrate on the works that lead to the famous publication in 1672, but not on the equally exciting further development of his thought, which was much shaped by the controversies the publication of his theory facilitated.

## A SHORT OVERVIEW OF MODIFICATIONISM

What is the current opinion about the modificationist tradition? In this short overview I will show the lack of common definition concerning the modification-nist tradition and the lack of agreement about its success or failure. This highlights a significant deficiency in modern history of science writing to treat a nearly two thousand-year old scientific tradition.

What is modificationism? Thomas Kuhn remarked in his introduction to Newton's optical papers, that coloured fringes seen in the emergence of the spectrum seem to strengthen the "ancient theory of the nature of the rainbow's colors, a theory which held that a succession of modifications of sunlight by the droplets of a rain cloud produced the colors of the bow" (Kuhn 1958: 31). He further added that this theory, first employed to explain the colours of the rainbow, was

doctrines" (Turnbull 1959: 237). See also part of the reply to Hooke: if the physical principles of optics are such that "on them a Mathematician may determin all the Phaenomena of colours that can be caused by refractions, & that by computing or demonstrating after what manner & how much those refractions doe separate or mingle the rays in which severall colours are originally inherent; I suppose the Science of Colours will be granted Mathematicall & as certain as any part of Opticks." (Turnbull 1959: 187). In his *Lectiones opticae* Newton wrote: "The relation between the properties of refractions and those of colors is certainly so great that they cannot be explained separately. Whoever wishes to investigate either one properly must necessarily investigate the other. Moreover, if I were not discussing refractions, my investigation of them would not then be responsible for my undertaking to explain colors; nevertheless the generation of colors includes so much geometry, and the understanding of colors is supported by so much evidence, that for their sake I can attempt to extend the bounds of mathematics somewhat … Thus although colors may belong to physics, the science of them must nevertheless be considered mathematical, insofar as they are treated by mathematical reasoning" (Newton 1984: 87).

present in all theories of colour in the 150 years preceding Newton's work. The mixture of light and shade "at the region of contact between the refracted beam and the dark" is a result of "varying 'condensation' and 'rarefaction' produced at the edges of the beam", or it might emerge "by some other mechanical modification." (ibid.). According to Kuhn there was "no consensus" as to what is the particular modification[4]. He acknowledges the multiplicity of modificationist theories, but his account is restricted to what I term boundary-modification, that modification was "a minor perturbation restricted primarily to the edges of the homogeneous beam of sunlight" (Kuhn 1958: 30).

Some commentators prefer an operative definition. Modification is when "colours are produced as a result of the contact of light with some reflecting or refracting body" (Thompson 1995: 7, also citing Sabra 1967: 294-5; Guerlac 1986). Shapiro gives a broader definition where modificationism is the idea that colours arise from some modification or alteration of pure white light, such as mixture with shadow or a compression by refraction or reflection (Shapiro 1990). He also suggests that until the seventeenth century it was believed that "colors arise from a mixture of light with darkness, that is white and black" (Shapiro 1994: 601). He also claims that a new theory was proposed in the seventeenth century by Descartes and Hooke, among others, "abandoning the idea that color arises from light and shadow and made it depend on the relative strength of successive light pulses or waves" (Shapiro 1994: 611). These citations indicate that modification could be the result of various processes. Homogeneous white light can interact with different types of surfaces: with reflecting surfaces, with refracting, transparent surfaces, it can be modified by the neighbouring shadow or darkness, or by other elements in the stream of light.

Although the group of theories broadly categorised as "modificationist" is very varied and wide-spread (the actors themselves used the terms in different senses), very little historical work has been done to group and classify them. One of the few articles focusing on the modificationist tradition compares Hooke's views with those of Aristotle (Nakijama 1984)[5]. For Nakijama, Aristotle's conception is summarised as: "(a) White is the original colour of light and other colours are produced by the modification of it. (b) The modification is raised by the admixture of darkness to light, and colour of light is determined by the quantity of darkness it contains. Red is the nearest approach to white. It contains the least darkness. As the admixture of darkness increases and the strength of light declines, there appear first green and finally violet, etc." (Nakijama 1984: 25) Claiming that Hooke subscribed to (a), but not to (b), Nakajima states that two distinct theories of modification existed, that of Aristotle, and that of Descartes

[4] It was usually agreed that there is only one such modification, and that "its positive or negative application … to white light could produce only two primary colors". These are extremes, and the other colours are generated by the appropriate mixtures. (Kuhn 1958: 31).

[5] Westfall also treats Aristotle as the originator, see (Westfall 1962; Westfall 1980). Schopenhauer remarked: "So finden wir denn auch von Goethes Grundgesetz der physischen Farben, oder seinem Urphänomen, die Hälfte schon vom Aristoteles ausgesprochen ..." (Schopenhauer 1972: 82).

and Hooke. Although this account is mainly accepted by other works on the modificationist tradition (Steinle 1994b), it is clearly not a detailed and systematic treatment of the subject. The differentia specifica of the two theories is a complex set of statements listed in (b), and it is far from clear what relation, if any, they have with each other and (a). A much more fine-grained analysis is needed, and even this article will only take some early steps in this direction.

More recently, Dennis Sepper gave a much broader definition of modificationism – again, without giving a detailed analysis of the different theories (Sepper 1988: 109): "the term characterises all theories that attribute color to some kind of modification or change of simple white light". I will start with this general definition $M_0$ that comprises all modificationist theories. To delineate some of the major types of theories will be the topic of the following pages, but first the general appreciation of modificationism should be established.

In the literature there is no agreement as the group of theories were all together successful or they necessarily failed. As for Kuhn, he claims that all modificationist theories "ultimately" fail because they cannot account for the elongated image of a white band of sunlight cast on a prism – the spectrum – viewed from a long distance, though this is not "immediately … apparent". Unfortunately he does not go into details. To stay with our investigated epoch, the seventeenth century, it was only at the angle of minimum deviation (when the angle of incidence on the prism equals the average angle of refraction) that the elongation was problematic for modificationist accounts. At all other angles elongation was expected using the received laws of optics. Even the refraction at the minimum deviation could only have raised problems once the age-old quest after the law of refraction had been perceived as accomplished. Earlier one could simply assume that refraction is more complicated than believed (i.e. no single and simple law can characterise it – as it could not until 1621). This view hails the Newtonian theory as victorious above all modificationist theories.

Sepper (1988) and Sabra (1967), however, claim that the debate was not restricted to Newton's cohorts and the tradition flourished long after Newton's death. Several eighteenth century (mostly French) writers supported modificationism, and Goethe's gigantic theory of colours is also firmly rooted in this tradition. In the nineteenth century a debate took place that was similar to the one between Newton and his contemporaries (Henri Poincaré as opposed to Lord Rayleigh, M. Gouy, and Arthur Schuster), this time more favouring the modificationist position concerning the original compositeness of white light. This view sees the Newtonian anti-modificationist theory as a small interlude in the overall more successful modificationist stream.

*In toto* in the literature no generally accepted view exists as to what exactly is the definition of an intellectual tradition that was highly significant in shaping views about colours for two thousand years. It is also unclear, whether the last appearance of modificationism was a success or a fiasco, and, worse than this, what actually counts as modificationism.

It is typical – as we have seen with Kuhn – that, following Newton's critique of modificationism, the tradition is restricted to theories where light is modified on surfaces, during reflection or refraction. This boundary-modificationism was common, but accepting this as the definition of the whole tradition important and obviously accepted theories are excluded, like that of Aristotle or of Goethe. Both these latter theories are medium-modificationist theories, based on a concept of media where (without boundaries or bounding surfaces, or change of direction of light) colour-changes can occur – light can be modified simply by being in a medium, or travelling through it.

