in dialogue

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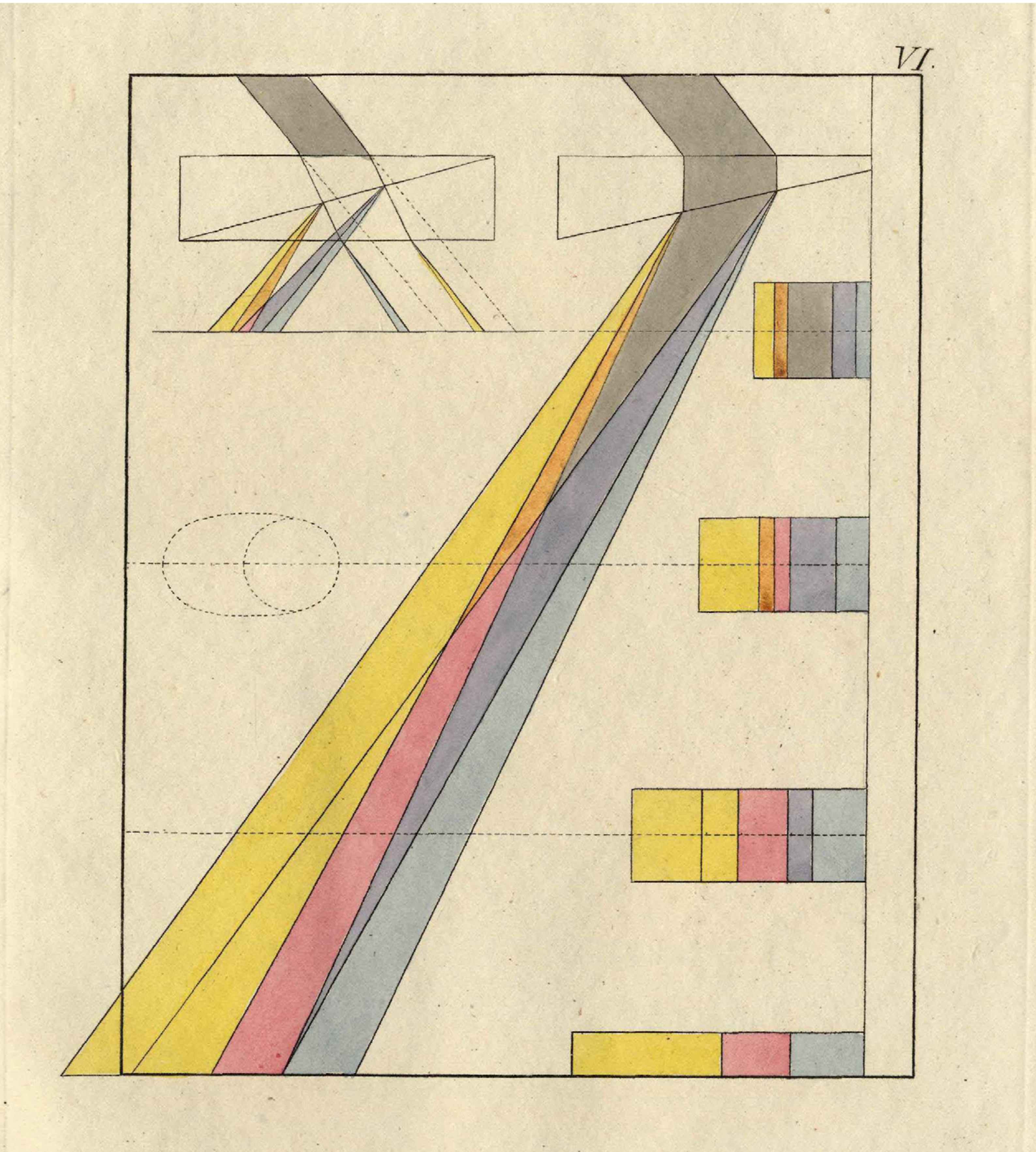

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The Heterogeneity of Darkness

Goethe's Critique of Newton's Experimental Proofs

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1. Introduction

As is well-known, Goethe was not only at war with Newton's theory of light and colour, but spent an enormous amount of his precious time writing his own theory of colours—the monumental *Farbenlehre* of some 1400 pages.[1] Is this merely an interesting scandal of the past? Do we have to abandon the achievements and methods of modern natural science if we do not want to dismiss Goethe's attack as merely the erring ways of an ingenious poet? If one prefers a conciliatory response, that is, if one respects both our science *and* Goethe, one might begin by extracting those passages from Goethe's writings on colours that anticipate results of current research.[2]

But it would not do justice to Goethe to praise him only for anticipating colour television or the neural coding of complementary colours.[3] Goethe strove for more than just a few isolated scientific successes. He wanted to triumph over Newton's theory of light and colour: Over a theory that had been accepted by nearly all the physicists of his time and that shapes our understanding of light and colour today. Goethe's three-part *Farbenlehre* is motivated, propelled and united by his uncompromising opposition to this well-established scientific theory. Thus, there seems to be little room for reconciling Goethe's *Farbenlehre* with modern science.

Nevertheless, I will attempt to defend Goethe's critique of Newton on the methodological grounds recognized by recent philosophy of science. Goethe discovered a deficiency in Newton's methodological self-assessment that must appear embarrassing to anyone familiar with scientific method. By that I do not mean to suggest that Newton's optical theory is wrong. With a little luck, one can attain good scientific results even when they are based on a deficient conception of the powers of one's method. On the other hand, with bad luck even the best methodological self-assessment can lead to a dead end. I will not address the question as to whether or not Newton simply had more luck than Goethe. I will only insist that Goethe produced solid methodological work with his critique of Newton, as well as in his own theory of colour.

In contrast to what is often claimed, Goethe understood very well how empirical science works.[4] He thought it through more deeply than Newton. This is where I locate Goethe's lasting contribution. With the help of his critique of Newton, we can analyse and criticize an exemplary case of overconfidence in the natural sciences; the goal is to transform it into a more appropriate self-conception. Thus, the results and methods of the natural sciences are not at issue. The issue is the uncritical attitude toward these results and methods—an attitude that can be traced back to Newton and his peers, and is still widespread today.

1. Goethe's *Farbenlehre* (*Theory of Colours*), first published in 1810, consists of three parts and several appendices; it is cited here according to the so-called Leopoldina-Ausgabe (LA). The original titles of the three parts are: *Entwurf einer Farbenlehre,* generally known as the didactic part (LA I.4; English translation: Goethe 1840 and Goethe 1995); *Enthüllung der Theorie Newtons*, generally known as the polemic part (LA I.5; English translation: Goethe 2016); and *Materialien zur Geschichte der Farbenlehre*, generally known as the historical part (LA I.6), from which only a few excerpts have been translated (e.g., in Goethe 1971, 198–200). All English quotations from Goethe's *Farbenlehre* given here have been translated anew. The didactic and polemic part are quoted according to paragraph number, which is the same across editions; wherever page numbers are given, references to the English translations are also given.

2. For some references, see next footnote. In passing, I want to mention two varieties of reaction to Goethe's *Farbenlehre* that I will not pursue here. One could claim that Goethe rejected the methods of modern natural science— but did so either for naïve reasons, as is urged by some science-friendly commentators (see, for example, Schöne 1987), or for laudable reasons, as is urged by some culture critics who think that the role of natural science in our society is too great (see, for example, Muschg 1986).

3. The reference to colour television can be found without further explanation in Hegge (1987, 202). On Goethe and the neural coding of complementary colours see Mausfeld (1996, 23–24); Mausfeld admits that Goethe would have resisted contemporary brain research (26).

4. Helmholtz, for example, claimed that Goethe did not understand the experimental, rational procedures of modern science (Helmholtz 1995).

Admittedly, scientists' adequate methodological self-conception does not have to play a large role for scientific practice—just as the bird does not need to understand aerodynamics in order to fly, or as the tango dancer does not need to know the geometry of their steps. Nevertheless, Goethe's methodological reflections serve an important purpose. They help us understand ourselves better in a world increasingly shaped by science.

2. Two Possible Levels of Controversy

I outlined above *in abstracto* what the controversy is about; we will now move to the heart of the controversy and consider the properties of sunlight. Newton's position is more or less as follows:

> The prism experiments (which Newton described in detail and to which I'll return) *prove* that sunlight is a heterogeneous mixture of variously coloured light rays.

Newton's position contains two claims. The first claim concerns the properties of light; it states his conclusion, which we still accept today—and which is on the object level, so to speak.[5] The second claim (whose decisive term is italicized) is made at a higher level. It concerns the status of the first claim. According to Newton, the heterogeneity of white light is an *experimentally proven fact*.[6]

Goethe attacked the uncritical attitude towards Newton's scientific results, and he was right to do so, as I will attempt to show. Thus, I want to demonstrate that Goethe was led to the following correct view:

> The prism experiments *do not prove* that sunlight is a heterogeneous mixture of variously coloured light rays.

This sounds like the complete opposite of the orthodox position as set out above. But it only contradicts Newton's second claim (on the higher level). Someone who denies that the gardener has been convincingly incriminated (given the burden of proof) can still think that the gardener was the murderer. And someone who denies that the prism experiments prove the heterogeneity of white light can still believe in its heterogeneity, and thus agree with Newton's first claim (on the object level). This is the position that I would like to offer to sympathizers of Goethe who do not wish to disagree with modern science.

Now, Goethe certainly did not want to accept Newton's first claim either. Objections to the heterogeneity of white light can be found throughout Goethe's *Farbenlehre*. As I do not want to question the results of modern science, and as I count the heterogeneity of white light as an integral part of its results, I shall downplay Goethe's disagreement with it: We can accept Goethe's main point without thereby adopting a verdict, one way or another, about Newton's claim on the object level.

Moreover, once we follow Goethe, we shall see that in the end it is not that important whether we say that white light is *really* a mixture of variously coloured rays of light. Admittedly, Goethe often appears to be concerned with physical reality (rather than with philosophy of science). But that can be explained. Goethe did not always sharply distinguish between the two different levels within Newton's position that I specified above; he did not always sharply distinguish between claims about the properties of light and claims about the *status* of these

5. It results from Newton's first two theorems in the *Opticks* (Newton 1964, 4:17, 4:21).

6. For example, the first official sentence of the *Opticks* (in the first part of the first book, directly after the preface) reads: "My design in this Book is not to explain the Properties of Light by Hypotheses, but to propose and *prove them by reason and experiments*" (Newton 1964, 4:5; my italics). A brief look at the first book of the *Opticks* reveals that Newton was serious about this. The book contains theorems and *proofs* (as well as definitions and axioms). Whenever Newton formulates a theorem, he provides an experimental proof. Thus, in the passage relevant here, he says: "THEOR. II. *The Light of the Sun consists of rays differently Refrangible*. The Proof by Experiments. *Exper. 3*. [...]" (Newton 1964, 4:21; italics in original).

claims. Whenever reasonably possible, I will lift Goethe's formulation onto the higher level, whereby his account becomes more plausible and poignant. This interpretation is in accordance with Goethe's intentions:

> We thus do not by any means imagine ourselves to have proven that Newton was wrong (LA I.5, §31).

Goethe refers here only to Newton's *first* theorem; in the context of this passage, however, he generalizes the point. The passage can be understood as an indication of a general restraint that, for the sake of brevity, Goethe does not always repeat. These considerations come under the heading "Proof through Experiment". Here is how they begin:

> We would not like to scare off our reader right at the start with some paradox. Nevertheless, we cannot refrain from claiming that nothing can be proven through experience and experiments (LA I.5, §30).

From this one could suspect that Goethe did reject the experimental method of the natural sciences after all—in contrast to what I promised at the start. If this were the case, then no possibility of reconciling Goethe's *Farbenlehre* with the achievements and *methods* of modern science would remain. However, the suspicion is baseless, as Goethe continues:

> The phenomena can be very precisely observed. The experiments can be performed immaculately, and one can exhibit experience and experiments in a certain order (LA I.5, §30).

Goethe is serious here. In his *Farbenlehre*, he describes an impressive number of experiments that he had carried out in his colour laboratory. And he encourages the reader to do the same. This is no mere lip service; Goethe's *Farbenlehre* contains coloured figures that are not merely *illustrations* of experiments. Rather, their main purpose is to function as part of one's own experiments.[7] Anyone who looks at these figures with a prism can reproduce the main phenomena under consideration in Goethe's writings on colours.

3. Goethe's Variations on Newton's First Experiment

In Goethe's view, careful observation of the phenomena has an educational function. Familiarizing ourselves with the phenomena protects us from hasty conclusions and guards against the dangers of confusing complex hypotheses with what we see with our own eyes. According to Goethe, most of Newton's readers succumb to these dangers, and not by accident. Again and again, Goethe accuses Newton of presenting his experiments obscurely, which complicates their replication, verification or falsification.[8]

Regardless of whether Newton intentionally gave muddled descriptions (which Goethe insinuates and I do not believe), there is no doubt that Goethe's descriptions of the experiments are superior in clarity, comprehensibility, and intelligibility. I emphasize this not so much because I wish to indicate whose writing style was better. Rather, I emphasize it so as to expose which of the two took experiments and observations deeper to heart.

The contrast between Goethe's style and Newton's reflects a more thorough methodological contrast. Goethe noticed that Newton only draws on a small number of prism experiments, and worse still, on exactly those that appear to favour his theory. To overstate the point—Goethe had to object to Newton *just because* he took the experimental method of the natural sciences more seriously than Newton.

7. "we were unable to dispense with plates, but we endeavoured to construct them so that they may be confidently […] considered as forming part of the [experimental—O.M.] apparatus" (LA I.4:9–10; Goethe 1840, x1ix; Goethe 1995, 162).

8. See, for example, Goethe's discussion of the first Newtonian experiment (LA I.5, §35, §37, §39, §41).

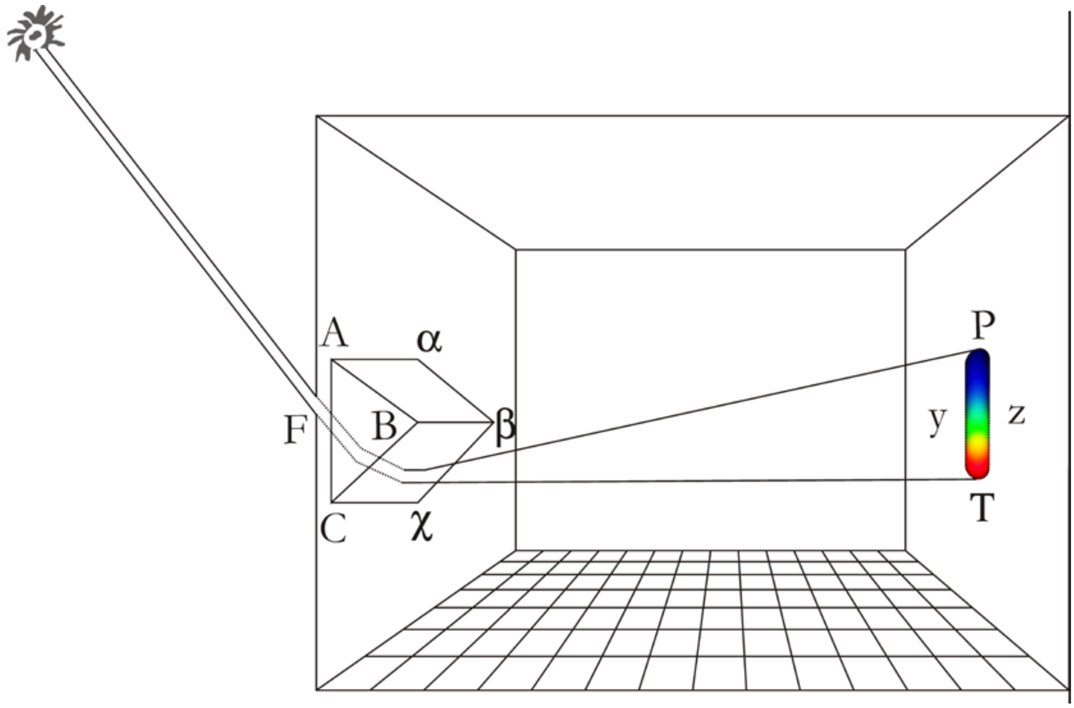

Figure 1. *Newton's most famous experiment.* In a darkened chamber, the sun's light is refracted by a prism (left). Newton captures his well-known spectrum (Figure 2) on a white screen (right). The light rays that are redirected from their path the furthest are violet. They can be seen in the upper part of the spectrum. (Based on a Newtonian sketch in black and white, redrawn by Ingo Nussbaumer; source: Müller 2015, colour plate 1).

Let us examine the conclusiveness of the most famous of these experiments, shown in Figure 1.[9]

On a sunny day Newton closes the doors and window shutters of a room facing south, and then turns off all the lights. He drills a tiny, round hole in one of the sun-splashed window shutters; and he places his famous prism to catch the light immediately after it passes through the hole. Twenty-two feet away, he puts a white board in a suitable location (as the light changes direction according to the law of refraction), so that all of the sunlight coming through the hole hits it. Newton observes two things (Figure 2): The light hitting the board is not white, but multi-coloured like a rainbow; and the image is not round, but five times longer than it is wide. At one end it is red. At the other end it is violet. The coloured band in between is yellow, green, and blue.[10]

Through careful measurements and calculations, Newton discovers that the width of the band of colours corresponds to his expectations, given the sun's size, the smallness of the hole in the window shutter, the prism's orientation, the distance from the prism to the white board, etc. What is surprising is the length of the band of colours—and the fact that it is coloured.

If one now imagines the multi-coloured band as a series of patches of colour (red, yellow, green, blue, and violet), then the suspicion arises that variously coloured light rays must have left the prism in slightly different directions. The prism thus splits the colourless light ray (emerging from the hole) into variously coloured rays of light. It splits the light ray by refracting its red component less than the yellow component, the yellow component less than the green component, and so on. In short, white sunlight is a mixture of variously coloured rays that are variously refracted as they pass through the prism.[11]

9. For the following, see Newton (1953, 68–71).

10. Whether the observed patches of colour are seen horizontally or vertically depends on the orientation of the prism. In my presentation, I have chosen the second possibility. Goethe and Newton often had the first possibility in mind (see e.g. Newton's sketch in Figure 1). For the sake of uniformity, I will adapt their considerations to my presentation, without noting this in each case.

11. Strictly speaking, it is insufficient to consider just five different colours of light rays. Rather there will be indefinitely many fine gradations between the five colours specified. For simplicity I will continue with five different colours.

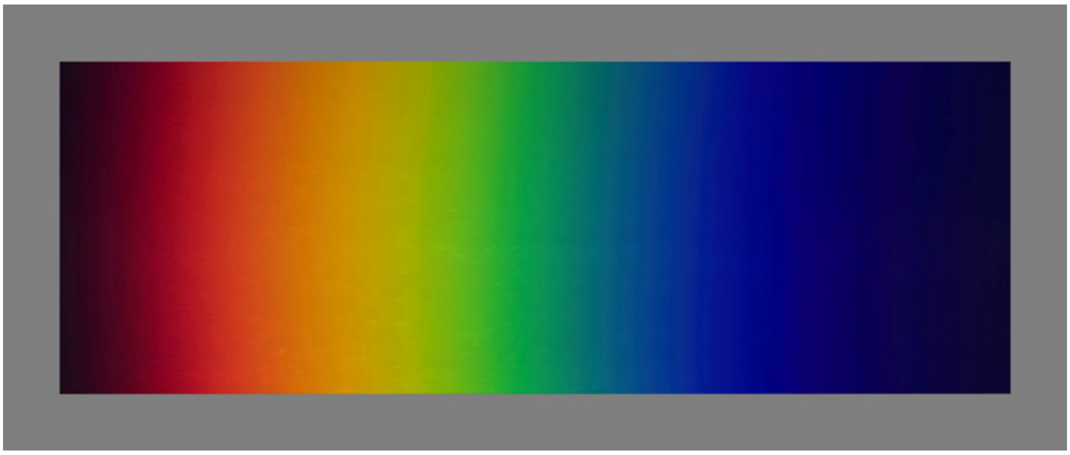

Figure 2. *Newton's spectrum*. Today, the result of Newton's most famous experiment (Figure 1) can be replicated with a water prism and a slide projector, whose light is sufficiently similar to sunlight. Against a dark background, an image of rich colours appears that contains (from left to right): red, yellow, green, blue, and violet areas with blurred boundaries. (Photographed by Ingo Nussbaumer, cropped by Matthias Herder; source: Müller 2015, colour plate 1).

So much for Newton's train of thought; it is not implausible, but is it a proof? Does the experiment force upon us the conclusion that white light from the sun is a mixture of variously coloured light rays, and that these variously coloured light rays were diversely refracted? Goethe challenges these claims. In taking Newton's result as a theoretical hypothesis that goes beyond what can be seen in the experiment, he does not challenge the *existence* of the elongated coloured band twenty-two feet behind the prism; he challenges its *conclusiveness* for the hypothesis of the heterogeneity of white light.

He is not just being obstinate by insisting that a band of colours on some particular board does not imply anything about the composition of light that passes through a hole in a window shutter far away.[12] Goethe does not play the notorious sceptic who sees non-sequiturs wherever there are arguments. Rather, he takes matters into his own hands and repeats Newton's experiment under varying conditions; he "multiplies" the phenomena.[13] He moves the board nearer to the prism, increases the size of the hole in the window shutter, changes the angle of the prism, and so forth. No doubt, if one of the two was obsessed with the experimental method, it was Goethe.[14]

Goethe's series of experiments delivers staggering results. Newton's colour spectrum is an extreme case and quite a special one at that.[15] The sequence of colours:

> red, yellow, green, blue, violet (Figure 2),

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12. Alan Shapiro has nicely exposed how Newton struggled with the obvious problem that no prismatic experiment whatsoever can *demonstrate* the heterogeneous composition of white light *before* that light passes through the (first) prism: "the correspondence between refrangibility and color was experimentally established only after the sun's light had been decomposed into colors and not before; and that correspondence cannot simply be extended to the sun's direct light before the colors become apparent through refraction" (see Shapiro 1980, 231; cf. Shapiro 1980, 215–216, 225). This is not the problem that Goethe found troubling.