It is also claimed that when explaining the spectral colours Newton’s theory connected a geometric and a chromatic problem, the problem of the elongated image and the coloured bands of the image. He proposed a solution where the law of sines, a major discovery of the seventeenth century could be saved in a modified form. According to this view (Sepper 1988: 109), modificationist theories separated the geometric and chromatic problems, and only tackled the latter. But it can be argued that again this separation does not apply for medium-modificationist theories, like that of Goethe, for whom both colour and elongation is the result of the superposition of images[6]. This shows that even views on the applicability of the modificationist theories differ.

As from the following it will become clear, a part of this confusion can be attributed to the success of the Newtonian theory and Newton's treatment of the modificationist tradition.

## NEWTON’S EARLY NOTES AND HIS REJECTION OF MODIFICATIONISM

Many aspects of the early development of Newton’s optical thought remain obscure. The chronology of his optical research and his manuscripts is confused, and some of the most plausible chronologies challenge the credibility of Newton’s account (Guerlac 1983). The notebooks investigated here include a section of a commonplace book, now pressmarked Add. 3996. It had been mainly neglected before (Hall 1948). The latest mentioned date in the Note-book is related to the observation of a comet on 5 April 1665, but of course later entries could well have been made. The book contains a section of notes collected under the heading “Questiones quædam Philosophcæ[7]”, which contains several sets of observations on colours. I will separate his earlier, rather haphazard ideas, and his first prismatic experiments.

Then I will investigate small fractions of two notebooks, the Waste Book (Add. 4004) and parts of another notebook, Add. 4000, both primarily concerned with mathematics. Following this, I am going to summarise Newton’s development in yet another notebook (Add. 3975), probably started in 1664 and used until at least 1693. In this I will investigate his ideas in ‘Of Colours’, folios 1-22[8]. I will

6 That the two problems are closely connected is clearly seen in Werneburg’s work, which, again, belongs to the modificationist tradition (Werneburg 1817).

7 The second i is omitted by Newton.

8 When analysing and citing the text of this notebooks Add. 3975 and Add. 3996, I will refer to the page numbers in (McGuire 1983), with unspecified page numbers in brackets, not to the

not treat his mathematical endeavours connected to optics, and his early work on the colours of thin plates in detail (Westfall 1965). For a more complete list of early notebooks see e.g. (Gjertsen 1986: 419-20)[9].

## QUESTIONES I. – FIRST NOTES

Newton's first entries in the Note-book on colours and light are mostly inspired by his early readings. From these the ones important for our present discussion are Walter Charleton's *Physiologia Epicuro-Gassendo-Charltoniana* (1654) and Robert Boyle's *Experiments and Considerations Touching Colours* (1664)[10]. Both writers held modificationist views.

Walter Charleton followed Gassendi, claiming that intermediate colours, like red, blue, and green[11] "are but the off-spring of the Extreme, arising from the intermission of light and shadow, in various proportions; or, more plainly, that the sense of them is caused in the Retina Tunica according to the variety or Reflections and refractions, that the incident Light suffers from the superficial particles of objects" (Charleton 1654 (1966): 191).

Boyle was cautious to take a stance in the subject (Boyle 1664: 90). While accepting modificationism, he wrote: "But whether I think this Modification of the Light to be perform'd by Mixing it with Shades, or by Varying the Proportion of the Progress and Rotation of the Cartesian Globuli Coelestes, or by some other way which I am not now to mention, I pretend not here to Declare." None of these accounts gave a clear mechanism of modificationism, that Newton could accept and further develop.

Concerning modificationism Newton states in *Of Colors* (389)[12] "That dark colours seem farther off than light ones may be from hence: that the beams lose

original MSS and folio numbers. Also, I use their corrected text, citing the odd, 'recto' pages of the work, not the 'verso' pages containing Newton's transcribed manuscript.

9 Newton's early response to Hooke's *Micrographia* (Hooke 1665) will not be discussed here, as it would necessitate a detailed analysis of Hooke's modificationist theory (one of the most detailed theories in the seventeenth century), and the significant concessions he later made as a response to Newton's critique. This topic will be treated elsewhere.

10 He had some knowledge of Descartes, e.g. the *La Géometrie* in van Schooten's edition. He was also influenced by two Cambridge luminaries, Henry More and Isaac Barrow – Lucasian Professor of Mathematics, supporter of Newton at Trinity College – whose courses on mathematics and optics Newton probably attended form March 1664. For a chronology of early readings see (Hendry 1980). Contrary to Westfall's accounts (Westfall 1965: 182; Westfall 1980) his early notes are probably not directed against Hooke, as probably he had not yet read his *Micrographia*.

11 Charleton wrote that white is the original colour of light, black is the lack or negation of light, and colours arise "from the intermission of Light and shadow, in various proportions". The sense of colour is caused in the Retina Tunica "according to the variety of Reflections and Refractions, that the incident Light suffers from the superficial particles of objects" (Charleton, 1654 (1966): 191-2).

12 This is a small section in the *Note-book*, as opposed to the larger set of notes with identical title in another notebook, investigated in Null.

little of their force in reflecting from a white body because they are powerfully resisted thereby, but a dark body, by reason of the looseness of its parts gives some admission to the light and reflects it but weakly. And so the reflections from whiteness will be sooner at the eye. Or else, because the white sends beams with some force to the eye and gives it a fiercer knock."

At this preliminary stage of investigation, Newton already investigates the plausibility of micro-explanations, and derives two basic colours from the interaction of light with differently resisting media. This entry is followed by a direct reference to modificationism: "Colors arise either from shadows intermixed with light, or stronger and weaker reflections. Or, parts of the body mixed with and carried away by light" (389). Here Newton refers to three possibilities concerning how colours may arise.

The first two are variations of the basic modificationist scheme $M_0$. Shadows intermixed with light is one possibility ($M_1$), light interacting with bodies in the course of suffering reflection is another ($M_2$). The first stresses the importance of two (possibly polar) entities: light and shadow, or darkness. Already here we should note that this explanation can work either on the boundaries of light and shadow ($M_{1a}$) or inside a medium or body, containing an element of darkness or shadow ($M_{1b}$). The second, on the other hand, is a mechanism constrained to surfaces – or at least to regions very near the surface of bodies. To summarise[13]

- $M_1$: Colours arise from shadows intermixed with light.
- $M_{1a}$: The mixing takes place on boundaries of light and shadow (boundary-modification).
- $M_{1b}$: The mixing is between light and a medium that contains darkness-shadow (medium-modification).
- $M_2$: Colours arise from stronger or weaker reflections.

On the same verso page (389) Newton already drew the conclusion concerning his previously mentioned three possibilities. Based on observations he writes: "No color will arise out of the mixture of pure black and white, for then pictures, drawn with ink would be colored, or printed would seem colored at a distance, and the verges of shadows would be colored, and lamp-black and Spanish whiting would produce colours. Whence they cannot arise from more or less reflection of light or shadows mixed with light."

The argument is rather sloppy:

$P_1$: No color will arise out of the mixture of pure black and white.

[13] The third explanation is, strictly speaking *non sequitur*. It is a very succinct way of referring to the ancient or medieval *simulacra* or *species* theory, positing corporeal *effluxions* from bodies. However, the *species* theory in its original form gives a general account of vision, not of colours. Concerning colours and modificationism, this theory supposes that as to the extent there are colours in the world, they are connected to the objects, or to the *effluxions* emanating from them, and are thus immutable: VS: Colours arise from parts of the body mixed with and carried away by light.

$C_1$: Colors cannot arise through $M_1$ or $M_2$.

Permitting $P_1$ which does not seem to be extremely controversial and is supported by the examples listed, it is not easy to see how the conclusion, the rejection of $M_1$ and $M_2$ follows. That white and black are not sufficient causes of colour-production does not mean that under certain circumstances they are not necessary[14]. What we could say is that Newton rejects a theory, according to which from two principal colours the other colours can be derived (see $M_1'$), in this specific case the principal colours being "pure black and white" (as in $M_1''$). I use the apostrophe to show that these are variants of the more general modificationist claims $M_0$ and $M_1$[15]

- $M_0'$: Colours are qualifications (modifications) of primary colours.
- $M_1'$: Colours are qualifications (modifications) of binary colours.
- $M_1''$: Colours are qualifications (modifications) of pure white and black, arise from black intermixed with white.

When looking at the list of examples, we can see that all of them belong to boundary modificationism ($M_{1a}$), or possibly to the stronger or weaker reflections ($M_2$), and none treat colour changes in media or objects that require no boundaries, reflections, or more than one medium ($M_{1b}$), although such modificationist accounts were known since Aristotle. One of the earliest extant texts that give a modificationist explanation of colour-production is in the third book of his *Meteorologica* discussing the formation of the rainbow, halos and other atmospheric phenomena. In Book III, Part 4 he writes that "the rainbow is a reflection of sight to the sun"[16]. To explain the colours, he lays down the basic facts (374b9-14): "first, that white colour on a black surface or seen through a black medium gives red; second, that sight when strained to a distance becomes weaker and less; third, that black is in a sort the negation of sight; so everything at a distance looks black, because sight does not reach it".

The outer band of the rainbow is the largest, this reflects the most sun, hence it is red, the middle band is green[17], the smallest band is violet[18]. Light is here

---

[14] That a boundary of different levels of luminosity is necessary for colours to appear in prismatic experiments was one of Goethe's main points in his *Contributions to Optics.*

[15] Here I do not follow Nakajima, who defines modification theory as "the theory which regarded white to be the primary original colour of light" (Nakijama 1984). Although his work on modificationism is one of the precious few, my later treatment of the tradition explains my departing from his ideas.

[16] 374a3. The translation is by E. W. Webster. The term 'anaklasis' can be translated both as reflection or refraction.

[17] "The appearance of yellow is due to contrast, for the red is whitened by its juxtaposition with green. So the whole of the red shows white by contrast with the blackness of the cloud around: for it is white compared to the cloud and green" (375a8-14).

[18] I will not discuss the highly controversial status of ancient Greek colour terms (Zemplén 2000a), but it seems that they were less clear hue indicators than those in modern European languages.

modified by a medium and as a function of the amount of modification, different colours arise. But Newton's rejection does not include this and similar concepts of modificationism.

Newton's disproof is against a narrow conception of modificationism, does not include medium-modificationism, like $M_{1b}$ but he uses it to reject the broader theses $M_1$ and $M_2$.

## QUESTIONES II. – EARLY PRISMATIC EXPERIMENTS

The second series of notes in the Note-book were written around mid-1664 (McGuire 1983: 262), probably preceding Newton's reading of Hooke's *Micrographia*. Thus the main influences remain to be Charleton and Boyle. His knowledge of the *Dioptrique* by Descartes is debatable. The description and a drawing of a subjective prismatic experiment with 16 numbered entries following it comprises three fully written folios ($122^r$-$124^v$). It is in his prismatic experiments that he first notices differential refraction of light rays[19]. He connects this with the alleged differences in the speed of the particles and claims that "slowly moved rays are refracted more than swift ones" (433). He also finds a connection between the property of the rays corresponding to the colours they 'arise' in us and the property determining their degree of refraction. The prism separates the different colours and thus "two kinds of colors arise, viz.: from the slow ones blue, sky colour, and purples; from the swift ones red, yellow"[20]. Newton identifies specific colours with specific ray-speeds. Moreover, he carries out rather painful experiments, and concludes that by strong pressure on the eye the perceived colour is red, by weaker pressure blue[21]. To answer the question of colour-perception Newton embraces a truly mechanistic model: the mechanical effect of the ray on the sensorium (437) determines the colour seen. At this stage, Newton operates with models

[19] The subjective prismatic experiment is a study of boundary colours. With eleven pairs of colours (among them *black* and *blacker*) Newton studied the colours seen through a prism held with the refractive angle upwards. Newton seems to think that the only difference in the objective and subjective prismatic phenomena is the order of colour (470, entry 14). In these experiments he uses the prism to collect light coming from a surface.

[20] It is possible that the source of this inference is the series of physiological experiments that he carried out on himself. But it could also be an idea taken from Descartes, for whom colours correspond to differing rates of rotation of the corpuscles of the subtle medium: accelerated along red rays, decelerated along blue. See the second discourse of the *Dioptrics* and the eight discourse of the *Meteors* (Descartes 1998: 76-84, 85-98).

[21] It is worth noting here that Newton's experiments on vision are very different from what the received view concerning seventeenth-eighteenth century studies of sight and vision is. Comparing the eye to a *camera obscura* was the standard practice in writings in optics (Yolton 1979). Opposing this static approach to the more physiological and subjective approach is one of the main points in, e.g. (Crary 1990). Seeing Newton's physiological experiments such a narrative is necessarily questioned. For a more comprehensive critique see (Zemplén 2000b).

that postulate different speeds (as seen before) or different sizes for the *globuli*[22]. He attempts to construct a mechanical model whereby the colour of the bodies would be reduced to the laws of elastic collision (Bechler 1974b). He arrives at a unified explanation operating with the speed of rays. This connects the physical (refrangibility), the psychological (colours seen) and physiological (pressure on the eye) experiments. The speed of particles can be modified, and with a change in speed the pressure they can exert can also change: the mechanical model proposed by Newton can readily be incorporated in a modificationist framework. Also Newton often employs a binary terminology ("two kinds of colours"), corresponding to the boundary colours of the prismatic experiments.

However, a significant departure from the received views also takes place: Newton draws a distinction between different colours (433): "The more uniformly the globuli move the optic nerves, the more bodies seem to be colored red, yellow, blue, green, etc. But the more variously they move them, the more bodies appear white, black, or grey". White, black or grey are thus fundamentally different from the slow blue, swift red, or "neither very swift or slow" green colours (435), as they arise from the commingling of rays. They are strictly speaking more complex than the other colours (which constitute what we would today call the new natural kinds), they are *explanandum*, not *explanans*, as most modificationist theories would suggest. This implies that Newton already separates lightness or luminosity from hue. If all sorts (hues) are mixed, the amount of *globuli* determines their lightness (white, grey, or black). Although Newton is by no means the first in this, he is clearly departing from the ordering of colours based on the subjective luminosity, the dominant trend since Aristotle[23]. Thus we have clear indication of

---

[22] In the first entries, only speed is referred to (433-435). In entry 8, his first quantitative discussion of the matter, Newton writes "Though two rays be equally swift yet if one ray be less than the other that ray shall have so much less an effect on the sensorium as it has less motion than the other. Whence, supposing that there are loose particles in the pores of a body bearing a proportion to the greater rays as 9:12; and the lesser globulus is in proportion to the greater as 2:9, the greater globulus, by impinging on such a particle, will lose a 6/7 part of its motion and the lesser globulus will lose 2/7 of its motion, and the remaining motion of the globuli will have almost such proportion to one another as their quantities, that is, 5/7:1/7::9:1 4/5 which is almost twice the lesser globuli, and such a body may produce blues and purples. But if the particles on which the globuli reflect are equal to the lesser globuli they shall lose their motion and the greater globuli shall lose 2/11 part of their motion and such a body may be red or yellow." (437-9) In the first case the lesser ray has a greater final motion than the greater ray, this implies the production of blue, in the second case the greater ray dominates, and the result is the production of red. It is thus not speed alone that counts for colour, but size (mass) and speed combined, the "motion" or momentum of the rays. About deciphering the details and the arithmetic mistakes see (Hendry 1980), who suggests a chronological order, a move from the velocity to the mass model, as opposed to (Westfall 1962; Sabra 1967). Of course other mechanical explanations are also possible, like Descartes's model operating with a rotation of the *globuli*. But this is not investigated by Newton – did he not know about this model at the time?