13. This expression—"vermannigfaltigen" in German—occurs often, see, e.g., LA I.5, §56, §168.

14. Friedrich Steinle convincingly argues that Goethe's experiments are cases of explorative experimentation, as often occurs in the history of the natural sciences (Steinle 2002, 151–157).

15. "The Newtonian theory that reigned for over a century was, however, based on a *limited* case, and it neglected the rights of all of the remaining phenomena; it is these rights that we have tried to restore with our proposal [Goethe is referring to the didactic part of the *Farbenlehre*—O.M.]. This was necessary, as we want to bring the hypothetical distortion of so many wonderful and pleasing natural phenomena back into balance" (LA I.7:7; my italics).

Figure 3. *Edge spectra*. The left end of this spectrum consists of the warm colours (red/yellow); the right end of cool colours (blue/violet). These colours become particularly saturated when the screen is moved close to the prism. (Photographed by Ingo Nussbaumer, arranged by Matthias Herder; source: Müller 2015, colour plate 2).

only appears when one coordinates the distance between board and prism precisely with the radius of the sun's disk (Figure 1). If the board is moved too close to the prism (or if, alternatively but impossibly, the apparent size of the sun is increased) the green patch at the centre of Newton's colour spectrum disappears. In its place one sees a colourless gap between the yellow patch on the one side and the blue patch on the other. The sequence is:

red, yellow, *white*, blue, violet (Figure 3).

And the white gap in the centre becomes larger (in relation to the coloured part of the sequence), the nearer the board is moved to the prism (Figure 4, top). When confronted with these observations, how should we react to Newton's claim that sunlight contains (among others) green light rays? Why doesn't Newton's green light appear directly behind the prism?

It is important to see that Newton's theory is equipped with an immediate answer (Figure 4). The white gap in the coloured band directly behind the prism can be interpreted as an overlap of multiple coloured rays of light that arrive at the prism from the sun's disk parallel, but (despite different directions of refraction through the prism) are not yet far enough from each other to appear separately on the board.[16]

As opposed to what is often claimed,[17] Goethe was familiar with this type of response.[18] Nevertheless, he remained discontent. And the reason for this was not because he did not understand Newton's theory. Goethe does not need to deny that the white gap (in the coloured band directly behind the prism) can be integrated into Newton's heterogeneity of white light. Remember, Goethe does not try to prove that Newton is wrong; the observation of a white gap does not serve him as an experimental refutation of Newton's theory. Goethe argues on a higher level and correctly directs the phenomenon of the white gap against Newton's claim to have experimentally *proven* that white light is heterogeneous. According to Goethe, the white gap exposes Newton's heterogeneity of white light as mere hypothesis. And this rebuke is justified, as I shall demonstrate in the next section.

16. It is remarkable how casually Newton treats the topic. See Newton (1964, 4:102); cf. Newton's figure 12. (The illustrations in Newton's *Opticks* were originally attached on extra sheets; figure 12 belongs to the second part of the first book; it is given on the third sheet, which has the title "Lib. I Par. II Tab. III").

17. See, e.g., Helbig (2004, 122).

18. See LA I.7, 87–91; see also 79–83.

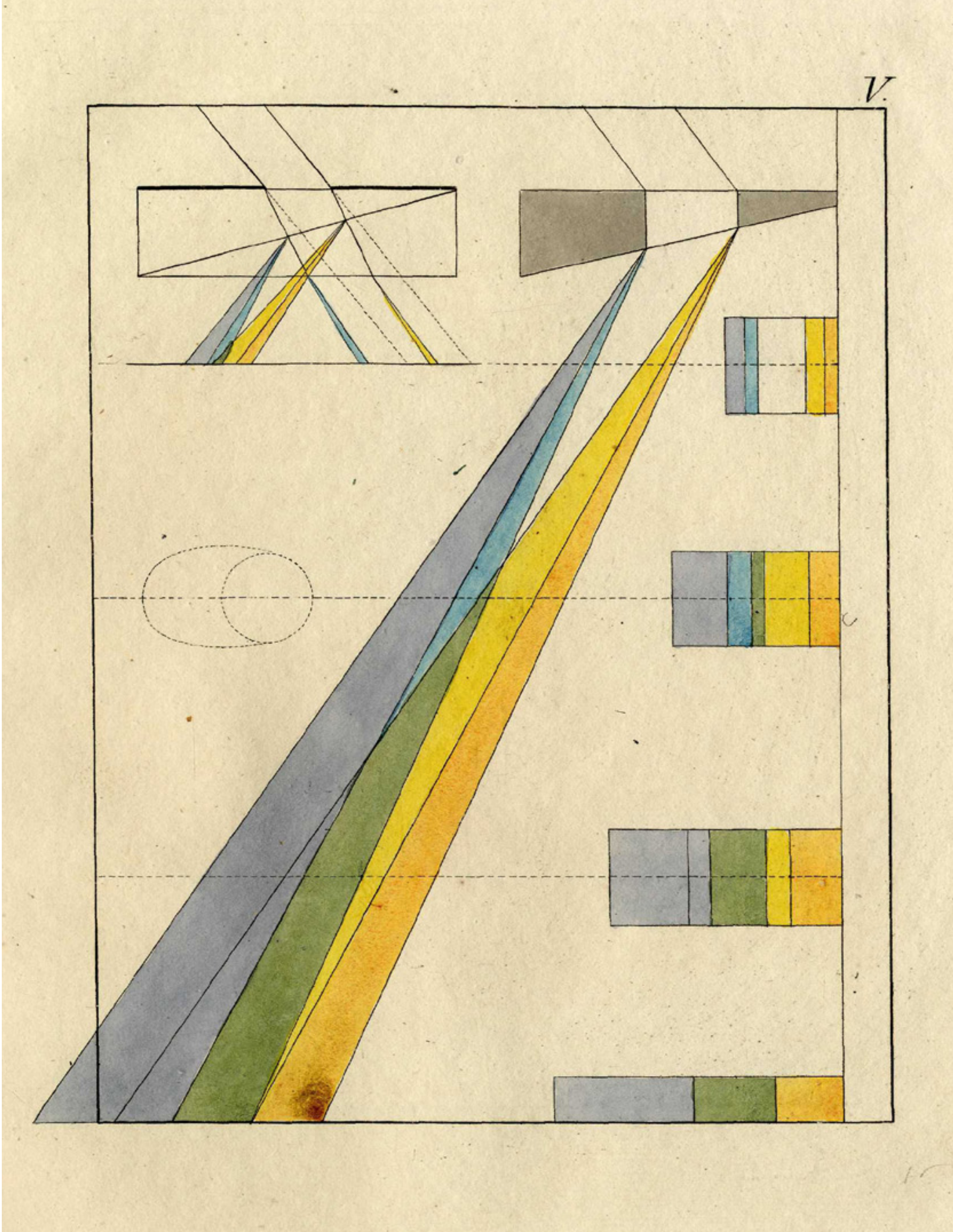

Figure 4. *Goethe's fifth colour plate with variations of Newton's experiment in the darkened chamber.* It shows how the spectral colours change according to the distance between a water prism and the screen. Newton holds that if the screen is positioned very close to the prism (top), the coloured light rays have not yet separated enough from each other and are superimposed in the centre of the image. As a result, the green centre of Newton's spectrum (Figure 2) is missing, with the warm edge spectrum visible on the left and the cool edge spectrum on the right (Figure 3). Halfway down, the coloured light rays have separated out enough to create Newton's spectrum with the colours red, yellow, green, blue, and violet. (The figure has been flipped so that the spectra have the same orientation as in the other figures; the original is shown and discussed in LA I.7, 63–65. For an English publication see Plate V in Goethe 1995, 206–207/VII. In the first English translation, Goethe's figures have different numbers, see PLATE IV in Goethe 1840, 192–193).

4. The Gap in Newton's Proof

Hypotheses non fingo: This was Newton's proud campaign slogan.[19] A hypothesis is less than a proof; it may be more or less in accordance with the phenomena—but even in the more favourable case, the hypothesis does not inevitably follow from phenomena alone. With this in mind, I want to ask: Is it a proven fact or just a hypothesis when Newton claims that white light is a heterogeneous mixture that contains green?

Goethe's multiplication of the experiments gave us two groups of phenomena that are on a par. We have prism experiments with a green patch in the coloured band on the board (Figure 2) and prism experiments without this green patch (Figure 3). Do these phenomena dictate a decision about the composition of white light? In particular, do they force upon us the claim that white light contains green rays?

They don't. As long as there is no reason to favour one group of phenomena over the other, we have a choice. We can *decide* to start from the prism experiment with a green patch. In this case, we travel along Newton's path and explain the experimental results without green —using assumptions based on experimental results exhibiting green. But this is not the only possibility. We could just as well decide to start from the experiments without green, and then use these results in order to explain the results that produce a green patch in the centre of the coloured band on the board. According to this view, the more distant spectrum's green centre arises as an overlapping of the yellow and blue colour patches that occur near the prism. These emerge directly behind the prism, so to speak, but do not yet overlap, and therefore can only mix somewhat further away.[20]

Given the symmetry of the situation, Goethe can make two piercing criticisms of Newton. First, in selecting the phenomena that he does, Newton makes a decision without ever identifying it as a decision. And second, he fails to justify the decision. In short, there is a gap in Newton's proof. We do not need to judge whether Newton was aware of this; the following questions are more instructive: Could he have closed the gap? Could he have justified his choice to base the proof on just those prism experiments in which a green patch can be observed in the centre of the coloured band?

Perhaps Newton could again draw our attention to the fact that his results are consistent with the experimental results without green. But in order to exploit this point in favour of his proof, Newton would have to show more. He would have to show that, taken as a whole, the reverse procedure is less successful. That is, he would have to *compare* the success of his suggestion with the success of competing suggestions—and that is exactly what Newton does not want to do, since he does not want to sell his heterogeneity of white light as a more or less successful hypothesis: In his eyes, it is an experimentally proven truth.[21]

If Newton wants to live up to these high aspirations, he must provide stronger reasons for favouring the experimental result with green. Or he must try to downplay the result without green as a degenerate, special case. At first glance, the prospects seem poor. His own choice of the distance between the prism and the white board appears arbitrary. Why does Newton put the board twenty-two feet from the prism? Why not three inches or fifty feet? When Goethe moved the board closer to the prism, he did not do this aimlessly, that is, not merely to multiply phenomena. Rather, he wanted to see what happens directly behind the prism

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19. The slogan can be found in a prominent place in the *Principia*, namely in the penultimate paragraph right at the end of the monumental work (in the "SCHOLIUM GENERALE" that appears for the first time in the second edition (Newton 1964, 3:174). Newton also applied the slogan to optics, see footnotes 6 and 21.

20. Goethe follows the second option in his own account of the prism experiments (LA I.4, §330, §214, §216). LA I.4, §214 and §216 refer to the *subjective* version of the experiments, see section 6 below, especially footnote 34).

21. See footnote 6 above. Newton was serious about this ambition, as can be seen in many places in the *Opticks*. See, for example, the summary of his results directly after formulation of "PROPOSITION VII. THEOREM V" (Newton 1964, 4:100). See also Shapiro 1996.

where the formerly white light is allegedly split into colours. If one wants to prove that white light contains a green component that the prism separates out, one must catch the green component in the act, not afterwards at an arbitrary distance of twenty-two feet.

This clearly speaks against Newton's experimental setup; but it is not the end of the story. Newton could try to divert our attention from the distance between the prism and the board. He could point out that another parameter of his prism experiment is crucial—the radius of the sun's disk as it appears in the sky. If we, say, increased the distance between us and the sun (or if we diminished the size of the sun itself), that is, if the sun's disk filled a smaller angle from our perspective, then we could move the board closer to the prism, without losing the desired green patch in the centre of the coloured band on the board.[22] Given this, it might serve Newton's purposes to grant a privileged status to those prism phenomena that would appear if the sun were infinitesimally small, or infinitely far away from us.

What could Newton say in favour of varying those astronomical parameters? He could say that he wants to examine light rays that are not disturbed by neighbouring light rays: The smaller the sun, or the further away, the fewer disturbances from other light rays. That sounds tempting; and it is exactly this tempting idea against which Goethe warned. First of all, we are unable to produce variations of the sun's size or of its distance from the earth; such variations, which would have to be tremendous, belong to science fiction. Second, and worse, shrinking the size of the sun's disk renders the entire observation more difficult—with an infinitesimally small sun, we would see nothing at all.[23] Third, in any real experiment, even with a smaller (but not disappearing) sun, we cannot observe a green patch in the band of colours *directly* behind the first refraction. As long as we neglect this phenomenon without green, we are still making a decision that is not imposed upon us by mere observation of phenomena.

These points raise the suspicion that Newton's appeal to single rays of white light (and to an infinitely small solar disk) had nothing to do with real experiments. Perhaps Newton wanted to say that *if* we could make the sun so small that only a single ray of white light could travel from it to us, then this light ray would be cleanly split by the prism into its variously coloured components—so cleanly indeed that we could attain a complete Newtonian spectrum directly behind the prism (which, however, would be much too weak to be seen by human eyes).

In a certain respect, the constellation so described has a special status compared to all other phenomena that appear with larger appearances of the sun in the sky—or with various distances from the prism: This special constellation does not belong to the realm of phenomena that can be directly observed. It is the result of idealization, and it contains an abstract hypothesis, namely, that light rays are infinitely thin. But the observable phenomena do not force us to idealize in the direction of Newton's hypothesis.[24]

Of course, it is not forbidden to idealize and hypothesize.[25] Modern science is replete with idealizations and hypotheses. Newton did not want to admit this, and he believed that he could build on more solid ground. If Goethe reminds the Newtonians that the alleged proof contains hypothetical elements, then one should not accuse Goethe of having misjudged the idealized, hypothetical character of modern natural science. Rather, one should give

22. See LA I.5, §115–118.

23. Thus at a similar point in the debate, Goethe says: "Why was the opening so small? Only so that the observation would be more difficult and each difference less noticeable" (LA I.5, §255).

24. Goethe says: "One never finds rays, one just explains the phenomena with rays […] That Newton and his school believe to see with their eyes what they theorized into the phenomena—that is precisely what one complains about" (LA I.5, §217). See also LA I.4, §310.

25. Goethe provides a brilliant discussion of abstract geometrical tools that are used in textbooks to clarify the law of refraction, see his eleventh colour plate (LA I.7, 93–95; reprinted (without Goethe's explanation) in Goethe 2016, 114).

him credit for having seen an inconsistency between the methodological self-conception of leading scientists and their actual practices.

What should we think about this inconsistency? If I am right, Goethe wants to reevaluate the self-conception of Newton and his fellow travellers. Goethe's attack does not aim at their practices of idealization and hypothesizing. As we shall see in the next sections, Goethe can accept mathematical idealizations of the prism phenomena without abandoning his main point. He can insist that the prismatic results thus achieved fail to be objective.

5. Idealization, Mathematics and Objectivity

I have claimed in the last section that the prism experiments do not force us to idealize towards Newton's hypothesis. In a trivial sense, this is obvious. The phenomena do not force us to any idealization. If we decide to stick closely to the observed phenomena, then of course the phenomena cannot force us to idealize at all. (How should they do that?)

Now, it is difficult to imagine how science would manage without idealizations. It would be a science without mathematics, or at least a science in which mathematics would play a role entirely different from the one to which we are accustomed. Speculation in this direction may have some philosophical attraction, but we had better not draw on Goethe in this regard. True, there are no mathematical calculations in Goethe's *Farbenlehre*. But that is no reason to praise or condemn Goethe for envisaging sciences without mathematics. The lack of mathematics in Goethe's *Farbenlehre* is due to two reasons. On the one hand, Goethe does not consider himself capable of profitably using mathematical methods.[26] He kept his project open to the assistance of mathematicians,[27] and in many places he shows due respect for mathematics.[28] On the other hand, Goethe believed (in my opinion, for the most part correctly) that he did not need mathematics to achieve the main purposes of the three parts of the *Farbenlehre*. First of all, qualitative vocabulary is sufficient for a clear and undistorted representation of colour phenomena in the didactic part of the *Farbenlehre* (LA I.4; Goethe 1840; Goethe 1995). Second, the criticism of Newton in the polemic part of the *Farbenlehre* (LA I.5; Goethe 2016) can be developed without appeal to sophisticated mathematical resources (as I am trying to show). And third, the historical development of the theories on colours from ancient times to 1800, which is the topic of the historical part of the *Farbenlehre* (LA I.6), can be presented without much in the way of mathematics.

One could ask: At what point would Goethe have needed the mathematicians he unsuccessfully invited to contribute to his project? Goethe does not say. However, in my opinion, the answer is obvious. Mathematicians might, for example, carry out a series of measurements aimed at developing a formula: This formula would predict the minimum distance from the prism at which we would observe a green patch in the centre of the coloured band on the board (as a function of material, angle, and position of the prism, as well as of the size of the sun's disk, or, more generally, of the size of the light source).[29] Such a formula would be based on idealizations. As soon as one wants to draw a mathematically respectable curve through a series of points acquired by real measurements, one has to embellish the measurements; Goethe could hardly want to protest against this—he too embellishes his measurements

26. See LA I.4, §723.

27. Goethe: "the mathematician will gladly join our endeavour, especially concerning the physical part of the *Farbenlehre*" (LA I.4, 23; Goethe 1840, lx, Goethe 1995, 167). See also LA I.4, §727.

28. Goethe demands that "in this way one would not have to exclude any human abilities from scientific activity. Deep intuition, a steady look at the present, *mathematical depth*, physical accuracy, reason at its best, sharp understanding […] nothing can be left out" (LA I.6, 77; my italics). And when Goethe cautions us about mathematics, he cautions us about its misuse. For example, he warns against viewing a theory about the world as having been proved true just because of its mathematical exactitude, see e.g. LA I.5, §7 as well as LA I.4, §724.

29. Perhaps no tools from the region of higher mathematics are necessary for the specification of such a formula. But so what? The mathematics in Newton's *Opticks* is also rather down to earth in comparison to the mathematics in the *Principia*.

in order to be able to draw clear borders between different colour zones, which in fact are blurred. (Compare, e.g., the photograph in Figure 2 with Goethe's schematic representation in Figure 4).

We can go a step further. Our formula would not only provide information about cases that we have observed or have not yet observed. Purely formally, it also treats extreme cases that we *cannot* observe in principle. What happens, for example, if we let the parameter for the size of the sun's disk (or of the light source) approach zero? Even if the formula gives us an answer—if for example it says (to Newton's benefit) that when the size of the sun's disk approaches zero, the green patch appears directly behind the prism—even then we ought not claim to have observed a single ray of white light, or to have experimentally proven that the prism decomposed such a single ray into the complete spectrum of colours.

Observed phenomena do not live up to the mathematically extreme case. The mathematically extreme case belongs to the realm of hypotheses. The phenomena belong to the realm of facts. As long as we do not confuse hypotheses (won through idealization) with the observed facts, Goethe would have no fundamental objection to idealizations.

A misunderstanding threatens to trivialize Goethe's point. Trying to downplay the dispute, one could ask: Is it a mere dispute about words? Perhaps Goethe speaks more strictly than Newton, and always banishes scientific results, on purely linguistic grounds, to the uncertain realm of hypotheses? Couldn't we instead simply say that we want to call a scientific result a proven fact when the result in question follows from idealized observations? This suggestion is in accordance with the self-conception of many scientists who may well be aware that they are idealizing, without being inclined to abandon talk of scientifically proven facts. Unfortunately, the suggestion conceals a crucial problem that Goethe saw with admirable clarity—a problem that remained hidden from Newton.

The problem is that the phenomena can be idealized in completely different directions. Even when we have opted for idealization (and thus for exact sciences), even then the phenomena do not dictate which way we have to go. We are repeatedly confronted with a choice between different theoretical options. Which of these options we pursue does not depend on observation and mathematical rigour alone, but also on considerations based on *our* preferences. It depends, for example, on considerations of elegance, simplicity, parsimony, generality, fertility, and on overall coherence with the theories we already accept.[30] Considerations such as these do not always point in the same direction. It could happen, for example, that we do not favour an ontologically parsimonious theoretical option of high generality because it becomes too complex. This indicates that even the most careful weighing of the pros and cons does not necessarily lead to determinate results. Our criteria for theory choice do not form an algorithm that, after having been fed the available observations, spits out *the* single best theory.[31]

What I outlined in the last paragraph is a minimal consensus among many philosophers of science today. Goethe anticipated the consensus, if not in all of its details, and not exactly in the terminology now used.[32] At the same time, he addressed a question that is forced upon us once we take seriously the position I have sketched: Are there real examples of equivalent alternatives to our well-established theories, or is this merely an abstract possibility—that is, a possibility that only occurs in philosophical discussions?

If there are examples of such alternative theories, our actual theories might be hypothetical in a far more dramatic way than has been suggested so far. Until now I have called Newton's

30. See, e.g., Quine and Ullian (1978, 66–80).

31. According to Thomas Kuhn, there is "no neutral algorithm for theory-choice, no systematic decision procedure which, properly applied, must lead each individual in the group to the same decision" (Kuhn 1970, 200). Cf. Duhem (1954, 218).

32. He talks, for example, of "prejudices" instead of theoretical preferences (LA I.5, §30).

claim about the heterogeneity of white light hypothetical because it lacks rigorous empirical proof. This alone need not worry us as long as we can assume that the claim represents the best-justified hypothesis. But we would find it troubling if we came across an alternative which fits the prism experiments just as well as Newton's claim. His claim would then not only be hypothetical because of a lack of *certainty*. It would also be hypothetical because it would lack *objectivity*. If we were to continue to support Newton's claim even in the face of an equally justified alternative hypothesis, we could not sincerely claim to be describing a world independent of us. In this case, our adherence to Newton's claim would trace back to an arbitrary decision on our part—and not to the world.

Goethe is concerned with the lack of objectivity in precisely this sense whenever he tries to banish Newton's claim (about the heterogeneity of white light) from the realm of objective facts. He does not only mean that Newton's heterogeneity is uncertain because it lacks proof. Rather, he means that it is arbitrary because it cannot rule out alternatives through objective procedures. And the objection cuts deep because Goethe can confront Newton's claim about the heterogeneity of white light with an equally justifiable alternative: The hypothesis of the heterogeneity of darkness.