[23] Newton acquired a book in 1669 containing a text attributed to Albertus Magnus: "All colours that can be conceived by men in the world appear there [in white] and then they will be fixed and complete the Work in a single colour, that is the white, and in that all colours come together." (Gage 1990: 140)

Newton's belief in the heterogeneity of light that is reflected from coloured bodies. Newton also believes that the prism, as a tool for analysis, separates the different rays by differential refraction, but this separability does not imply unmodifiability. It is, however, unclear how many colours are primary, and also whether all light is heterogeneous[24]. Although Newton clearly rejects $M_1''$, his position concerning other modificationist theories is debatable at this stage[25].

The development of Newton's ideas is remarkable. After rejecting white and black as origins of all colours ($M_1''$) he endorses the concept of the heterogeneity of light. By connecting physics and the physique (using prismatic and physiological experiments) he has a grip on colour-phenomena: a secondary quality (as colour is described in Boyle's Touching Colours) is associated with a physical property (speed), even if not every, but only sufficiently large change in speed produces a change in colour. But the model is not yet coherent, the number of basic colours is not determined, the question of immutability and refrangibility is not settled. It is vague and it gives very little control over the phenomena that he wishes to explain. While modificationism was previously rejected in general,

[24] Rupert Hall suggests that the property of the ray that causes the colour is intrinsic to it (Hall 1948; Hall 1993). The same holds for Westfall (Westfall 1980: 159-161). Hendry claims that after entry 8 colour was "related to the innate and immutable property mass" and Newton's theory was essentially complete (Hendry 1980: 242). Sabra denies this: "the physical property responsible for producing a given colour is not original or connate with the ray" (Sabra 1967: 247). I believe that *if* Newton uses only mass to differentiate between the *globuli*, this implies immutability, but in the *Questiones* I do not believe this to be the case, siding with Sabra and opting for vagueness. It is also important that taking *this* mass-model for granted Newton is stuck with a two-colour theory hard to dispose. I would rather look at both models as attempts, with different preliminary considerations, and not necessarily as stages in a linear development. McGuire and Tamny conclude: "It is clear that Newton supposes bodies to have the capacity to alter or 'modify' the speed with which rays are reflected. This should not be seen as evidence that he adheres to a modification theory of colours" (McGuire 1983: 251, 260). They do not see in Newton a modificationist in "any ordinary sense", as they show that to posit a dualist theory, like Westfall does, is strained (Westfall 1980: 171). At the same time they admit that "contingent circumstances (pertaining to the structure of bodies) can alter the speed and size of the rays in reflection and transmission." This shows that McGuire and Tamny connect two-colour theories ($M_1'$) to modificationism. As I take $M_0$ to be the most general and at the same time the most intelligible modificationist starting point, I believe that at this stage Newton had not clearly abandoned the modification theory.

[25] Rejecting $M_1''$ does not mean that one willy-nilly rejects $M_0'$. It may be that colours *per se* are not modifications of light. Even accepting heterogeneity one can claim that the two basic colours are blue and red, themselves not a result of modification, but their mixing can give rise to the other colours. Although this is not a very plausible explanation, ruling it out leaves the importance of blue and red for Newton unexplainable in this set of notes, and in other early notebooks. This would be a hybrid theory, not using a modificationist explanation for the emergence of primary colours. Originally Hooke's solution operated with two basic colours, blue and red. These arise from a pulse of light, but are *modified*: for blue the weakest part of the oblique and confus'd pulse of light procedes, and the strongest part follows, for red the other way round (Hooke 1665: 64). In a letter to Newton, however, he maintained that these two colours can be treated as original and primary – suggesting an explanation compatible with a restricted version of $M_0$, accepting $M_1'$, $M_0'$, but rejecting $M_1''$.

there is no sign of further pursuing the subject: neither systematic rejection nor conscious rehabilitation can be seen in the notes.

## ‘Of Refractions’

In his early notes and experiments Newton’s main aspiration was to understand the colour of physical bodies and the physiology of perception. In the famous *Waste Book* (Add. 4004) several series of notes are on geometrical optics, starting possibly from September 1664 (Whiteside 1966: 551). During 1665, he undertook a more systematic study of Descartes and refraction. There is a series of abortive proofs relating to Descartes’s discussion of the problem of finding the surfaces of a lens which shall, by double refraction, send all rays of incident white light emanating from a point through a second point. Their failure notwithstanding, these attempts were important for Newton in developing his theory of spherical lenses (Whiteside 1966: 558-9). These notes show that he was aware of the problem of spherical aberration. At some stage, however, he considered chromatic aberration a much greater obstacle.

In yet another notebook (Add. 4000: $26^r$-$33^v$) there are further notes on geometrical optics and an essay *Of refractions*, probably composed in the winter of 1665-6. There are several devices constructed to grind lenses, numerous calculations, but what is of significance for the present work is his *Notes on the theory of compound lenses* (Whiteside 1966: 575). These notes prove that at this time Newton already recognised differential refrangibility, he considered it a problem (possibly of greater scope than spherical aberration), and was prepared to work on the solution (Whiteside 1966: 576; Bechler 1975). In these notebooks there are no further considerations on the nature of colours or that of modification.

## ‘Of Colours’

The notebook in question (MSS. Add. 3975) contains as much as 22 folios written in 1665-6 on the nature of light and colours. The first five entries are about Boyle’s observations on the colours of physical objects, the others are on Newton’s own experiments. Some are repeated from the *Questiones*, but new ones also appear. In general, it can be said that the notebook contains a mature theory, based on notions previously arrived at. Heterogeneity is extended not only to light arriving from bodies, but also to the light arriving from the Sun. A major difference from his published views is that unequal refrangibility of the Sun’s rays is not connected to the claim that specific colours are immutably present in the rays (McGuire 1983: 269, also Shapiro 1980).

One very curious fact concerning *Of colours* is its treatment of colours. Newton is clearly on the track of formulating his famous proposition in the *New Theory* of 1672, and yet a polar conception of colour pervades his notes. To state that Newton works in a strict two-colour system, however, as Westfall suggests, is too strong, as sometimes he lists all spectral colours and treats them as equal. But the efforts to ascribe to this stage the same attitude towards colours as in the 1672 *New Theory* is thwarted by the ubiquity of a binary colour system, operating with the colours red and blue.

## Optical Lectures

When accepting the Lucasian chair for mathematics, Newton held his first series of lectures in optics. He was continuing his mentor's, Barrow's work, and structured his course to continue his predecessors work. He proof-read the lectures Barrow published (Barrow, [1669] 1987), and might have attended his course in 1665. Barrow's vague modificationist ideas[26], however, have been thrown out with the rest of the tradition and Newton boldly put forward his anti-modificationist theory of colours. The optical lectures survive in two versions, and the latter appeared in print after Newton's death. Containing 31 lectures and deposited in the University Library in October 1674, the *Optica* contains the most detailed mathematical treatment of certain optical problems Newton ever wrote. However, as it is possible that the work was revised or partly written after 1672, I will focus on the first, unfinished draft of the *Lectiones Opticae*, somewhat shorter and probably finished around October 1671 and revised April 1672.