6. The Heterogeneity of Darkness

Goethe does not advocate this hypothesis. He only uses it to trump Newton's claim to objectivity. This is one of the most fascinating moves in the entire *Farbenlehre*.[33] Goethe bases this hypothesis on a prism experiment that we have not yet considered. It is an experiment whose results electrified him as he multiplied observations. In the experiments that have been described so far, we began with an illuminated hole in a window shutter of an otherwise dark room. Goethe proposed to exchange the roles of light and darkness; he wanted to see what prismatic phenomena appear given a dark spot in an illuminated room So he replaced the white spot with a dark spot, and the dark room with an illuminated room.

The experiment can be carried out easily. Just replace the board (that catches the coloured band of light) with the eye's retina. In other words, instead of looking at a board that registers what passes through the prism, we look directly through the prism. Without the board as an intermediary, we come more directly in contact with the phenomenon, and thus lose fewer nuances. The prism experiments considered thus far can be repeated at low cost with this more direct procedure.[34] If, for example, we look through the prism at a tiny white spot against a black background in sufficient daylight, we see Newton's famous band of colours:

> red, yellow, *green*, blue, violet (Figure 2).

And once we increase the size of the spot, or decrease the distance between the spot and the prism, a white gap appears in the centre of the band of colours, just as in the previous experiment with the white board (Figure 4). We see

> red, yellow, *white*, blue, violet (Figure 3).

33. For the following, see LA I.7, 68–69, 86–87. See also LA I.5, §132.

34. For understandable reasons, Goethe calls the first experiments discussed here "objective experiments" whereas the experiments in which the experimenter looks through a prism he calls "subjective experiments". The objective and subjective experiments have a clear relationship to each other (LA I.4, §299–305). There are also subjective experiments in Newton's research (not, however, with that name). The very first experiment in the *Opticks* is a subjective experiment (Newton 1964, 4:17–18).

Figure 5. *Goethe's inverted spectrum.* This inverted spectrum appears when the roles of light and darkness in Newton's experiment (Figure 1) are exchanged, i.e. when the narrow ray of light is replaced by a shadow that is sent through the prism in light surroundings (Figure 6 top). The resulting spectrum is just as big and colourful as Newton's (Figure 2). It consists of the colours blue, violet, magenta, red, and yellow. As Goethe was the first to produce this spectrum on a screen, it is known as 'Goethe's spectrum'. (Photographed by Ingo Nussbaumer, cropped by Matthias Herder; source: Müller 2015, colour plate 6).

Now Goethe introduces his new experiment. He does everything in reverse. He looks at a tiny *black* spot on white background.[35] The result is surprising (Figure 5). Once again, there is a band of colours. As long as the two spots are the same size and as long as the same prism is used from the same distance, the new band of colours can be seen just as clearly as the original band of colours, and it is also the same size as the original one. However, the new band of colours contains some new colours, and the colours have an entirely unusual order. Instead of the band

> red, yellow, green, blue, violet (Figure 2),

which results from the original experiment (when looking at a white spot against dark background), we now see (when looking at a dark spot against a white background) the following band:

> blue, violet, magenta, red, yellow (Figure 5).

Green does not appear anywhere in this new band of colours, which means that the centre of the original band of colours is missing. The new band of colours begins on the right side of the centre of the old band (blue, violet), as it were, and then jumps to the left (red, yellow). At the same time, it bridges the distance jumped over (from violet to red) by inserting a new colour: magenta.

To the impartial eye, the two bands of colours are on a par. They are equally luminescent, clear, big, and colourful. There is not the slightest reason to favour one band of colours over the other. And on the basis of parallel experiments with large water prisms, Goethe shows that in these circumstances nothing changes even by returning to the objective experiments (compare Figure 6 with Figure 4). Goethe concludes: If Newton was justified in inferring that white light splits into its component colours

> red, yellow, green, blue, violet (Figure 7)

when passing through the prism in his original experiment (with a white spot on dark background), then another, unorthodox inference would have to be equally justified: According to this unorthodox inference, *darkness* splits into its component colours

> blue, violet, magenta, red, yellow (Figure 8)

35. See LA I.4, §215.

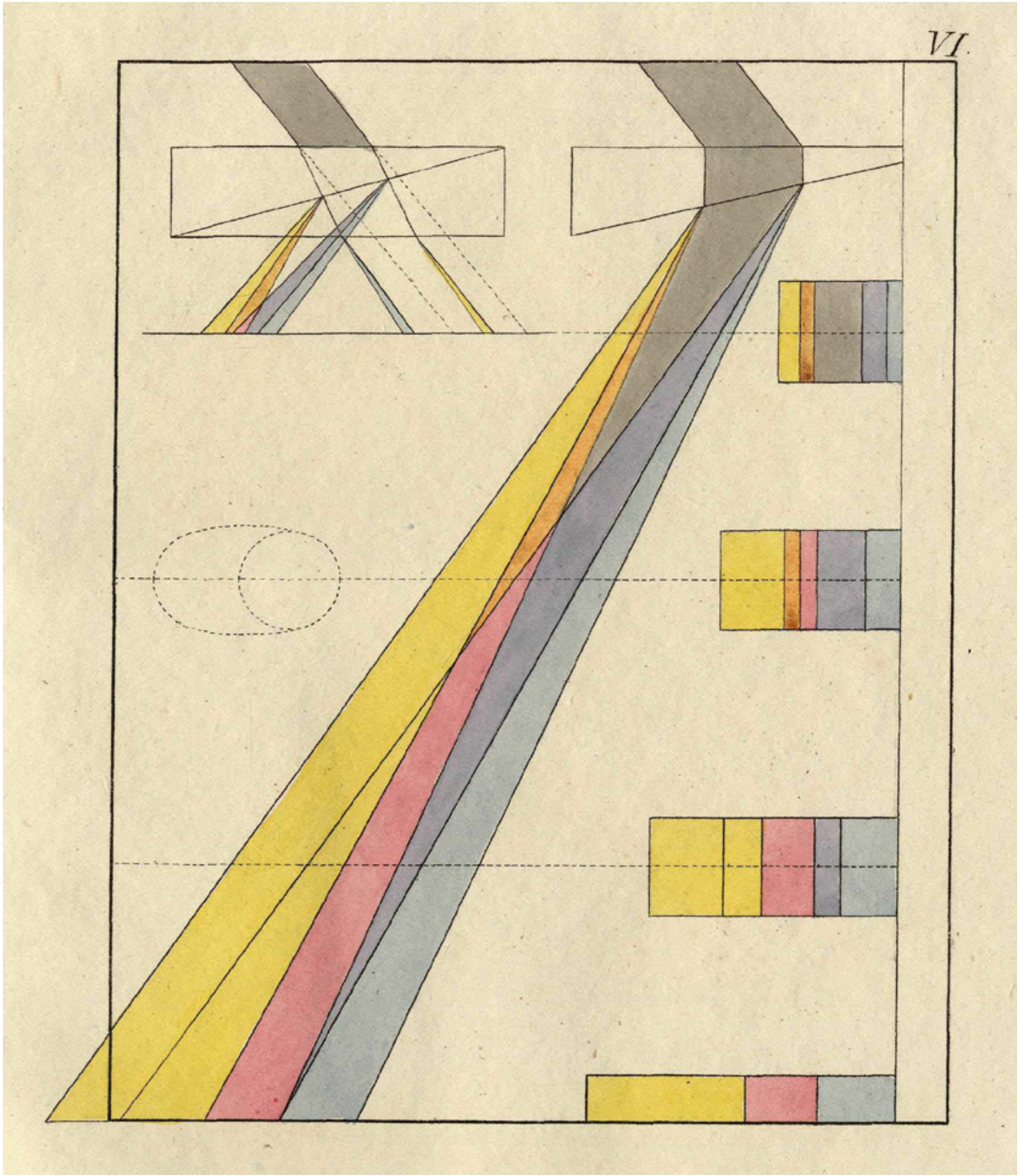

Figure 6. *Goethe's sixth colour plate with his inversion of Newton's experiment.* A shadow passing through the large water prism at the top of the diagram is split into colours complementary to those of Newton's spectrum. Halfway down the coloured darkness rays have separated out enough to create Goethe's spectrum with the colours blue, violet, magenta, red, yellow (Figure 5). The geometry of this plate is identical to that of Goethe's fifth plate (Figure 4); each plate is the colour negative of the other. (The figure has been flipped so that the spectra have the same orientation as in the other figures; the original is shown and discussed in LA I.7, 68–69. For an English publication see "Plate VI" in Goethe 1995, 206–207/VIII. In the first English translation see PLATE IV in Goethe 1840, 192–193).

when passing through the prism in the new experiment (with a dark spot on white background). This is what I call the heterogeneity of darkness.[36] According to this new idea, darkness and blackness are composite phenomena. They result from the overlapping of the colours blue, violet, magenta, red, and yellow—of variously coloured darkness rays, so to speak.

36. Goethe does not use that expression (or its German equivalent). He says: "Thus these phenomena seemed completely parallel to me. What was a correct explanation of the one seemed equally applicable to the other, and from that I concluded the following: If the [Newtonian—O.M.] school can claim that the white image on dark background is dissolved, separated, and scattered through refraction, then the school can and must just as well claim that the black image was dissolved, split, and scattered through refraction" (LA I.7, 86).

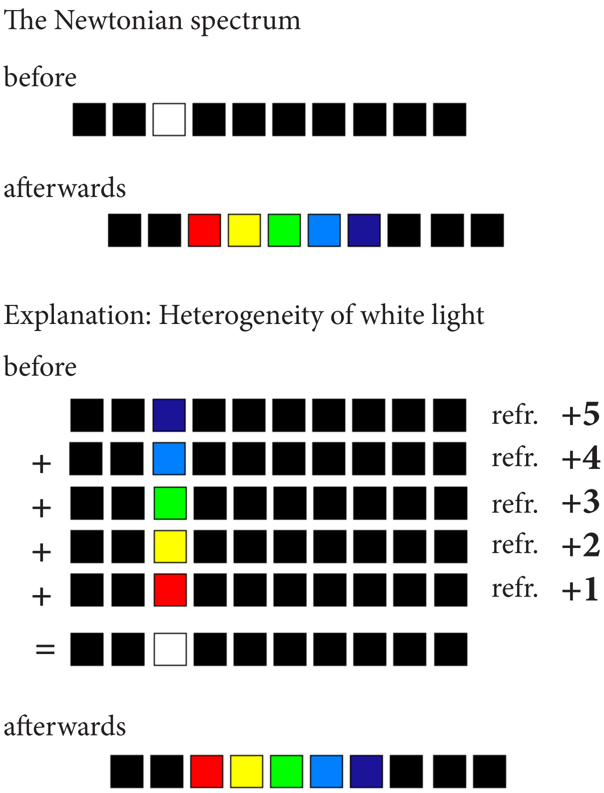

Figure 7. *The heterogeneity of white light.* In Newton's experiment (Figure 1, Figure 4), the light rays appear white before they pass through the prism (upper part of the figure). Newton interprets these as the sum of red, yellow, green, blue, and violet light rays (centre of the figure). The violet light rays are refracted the furthest (a whole five units). The red light rays are refracted the least (only one unit). The black boxes represent missing light, which Newton's explanation ignores as it is taken to be causally inefficacious. (Design by O.M.; source: Müller 2016, 330).

At first glance, this appears to be an extravagant hypothesis that invites a number of objections. I will deal with two of them. But before we delve into controversies concerning the heterogeneity of darkness, I would like to repeat that Goethe does not himself defend this hypothesis. He merely wants to transform our instinctive resistance to the heterogeneity of darkness into resistance to Newton's heterogeneity of light. According to Goethe, *both* hypotheses are extravagant and equally improbable. The only difference is that we have become accustomed to Newton's heterogeneity of light, whereas the heterogeneity of darkness is an unusual, novel idea.

The first objection to this novel idea is that darkness, as opposed to light, cannot be sent through prisms. Only light rays move through space. If one presupposes the traditional theory of optical phenomena, then that is surely correct. But talk of light rays is hypothetical and replete with theoretical assumptions. Who has ever seen a ray of light? One may infer from what one sees that light rays are transmitted into our eyes.[37] However, one could equally infer darkness rays emanating from the image. Neither can be observed directly.[38]

37. See LA I.5, §217.

38. See Goethe's translation of Kepler, which Goethe comments with approval (LA I.6, 157–158).

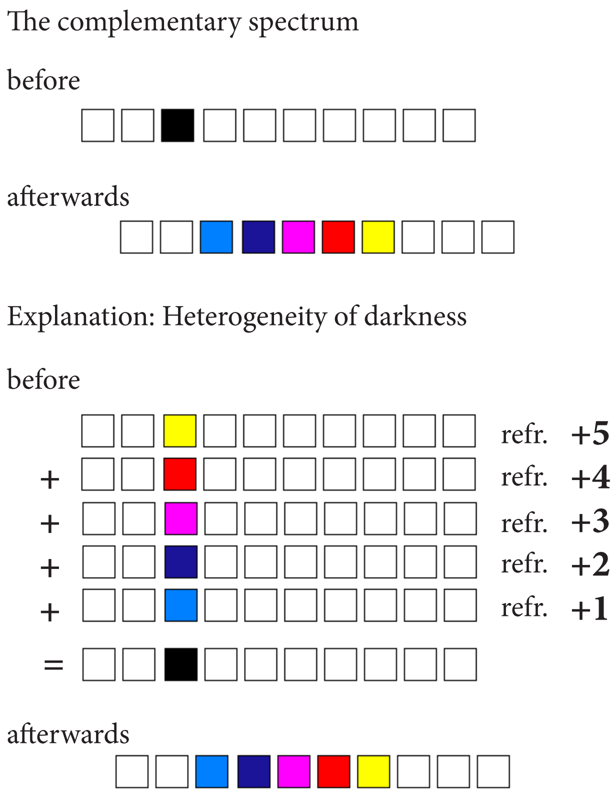

Figure 8. *The heterogeneity of darkness*. In his new experiment (Figure 6), Goethe produces the complementary spectrum. A black spot appears coloured when viewed through a prism (upper part of the figure). In the unorthodox explanation, the black spot is interpreted as a summation of blue, violet, magenta, red, and yellow *darkness rays* (centre of the figure). The yellow darkness rays are refracted the furthest (a whole five units). The blue darkness rays are refracted the least (only one unit). The white boxes represent missing darkness, which is ignored by this explanation as it is taken to be causally inefficacious. (Design by O.M.; source: Müller 2016, 330).

The notion of darkness rays is a theoretical concept—just as is the notion of light rays. Neither light rays nor darkness rays can be observed. One can only see patches (in at least two dimensions), be they magenta, yellow, blue, white or black. These patches *can* (but need not) be theoretically explained with the help of light rays (in which case black patches will be explained as the absence of light rays). However, one could also explain the magenta, yellow, blue, and black patches with the help of darkness rays. In this case, white patches would be explained as the absence of darkness rays. If we project a coloured scene with some black and white elements inside a *camera obscura*, we will see the very same scene (though upside down): A coloured image with black and white patches. Is it not obvious that those black patches could very well be understood as effects of darkness rays that pass through the *camera obscura's* aperture?

7. The Newtonian Explanation of Complementary Colour Spectra

According to the second objection to the heterogeneity of darkness, this hypothesis is redundant. Newton's heterogeneity of white light suffices for explaining the new band of colours that appears when one looks through a prism at a black spot. According to Newton's hypothesis, the light rays coming from the white surrounding the black spot contain many different colours that will be variously refracted as they pass through the prism. Consequently, many different overlapping colour combinations should meet at different points on our retina, and their overlapping ought to result in exactly the observed band of colours:

> blue, violet, magenta, red, yellow (Figure 5).

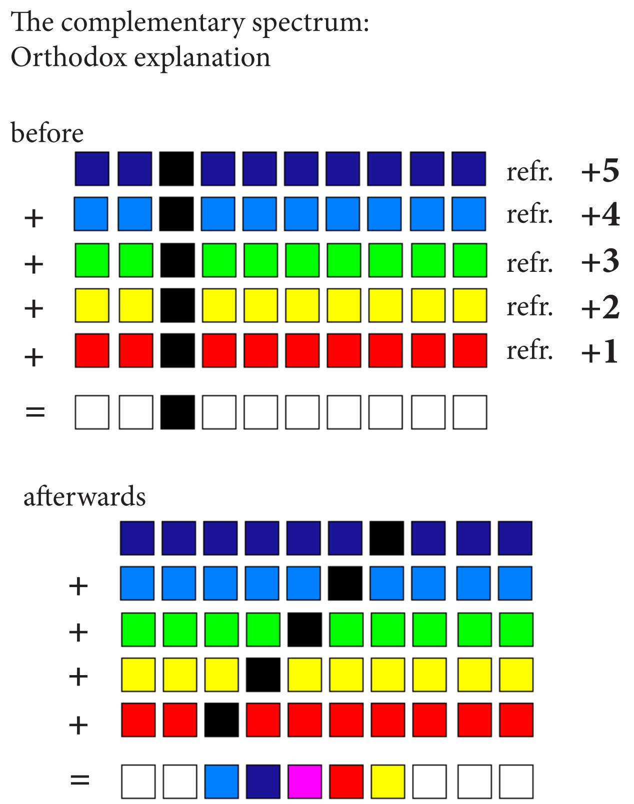

Figure 9. *Orthodox explanation of Goethe's spectrum.* Newton can explain Goethe's experiment (Figure 6) in an orthodox fashion. The absence of light is supposed to have no causal powers. Only the surrounding white light sends coloured composite rays through the prism, which are then variously refracted by the prism according to the known rules (for example, violet rays are refracted the furthest—five units). When the results are combined, each colour of the complementary spectrum can be explained (lower part of the figure). Magenta, for example, is the sum of violet, blue, yellow, and red—i.e., the sum of all the colours except green (which in turn is the complement of magenta). Magenta is the result, so to speak, of removing green from the colour mixture white. (Design by O.M.; source: Müller 2016, 332).

The objection is based on a promise—a promise to provide an explanation that has yet to be formulated. Let us examine the first step of this explanation more closely (Figure 9).

Let us consider, for example, the point where the violet component of a given white light ray strikes the retina. The light ray must have departed far to the left of the black spot (see the first row of colours in Figure 9). The other coloured components of the ray of light would then be refracted by the prism less strongly to the right than the violet component and would therefore miss the point on the retina under consideration. Nevertheless, additional refracted light rays also arrive at this spot on the retina. For example, the blue component of another white light ray that began less far to the left of the black spot and consequently does not need to be refracted as strongly by the prism in order to strike the retina at exactly the point under consideration (Figure 9, second row). For according to Newton, blue light is refracted less strongly than violet light as it passes through a prism.

Now if green light came from the dark spot viewed through the prism, this green light would also strike the point on the retina under consideration. Green light would be refracted even less to the right than the more strongly refracted blue and violet light rays (which originate from further to the left). However, the spot in our experiment is black, and it does not emit green light. It does not emit light at all (Figure 9, third row).

Does it follow that only blue and violet light should reach the point on the retina under consideration? No, as until now we have only considered the light coming from the left side of the black spot. The yellow component of a white light ray emitted from immediately to the *right* of the black spot is refracted even less strongly than the rays mentioned earlier, and consequently it also arrives exactly at the point on the retina under consideration. And red light will arrive there from even further to the right of the black spot (Figure 9, fifth row).

That completes the story about the point on the retina under consideration. As they pass through the prism, all other coloured rays of light from around the black spot are either not refracted enough to reach the spot on the retina, or they are refracted so strongly that they pass over it. Thus, all the colours from Newton's spectrum except green will reach the point on the retina under consideration. And if light rays with the colours:

red, yellow, —, blue, violet,

all overlap, the result is magenta (see Figure 9, lowest row, fifth column from the left).

This is the Newtonian explanation of the magenta patch in the centre of the band of colours that we see when we look through a prism at a black spot. Similar explanations can be given for each of the other colours observed in the experiment. Thus, all colours except blue strike the retina a short distance from the point under discussion. (Blue would reach this point on the retina only if blue light had been emitted from the dark spot viewed through the prism. But the spot is black, and it does not emit any light). Now, if one overlaps all of the Newtonian colours except blue:

red, yellow, green, —, violet (Figure 9, bottom, sixth column from the left),

then the result is red. And, in fact, in our experiment we see a red patch directly next to the magenta patch in the centre.

To summarize, it seems that for each of the colours from the new band of colours

blue, violet, magenta, red, yellow (Figure 5),

a Newtonian explanation can be given. These colours result from a complicated overlapping of variously coloured light rays—an overlapping of light rays that come from the white surroundings of the black spot. The upshot is that Newton's heterogeneity of white light is robust enough to deal with the new band of colours; the new band of colours does not require some new, extravagant hypothesis—it does not require the heterogeneity of darkness. And that seems to imply that the heterogeneity of darkness is superfluous. Goethe's reaction to the objection does not show him in at his best:

> Future generations will regard such a sample specimen with astonishment, as towards the end of the eighteenth century, the sciences proceeded in ways of which the darkest monasticism and self-confusing scholasticism would not have to be ashamed (LA I.7, 89).

According to Goethe, the Newtonian explanation of the new band of colours seems too cumbersome. Whereas Goethe becomes polemic and makes no effort to defeat his opponents with their own weapons, I claim that he could have undermined the objection more thoroughly than he found necessary. He repeatedly pointed out that the prismatic colours that appear when looking at a black spot can be handled exactly like Newton's spectral colours when looking at a white spot. But with regard to the present situation, he failed to extend the parallel between the two phenomena far enough.

8. A Possible Response from Goethe

In order to meet the objection against the heterogeneity of darkness discussed in the last section, Goethe could have turned the objection around. He could have used it against Newton's heterogeneity of light; he could have said that Newton's heterogeneity of light is redundant because the Newtonian spectrum

red, yellow, green, blue, violet (Figure 2),

which appears in the prism experiment with a white spot, can be explained as a complicated overlapping of darkness rays that come from the *black surroundings* of the white spot (see Figure 10).