The first two lectures are devoted to support the claim that light rays suffer unequal refraction, and contained detailed description of experiments with one prism. In the third lecture Newton formulates his first pronounced critique of earlier theories of colours, and rejects modificationism in general. Although he is occupied with prismatic colours, the following discussion treats colours in general. While in the preceding two millennia the colours of object ("surface" colours, treated as "real") have been explained separately from colours of the rainbow, spectrum and other "emphatic", "apparent" or "unreal" colours, Newton, following Descartes and other seventeenth century theorists, breaks away from this distinction and treats the "apparent" colours as the basis of all colour phenomena.

He is clear from the start that nothing less than a causal account of colour can be satisfactory and dismisses earlier attempts of the Peripatetics as "of no value" for the purpose (Newton 1984: 81), but also Epicurean (atomist) theories. Highly significantly he does not attack Peripatetic modificationist theories, as could be expected, only launches a methodological and epistemological attack: the ac-

[26] Barrow suggested a corpuscular modificationist theory. In this changes in the motion, the power of action, or the quantity of light results in the appearance of colour [Barrow, [1669] 1987 #285]: "Colour too is, it seems, practically nothing else but light impinging on rather larger bodies that it meets, retaining to some extent the stable position of their parts, and, according to the differing shape, disposition or texture of the particles of which they consist, diverted or bouncing off in some way or other; with the result of course that the light that had fallen on these bodies comes out such as it does, whether in its motion, or its power of action, or simply in its quantity (I mean in regard to its rarity or density and the copiousness or scantiness of its rays), and according to the distinction of its type produces different appearances, which we denote by the various colour-names."

counts are not causal, do not explain how colours are generated, and fail to be acceptable explanations. The paradigmatic differences between Aristotelian and Newtonian science are listed. On one score he is definitely wrong, as Aristotle does account for the generation of certain colours in his earlier cited Meteorology.

Instead of working with the colour theory in the meteorological writings, where Aristotle gives a much laxer definition of explanation – "We consider a satisfactory explanation of phenomena inaccessible to observation to have been given when our account of them is free from impossibilities" (Barnes 1984: I/562, 344a5-7) –, Newton only deals with the account of colours presented in the *De Sensu*. He criticises theories that derive colours from the mixture of black and white, and exerts very strong statements about colour-constancy: "for a red body, for example, will always appear red whether it is viewed at twilight or at brightest midday" (Newton 1984: 83). Not only a modern-minded contemporary, well versed in current knowledge about the physiology of vision is astonished by such statements. The nineteenth century physiological tradition also emphasised the changes in perceived colour depending on various factors. But two millenia before Newton the pseudo-Aristotelian (Theophrastian?) *De Coloribus* (Aristoteles 1999) also drew attention to the changes in apparent colour (e.g. 193b14-794a11).

Newton criticises the Aristotelian colourdefinition – that colour is the extremity of the transparent in a determinately bounded body – as it is not applicable for the colours of rainbows, prisms, coloured glasses or liquids, sea water, air, or flame. As he grounds his objections: "In sea water, which often appears green, which colour is nonetheless produced not in the extremity of the water but in its entire thickness; in air, which although exceedingly transparent and not bounded by a dense body nevertheless appears blue on a clear night …" (Newton 1984: 83) This reading is far from being sympathetic. Right before the quoted text in *De Sensu* 439 b12-13 Aristotle writes: "Air and water, too are evidently coloured; for their brightness is of the nature of colour. But the colour which air or sea presents, since the body in which it resides is not determinately bounded, is not the same when one approaches and views it close by as it is when one regards it from a distance; whereas in determinate bodies the colour presented is definitely fixed, unless, indeed, when the atmospheric environment causes it to change." (Barnes 1984, 439b1-8).

How come this disregard for Aristotle's text? We know that in Newton's time the Peripatetic teaching still constituted a significant part of the University curricula, and it was expected from professors to teach and comment on Aristotelian topics. We also know that Newton read some Aristotle in his undergraduate years, and took extensive notes from Johannes Magirus's *Physiologiae peripateticae libri sex* (Newton 1984: 2). In this work the text cited by Newton is reproduced verbatim, but the preceding discussion is not present. It is possible – and Shapiro editing the *Optical Lectures* seems to think so – that Newton never read the relevant Aristotelian texts, the originator of the tradition he wanted to see replaced by his own theory. This conjecture is not unsupported.

The distinction between colours of bodies (where the colour is the extremity of the body[27]) and changeable colours is already apparent with Aristotle (although the strict separation of apparent and real colours took place only in the writings of later interpreters). Newton, however, disregards the Aristotelian and later Peripatetic theories of apparent colours (as in the *Meteorology* of Aristotle), and combats only the theories of real colours, although even in his own theory the explanation of colour-phenomena is based on the explanation of apparent colours. This suggests unfamiliarity with the Aristotelian theory.

Newton also states that all previous theories “agree in a certain common error; namely, the modification of light by which it exhibits individual colours is not innate to it from its source but is acquired by being reflected or refracted” (Newton 1984: 85)[28]. This statement covers most seventeenth century corpuscular modificationist theories, but fails to address the Aristotelian theory of apparent colours. When discussing the colour of the rainbow Aristotle claims that it is a special case of reflection (*anaklasis*, can also be translated as refraction). This type of reflection renders only the colour of objects and not their shape – the optical theory of reflection can not treat this case – (Barnes 1984, 373b19), and the visual ray is reflected from a dark cloud such that it is coloured. Such coloration occurs under several circumstances: “Bright light through a dark medium or on a dark surface (it makes no difference) looks red. We can see how red the flame of green wood is: this is because so much smoke is mixed with the bright white firelight: so, too, the sun appears red through smoke and mist.” (Barnes 1984, 374a2-8 ).

This account, while taking recourse to a curious theory of reflection actually describes colour-modification that takes place inside media, and where no boundary with shadow, no mathematically analysable reflection or refraction takes place. I term such theories “medium-modificationist theories” – and considering these are non-existent in Newton’s rejection. This gives further support to the hypothesis that Newton had only very patchy knowledge of the Peripatetic theories of colours that were to be replaced by his theory. It is a very similar, one-sided attack on modificationism, that can be seen in his first publication, the 1672 *New Theory*. This neglect of medium-modificationist theories by Newton still affects the history of science community, as Newton had an enormous effect not only on how we think about colour, but also about how to tackle the history of theories of colour[29].

## The 1672 *New Theory*

27 The Greek word *chroma* is translatable not only as colour, but as “skin”, too.

28 Later he also includes “the qualities or any modes whatsoever of bodies” (Newton 1984: 85n), but does not give examples.

29 The Newtonian rhetoric proved to be very powerful. Even in the twentieth century Rosenfeld stated the inaccurateness of Newton’s opponents (Rosenfeld 1927), similarly to (Westfall 1966: 306), both seeing thus the superiority of Newton’s experimental practice. The eighteenth century acceptance of Newton’s theory of white light and colours, and his heralding as the successful empirical scientist (Hakfoort 1988) was only achieved at the cost of disregarding many colour phenomena.