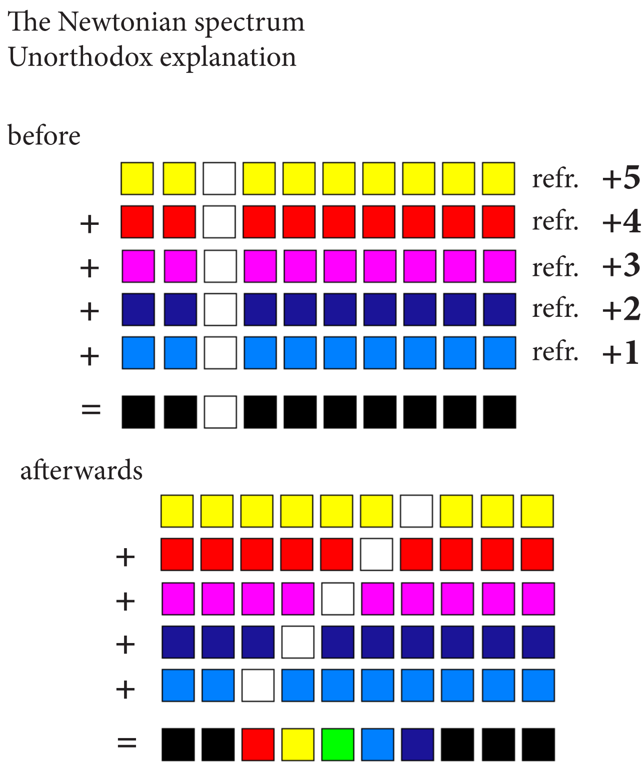

Figure 10. *Unorthodox explanation of Newton's spectrum.* If we turn Newton's explanation of the complementary spectrum (Figure 9) into its colour negative, we arrive at the unorthodox explanation of the Newtonian spectrum. The darkness rays are shown separately as they pass through the prism and then summed underneath. (Design by O.M; source: Müller 2016, 332).

Thus, what meet at a certain point on the retina of the observer's eye are the more strongly refracted yellow and red darkness rays that are emitted from left of the white spot, and the much less strongly refracted blue and violet darkness rays that are emitted from the area to the right. Only magenta darkness rays (which are refracted more strongly than blue and violet darkness rays but less strongly than yellow and red darkness rays) are missing at this point on the observer's retina. They are missing because in order to hit the appropriate point on the observer's retina, they would have to come from exactly where the white spot is—and according to the heterogeneity of darkness, there are no darkness rays whatsoever that come from the white spot. Now if we look through a prism at a white spot (as Newton did), then the overlapping of darkness rays

> blue, violet, —, red, yellow,

results in the impression of the colour that we find in the centre of the spectrum: green.

This explanation of the green patch in the centre of the Newtonian spectrum, which is based upon the heterogeneity of darkness, functions just as well as the Newtonian explanation of the magenta colour at the centre of the complementary spectrum. Moreover, it follows exactly the same pattern as the Newtonian explanation of the complementary spectrum, and of course, the other colours of the Newtonian spectrum can be accounted for in the same way (for details see Figure 10).

I conclude that the heterogeneity of darkness (and the unorthodox explanations developed from it) is indeed an exact mirror image of the Newtonian heterogeneity of light (and the orthodox explanations developed from it). Newtonians take the colour series

> red, yellow, green, blue, violet (Figure 2),

to be fundamental. From this they infer the heterogeneity of light and claim:

> As they pass through a prism, violet light rays will be more strongly refracted than blue rays, blue rays more strongly than green rays, green rays more strongly than yellow rays, and yellow rays more strongly than red rays (Figure 7).

Newtonians use this and certain assumptions about the results of overlapping variously coloured light rays (see the previous section as well as Figure 9) to explain the new band of colours:

> blue, violet, magenta, red, yellow (Figure 5),

which appears when a black spot is viewed through a prism.

Their unorthodox opponents proceed exactly the other way around. They consider the last mentioned band of colours to be fundamental, and from this they infer the heterogeneity of darkness. They claim:

> As they pass through the prism, yellow darkness rays are refracted more strongly than red darkness rays, red darkness rays more strongly than magenta darkness rays, magenta darkness rays more strongly than violet darkness rays, and violet darkness rays more strongly than blue darkness rays (Figure 8).

Newton's opponents use this and certain assumptions about the results of overlapping variously coloured darkness rays (see Figure 10) to explain the band of colours:

> red, yellow, green, blue, violet (Figure 2),

which appears when a white spot is viewed through a prism.

Earlier, I called this unorthodox interpretation an exact mirror image of the Newtonian interpretation. This expression is somewhat misleading, as a mirror image always has the same colours as the original. It would have been more appropriate to call it an exact *colour negative* of the Newtonian interpretation, because just as in the good old days the print of a colour photograph transformed all colours of its negative into their complements, the unorthodox interpretation of the prism phenomena transforms the Newtonian interpretation through colour complementarity. If we exchange the roles of the colours:

> violet with yellow,
> blue with red,
> green with magenta,
> white with black,

and if we exchange talk of light rays with talk of darkness rays, then the Newtonian theory transforms into its unorthodox complement. Both accounts have the same structure. (Yet the two accounts contradict one another!)

And this means that the two competing accounts fare equally well in terms of elegance, economy, simplicity, and parsimony. With Goethe's help, we have uncovered an example of two competing theories between which an unbiased decision cannot be made. To be more precise: The prismatic phenomena cannot determine a decision between the two theories; nor can we make a decision by trying to draw on the structural properties of the two theories.

9. A New Experiment Against the Heterogeneity of Darkness?

In the previous section, I proposed the empirical claim that both Goethe's unorthodox heterogeneity of darkness and Newton's heterogeneity of white light are on a par because they fit the prismatic phenomena equally well. Is this true? It is certainly true for the prism experiments that have been considered so far; it is true for the experiments in which *either* a little white light and a lot of darkness *or* a lot of white light and a little darkness are sent through a prism—regardless whether this is done in an objective or subjective fashion.[39]

However, there are more prismatic experiments than have been hitherto considered. So we must investigate whether we can come up with additional prismatic experiments that are decisive in the conflict between the heterogeneity of darkness, on the one hand, and that of white light on the other.

In an oral criticism of my defence of Goethe, someone suggested one such experiment that aims to refute the heterogeneity of darkness. My objector reasoned as follows: Goethe's experiment with the complementary spectrum (which arises when a black spot on a white background is observed through a prism, as described in section 6) creates the *appearance* that there are colours in the black spot, while in fact they come from its illuminated surroundings and are thus a result of Newton's heterogeneity of white light. In order to show that there is no colour spectrum in the black spot itself, my objector suggested repeating the experiment in a room illuminated with homogeneous light—for example in a room whose only light source emits homogeneous green light.[40]

Here we have the new experiment that I want to consider in this section: In a chamber illuminated only with homogeneous green light, we look through our prism at a black spot on a white board—that is, on a board which is painted white. Certainly, as long as we do not look through the prism the white board appears green, because it is illuminated with green light and thus can only reflect green light; the black spot reflects nothing and still looks black. What will happen when we observe it through our prism? The answer is readily available. We will still see a black spot appearing against a green background (redirected according to the law of refraction). This observation is predicted by Newton's theory; according to Newton, the green light rays from our new experiment will all be refracted by an equal amount —without changing their colour. And since (in Newton's view) the black spot does not emit any light rays, there will be no optical processes at the corresponding spot on the observer's retina; hence it will appear black to the observer.

I do not want to question whether the new experiment leads to the observations demanded by Newton's theory—although I have not tried it out for myself and it certainly could not have been tried out in Newton or Goethe's time.[41] But let us suppose the observer looking through the prism sees a black spot against a green background—I do not need to challenge this result as I do not claim that Newton's predictions are false. My claim is rather that these predictions fit the views of the unorthodox heterogeneity of darkness equally well.

My objector disagrees. On his view, the new experiment does not conform to the unorthodox hypothesis. Here is why: *If* (as unorthodoxy has it) the darkness emitted from our black spot really does contain all of the colours of the complementary spectrum, then they should appear in our new experiment. However, in the new experiment no spectrum appears.

39. The difference between objective and subjective experiments is explained in footnote 34.

40. For present purposes it does not matter whether the homogenous light in question is green or some other colour, such as blue or yellow, as long as it is homogeneous.

41. In those days scientists were unable to *produce* enough homogenous light. Even so, they were able to *test* whether some rays (however produced) deserve to be called "homogeneous" according to Newton. That is the case when in a *darkened* chamber (i.e., without disturbing light) the rays in question will be equally refracted and thus not be split into various colours. Proponents of the unorthodox heterogeneity of darkness, however, will find Newton's test tendentious, as they believe that the chamber's darkness can and does produce its own optical processes. Even so, they could carry out Newton's test and perhaps speak of "homogeneity à la Newton" —in case Newton's test produces positive results. But, of course, from the perspective of their unorthodox view, the test criteria for homogeneous rays function exactly opposite: According to the unorthodox heterogeneity of darkness, rays are called "(unorthodox) homogeneous" if *in daylight* they are equally refracted (and thereby not separated into various colours). It is clear that unorthodox homogenous rays are heterogeneous à la Newton and *vice versa*.

Only the green that can already be seen without the prism remains visible after refraction by the prism. And thereby, according to my objector, the heterogeneity of darkness is empirically refuted.

This conclusion is too hasty. To show why, I will demonstrate how the experimental result can be explained by appeal to the heterogeneity of darkness. According to proponents of the heterogeneity of darkness, different darkness rays have different angles of refraction; yellow darkness rays are refracted the farthest as they pass through the prism, and blue rays the least. In this view, Newton's alleged homogenous green light is a heterogeneous mixture of

> blue, violet, red, and yellow

darkness rays, without magenta darkness rays.[42] All but the magenta darkness rays are reflected by the white board. Now, on the one hand, the dark spot also emits all these darkness rays

> blue, violet, —, red, yellow,

and on the other hand, it emits magenta darkness rays. Taken together, our observer sees an image (through the prism) that emits blue, violet, red and yellow darkness rays *throughout* and in addition magenta darkness rays *at one single location* (where the black spot is).

Since no darkness rays are lost as they pass through the prism, and since they are only refracted as they pass through the prism but do not change their colour, it follows that blue, violet, red, and yellow darkness rays will arrive everywhere on the observer's retina. And on exactly one location, additional magenta rays will arrive. The observer will see a black spot at exactly this location, as here and only here all the components of darkness come together (namely blue, violet, red, yellow, *and magenta* darkness rays). At all the other locations on the retina, blue, violet, red, and yellow darkness rays arrive—and the optical sum of these is green, which the observer actually sees surrounding the black spot.

That completes the unorthodox explanation. As the result of our new experiment can be explained by appeal to the heterogeneity of darkness, I maintain that we can deliver such an unorthodox explanation for every prism experiment in Newton's *Opticks*. If that is the case, then Goethe was right when he objected to Newton (as presented in section 2):

> The prism experiments do not prove that sunlight is a heterogeneous mixture of variously coloured light rays.