The Philosophical Transactions of the Society for 19 February 1672 (Hall 1993: 47 writes March) announced the publication of Newton's first scientific article, a letter that lacked a title, but contained a: "New Theory about Light and Colors: where Light is declared to be not Similar or Homogeneal, but consisting of difform rays, some of which are more refrangible than others: And Colors are affirm'd to be not Qualifications of Light, deriv'd from Refractions of natural Bodies, (as 'tis generally believed;) but Original and Connate properties, which in divers rays are divers: Where several Observations and Experiments are alleged to prove the said Theory." (Newton, 1671-72: 3075). It was a groundbreaking theory of light (arguing for its heterogeneity and different refrangibility) and of colour (negating the accepted view that 'qualified' or modified light gives rise to colours). His theory was trespassing accepted disciplinary boundaries connecting optics, the study of light, with chromatics, the study of colour, and both areas, at least according to their author's hope, were tackled with the method of mathematics (Mamiani 2001). The employment of the mathematical method might have seemed suspicious for the naturalists of the Society. At this time they were the dominant force, but the process had already started, which gradually led to the election of Edmond Halley in 1686, the publication of the Principia, and the predominance of mathematicians in the Society (Feingold 2001)[30]. So Newton's 'mathematical' approach, though unusual, was not unprecedented.

The letter had two parts, one culminating in the experimentum crucis, and establishing the different refrangibility of light rays (Newton 1671-72: 3075-80)) the other unfolding the origin of colours (Newton, 1671-72: 3081-87). I will not embark on the project of giving a detailed analysis of the letter, as this has been done frequently with different aims in mind (Lohne 1968; Bechler 1974a; Laymon 1978; Sepper 1988; Schaffer 1989; Sepper 1994; Fehér 1995; Thompson 1995; Lampert 2000; Zemplén 2002). Most of these narratives concentrate on the crucial experiment, undoubtedly the most exciting and epistemologically most significant part of the letter. The bearing of this experiment on the theory of colours and especially modificationism is not downright obvious.

In the first half of the letter the experimentum crucis is aimed at positively proving Newton's own proposition that "Light consists of Rays differently refrangible" (Newton, 1671-72: 3079) and thus (if refrangibility determines colour) entailing the rejection of the general modificationist thesis $M_0$. The major theoretical result presented by Newton in this part is the compositeness of light, which predicts a grim future for the makers of refracting telescopes. The success of the attempt was interpreted variously by contemporaries, and even among historians the opinions greatly differ. Rupert Hall writes: "They could not see that Newton had positively demonstrated – rather than inferred – the existence of innumerable colours in white light … How could there not be an infinity of coloured rays forming

30 This does not mean of course that this tendency was maintained throughout the eighteenth century, after the presidency of Newton. For more see (Sorrenson 1999). It was not only Newton, who decided to use singular experience when presenting material that he thought was a mathematical scientific argument, John Wallis used similar techniques in 1666 to present the Royal Society his explanation of tides (Dear 1995: 230).

the spectrum when each part of it is illuminated by a ray following a uniquely refracted path?" (Hall 1993: 64), while Sabra holds that "the effect of this 'demonstration' is, it must be admitted, almost hypnotic. Nevertheless, it is certainly inconclusive." (Sabra 1967: 249) I admit that my sympathies lie with Sabra, and the contemporaries had similar views. The different interpretations result from Newton's highly compact description of his crucial experiment, omitting much of his reasoning that led him to the conclusion. In the crucial experiment parts of the light refracted through a prism are directed towards a second prism and this second refraction is investigated. The rays are refracted differently, although they have the same angle of incidence at the second prism. This clearly implies heterogeneity – after the first refraction. That this heterogeneity is immutable means subscribing to a weak immutability thesis (Shapiro 1980), not contradicting modificationist accounts. The much-debated inference is whether to ascribe to light strong immutability, a thesis that holds that this heterogeneity existed before the first refraction and is in both cases the cause of the differential refraction. For this inference one has to rule out the possibility that causes external to the properties of the rays could cause the difference of refraction at the second prism. Albeit the differently refracted rays have the same angle of incidence at the second prism, to achieve this, the position of the first prism has to be modified (thus changing the angles of incidence and refraction here, as well as the trajectory of light within the prism). Thus it is not a trivial claim that there could be no external causes responsible for the heterogeneity of the rays at the second prism[31].

The composite nature of light offers a "theoretical bonus" (Sepper 1994: 43), as a radically new theory of colours can be constructed upon this fundament. Newton clearly connects the previously established 'difformity' of rays with the origin of colours. But, instead of further following the (apparently) Baconian method, he lays down the Doctrine first in thirteen propositions, followed by only 'one or two of the Experiments, as a specimen of the rest.'

It seems that based on the result of the *experimentum crucis*, Newton has trust in the truth of the propositions. The verification of heterogeneity for Newton probably carries the verification of his theory of colours, and also perhaps his corpuscular background assumption (at least at this stage he seems to think so, even though in later debates he calls this merely a hypothesis[32]). In response a modificationist could either question the experimentum crucis, or the doctrine, or the connection of the theory of light to the doctrine. This connection is far from obvious. Why does Newton trust the doctrine? Because he thinks that they self-evidently follow from the result of the *experimentum crucis*? In which case the other experiments are further support for confirmation? Or is the doctrine merely

31 The Newtonian theory can explain that there is an elongated image after the first prism, but so can the modificationist accounts – a thick bundle of light (i.e. a physical, not a mathematical ray) can be modified at the edges as it reaches the glass surface and enters a different medium, resulting in the elongation of the spectrum and the array of colours in the iris.

32 The famous corpuscular Query (29 in the fourth edition) is described by Worrall as a "perfectly kosher hypothetico-deductive argument" (Worrall 2000: 47). In his article Achinstein investigates several interpretations (Achinstein 1990).

an outline of a theory – simply presented without being argued for? Why does then Newton believe that the science of colour is mathematical? Or is it just asserted without being argued for?[33] The doctrine is followed by a conclusion. Newton asserts theses that he could by no means hold as hypothetical: that there are no colours in the dark, that colours are qualities of light, and that light is, perhaps, a body. Were they put forward as more than purely conjectural statements, and were they seen by Newton as natural consequences of the crucial experiments?

From a modificationist point of view the *New Theory* presents a dangerous alternative to explain the various apparent colours, but in this form the arguments can be attacked from various perspectives – as had actually happened in the following years. While hailed as an ingenious scientist, Newton was also fiercely criticised[34]. The status of his corpuscular starting point as the only possible one was questioned (Hooke, Pardies). His theory was considered hypothetical, but no real rival (modificationist) theory was proposed to account for the same phenomena with the same gracefulness. His interpretation of the crucial experiment, employing a principle of economy of causes was challenged by contemporaries employing a principle of economy concerning the number of basic colours (Hooke, Huygens). These critics pointed out that rejection of modificationism does not follow from the crucial experiment, and thus Newton's claim to the heterogeneity of light (a negation of modificationism) is not demonstrated. Newton also had to learn that his concepts of demonstration, of true causes, etc. were far from being obvious for his opponents, suspicious to any signs of dogmatism – seen as one of the main threats in the scientific circles of the time. Probably under the influence of Isaac Barrow[35] he developed ideas radically different from most members of the Royal Society, who mostly presented their findings as singular experienced events. For him, his work on colours had the same status as any

[33] A letter to Lucas four years later suggests this (Turnbull 1960: 258).

[34] He had to learn that several new phenomena had to be incorporated into his theory to achieve the success he had thought he had already achieved. He knew Hooke's work on thin-plate-colours, (1665), but learnt only later about Grimaldi's observation of diffraction (1665), or the curious double refraction (birefringence) of Islandic spar as described by Erasmus Bartholin (1669), or Rømer's measurement of the velocity of light (1676). As a consequence in his later works he had to employ explanations more suiting a wave-theory, and *in toto* he "left the physical concept of light no more intelligible than before" (Hall 1993: 59), a significant departure from his basic corpuscular insight, sacrificed for higher explanatory power. Newton first added an account of 'fits' to his theory, but to incorporate double refraction, he had to add 'sides' to the corpuscles as well. Goethe ridiculed Newton for the claim to polarize little balls of light (Burwick 1987).