10. Two Considerations in Favour of Empirical Equivalence

I cannot prove in every detail here that Newton's theory of prismatic colours is empirically equivalent with its unorthodox complementary theory of darkness rays. It would be even beyond the scope of this essay to prove that both theories fit all *prismatic* phenomena equally well. So let me just give a sketch of the proof.[43]

The proof is based on two lines of thought. On the one hand, it is based on the unorthodox explanation of additional prismatic phenomena, each of which—up until now—has always been explained in terms of Newtonian orthodoxy; and on the other hand, the proof is based on the complementary multiplication of phenomena. For each phenomenon that appears to

42. See section 8 above as well as the previous footnote. In light of that footnote, I'd have to call this mixture "*unorthodox* heterogeneous green". For the sake of brevity, I'll skip the italicized qualification in what follows.

43. For the full proof (in German) see Müller (2015, 202–216) [reference added in 2021]. Apart from the proof, there are two questions that would take us too far afield and thus cannot be pursued here. First, if it is the case (as I claim) that none of the Newtonian *prism* experiments can be used against Goethe's heterogeneity of darkness, then which other experiments against this hypothesis could Newton offer? (For example, how about experiments concerning emission, reflection, or absorption of light, or concerning its energetic effects?) Secondly, what experiments could best be used today to repudiate Goethe's heterogeneity of darkness?

support Newton's theory, there would be a complementary phenomenon that is its colour negative, as it were, and would therefore support the unorthodox theory as clearly as the original phenomenon would support Newton's theory.

In order to roughly sketch the two lines of thought, let's take a look at Newton's white synthesis. That is an additional prism experiment that appears *prima facie* to support Newton's heterogeneity of white light. Given these two lines of thought, the appearance will fade. We will first acquaint ourselves with the colour negative of that experiment (the black synthesis), and then consider the unorthodox explanation of the original experiment.

In the white synthesis experiment, a prismatic colour spectrum is spread out in the dark

> red, yellow, green, blue, violet (Figure 2),

and by means of a second refraction (in the opposite direction) we obtain a white spot.[44] The black synthesis functions exactly the other way around. We reproduce a black spot by recombining a complementary colour spectrum

> blue, violet, magenta, red, yellow,

that spreads out in an illuminated room (Figure 5).

If the white synthesis supports the heterogeneity of light, then the black synthesis supports the heterogeneity of darkness. Of course, we cannot consider both hypotheses to be true simultaneously. (One hypothesis can only be true if the other one is false. Newton's explanations are based on the assumption that we may ignore black backgrounds. The unorthodox explanations of its competitor are based on the opposite assumption, i.e. that we may ignore white backgrounds. In short, the two hypotheses are mutually exclusive).

Of course, the new consideration can support the heterogeneity of darkness only if the black synthesis experiment really works. Interestingly, we do not need to check whether the experiment does in fact result in the desired black spot. Why not? *Because Newton's theory entails that this will happen*.[45]

Here is a sketch of the reason. In the magenta patch at the centre of the overlapping complementary spectrum, two groups of light rays come together, which, according to Newton, do not belong together and move in very different directions when refracted. As they pass through the prism, blue light is refracted very strongly, whereas red light is refracted much less strongly. This opens a lightless gap, so to speak, in the centre of the image.

If this is so, then Newton's theory predicts phenomena that can be explained à la Newton, but which speak just as clearly in favour of the heterogeneity of darkness. In addition, we also have the starting point for the second line of thought with which I can support my claim about the empirical equivalence of the two theories. Once we transform the Newtonian explanation of the black synthesis word for word into its complementary counterpart, then we obtain the unorthodox explanation of the Newtonian white synthesis experiment!

And this means that we do not necessarily have to tie the white synthesis to Newton's heterogeneity of white light. The white synthesis experiment fits equally well with the heterogeneity of darkness. Both theories remain empirically, or at least prismatically, equivalent.

11. Back to Goethe

I cannot delve deeper into a comparison of the two theories. We have already travelled too far from what Goethe had to say about this topic. He was not interested in the tedious details. The astonishing symmetry between Newton's colour spectrum and its complementa-

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44. See Newton 1953, 79.

45. Ingo Nusbaumer (an artist from Vienna) has performed a series of objective experiments that fit well with my considerations; for his black synthesis see Müller 2010, 164 [reference added in 2021].

ry counterpart was sufficient for him to see that the phenomena do not give unequivocal support for Newton's theory. My examination of the details confirms Goethe's insight. He would have probably protested against my claim that Newton's heterogeneity of white light is equally as *good* a hypothesis as its unorthodox alternative (the heterogeneity of darkness). He would have said that both hypotheses are equally *bad*. And that explains why he was not inclined to invest more in the details of their comparison.

The astonishing symmetries in the domain of phenomena impressed Goethe so much that any theory not exhibiting these symmetries would not have satisfied him.[46] Newton's theory of the heterogeneity of white light misrepresents this symmetry by taking the original colour spectrum as fundamental, and then treating its complementary counterpart quite differently. The unorthodox, alternative theory of the heterogeneity of darkness makes the same mistake—only in reverse.

If one wants to avoid the mistake (that is, if one wants to give a theoretical account of these symmetries), one must treat light and darkness on a par. Goethe's own theory is more resolute in this regard.[47] It is important to see that Goethe's theoretical considerations were not dictated by phenomena alone, but rather by his own preference for certain symmetries. We could say that Goethe demanded a very particular structure from the theory of colours; or to put it more dramatically, he demanded beauty.

There is nothing objectionable about this. Some world-famous twentieth century physicists were driven by a comparable demand for beauty;[48] and twentieth century philosophy of science could not avoid accepting aesthetic principles into the canon of respectable criteria for theory choice.[49]

I cannot discuss here how well Goethe's theory fulfils the other criteria of this canon. Goethe's theory might perhaps fit the prism phenomena as much as Newton's theory and its complementary counterpart. If it does, then this cannot be easily shown as Goethe's theory differs significantly in structure from these two mirror-image alternatives. For the same reason, it is difficult to compare Goethe's theory with the two alternatives in terms of simplicity.

In any case, it seems that Goethe's theory is ontologically less economical than Newton's theory of light and its dark counterpart. It presupposes light and darkness, and thus pays an ontological price for the desired symmetry between light and darkness. On the other hand, it is less abstract, as it avoids resorting to (infinitely thin) light or darkness rays.

12. Conclusion

I would like to leave open the question as to whether, all things considered, we have good, objective reasons to favour Newton's theory over Goethe's (which I have not even so much as sketched in my discussion). For the purposes of this essay, it suffices to show that the prism experiments do not provide good, empirical reasons for favouring Newton's theory over its colour-negative counterpart. My goal here is to support Goethe's arguments against Newton's claim to objectivity. These arguments are convincing even if we do not accept Goethe's own theory of colours.

And we have enough reasons not to accept Goethe's theory. It would be a disturbing foreign body in the fabric of contemporary physics. Naturally, we cannot blame Goethe for this. At the time he wrote his *Farbenlehre*, not much physics had been developed on the basis of Newton's theory of light.[50] Goethe hoped, not without good reasons, that his view could

46. See LA I.5, §506.

47. See LA I.4, §696ff.

48. For example, Dirac (1979, 21–22) and Weinberg (1993, 133 *et passim*).

49. See, e.g., Kuhn (1970, 155–156).

50. See Sepper (1987, 179).

be included into the family of more comprehensive physical theories. Subsequent developments in physics undermined this hope.

But what does that prove? If we knew for sure that physics moves forward along a firm, objective course, then later developments in physics would speak objectively against Goethe's theory of colours. However, my considerations of prism experiments give rise to serious doubts about the objectivity of physics, or anyway, about its unique determination by observation and experiment. When the scientific world opted for Newton's theory of light, there could be no talk of objectivity, or uniqueness. (I have not decided whether this is a rare case or the general rule). Even if the subsequent history of successes fits well with that choice, this would not prove that another choice would have led to a less successful science. Perhaps Goethe's theory of colour or the theory of the heterogeneity of darkness do not fit well with contemporary physics just because contemporary physics is based on the *decision* to pursue only Newton's theory.[51] Since this decision has paid off in the meantime, there is no need to retract it. Nevertheless, we would do well not to read more objectivity into the decision than is really sanctioned.

Goethe does not have anything against the attempt to describe the world with the help of idealized, even abstract, theories. But his recommendation is that we should treat our theories more cautiously:

> It is sometimes bizarrely demanded by people, who do not themselves attend to such demands, that experiences be described without any theoretical connections […] Surely the mere inspection of some object can profit us but little. Every act of seeing leads to consideration, every consideration to reflection, every reflection to combination, and thus it may be said that in every attentive look at nature we already theorize. Let us engage in it with consciousness, with self-awareness, with freedom, and to use a bold word, with irony: All of this is needed if the abstraction we fear is to be harmless, and the empirical result we hope for is to be quite lively and useful (LA I.4, 5; Goethe 1840, x1–x1i; Goethe 1995, 159).

Newton lacked the freedom that Goethe demanded. Newton was unaware of his own free decision involved in the leap from phenomena to theory. Worse, he was not even aware of the gap between experience and theory that he needed to bridge. Goethe's criticism of this unreflective attitude is still relevant today. The famous poet, lover and politician had a nose for philosophy of science.[52]

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51. For example, according to contemporary physics, Newton's spectrum is (and Goethe's spectrum is not) fundamental because green photons exist but magenta photons do not; magenta light is a mixture of violet, blue, yellow and red photons.—But perhaps we do not acknowledge the existence of magenta photons *merely because we haven't searched for them*; interestingly it appears to follow from Heisenberg's uncertainty principle that individual magenta photons can be produced; for the details see Filk 2021 [reference added in 2021].

52. Many thanks to Eric Oberheim and Troy Vine for help with the English translation of this text, which is a revised version of lectures delivered at the conference *Out-of-text: A Philosophy of Nature Today?*, Turin (*October 2019);* at the Department of Philosophy, University of York (February 2015); at the *logos colloquium* of the *Institució Catalana de Recerca i Estudis Avançats* (*ICREA),* Barcelona (*October 2009);* and at the Department of Philosophy, Norwegian University of Science and Technology, Trondheim (*October 2007*). I'd like to thank the audiences for many valuable comments. While abridged portions of these lectures have been published in English before (Müller 2016 and 2017), this is their first complete English presentation; the German original was published in Müller 2007. Apart from additional illustrations and the previous footnote I have not changed much compared to the original text. The bibliography, however, has been enlarged so as to include recent research presented in English (to be mentioned in what follows). No attempts have been made to incorporate new empirical results that support the views proposed here; see the details about the inverted *experimentum crucis* in Sällström (2010), Grebe-Ellis and Passon (2018, 132–134 *et passim*) as well as the new findings concerning infra-cyan "frigorific rays" in Rang and Grebe-Ellis (2018), Grebe-Ellis and Passon (2018, 136–137); further experiments are documented in Löbe, Rang and Vine (2022, 89–103). For critique from both physics and philosophy see Lampert (2017), Lyre (2018), Schreiber (2018) and Vijaya (2020); for some replies see Müller (2018b); for more historical context see Lande (2017), Zemplén (2018), Müller (2018a), Müller (2020) and Vine (2020). Related work, which has come to my attention in the meantime, has been published fifty years ago (Holtsmark 1970) and builds upon the pioneering research of Bjerke (forthcoming).

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