[35] Barrow wrote about the Peripatetic or Aristotelian "perpetual Observation of Particulars", that they are unnecessary, "since only one Experiment will suffice (provided it be sufficiently clear and indubitable) to establish a true Hypothesis to form a true Definition; and consequently to constitute true Principles. I own the Perfection of Sense is in some Measure required to establish the Truth of Hypotheses, but the Universality or Frequency of Observation is not so." Quoted in (Dear 1995: 224); see also (Shapiro 1993: 32-40). A parallel could also be made with some of Bacon's 'prerogative instances', but the level of Newton's acquaintance with Bacon's ideas is debatable.

of the mixed mathematical sciences. For most of his opponents he simply put forth a hypothesis about the nature of light – belonging to physics, and having a much more modest epistemic status.

But the investigation of these debates is not treated here, together with the further development of his ideas. It is to be observed that also in the *New Theory* there is no mentioning of medium-modificationism (or even of light-shadow boundaries) as a valid alternative, and no systematic refutation of the most prevalent contemporary theory[36].

## SUMMARY

Newton's early encounter with the rather primitive modificationism in Charleton's work was followed by his rejection of the whole research tradition. There are no traces in the notes that he investigated certain – plausible – types of modificationism (like $M_{1b}$). It is suggested that Newton was simply unaware of instances of medium-modificationism, like Aristotle's account, which clearly imply colours modified by a medium. Newton did not pursue a systematic attack on modificationism, he was merely following his own line of research. As is clear from the early notebook-entries, he was busy harmonising and equalising the results coming from various modes of investigation. He tackled the question from at least three sides: carrying out physiological experiments, observing the colours of physical phenomena, and probing different mechanistic models to account for colours (Steinle 1994a: 569).

In his formative years Newton started working on a highly original and promising corpuscular research program. This worked extremely well for many of the phenomena he encountered in his various (physical, physiological, optical) experimentations. He found phenomena (like the elongated spectrum with the prism at minimum deviation) which seemed to be unaccountable for by the rival theories he knew. His theory had only partial success, but at this time he was not familiar with many of the phenomena the incorporation of which would later be highly problematic[37]. With the physiological experiments he established a connection between force and colour of *globuli*. This could be implemented in a velocity model, very favourable towards modificationism, and in a mass/size model, which is clearly hostile to it. Opting for a mass/size model entails rejection of modification – at least as far as the creation of the (two?) basic colours are concerned. Given his early rejection of a wave model Newton was on a fairly narrow track to

36 This type of modification does not get refuted even in the *Opticks:* in Prop. II, Theor. II he writes: "All homogeneal Light has its proper Colour answering to its degree of Refrangibility, and that Colour cannot be changed by Reflexions and refractions".

37 Shapiro argues that the delayed publication of the *Opticks* was not the result of Newton's wariness of Hooke (he only published the *Opticks* after Hooke's death), but that the book was simply not ready: Newton still had to work out the part on diffraction – admittedly not the most successful part of the book (Shapiro 2001).

reach his conclusions concerning heterogeneity, and with the mass/size model to support his immutability thesis.

His radically unconventional solution stemmed from his corpuscular philosophy just as much as his novel experimental uses of the glass prism (Schaffer 1989), his mastery of contemporary geometrical optics, his patchy knowledge of rival theories of modification, and a limited acquaintance with newly discovered optical phenomena. He based his theory on experiments with refraction, and to a lesser extent reflection and interference. He did not pursue the study of double-refraction (the basis of Huygens's theory) or diffraction (as in the work of Grimaldi), both known by this time, both of which would have posed serious obstacles at this, preliminary stage of research[38].

In this *Rückblick* it becomes clear that, as opposed to his intentions when scribbling the Latin motto in his Note-book "Amicus Plato, amicus Aristoteles, magis amica veritas" (McGuire 1983: 337), Newton clearly did not equate what he considered truth with the friendship of Plato and Aristotle. Little acquainted with their works on light and colours, Newton in his quickly maturing theory radically departed from the ideas of the ancient philosophers, and developed a highly successful anti-modificationist theory of colour.

## BIBLIOGRAPHY

Achinstein, Peter: Newton's Corpuscular Query and Experimental Philosophy. In: Hughes, R. I. G.; Bricker, P. (eds.): *Philosophical Perspectives on Newtonian Science*. Cambridge, Mass.: MIT Press, 135-173, 1990.

Aristoteles: *De coloribus*. In Werke in Deutscher Übersetzung. Flashar, H. (ed.) Darmstadt: Wissenschaftliche Buchgesellschaft, 1999.

Barnes, Jonathan (ed.): *The Complete Works of Aristotle - The revised Oxford Translation* Princeton; Princeton UP, 1984.

Bechler, Zev: Newton's 1672 Optical Controversies: A Study in the Grammar of Scientific Dissent. In: Elkana,Y. (ed.): *The Interaction Between Science and Philosophy*. Atlantic Highlands, N.J.: Humanities Press, 115-142, 1974 (a).

Bechler, Zev: "Newton's Search for a Mechanistic Model of Color Dispersion: A Suggested Interpretation." *Arch. Hist. Exact Sci*. 11, 1-37, 1974 (b).

Bechler, Zev: "'A Less Agreeable Matter': The Disagreeable Case of Newton and Achromatic Refraction." *The British Journal for the History of Science* 8(29), 101-127, 1975.

Boyle, Robert: *Experiments and Considerations Touching Colours*. London, 1664, (reprinted in 1964).

Burwick, Frederick: Goethe's Concept of "Polarized Light" in View of Late Twentieth-Century Optical Theory. In: Ugrinsky, A. (ed.): *Goethe in the Twentieth Century*. New York: Greenwood Press, 95-105, 1987.

Charleton, Walter: *Physiologia Epicuro-Gassendo-Charltoniana*. London, 1654 (reprinted New York, 1966).

Crary, Jonathan: *Techniques of the observer: on vision and modernity in the nineteenth century*. Cambridge, Mass.: MIT Press, 1990.

---

38 Newton probably learnt about Diffraction through Honoré Fabri's work. A summary of Grimaldi's work appeared in the issue previous to his *New Theory* in the *Transactions*. But until 1675 he probably still had not done any experiments (Hall 1990).

Dear, Peter Robert: Discipline & experience: the mathematical way in the scientific revolution. In: *Science and its conceptual foundations*. Chicago: University of Chicago Press, 1995.
Descartes, René: The World and Other Writings (trans. Gaukroger, Stephen). In: *Cambridge Texts in the History of Philosophy*. Ameriks, K. C., Desmond M. (ed.) Cambridge: Cambridge UP, 1998.
Fehér Márta: *The Rise and Fall of Crucial Experiments. Changing Tools – Case Studies in the History of Scientific Methodology*. Budapest, Akadémiai Kiadó, 55-93, 1995.
Feingold, Mordechai: Mathematicians and Naturalists: Sir Isaac Newton and the Royal Society. In: Buchwald, J. Z. and Cohen, I. B. (eds.): *Isaac Newton's natural philosophy*. Cambridge, Mass.: MIT Press, 2001.
Gjertsen, Derek: *The Newton Handbook*. London, New York: Routledge & Kegan Paul, 1986.
Guerlac, Henry: Can There be Colors in the Dark? Physical Color Theory before Newton. *Journal of the History of Ideas* 47(1), 3-20, 1986.
Guerlac, Henry: Can We Date Newton's Early Optical Experiments? *ISIS* 74, 74-80, 1983.
Hakfoort, Caspar: Newton's 'Opticks' and the Incomplete Revolution. In: *Newton's Scientific and Philosophical Legacy*. Scheurer, P. B. D., G. Dordrecht; Boston; London: Kluwer Academic Publishers. 123, 99-112, 1988.
Hall, Alfred Rupert: Sir Isaac Newton's Note-book, 1661-1665. *The Cambridge Historical Journal* 9, 239-250, 1948.
Hall, Alfred Rupert: "Beyond the Fringe: Diffraction as Seen by Grimaldi, Fabri, Hooke and Newton." *Notes and Records of the Royal Society* 44, 13-23, 1990.
Hall, Alfred Rupert: *All Was Light: an introduction to Newton's Optic*. Oxford, New York: Clarendon Press; Oxford University Press, 1993.
Hendry, John: "Newton's Theory of Colour." *Centaurus* 23(3), 230-251, 1980.
Hooke, Robert: Micrographia. London, 1665.
Kuhn, T. S.: Newton's Optical Papers. In: *Isaac Newton's Papers & Letters On Natural Philosophy*. Cohen, I. B., 27-45, 1958.
Lampert, Timm: Zur Wissenschaftstheorie der Farbenlehre –Aufgaben, Texte, Lösungen. In: *Bern Studies for the History and Philosophy of Science*. Graßhoff, G. (ed.) Bern, 2000.
Laymon, Ronald: Newton's Advertised Precision and his refutation of the Received Laws of Refraction. In: Machamer, P. K. T.; Robert G. (eds.): *Studies in Perception: Interrelations in the History of Philosophy and Science*. Columbus, Ohio State UP, 1978.
Lohne, Johannes August: "Experimentum crucis." *Notes and Records of the Royal Society* 23, 169-199, 1968.
Mamiani, Maurizio: To Twist the Meaning: Newton's Regulae Philosophandi Revisited. In: Buchwald, J. Z.; Cohen, I. B. (eds.): *Isaac Newton's natural philosophy*. Cambridge, Mass.: MIT Press, 2001.
McGuire, John. E., Tamny, Martin: *Certain Philosophical Questions: Newton's Trinity Notebook*. Cambridge: Cambridge UP, 1983.
Nakijama, Hideto: "Two Kinds of Modification Theory of Light: Some New Observations on the Newton-Hooke Controversy of 1672 Concerning the Nature of Light." *Annals of Science* 41, 261-278, 1984.
Newton, Isaac: "New Theory about Light and Colors." *Philosophical Transactions* (80): 3075-3087, 1671-1672.
Newton, Isaac: *The optical papers of Isaac Newton*. Shapiro, A. E. (ed.), Cambridge, New York: Cambridge University Press, 1984.
Rosenfeld, L.: "La théorie des couleurs de Newton et ses adversaires." *ISIS* 9, 44-65, 1927.
Sabra, A. I.: Theories of light from Descartes to Newton. In: *Oldbourne history of science library*. London: Oldbourne, 1967.
Schaffer, Simon: Glass works: Newton's prisms and the uses of experiment. In: Gooding, D.; Pinch, T.; Schaffer, S. (eds.): *The uses of experiment: Studies in the natural sciences*. Cambridge: Cambridge UP, 1989.
Schopenhauer, Arthur: *Ueber das Sehen und die Farben. Schriften zur Erkenntnislehre* (Sämtliche Werke 1.). Wiesbaden: Brockhaus, 1972.

Sepper, Dennis L.: *Goethe contra Newton: polemics and the project for a new science of color*. Cambridge; New York: Cambridge University Press, 1988.
Sepper, Dennis L.: *Newton's optical writings: a guided study*. In: *Masterworks of discovery*. New Brunswick, N.J. : Rutgers University Press, 1994.
Shapiro, Alan E.: The Evolving Structure of Newton's Theory of White Light and Colour. *ISIS* 71, 211-235, 1980.
Shapiro, Alan E.: The Optical Lectures and the foundations of the theory of optical imagery. In: Feingold, M. (ed.): *Before Newton: The life and times of Isaac Barrow. Cambridge*: Cambridge UP, 250-290, 1990.
Shapiro, Alan E.: *Fits, passions, and paroxysms: physics, method, and chemistry and Newton's theories of colored bodies and fits of easy reflection*. Cambridge, New York: Cambridge University Press, 1993.
Shapiro, Alan E.: "Artist's Colors and Newton's Colors." *ISIS* 85, 600-630, 1994.
Shapiro, Alan E.: Newton's Experiments on Diffraction and the Delayed Publication of the Opticks. In: Buchwald, J. Z., Cohen, I.B. (eds.): *Isaac Newton's Natural Philosophy*. Cambridge, Mass.: The MIT Press, 2001.
Sorrenson, Richard (Guest Editor): Did the Royal Society matter in the eighteenth century? *The British Journal for the History of Science* 32, A special issue, 1999.
Steinle, Friedrich: Newton's Colour-theory and Perception. In: Cohen, R. S.; Wartofsky, Marx W. (eds.): *Hegel and the sciences*. Dordrecht; Boston, Hingham, MA.: D. Reidel. 64, 569-577, 1994 (a).
Steinle, Friedrich: *Newton's Rejection of the Modification Theory of Colour*. In: Cohen, R. S.; Wartofsky, Marx W. (eds.): *Hegel and the sciences*. Dordrecht; Boston, Hingham, MA.: D. Reidel. 64, 547-556, 1994 (b).
Thompson, Evan: Colour Vision – A Study in Cognitive Science and the Philosophy of Perception. In: Newton-Smith, W. H. (ed.): *Philosophical Issues in Science*. London, New York: Routledge, 1995.
Turnbull, H. W. (ed.): *The correspondence of Isaac Newton I*. 1661-1675. Cambridge: Cambridge UP, 1959.
Turnbull, H. W. (ed.): *The correspondence of Isaac Newton II*. 1676-1687. Cambridge: Cambridge UP, 1960.
Werneburg, J. Friedrich Christian: *Merkwürdige Phänomene an und durch verschiedene Prismen – Zur richtigen Würdigung der Newton'schen und der von Göthe'schen Farbenlehre*. Nürnberg: Johann Leonhard Schrag, 1817.
Westfall, Richard S.: The Development of Newton's Theory of Colour. *ISIS* 53/3(173), 339-358, 1962.
Westfall, Richard S.: "Isaac Newton's Coloured Circles twixt two Contiguous Glasses." *Arch. Hist. Exact Sci*. 2, 181-196, 1965.
Westfall, Richard S.: "Newton's Optics: The Present State of Research." *ISIS* 57/1, 102-7, 1966.
Westfall, Richard S.: *Never at rest: a biography of Isaac Newton*. Cambridge, New York, Cambridge University Press, 1980.
Whiteside, D. T.: *The Mathematical Papers of Isaac Newton 1664-66*. Cambridge: Cambridge University Press, 1966.
Worrall, John: The Scope, Limits, and Distinctiveness of 'Deduction from the Phenomena': Some Lessons from Newton's 'Demonstrations' in Optics. *Brit. J. Phil. Sci*. 51(1), 45-80, 2000.
Yolton, John W.: As in a Looking-Glass: Perceptual Acquaintance in Eighteenth-Century Britain. *Journal of the History of Ideas* 40(2), 207-234, 1979.
Zemplén, Gábor Áron: Homo delectans, avagy a szaktudományok elotti tudós. *Magyar Tudomány* 2000(4), 2000 (a).
Zemplén, Gábor Áron: A mgfigyelo mgfigyelése. *BUKSz* 12(3), 242-246, 2000 (b).
Zemplén, Gábor Áron, (ed.): Introduction to Theories of Light, Colour, and Vision. *Bern Studies in the History and Philosophy of Science*. Bern: University of Bern, 2002.